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ACOUSTICS OF CHANTS, CONCH-SHELLS, BELLS AND GONGS IN HINDU WORSHIP SPACES

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Sound plays a very important role in Hindu worship spaces both at homes and temples. In Hindu temples the two chambers that have reverberant acoustic characteristics are the Garbha-Griha where the deity is consecrated and the Ardha-Mantapa which is a chamber in front of Garbha-Griha. The Vedic chants and prayers are recited and the sacred instruments such as conch-shells, bells, and gongs are played in these chambers. The Vedas, which are the foundational literature of Hinduism, are the collection of mantras chanted with precise acoustical characteristics. It is for this reason oral tradition has been very efficient in transmitting the Vedic chanting from master to disciple. The use of Vedic chants in Hindu worship is well known. In addition to Vedic chants, conch-shells, bells and gongs are also very commonly used to enhance the spiritual experience of the devotees during the worship. The sounds from these acoustically well designed conch-shells, bells and gongs are considered as sacred when they are used during worship. These sacred sounds help devotees in their concentration during worship in the sacred space. The sounds of conch-shell, bell and gong are used at various times during the worship. However, all of these sounds are simultaneously used at the end of the worship when camphor flame is offered to the deity. This acoustical experience is significant to the devotees in the worship. The conch-shell when unwound on an axis can be seen as a French horn. The sound from a conch-shell has very high quality factor indicating the sharpness of its resonance. The conch-shell is generally used at the beginning of the worship. Given the tonal quality of its sound, it captures the attention of the devotees and helps in focusing the mind to the worship. Similarly the bell is also used at the beginning of the worship. The sound of well-designed bell has a ringing sound that sustains for considerable duration. It is also noted that both the conch-shell and bell sounds acoustically resembles the chant of sacred sound of OM. The gong is generally played during the end of the worship along with bell and conch-shell. The gong is played as a percussion instrument with a nice rhythm. Generally the rhythmic gong sound is loud. When all these three instruments are played together at the end along with the chanting, one can experience the synergy of the various sounds adding to the spiritual experience of the devotees. The Hindu worship is seen as a celebration of the devotees having communion with God. This paper presents acoustical studies of chants and also of these instruments. The paper also discusses the importance of these sounds in their contributions to the acoustics of the worship spaces.

1. Introduction

Worship is the pinnacle of communication between God and human beings in many religions. Worship can be individualistic or communal. Individual worship can happen anywhere and anytime. However, the communal worship usually requires dedicated spaces such as temples, gurdwaras, churches, synagogues and mosques. Communication during the worship can take several forms. Praying mentally and contemplation can be silent whereas other forms of worship such as chants, songs and music all will involve sound [1-3]. Acoustics plays an important role in worship spaces in all cultures and religions of the world. This is natural as acoustics deals with sound, one of the senses of perception [4]. In Hinduism, acoustics is of major importance in various aspects of life namely spirituality, religion, culture, science, art etc. It is well known that sound plays a very important role in Hindu worship spaces namely homes, community halls and temples. The Vedas, which are the foundational literature of Hinduism, are the collection of mantras chanted with precise acoustical characteristics [5-8]. It is for this reason oral tradition has been very efficient in transmitting the Vedic chanting from master to disciple [7]. The use of Vedic chants in Hindu worship is well known. In addition to Vedic chants (vocal), conch-shells, bells and gongs are also very commonly used to enhance the spiritual experience of the devotees during the worship [9]. This paper presents acoustical studies of chants and of these instruments sounding individually as well as collectively. Figure 1 shows typical Conch-Shell, Bell and Gong instruments used for the study. The paper also discusses the importance of these instruments and their contributions to the acoustics of the Hindu worship spaces.

Figure 1. Conch-Shell, Bell and Gong used in this study.

