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THE HARMONIC POTENTIAL OF THE TABLA'S PUDI: CONSTRUCTION AND ACOUSTIC ANALYSIS

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ABSTRACT
The tabla is one of the most widely used and acoustically sophisticated membranophones in the world. Its prominence stems mainly from its ability to produce harmonic overtones. This feature sets it apart from most Western membranophones, which typically generate inharmonic partials; the timpani is a notable exception. This harmonic behaviour is primarily achieved through the application of a central loading paste (syahi) on the drumhead (pudi), creating a non-uniform mass distribution that alters its vibrational modes. This study examines the construction and acoustic behaviour of the pudi, focusing on how its materials and craftsmanship impact the tabla's harmonic sound production. Through a combination of material-based descriptive analysis and frequency-domain analysis using the Fast Fourier Transform (FFT), the paper evaluates how variations in pudi quality, particularly in the syahi, affect the overtone structure and harmonic profile of the instrument.
Keywords: *Tabla, Acoustics, Membrane Vibration, FFT, Harmonic Overtones*

Introduction

As with many instruments in the Indian classical tradition, the tabla is entirely handcrafted. While this artisanal process is central to the instrument's cultural and aesthetic value, it has also contributed to inconsistencies in quality, particularly in the construction of the pudi. Variability in the sourcing and treatment of raw materials, coupled with the subjective nature of individual craftsmanship, has historically led to a lack of standardisation in tabla manufacture.

The tabla comprises two drums: the dayan (right-hand, often simply referred to as the tabla) and the bayan (left-hand), each covered by a membrane called the pudi. A black paste, syahi, applied at the centre of the dayan, enables the production of harmonic overtones. As syahi is applied manually in layers, inconsistencies in its distribution can cause tonal variation. This study examines how the quality and preparation of pudi materials affect the harmonic character of the dayan and analyses the syahi's role in overtone generation.

Construction of the Pudi

The quality of goat skin used in crafting the pudi (the drumhead of the tabla) plays a crucial role in the production of aesthetically pleasing sound. Goat skin is favoured over other animal hides for its exceptional balance of tensile strength and thinness, providing both resilience and durability. Premium-grade skin is typically sourced from the belly region of young, disease-free goats, as this area yields skin that is more flexible, softer, and acoustically superior. The skin is considered premium if it comes from a young, healthy goat, specifically from the belly region. In contrast, the skin of older goats tends to be stiffer, thicker, and more brittle.[1] These properties contribute not only to enhanced tonal clarity and ease of tuning but also to greater longevity, as more flexible membranes are better equipped to withstand environmental changes and frequent tuning, which cause the skin to expand and contract over time.

Before use, the skin undergoes meticulous inspection to ensure it is free from defects such as scars, tick bites, or insect damage.[2] The processing method significantly influences the acoustic behaviour of the resulting Pudi. The rawhide is first cleaned to remove residual fat and hair, then soaked in water to soften the fibres. It is subsequently stretched and sun-dried to achieve the desired thickness, tension, and surface texture.[3] Each stage of this preparation affects the skin's elasticity, density, and tonal response, thereby directly impacting the tabla's sound production. Hair removal is commonly carried out using a chemical solution of sodium hydrosulfide and lime, which helps achieve a smooth, uniform membrane surface.[4]

There are two primary methods for removing fat and hair from raw goat skin during the tanning process.[5] The first relies on traditional techniques using natural materials, while the second involves the application of chemical agents. Traditional hide treatment methods include natural drying, oiling, and water curing, which help retain the skin's elasticity and enhance its ability to resonate sound. In some regions, artisans use alkaline plant ash to remove hair from the hide, preserving the organic quality of the membrane. In contrast, modern practices may involve chemical tanning agents such as basic chromium sulfate, which can result in visually lighter (whitened) skin. However, hides processed through traditional methods typically retain a yellowish tint, indicating a more organic preparation. Excessive chemical treatment can lead to skin stiffening, which negatively impacts the membrane's ability to produce the rich, resonant overtones characteristic of the tabla. Furthermore, the uniformity of the treated skin plays a crucial role in ensuring that the acoustical response remains consistent across different playing zones on the drumhead.[6]

The goat skin stretched across both the Dayan and Bayan of the tabla is composed of three distinct membrane layers: one full membrane and two additional layers positioned at the periphery. The first layer, known as the Bharti, is attached to the rim of the wooden shell (kaath) and provides structural support to the pudi. The second layer, called the Maidan or Lao, serves as the primary vibrating surface, while the third layer, shaped into a ring with its centre cut out, forms the Chanti. This non-vibrating reinforcement encircles the active membrane.

