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Research article

Verification of Raman's observations about the Indian Percussion Instruments

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ABSTRACT

Tabla is a highly significant percussion instrument, originally from northern part of India. It is mainly used to accompany vocal, instrumental and dance music. It has two parts as dayan/ Tabla (right hand drum) and dagga/ bayan (left hand drum). Tabla produces different sounds from its both parts (Dayan and Bayan), which are called as 'alphabets', `bol' or syllables. The art of a Tabla player is to selectively excite and suppress mechanical vibrations by sophisticated striking and fingering techniques. Any musical sound, even a single note from an instrument, contains multiple frequencies components, where some are in harmonic and do not follow integer multiples of the fundamental frequency. The unique acoustic characteristics of the percussion drums Mridangam and Tabla were first reported by the great physicist C.V. Raman. He reported that overtones produced by the sound of these drums are in an integer ratio as are the overtones of a vibrating string. The harmonic character of Tabla syllables was further modified by different scientists and researchers. The relation of fundamental and overtones of the sound of Tabla is a very important factor to analyze the physical characteristics of the syllables produced by Tabla. The purpose of this research work is to verify Raman's observation on Tabla harmonics. Overtone relationships, harmonic tendencies and traditional beliefs were examined by spectral analysis of Tabla syllables using 3D spectrum. This affects acoustic modelling, which will be useful in designing of percussion instruments.

1. Introduction

In 1919, great physicist Sir C.V. Raman initiated a series of experiments to investigate the physics of the Mridangam, an instrument that predates the Tabla. Further, he ~~has~~ conducted extensive research on the science of vibrations produced by the Indian percussion instruments. The first available scientific study for a scientific description of the sound produced by Indian percussion instruments was presented in his book "Musical Drums with Harmonic Overtones" in 1920 (Raman, 1920). His findings were published in 1934 in the Proceedings of the Indian Academy of Sciences under the title "Indian Musical Drums" (Raman 1934). Further, he reported that "Equal tension around the dayan is a critical process and is required for the proper tuning of this part. Therefore, it is evident that the inventors of the drum not only recognized the importance of equalizing the tensions but also emphasized having precisely the correct number of tension equalisers, i.e.

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sixteen. This structure is common all over the world. Raman later expanded on this work in subsequent studies, as documented in later publications (Banerjee and Nag, 1989; Banerjee 1989; Rossing 1992). David R. Courtney explained the characteristics of the multi-layered composite membrane of tabla (Courtney, 1999). G. Venkataraman explained about the effect of non-linear density distribution on the tonal quality of Tabla/Mridangam (Venkataraman et al. 2005). Siddharthan, Pinaki Chaterjee and Vikram Tripathi at St. Stephen's College, Delhi, India studied the harmonic overtones produced in Indian drums. The first time, the result of their experiment differed slightly from that of C.V. Raman's experiment (Siddharthan et al. 2019). Raman's experiments were done mainly on Mridangam. He offered only suppositions and suggestions about the vibrations produced by the Tabla, in a similar way to the Mridangam.

Tabla is the most popular percussion instrument for accompanying with all the three forms (Geet-Vocal, Vadya-Instrumental and Nritya-Dance) of the music. It has two parts known as Dahina (Right) and Bayan (Left). The sounds, created by striking with the fingers at different locations on the tabla, are called 'Alphabets' or 'Varnas' or 'Syllables' or Bols of Tabla. The central black paste of the exposed skin is called Syahi, while the empty space on the drumhead between the rim and syahi is called lav or maidan. Both skins are laced to an interwoven leather thread having 16 holes around the edge. A long leather thread (Baddhi) weaves these 16 points (Ghar) on the outer edge of membranes to a leather hoop (Gujari or Gurri) located at the base of the drum. This baddhi fastens the skin to the drum itself. In Dayan, 8 cylindrical wooden wages (Gattas) are equally placed between the wood and these straps. The holes on the upper ring of weaved leather are always 16 in both parts of the tabla. To make a balance, a player uses the rings at the bottom of the tabla, which are prepared by cotton cloth and baddhi. Due to the geometry of the tabla, by lowering the gatta position, one can increase the tension (pitch) on the membrane. A tabla player fine-tunes the drum by tapping on the edge of the membrane.

In the case of tabla, membrane is not a uniform one but a composite one whose thickness and density vary along with the diameter of puri (head skin). After loading the membrane, it acts in such an acoustic manner as that of a string instrument. It converts the nine inharmonic tones to the five harmonic tones.

Fig. 1. Dahina of Sagwan wood and Bayan of Brass and Nickel polish

2. Mechanics of the stretched membrane of Tabla

Mechanics of a stretched membrane has been explained by Raman (1934) for the first time. He wrote that the tabla's membrane is tuned and damped in such a way that all overtones above the ninth are eliminated, while the remaining nine are arranged to produce a sequence of five tones in harmonic order (Raman 1934). Raman's theory was further modified by different scholars at different times. Non-uniform loading of a Tabla puri is shown in Fig. 2. In reference of this non-linear Tabla is a drum set having a membrane of fine goatskin on its upper surface (drumhead). If it is struck, a disturbance (wave), a two-dimensional pulse travels outward from the struck point

density of loading, great physicist G. Venkataraman writes; "Mathematical analysis shows that, because of this non-linear density distribution, the higher modes of vibration become harmonics, and that is what adds to their tonal quality. This was a beautiful though empirical discovery of our ancients, and Raman provided a scientific explanation (Venkataraman, 2005).