2. Vedic perspectives on sound

Vedas are categorized into four namely Rig-Veda, Yajur-Veda, Sama-Veda and Atharvana-Veda. Vedas refer to the body of the knowledge that deals with physical, psychological and spiritual aspects of life and cosmos. The word "Veda" is etymologically related to a verbal root "Vid" meaning "to know". In addition it is interesting to know that Vedas are collection of very large number of "mantras", which are referred as Vedic chants. These Vedic chants have phonetic characteristics such as pitch, duration, emphasis, uniformity and juxta-position [7]. These Vedic chants are orally transmitted with extraordinary acoustic precision from master to disciples from ancient times to present times. It is well known that the acoustic precision in the oral transmission of Vedic chants, music and speech cannot be surpassed through writing [5, 7]. In 2003, UNESCO proclaimed that the oral tradition of the Vedic chanting as an intangible cultural heritage of the world. The proclamation recognizes that *"..To ensure that the sound of each word remains unaltered, practitioners are taught from childhood complex recitation techniques that are based on tonal accents, a unique manner of pronouncing each letter and specific speech combinations"* [7].

The art and science of acoustics have received a high importance in the Vedic literature. The chants along with both vocal and instrumental music are playing major role in Hindu tradition from ancient times to the present. This is noted by Sir C.V. Raman that *"it would form a fascinating chapter of history to try and trace the gradual development of musical instruments and musical knowledge, from the rhythmic chanting of the Rig-Veda in the ancient home of Aryan race to the Indian music of the present day"* [8]. In Vedic literature the production of human speech is emphasized. This could be due to the importance of acoustical aspects of Vedic chants. The speech production according to Vedic view can be described through four stages. These four stages are called as Para, Pashyanti, Madhyama and Vaikhari. These four stages are integrally connected to the yoga aspects of Vedic tradition. Among these four stages the last stage namely Vaikhari refers to fully manifested speech sounds from the human speaker propagated to the listener. The other three stages namely Para, Pashyanti and Madhyama refers to the stages internal to the human speaker. The fourth stage of Vaikhari encompasses various types of acoustic expressions in human life. They can be represented (as shown in Fig. 2) by speech, music, literature and spirituality. This model for four stage development of speech sounds can also be generalized conceptually to production of sound [10].

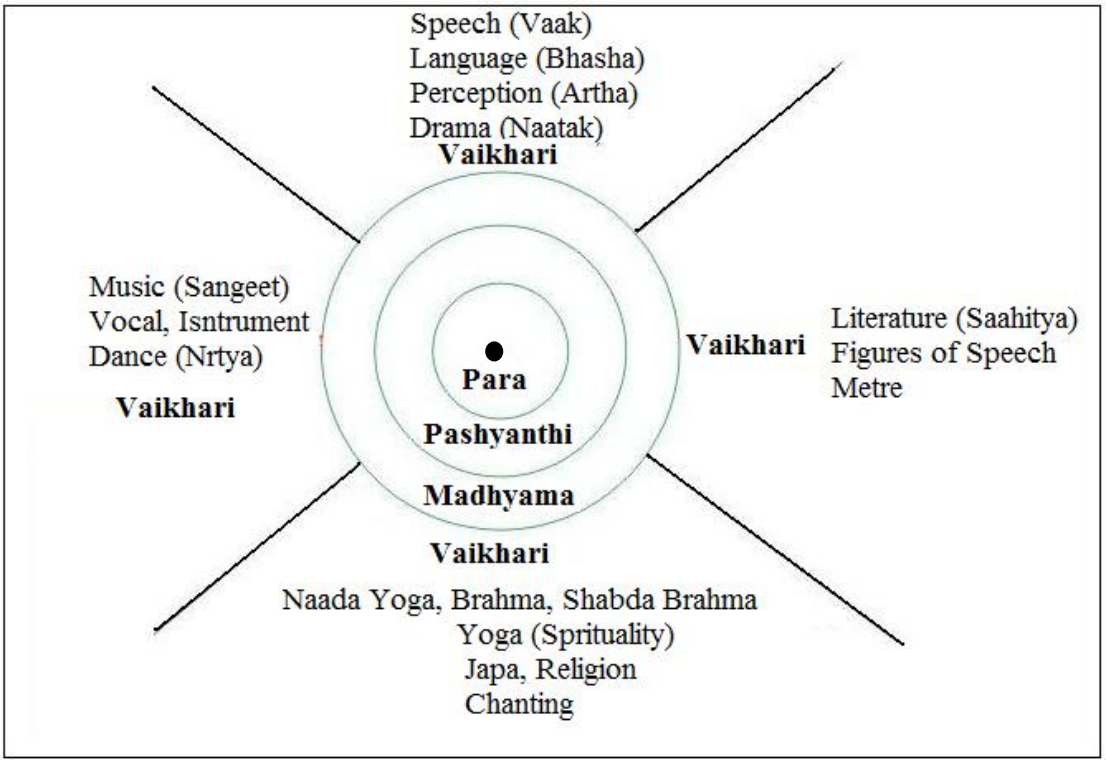

Figure 2. Representation of the four fields of sound at **Vaikhari** level.