These layers are assembled and secured using a braided cord known as the Gajra, which is laced through a series of holes pierced into the edge of the pudi. In smaller tablas, this typically involves 48 holes, while larger tablas (with diameters exceeding 6 inches) may require 64 holes. The Gajra is then tensioned with leather braces (Baddi), which connect the membrane to another stabilising ring at the base of the drum. To ensure uniform tension and tuning stability, sixteen evenly spaced holes guide the placement of these braces. Precise tuning is essential; a tabla that is accurately tuned produces a more resonant and harmonically rich sound than one that is even slightly mistuned.[7]After this, the black paste (syahi) is applied to the tabla head to enable the production of harmonic overtones; without it, the instrument would resemble the timbre of a bongo, lacking tonal richness and pitch stability.

Syahi

The syahi, a specialised black paste composed primarily of iron filings, natural gum, and other organic materials, is applied in concentric layers to the central region of the pudi (drumhead). To expedite drying between successive applications and to ensure uniform distribution, artisans use a basalt stone, which is continuously rubbed over the syahi surface.[8] For optimal production of harmonic overtones, the diameter of the syahi should be around 50% that of the pudi.[9] When the syahi is applied at the membrane's centre, the drum is referred to as centrally loaded. In contrast, most non-loaded drums (the Timpani being an exception) typically produce inharmonic vibrations, which differ significantly from the harmonic overtones produced by loaded membranes, such as the tabla.

The syahi, or black tuning paste applied to the tabla's drumhead, is traditionally applied by hand, most commonly using the thumb to provide both control and uniform pressure during application. The preparation of the paste typically involves soaking rice in water for two to three days, after which it is mixed with finely ground charcoal and iron powder to create a dense, malleable paste. In certain regional traditions, powdered stone may be used as a substitute for iron filings, depending on local availability and tonal preferences. While many tabla makers continue to rely on family recipes and artisanal methods passed down through generations, others obtain pre-made syahi from commercial vendors who produce the paste in bulk for widespread distribution.[10]

To apply the syahi to the membrane, a small ball of the prepared paste is placed at the centre of the drumhead and carefully spread outward in a spiral pattern to achieve the desired thickness and acoustic response.[11] Multiple thin layers are applied sequentially, each polished and compacted using a smooth basalt stone. This polishing not only facilitates drying but also promotes the formation of characteristic microcracks, which are critical to the tonal quality of the instrument. While syahi has traditionally been dried naturally, modern tabla makers, particularly in urban centres such as Delhi, have adopted the use of filament bulbs to accelerate the drying process. These bulbs provide localised heat, enabling faster setting of each layer. This shift has been necessitated by the growing demand for tabla production and the challenges posed by unpredictable environmental conditions, including humidity and temperature fluctuations, which hinder consistent natural drying.

Both construction style and playing technique significantly influence the acoustic output of the tabla. Among the major regional traditions, the Calcutta and Bombay (or Pune) styles are particularly prominent. Assuming a high standard of craftsmanship, the style of construction contributes to the instrument's tonal identity. Calcutta-style tablas feature thinner membranes and a more delicate syahi application, producing a lighter, sweeter, and more resonant tone. In contrast, Bombay-style tablas use thicker skins and a denser syahi, resulting in a deeper, fuller, and more robust sound. These structural differences also affect durability; Bombay-style tablas are generally considered more resilient and suited for frequent use and travel.[12]

Understanding the acoustical properties of the tabla requires an examination of the underlying physical principles, most notably through the lens of Fourier analysis, a foundational concept in mathematical physics. The French mathematician and physicist Joseph Fourier demonstrated that any continuous function can be expressed as the sum of an infinite series of sine and cosine waves, a principle now central to modern signal processing.[13] This approach has widespread applications, particularly in the synthesis and decomposition of sound. The process of breaking down a complex waveform into its constituent sinusoidal components is known as Fourier analysis.[14]

To analyse a time-domain sound signal, such as that produced by the tabla, and convert it into the frequency domain, researchers use the Discrete Fourier Transform (DFT). However, due to the computational intensity of the DFT, a more efficient algorithm known as the Fast Fourier Transform (FFT) is employed.[15] This method enables detailed spectral analysis, allowing for the identification of the tabla's fundamental frequency and overtone structure, which are crucial to understanding its unique tonal characteristics.