3. Vibrations in the membrane of Tabla

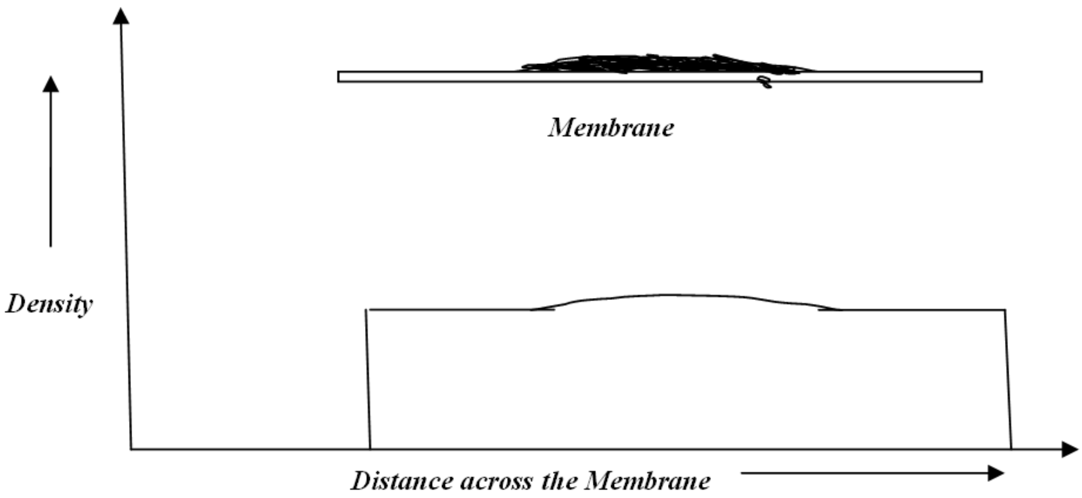

Fig. 2. Schematic of the density variation of the membrane of Tabla

and is reflected repeatedly at the boundary of membrane. The nodes of a vibrating membrane are lines rather than points (as in a vibrating string). Since the boundary of membrane is fixed, it must be a nodal line. For a circular membrane fixed at its boundary, possible modes of vibration together with their nodal lines are shown in Fig. 3.

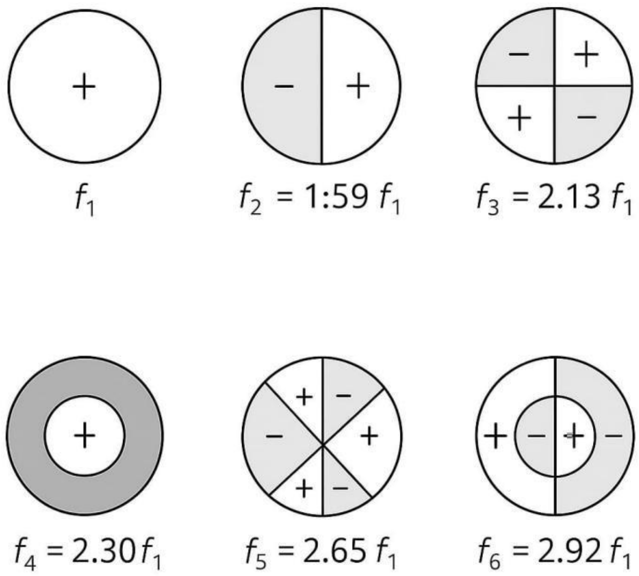

Fig. 3. Modes of vibrations in an unloaded membrane on Tabla

The natural frequency of each mode is given in terms of the fundamental f_1. The frequencies of the overtones (f_2, f_3....f_6) are not harmonics means they are not the integral multiples of f_1. Lower six resonant modes of a circular drumhead fixed at its rim are shown in the Fig. 3. The lines represent nodes. The rim is also a nodal line. The '+' (positive) and '–' (negative) signs indicate that a particular region is moving up out of the page or down into the page, respectively. In this case, the overtones are not integral multiples of the fundamental and are thus not harmonics (Resnick et al.1994).

The modes of vibrations of a loaded tabla membrane (with syahi), according to C. V. Raman are shown in Fig. 4. Sir C.V. Raman explained the harmonic relationship between the five resultant frequencies. According to him, the harmonic relationship among the five tones of the drum becomes evident when they are excited sequentially in a specific manner. The fundamental tone corresponds to the vibration of the drumhead as a whole. The second harmonic arises when the drumhead vibrates in two equal sections, divided by a nodal diameter. The third harmonic occurs when the drumhead is divided into three sections by two parallel nodal lines. In the fourth harmonic, it vibrates in four parts separated by three parallel nodal lines, while the fifth harmonic corresponds to vibration in five parts divided by four nodal lines. This behavior shows a striking resemblance to the simple case of a stretched string set into vibration (Raman, 1934).