To understand the vibrational behaviour of the tabla's membrane, it is helpful to draw an analogy with the vibration of a stretched string. A vibrating string oscillates along its length and naturally produces a series of harmonic overtones, which are integer multiples of its fundamental frequency. In contrast, the vibration of a circular membrane, such as that of a drumhead, is characterised by nodal circles and nodal diameters, which typically result in inharmonic overtones.

In theoretical models of an ideal circular membrane, the fundamental mode (0,1), where the entire membrane moves in unison, produces the lowest frequency. The first overtone (1,1) includes one nodal diameter and one nodal circle, occurring at approximately 1.59 times the fundamental frequency. The second overtone (2,1) features two nodal diameters and one nodal circle, with a frequency approximately 2.14 times that of the fundamental. The third overtone (0,2) consists of two concentric nodal circles and vibrates at approximately 2.30 times the fundamental frequency. [16]

However, in the case of loaded membranes, the introduction of mass loading through the syahi modifies the membrane's mass distribution and significantly alters its vibrational modes. The application of the syahi enables the generation of harmonic-like overtones, despite the membrane's inherent inharmonicity. This unique acoustical behaviour was first observed and explained by Sir C. V. Raman, who demonstrated that the tabla's tuning paste (syahi) enables a membranophone to produce tones that approximate a harmonic series, a property otherwise uncommon among drums.[17] Subsequent studies have refined Raman's findings, concluding that tabla overtones are nearly harmonic, though not perfectly so.[18]

The variations in the sound production among tablas tuned to the C# scale were examined by comparative frequency analysis conducted on nine different tablas. While multiple factors influence tonal quality, including drum dimensions, skin quality, and wood type, this analysis was designed to control for one variable in particular. All tablas examined were made from Red Sheesham wood, ensuring material consistency. However, each tabla was constructed by a different craftsman or workshop, thus allowing for an evaluation of variability due to craftsmanship and manufacturing practices. The tabla stroke "Na" was recorded from the moment of excitation until the sound fully decayed. This audio sample was then analysed using a Python program that applied the Fast Fourier Transform (FFT) to generate its frequency spectrum.

Of the nine tablas analysed, six were manufactured by Jonty Tabla Maker based in Delhi, one by Qasim Tabla Maker, one by Somnath Kakde from Pune, and one synthetic tabla by Vijay Vhatkar Tabla Makers in Mumbai. Despite the majority of instruments being sourced from the same maker (Jonty), there was no uniformity in tonal quality, highlighting the inherent inconsistencies in handmade instrument construction. This lack of consistency can be attributed to two main factors. First, the tabla-making process remains manual and artisanal and, therefore, subject to human variability. Second, many well-known tabla makers do not personally construct each instrument; instead, they employ teams of 8-10 craftsmen from different regions of India. These craftsmen handle the majority of the production process, while the lead maker is typically responsible for fine-tuning and final quality control.

Although only some of the tablas were precisely tuned to C#(554.7Hz), they all fell within a similar fundamental frequency range. The primary focus of this analysis, however, is not exact tuning but rather the spectral content of the overtones produced by each drum. Moreover, tabla players typically tune their instruments by ear, aligning them with the pitch of a tanpura rather than using electronic tuners. To reflect this real-world practice, the tablas analysed in this study were also tuned by ear. Among tabla players, there are two prevailing perceptions regarding overtones. One view holds that a greater number of overtones leads to a fuller and more resonant tone. Conversely, others believe that fewer overtones yield a clearer and more aesthetically pleasing sound, emphasising tonal purity over harmonic richness. These contrasting viewpoints frame the interpretation of the FFT spectral graphs provided in the following section.

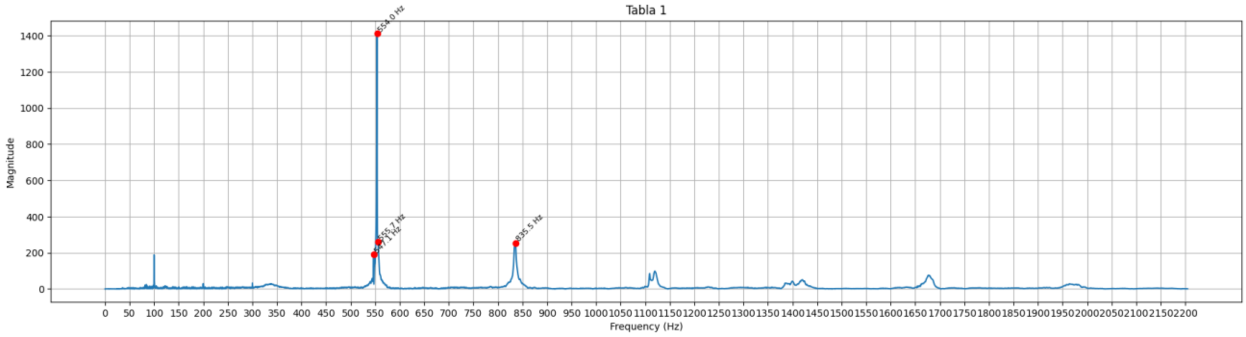


Tabla 1
Magnitude
Frequency (Hz)

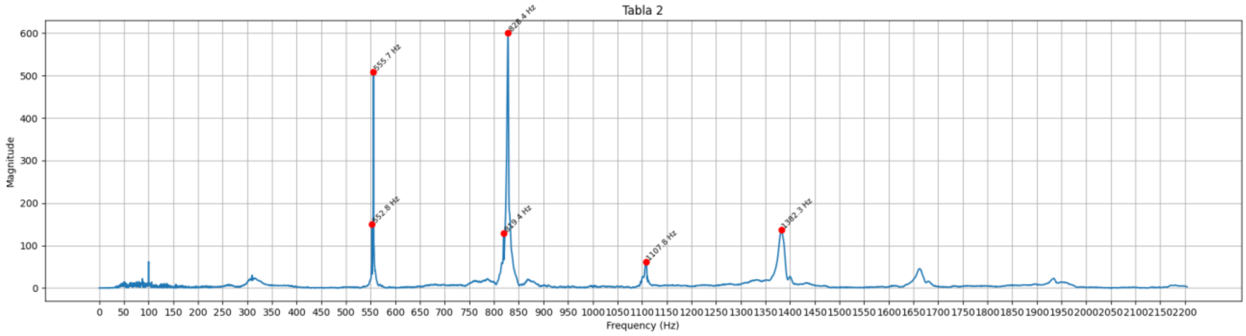
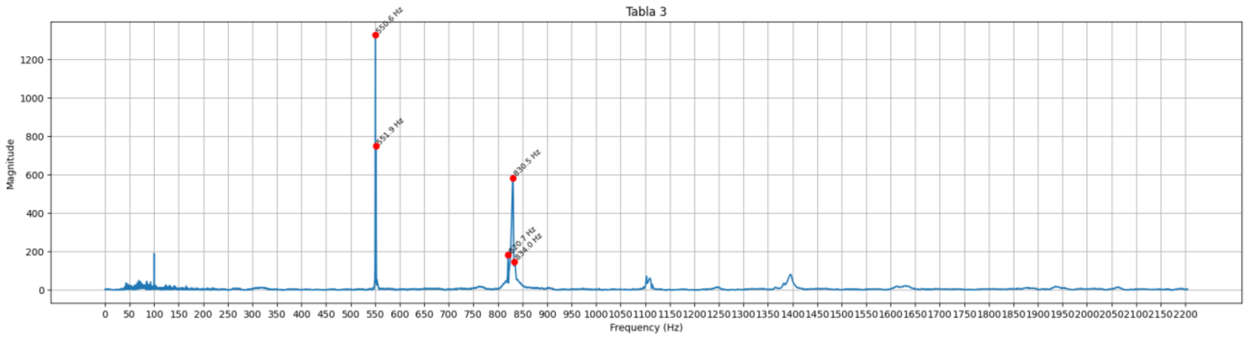