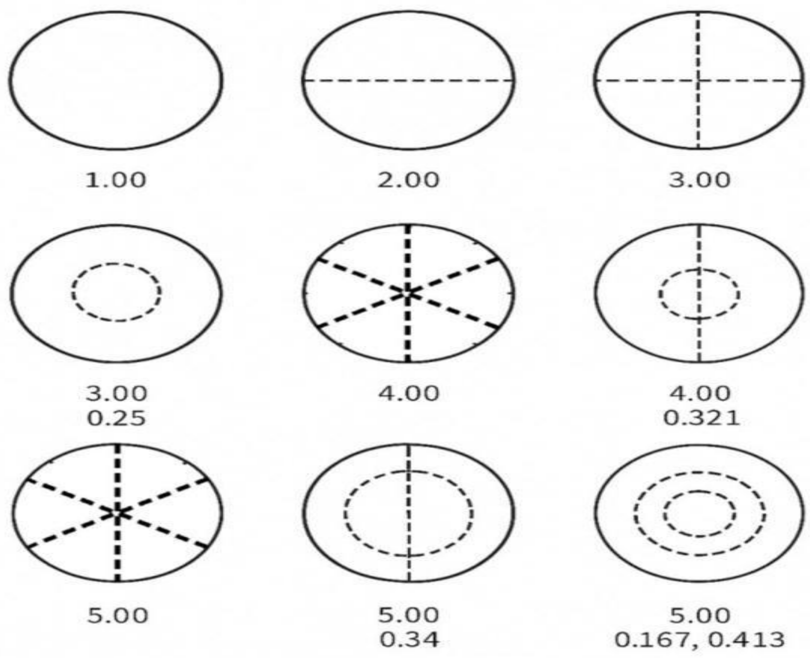

Fig. 4. Normal modes of a loaded harmonic drum with Syahi

Researchers showed that with the application of each successive layer of syahi, certain overtone frequencies which are normally produced by different vibration modes and gradually shift closer together, approaching a corresponding harmonic overtone. By the time the process is complete, several distinct overtones converge to share the same frequency (Courtney, 1999). The objective of this research work is to verify Sir Raman's observations about Indian Percussion Instrument. Analysis of the relation between overtones and their respective frequencies for a single syllable (hit) is very important to understand the timbral beauty of syllables of Tabla. These parameters have not been discussed enough till now. The Tabla certainly gives the impression of a definite pitch or sruti and is tuned to the tonic, 'sa', of the scale in the performance. It was reported by Raman that the first nine normal modes of these drums do, in fact, have frequencies in integer ratios, so that the resulting sound is periodic. This is achieved by carefully "loading" the membrane at the centre with a heavy paste to modify the modes of vibration and cause the eight inharmonic overtones to convert to four harmonics.

On the observation of above, the major finding by measuring the frequencies of several drums, it was found that the overtones were, in fact, not harmonic, though they were in integer ratios to each other. Practically, 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.

The effect is in fact quite noticeable when the instrument is played: most notes excite higher harmonics and are tuned to the tonic sa, but one particular note, called 'Dhin' and played by striking the membrane sharply at the centre excites primarily the fundamental and sounds notice this higher than the tonic. Neither Raman nor later authors e.g. Rossing, appear to have noticed this." Later, Siddharthan, (2019) has reported an article on 'A Study of Harmonic overtones Produced in Indian Drums' but could not successfully explained it.

In this continuation, we have tried to analyze the physical parameters through the experiments on the different syllables of Tabla to verify the results obtained by Raman etc, and fill the research gap.

4. Syllables of Tabla:

According to general accepted phenomenon, there are 10 basic syllables of Tabla as follows:

On right hand drum (Dahina)

1. Ta or Na, 2. Tin or Ti, 3. Din or Thun, 4. Tai or Te, 5. Tte or Re, 6. Tun or Tu

On left hand drum (Bayan)

7. Ka / Ke / Kai / Kat, 8. Ga or Ghe

Joint syllables

9. Dha and 10. Dhin (Sharma, 1987).

5. Experimental setup

Experimental analysis of the syllables of tabla is an important factor to understand the characteristics of the sound produced by tabla. Five Dahinas, two Bayans, Recording software Nuendo 8, Mixer Sound craftlive 8 and Audio interface Apollo 8 by universal audio, Condenser microphone – mxl 603, were used to analyze the sound characteristics of Tabla.

To analyze all these parameters, the spectral frequency graph (3D Spectrum) with time (in seconds) on X-axis and frequency (in Hertz) on Y-axis and amplitude (as the third component of 3 D Spectrum) as warmth of colour has been analyzed for prominent syllables of tabla. For accurate measurement of amplitude, a waveform graph was used with time (in ms) on X-axis and amplitude (in 'dBFS' stands for decibels relative to full scale) on Y-axis. To complete this experimental work, several strokes of different syllables were recorded on different sets of tabla pairs in a digital studio in a professional recording studio environment, using balanced audio at every part of the signal flow to reduce any electromagnetic interference. Room temperature was 21-24°C and variation in % relative humidity was 30-50%. Recording of syllables was done in an acoustically treated room with minimal reflections. Microphone distance was set as 10 to 12 inches, mid-top facing down. A single expert player was used.