Tabla 2
Magnitude
Frequency (Hz)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Magnitude
Frequency (Hz)

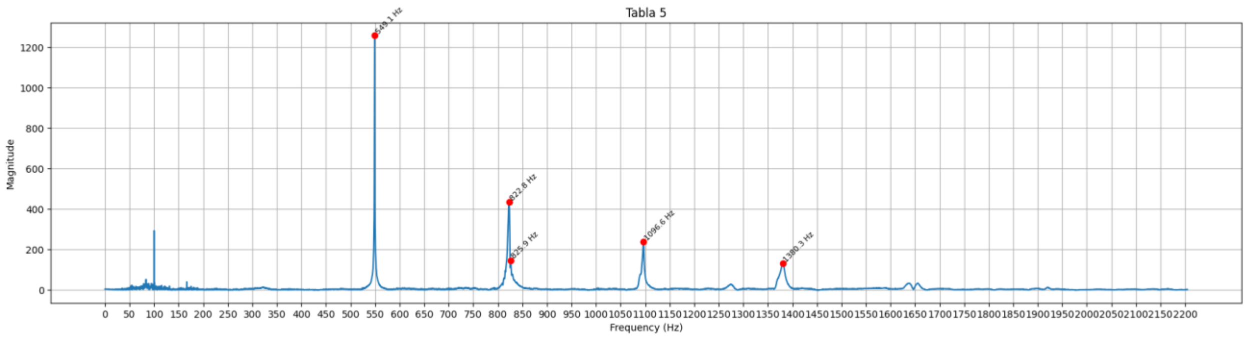
Tabla 5
Magnitude
Frequency (Hz)

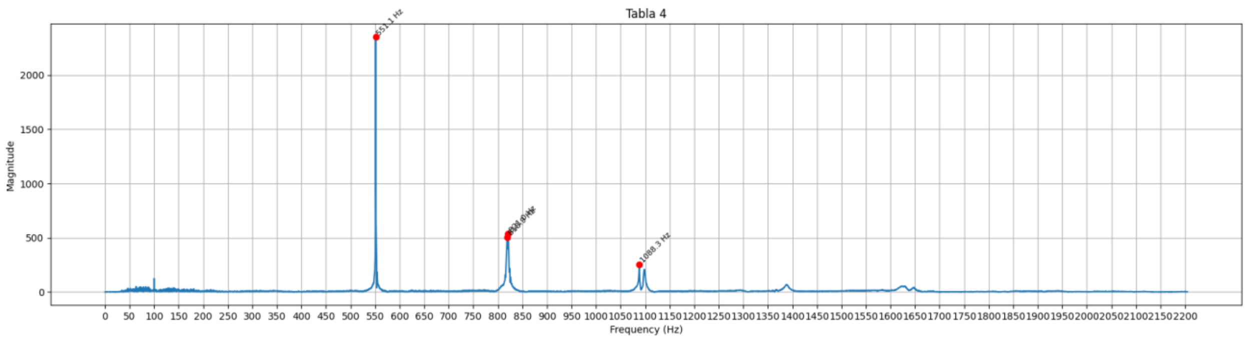
Tabla 4
Magnitude
Frequency (Hz)

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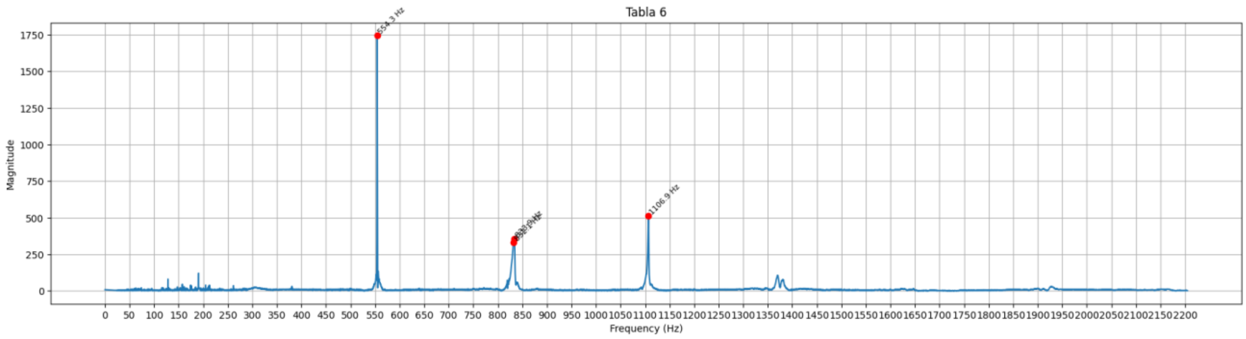