5.1. Data Analyzing Procedure:

The spectral frequency graph (3 D Spectrum) with time (in seconds) on X-axis and frequency (in Hertz) on Y-axis was analyzed for each syllable from the 'Adobe Audition Software (2015)' at sample rate 48 KHz and a bit depth of 32 bits. The amplitude (as third component of 3D spectrum) is represented by warmth (in colour and brightness) of the band. The blue colour with low brightness depicts low amplitude of that particular frequency band (on right) and yellow with high brightness depicts high amplitude. Bands can be separated, and their amplitude can be measured on a scale of dBFS. In digital sound recordings, it is used for amplitude levels with a maximum available peak level. The level of '0' dBFS is assigned to the maximum possible digital level.

While analysing the 3D spectrum of some resonating syllables, we got a band of frequencies below the fundamental also. These bands are undertones and are responsible for a significant part of energy of the syllable i.e. energy of the hit in case of Tabla playing. These frequencies also include sub-harmonic frequencies. These are the frequencies below the fundamental frequency in a ratio of $1/n$, where 'n' is a positive integer. An audio signal below -59 dBFS threshold is considered to be silence. Time - Amplitude Graph was also analyzed for some syllables.

In Tabla, fundamental and resonating frequencies or harmonics have particular frequencies and they are usually fixed, but, non-harmonics are not well defined and actually cover a bandwidth as per the reference (Sharma et al. 1986). Therefore, during analysis, it was found that only a band of frequencies, although very narrow, can be analyzed. Analyzed frequencies may vary from ±10 to ±25 Hz in different overtones. Mean of the band has been used to analyze the ratio of frequencies for overtones. DahinaTabla, used for the experiments, was tuned at 'C_5' note.

5.2. Experiments with different Syllables of Tabla

The characteristics of many syllables of Tabla were analyzed. Here the analysis of two syllables from dayan ('Ta'- Lav Part and 'Tun') and one of the joint syllable (Kran) are discussed below:

5.2.1 'Ta' from Lav part of Dahina:

The spectral frequency graph (3 D Spectrum) with time (in seconds) on X- axis and frequency (in Hertz) on Y-axis was analyzed for this syllable from the Adobe Audition Software. By analyzing the syllable 'Ta', we got most bright fundamental tone between 520 Hz to 534 Hz (Mean – 527 Hz) at the sample rate 48 kHz and bit depth 32 bit. This fundamental tone lasts for 2.5 s. It is indicated by the largest impression in Fig. 5.

A clear sub-harmonic (C note of the lower octave) between frequency range 260 Hz to 264 Hz (Mean – 262 Hz) was observed and it lasts for 2.8 s.

First overtone was obtained between 776 Hz to 790 Hz (Mean – 783 Hz) and it lasts for 0.9 seconds. The intensity and duration of the first overtone were less than half of the fundamental.

The second overtone was obtained between 1.03 kHz to 1.06 kHz (Mean – 1045 Hz) and it lasts for 0.82 s. This was less bright in comparison to the first overtone. The third overtone was obtained between 1.35 kHz and 1.39 kHz (Mean – 1370 Hz), and it lasts for about 0.40 s. This was a little brighter than the second overtone, with less sustaining.

The fourth overtone was noted between the frequency range from 1.62 kHz to 1.66 kHz (Mean – 1640 Hz), and it lasts for about 0.72 s. The fifth overtone was recorded between 1.92 kHz and 1.97 kHz (Mean – 1945 Hz) and it lasts for about 0.15 to 0.20 s. This was brighter than 3^{rd} and 4^{th} overtones. The sixth overtone was obtained between 2.23 kHz and 2.26 kHz (Mean – 2245 Hz), and it lasts for about 0.17 s. This was noted with light intensity.

The seventh overtone was recorded between 2.58 kHz and 2.62 kHz (Mean – 2600 Hz) with longer sustain, and it lasts for about 0.67s. This was a bright overtone. This overtone was producing *'G'* (Pancham) note.In an octave, G note is the 7^{th} semitone in the right. The seventh overtone produces the sound of G note, thus it is a scientific verification of the traditional concept.

The eighth overtone was noted between 2.88 kHz and 2.92 kHz (Mean – 2900 Hz) and it lasts for about 0.26 s. The ninth overtone was obtained between 3.12 kHz and 3.16 kHz (Mean – 3140 Hz) and it lasts for about 0.49 s. This was noted with light intensity. 10^{th} and higher overtones were not cleared, and hence it was not possible to observe them with accuracy. In Tabla playing, Attack is the most important factor to produce sound. This factor greatly affects the acoustic nature of the sound produced by the tabla. The ratio of these frequencies starting from sub-harmonic, first harmonic, first overtone, second overtone…..up to ninth overtone of this syllable was calculated up to three points after decimal.

The result thus obtained was;

1: 2.011: 2.989: 3.989: 5.229: 6.260: 7.424: 8.569: 9.924: 11.069: 11.985

Here we see that this ratio is almost linear up to the second overtone (underlined-3.989). After the second overtone, frequency increases in a slightly greater manner. This depicts that the tones with higher frequencies, which are present due to characteristics of the skin and body of the Tabla, correlate less with the fundamental as the frequency goes high. Further, the variation in amplitude verses time graph through ADSR envelop was analyzed (In sound and music, an envelope describes how a sound changes over time). The most common kind of envelope generator is ADSR i.e. Attack, Decay, Sustain and Release). Attack refers to the time it takes for the sound to go from silent to the loudest level. The decay time refers to the duration in which the sound goes from the initial peak of the attack to the sustain level. In case of the sound produced by Tabla, the sustain time is almost zero. Release time depicts the time which is taken by the sound to return to silence after hitting the finger on the skin of the Tabla. In musical terms, the release of the non-sustaining instruments is often termed as sustain. A longer release time represents a longer sustain.

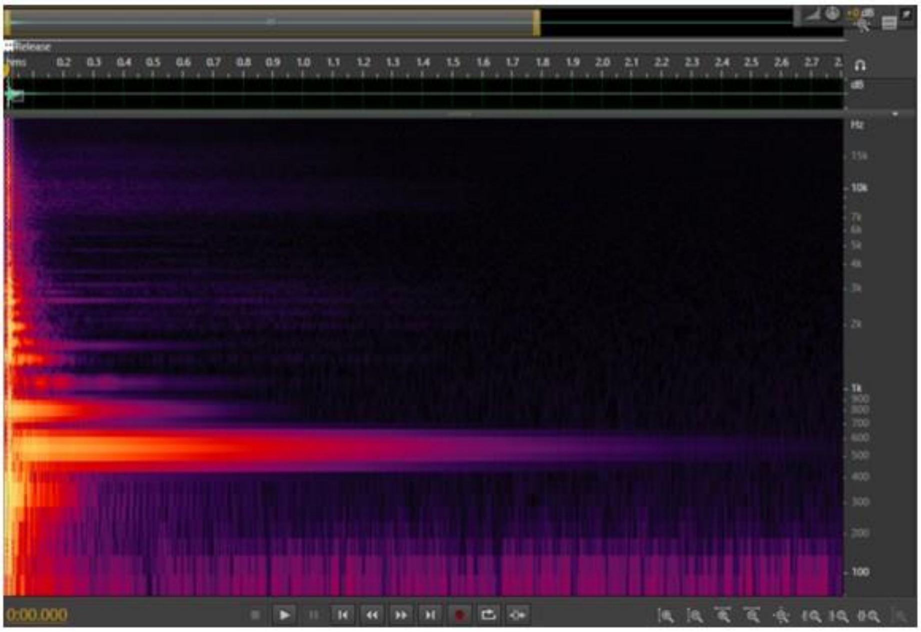

Fig. 5. 3D Spectrum of 'Ta' Syllable on Lav Part of Dahina

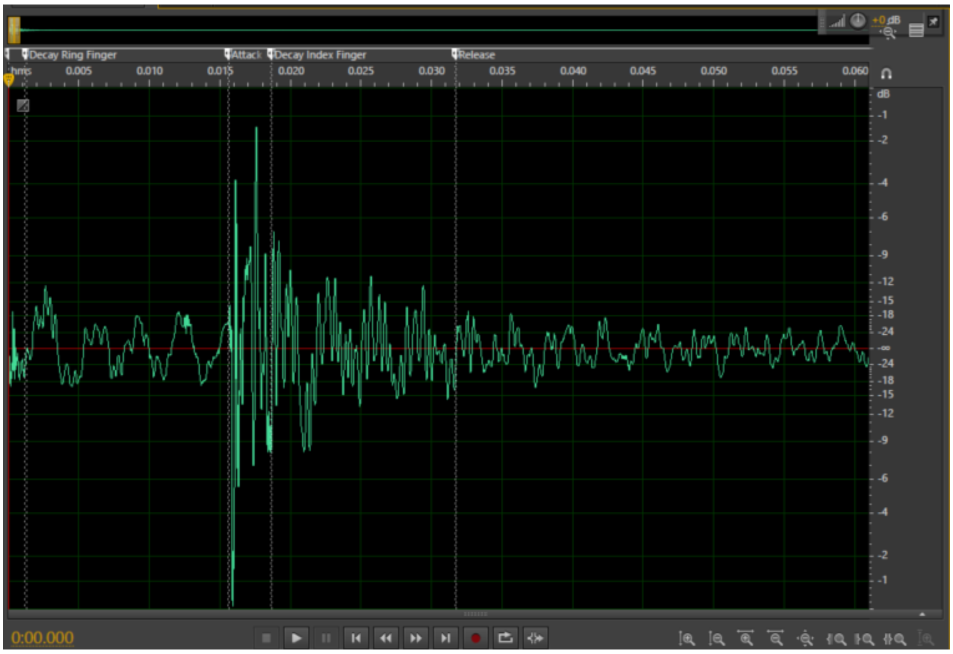

Fig. 6. Attack, Decay and Release Graph for the Syllable 'Ta'

Here, time (in seconds) is on the X-axis and amplitude (in dBFS) is on the Y-axis. Fig. 6 represents the overall variation of amplitude (hence intensity) of the produced sound with respect to time. The beginning part of the Time – Amplitude graph is elaborated in Fig. 7. Here, the attack and decay timings of the ring finger and index finger are separated by the bright vertical lines. The first section from the left represents attack time of the ring finger. This time was measured as 0.0013 s i.e. 1.3 ms. Decay time for this hit was measured as 0.0140 s i.e. 14.0 ms.

By above data we conclude that the ring finger hits the membrane around 15.3 ms before than the hit of the index finger on the membrane, while playing the syllable ‘Ta’ on the Lav part of Dahina. The attack time for the index finger was noted as 3 ms, and the decay time for the same was 13 ms. The release time for the sound produced by the index finger was noted as 2.5 s.