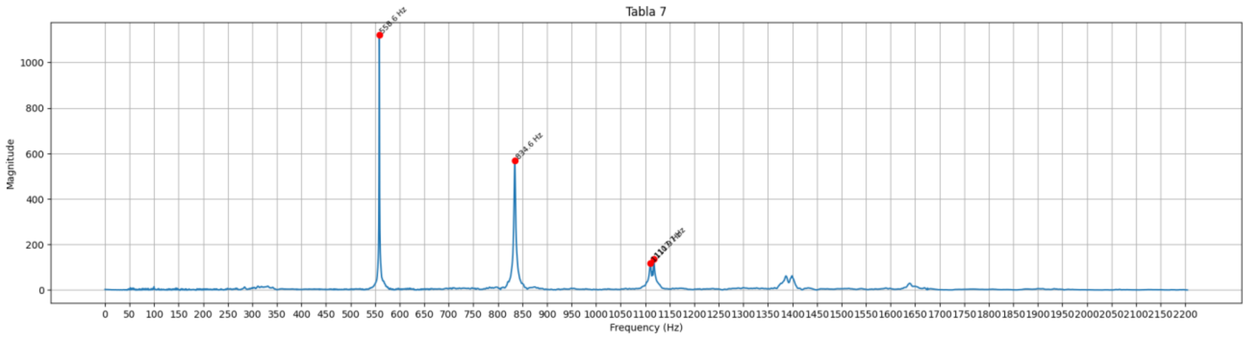

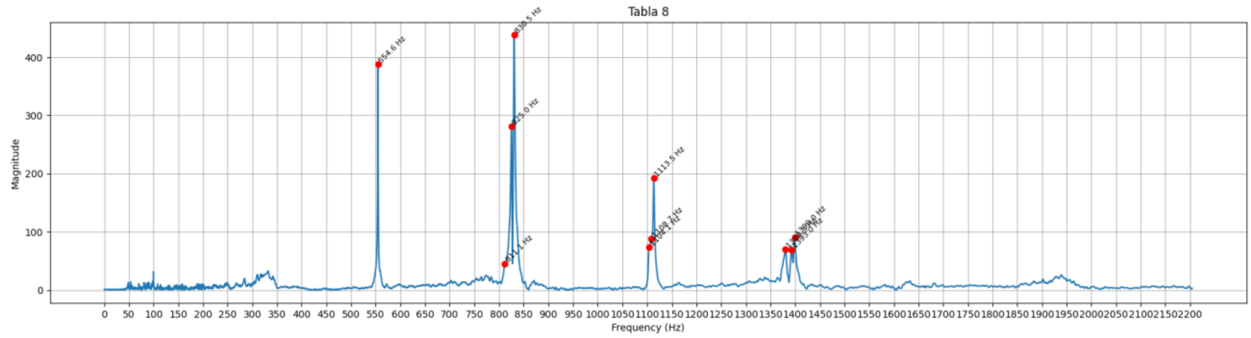

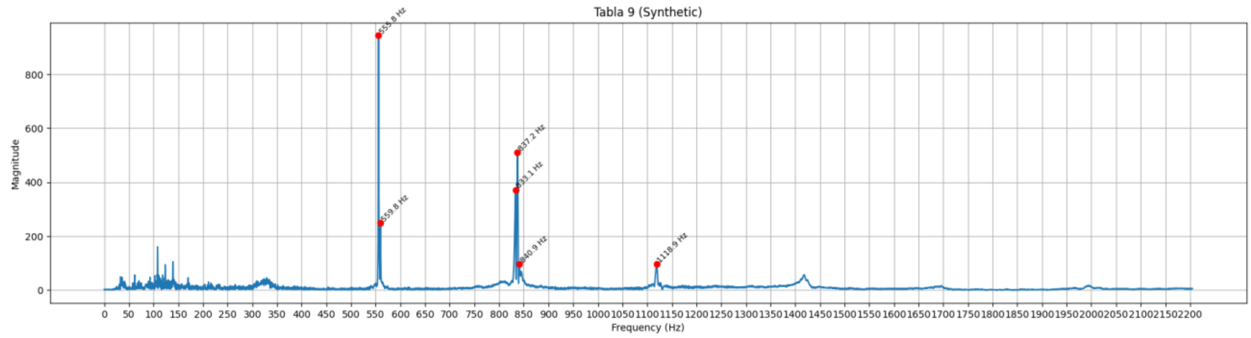

All of the nine tablas analysed in this study produce a distinct set of overtones, reflecting variations in construction and the application of syahi. In the context of Indian classical music theory, and taking the fundamental frequency as Shadaj (Sa), the most commonly observed overtones correspond to Pancham (Pa) at approximately 832 Hz, the upper Shadaj (Sa') near 1109 Hz, and the upper Gandhar (Ga') around 1386 Hz.

As established in prior studies, the overtones often appear as partial harmonics of a slightly lower fundamental, a phenomenon consistently observed across multiple investigations. Research by Patranabis et al. (2015), Malu and Siddharthan (2000), Gopalakrishnan and Adhikari (2009), and Rossing and Pujara (2003) confirms that while the tabla is unique among membranophones in producing overtones that closely approximate a harmonic series, these are not perfectly harmonic. Instead, the instrument achieves what may be termed psychoacoustic harmonicity, in which the listener perceives the tones as harmonic, even though spectral measurements reveal minor deviations, particularly in the higher frequency regions.

Given the availability of empirical data from nine different tablas, the following section attempts to quantify the degree of deviation between the fundamental frequency and its observed overtones. The following table presents the measured fundamental frequency (Sa) for each tabla, along with the ideal Sa derived from analysing the overtone structure. The “Adjustment (Hz)” column quantifies the difference between the measured and ideal fundamental, indicating how much the current Sa would need to be adjusted to achieve just intonation. The “Adjustment (%)” provides the corresponding deviation as a percentage of the measured Sa, offering a normalised view of tuning accuracy.

Frequency Adjustments of Fundamental (Sa) Across Nine Tablas

Tabla	Original Sa (Hz)	Ideal Sa (Hz)	Adjustment (Hz)	Adjustment (%)
1	554.00	557.00	-3.00	-0.54
2	555.70	553.02	2.68	0.48
3	550.60	552.78	-2.18	-0.40
4	551.10	545.74	5.36	0.97
5	549.10	549.65	-0.55	-0.10
6	554.30	554.69	-0.39	-0.07
7	558.60	555.92	2.68	0.48
8	554.60	555.87	-1.27	-0.23
9	555.80	558.79	-2.99	-0.54

As noted by Rahul Siddharthan, Pinaki Chatterjee, and Vikram Tripathi (1994), “Typically, the frequencies were in the ratio 1.07:2:3:4... The overtones can thus be regarded as harmonics of a missing fundamental, the actual fundamental being too high.” While this model suggests that tabla overtones can be interpreted as harmonics of a missing lower fundamental, the present study was unable to replicate these ratios for all 9 tablas. As observed in the data, some tablas do exhibit higher-than-ideal fundamentals; in contrast, others fall below, a deviation likely due to underdeveloped or inconsistently applied syahi or uneven tension on the membrane. There appears to be a “sweet spot” in the syahi application, both in mass and distribution, that enables the fundamental frequency to align more closely with the overtone series. According to the RS54 model proposed by Ramakrishna and Sondhi (1954), the thickness of the syahi should be approximately 9.765 times that of the base membrane, with its radius being 0.4 times the radius of the circular membrane.[19] However, in practical observations, most tabla makers construct the syahi with a radius closer to 0.5 times that of the membrane, rather than the theoretically suggested 0.4, and the density of the syahi is according to their experience and intuition.