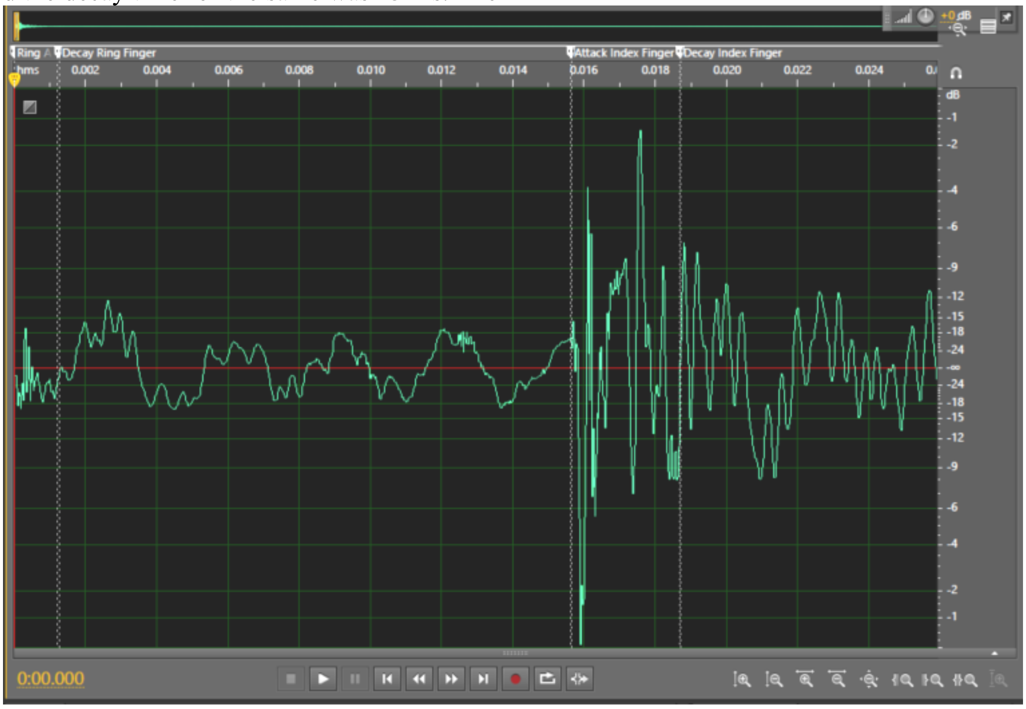

Fig. 7. Attack and Decay of Ring and Index Finger for ‘Lav ka Ta’.

5.2.2 Syllable ‘Tun’

By analyzing the syllable ‘Tun’, a most bright and long-lasting fundamental tone was obtained between 286 Hz and 302 Hz (Mean - 294 Hz). This fundamental tone lasted for about 2.9 s. This tone was producing *‘D’* note of the lower octave. This is the traditional saying that if Dahina is well constructed (right placement of syahi) then the Syllable ‘Tun’ should produce next sur i.e. *‘D’* in our case. This traditional saying is verified scientifically by the experiment. 3D Spectrum for the syllable ‘Tun’ is given in Fig. 8. **First overtone** was weak, long lasting, producing the note ‘*C’*. This was recorded between 510 Hz to 540 Hz (Mean - 525 Hz) and it lasts for 1.9 s. **Second overtone** was bright and was producing note *‘G’*. This was obtained from 775 Hz to 800 Hz (Mean ≃ 788 Hz) and it lasts for 0.47 s. **Third overtone** was again weak. It was obtained between 1.05 kHz to 1.08 kHz (Mean - 1065 Hz) and it lasts for 0.24s. This overtone was producing note *‘C’* of higher octave. **Fourth overtone** was brighter (of higher intensity) than third one. It was noted between the frequency range from 1.34 kHz to 1.37 kHz (Mean - 1355 Hz) and it lasts for 0.19 s. **Fifth overtone** was recorded between frequency range 1.60 kHz to 1.63 kHz (Mean - 1615 Hz) and it lasts for 0.13 s. **Sixth overtone** was obtained between 1.93 kHz to 1.96 kHz (Mean - 1945 Hz) and it lasts for 0.09 s. This was brighter than the fifth one. **Seventh overtone** was obtained between 2.21 kHz to 2.24 kHz (Mean – 2225 Hz) and it lasts for 0.06s. **8th and higher overtones** of this syllable were not clear and hence it was not possible to observe.

‘Tun’ syllable is a powerful stroke of tabla and has a characteristic fundamental producing the note *‘D’* of the lower octave. Expert tabla players play the compositions of ‘Tun Na’ very clearly and thus emits the melodious sound of ‘Re – Sa’ of the Saptak. To observe the frequencies, we calculated the ratio of these frequencies starting from the fundamental, first overtone, second overtone…..up to seventh overtone of this syllable.

The ratio was calculated up to three points after decimal. The result obtained was:

1: 1.735 :2.636 :3.622 :4.609 :5.493 :6.616 : 7.568

Here it can be seen that this ratio is almost linear with high fundamental. This result is very important and verifies the results obtained by the Siddharthan (2019).