Among the tablas tested, tabla 6 demonstrated the lowest discrepancy, requiring only a –0.39 Hz adjustment (–0.07%), suggesting it is nearly perfectly harmonic. In contrast, tabla 4 showed the highest discrepancy, with a +5.36 Hz adjustment (+0.97%), indicating that its current Sa is significantly higher than the harmonic ideal.

Overall, most tablas exhibited deviations of less than 1%, reflecting a generally high degree of tuning alignment with harmonic overtones. This variation invites further inquiry into the physical characteristics of the syahi in each instrument. A comparative analysis of the syahi used in tabla four and tabla six may offer additional insight into how construction techniques influence acoustic outcomes.

Image 1: Tabla 4

Image 2: Tabla 6

The well-defined concentric circles observed on tabla 6 (image 2) indicate a well-developed and evenly applied syahi, which correlates with its minimal deviation from the ideal Shadaj frequency. In contrast, tabla 4 (image 1) exhibits signs of an underdeveloped syahi (lacking concentric circle development), which likely accounts for its higher discrepancy from the ideal fundamental.

Tabla 9, constructed with a synthetic membrane, produced results comparable to traditional goat-skin tablas, suggesting that synthetic alternatives could standardise tonal quality. Unlike natural materials, synthetics allow precise control over thickness, tension, and syahi application, minimising artisanal variability. They also offer an environmentally sustainable option. With advances in high-resolution 3D printing, production could soon be calibrated to replicate the acoustic performance of handcrafted tablas, enabling consistent, high-quality instrument design.

Conclusion

The tabla has evolved into one of the most complex and expressive percussion instruments, not only in terms of its intricate playing techniques and broad applicability across musical genres but also due to its unique ability to produce harmonic overtones. Traditionally, most Western membranophones generate inharmonic partials; the tabla, however, stands out by producing overtones that closely approximate a harmonic series. This feature is primarily attributed to the central mass loading (syahi) applied to the membrane, which alters the vibrational modes of the drumhead.

C. V. Raman (1921) was the first to document this acoustical phenomenon, asserting that the tabla produces harmonic overtones that are integral multiples of the fundamental frequency. His hypothesis was later nuanced by studies such as those by Patranabis (2015), Gopalakrishnan and Adhikari (2009), and Rossing (2003), which showed that the tabla's overtones, while perceived as harmonic, exhibit slight deviations from exact harmonicity. These studies also observed that the perceived pitch (Sa) may not always align with the actual fundamental frequency, which is often suppressed or slightly detuned and may instead emerge from the second or third partials.

This study reinforces these findings, particularly concerning the role of syahi application, while also addressing gaps in previous research by suggesting that the fundamental frequency may not only be higher but could also be lower than the theoretical ideal. Tabla six was perceived as the most pleasing in tone. This may be due to the absence of overlapping or closely spaced overtones, which can lead to degenerate modes and diminished tonal clarity. Moreover, the magnitude and sustain of overtones relative to the fundamental shape the instrument's psychoacoustic perception: listeners often perceive a stable pitch even when the fundamental is not strictly harmonic.

While sustained resonance is desirable, the strength and spectral distribution of overtones are equally important. This study found that insufficient syahi produced excessive, diffuse overtones. The most favourable tonal outcome occurred with an evenly distributed and well-constructed syahi, which is thickest at the centre, yielding strong sustain (aans) and an optimal overtone balance.

The question of how many overtones a tabla should ideally produce remains subjective, depending on aesthetic preferences and musical context. What is clear, however, is that the balance between the fundamental frequency and overtones, rather than the sheer number of partials, plays a defining role in tonal perception. While this study focused only on C# scale tablas, future research could be done to include tablas in other pitch ranges, as well as a larger sample size for more generalisable results.

Given the inherent inconsistency in the construction of traditional tablas, due to variations in animal skin, syahi mixture, and artisanal craftsmanship, this study suggests that synthetic tablas offer the most viable path toward standardisation. Moreover, such synthetic alternatives are also more environmentally sustainable, as they avoid the unethical and logistical complexities associated with animal-derived materials.

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