5.2.3. Syllable ‘Kran’:

For analysis, this syllable was taken with configuration;

‘Ka’ + ‘Ta’ = ‘Kran’.

(from Bayan) (immediately after from Lav part of Dayan)

In this syllable, the Attack time of syllable ‘Ka’ was noted as 0.0057 s. Decay duration (decreasing vibrations) was found as 0.035 s for the syllable ‘Ka’.

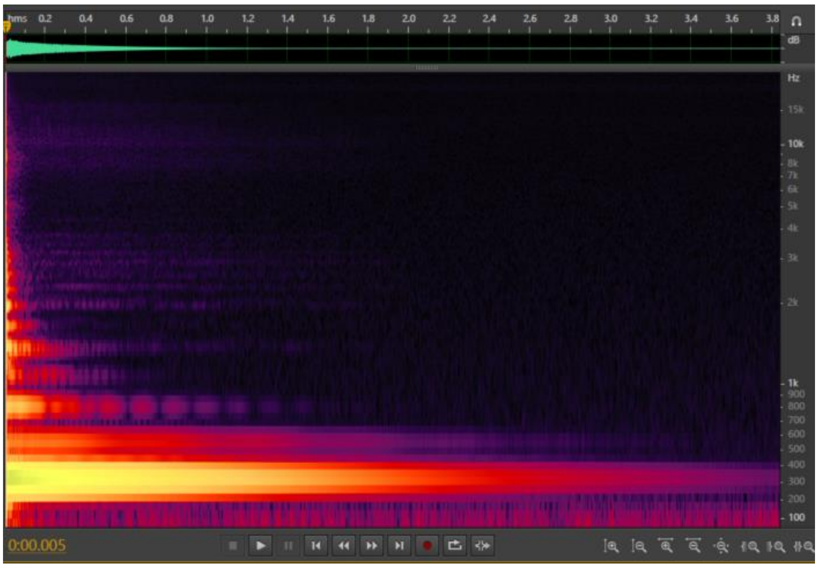

Fig. 8. 3D Spectrum for the syllable 'Tun'

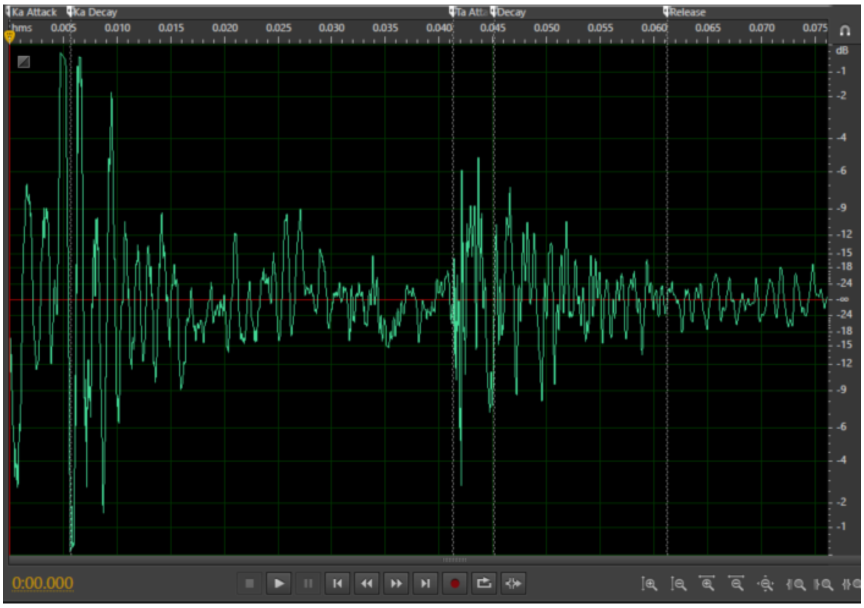

Fig. 9. Time verses Amplitude graph, showing Attack/ Decay/Release for the syllable 'Kran'

Decay time of syllable 'Ta' was noted as 0.016 s. Release time was recorded as 1.929 s. It was also noted that 'Ta' hits after 0.0413 s after 'Ka' syllable. An average human air cannot distinguish the variation of intensity if the variation is more than 16 times per second. That means time difference between two strokes should be more than 0.0625 s to be heard separately (Verma, 1996).

By analyzing the 3D spectrum for the syllable 'Kran'(Fig. 10), a bright, long lasting and dominating fundamental tones between 520 Hz to 550 Hz (Mean - 535 Hz) were obtained. This fundamental tone lasts for 1.9 s and produces the sound of *'C'* note. First overtone was initially brighter than fundamental for this syllable.

First overtone was obtained between 778 Hz to 796 Hz (Mean - 787 Hz) and it lasts for 0.80 s. This overtone was producing the sound of *'G'* note (pancham).

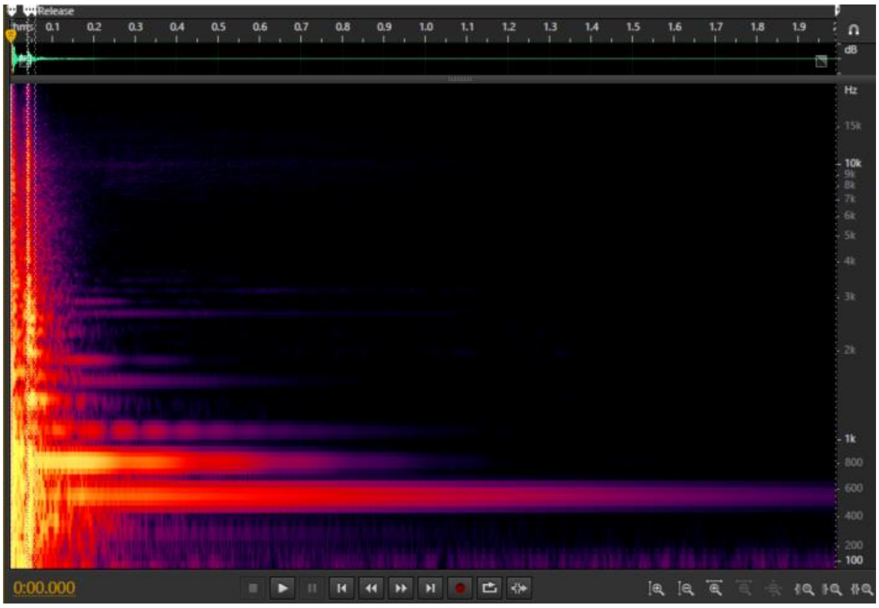

Fig. 10. 3D Spectrum for the joint syllable 'Kran'

Second overtone was also well defined and was producing *'C'* note of the upper octave. It was obtained between 1.05 kHz to 1.07 kHz (Mean - 1060 Hz) and it lasts for 0.25 s. **Third overtone** was also with clear intensity and was producing 'E' note (Shudhha Ga). It was obtained between 1.36 kHz to 1.40 kHz (Mean - 1380 Hz) and it lasts for 0.14s. **Fourth and higher overtones** were not clear and hence it was not possible to observe them with accuracy.

A comparative study for overtones at different frequencies is presented in Table 1.

Table 1 Comparative frequency for overtones

Syllable	Lav ka 'Ta' (Frequency in Hz)	Tun (Frequency in Hz)	Kran (Frequency in Hz)
Sub-Harmonic	262	-	-
Fundamental	527	294	535
1^{st} Overtone	783	527	787
2^{nd} Overtone	1045	788	1060
3^{rd}	1370	1065	1380
4^{th}	1640	1355	-
5^{th}	1945	1615	-
6^{th}	2245	1945	-
7^{th}	2600	2245	-
8^{th}	2900	-	-
9^{th}	3140	-	-
Ratio Pattern	**1: 2.011: 2.989: <u>3.989</u>: 5.229: 6.260: 7.424: 8.569: 9.924: 11.069: 11.985**	**1: 1.735 :2.636 :3.622 :4.609 :5.493 :6.616 : 7.568**	**1: 1.471 :1.981 : 2.579**

It was observed during analysis of 3D spectrum of the syllable 'Tun' that the fundamental dominates the sound of overtones due to high intensity and has the characteristic sound of note *'D'*. This fact is very important because of traditional beliefs. This property is a prime factor for a tabla of balanced tuning This important traditional belief was verified by experimental results. It was also observed that if fundamental is muted, the resultant sound produced by all overtones is similar to the sound of the syllable 'Lav ka Ta'. An average human ear cannot distinguish the variation of intensity if the variation is more than 16 times per second. This means the time difference between two strokes should be more than 0.0625 s to be heard clearly (Verma, 1996). While playing 'Kran', syllable 'Ta' and appropriate syahi. It is believed that if syllable 'tun' gives sound of note 'Re' then its syahi and tuning is perfect (Paranjape, 2015).

comes after 0.0413 s of the syllable 'Ka'. This duration of 0.0413 s is less than 0.0625 seconds. As a result, we hear the resultant sound of this syllable. Hence, 'Kran' syllable should be treated as a distinct syllable from 'Ka Ta', where we hear different sounds of 'Ka' and 'Ta' syllables.

6. Conclusions

Great physicist Sir C. V. Raman first reported the unique acoustic characteristics of the percussion drum Mridangam. He reported that overtones produced by the sound of these drums are in an integer ratio, as are the overtones of a vibrating string. He gave only suppositions and suggestions for vibrations produced by Tabla in a similar view of Mridangam, while in this experiment it was found that the overtones for the syllables ('tun' in our experiment) were, in fact, not harmonic, though they were almost in integer ratios to each other. Experimental results gave the frequencies of the syllable 'Tun' and it was found that the overtones were, in fact, not harmonic, though they were almost in integer ratios to each other. The frequencies were in the ratio 1.153:2:3.039:4.176:5.314 :6.333:7.628: 8.726 (Ratio was obtained by multiplying above ratio by the digit 1.153). The overtones thus can be regarded as harmonics of a missing fundamental. The actual fundamental was noted too high for this syllable**.** This fact was missed by C. V. Raman and later concerning authors. Thus, the outcomes of this experiment show slight deviations from the findings reported by C. V. Raman. The overtones generated by the tabla syllables did not follow the exact integer ratios.

Conflict of interest: There are no conflicts of interest declared by the authors.

Contribution of authors

Dr. Rajeev Shukla conducted all experiments and drafted manuscript and Prof. B. C. Yadav supervised the work, edited and reviewed the manuscript.

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