The philosophical and spiritual aspects of sound are also very much emphasized in Vedic Hindu tradition. It is interesting to note that the commonly referred five basic elements in Vedic literature namely space, air, fire, water and earth are related to corresponding senses of perception [5, 11]. The subtle to gross order of correspondence according to the Vedic tradition is shown in Table 1. It is interesting to note that the spatial experience is solely related to the sense of sound perception.

Table 1. The order of correspondence according to the Vedic tradition.

Space	Sound
Air	Touch, Sound
Fire	Form, Touch, Sound
Water	Taste, Form, Touch and Sound
Earth	Smell, Taste, Form, Touch and Sound

3. Acoustical aspects of Hindu worship spaces

Temples (devaalayas or mandirs) as worship spaces have been an integral part of Hindu religion from ancient times. Hindu temples in India and around the world are marvels of art and architecture. Hindu temples play a major role in not only performing various sacraments and celebrating festivals but also a resource for spiritual development. In addition to Hindu temples as worship spaces, Hindus also use spaces such as community halls and specified space in their homes as spaces of worship. The worship practice in general consists of a priest performing the worship on behalf of the congregation. However, at some stages of worship devotees chant together mantras and recite prayers along with the priest. Devotees also sing together songs as prayers and they are known as bhajans and kirtans. In addition to the mantras and bhajans, instruments such as bells, gongs and conch-shells are also used in the worship.

The most important space in a Hindu temple is the space where the deity is installed. This space is known as "Garbha-Griha" in Sanskrit, which means a "womb-chamber". This is also referred as sanctum-sanctorum. The dimensions of this chamber are based on the size of the deity. This chamber has only a door and no windows. Only the priest is allowed in this chamber for worship through chants and prayers. Generally the priest also rings a hand-bell during the worship along with chants. Generally this chamber is built of walls made of stones. The interesting acoustical fact is that this chamber is highly reflective and has a high reverberation time. In addition, this womb-chamber is generally connected to another space through its door opening. This attached second space is generally called as "Ardha-Mantapa" which means "half-chamber" to indicate that this space is about half the floor size of the Garbha-Griha. The Ardha-Mantapa is also made of stones and is highly reflective with high reverberation time. The scriptures called *Agama Shastras* on temple design prescribe that the whole temple is designed based on the size of the deity installed in the Garbha-Griha. The acoustical importance of Ardha-Mantapa is that a number of priests in addition to the main priest in the Garbha-Griha chant in unison and also the instruments such as conch-shells, bells and gongs are sounded. Generally the Ardha-Mantapa leads to a "main hall" referred as "Maha-Mantapa". It is in this Maha-Mantapa where a large number of devotees assemble and participate in the worship [12-14]. The Narayanaswami temple at Melkote, near Mysore city, Karnataka, India is a well-known temple dated back to 11th century A.D. Figure 3 shows the floor plan of the temple. The spaces noted as 1, 2 and 3 in Fig. 3 are the Garbha-Griha, Ardha-Mantapa and Maha-Mantapa respectively. The dimensions of the Garbha-Griha are 7 ft 10 in. x 8 ft 2 in. (2.39 m x 2.49 m) with a height of 10 ft (3.05 m). The dimensions of the Ardha-Mantapa are 13 ft x 6 ft 9 in. (3.96 m x 2.06 m) with a height of 10 ft (3.05 m) [15].

The two temples in which acoustical measurements were made are Sri Venkateswara Temple of the *Hindu Temple and Cultural Society* in the Bridgewater, New Jersey, USA shown in Figure 4(a) and The Sri Lakshmi- Sri Narayana Temple of the *Hindu Temple Society of Capital District* in Albany, New York, USA shown in Fig. 5(a). Figure 4(b) shows the details of Ardha-Mantapa and Garbha-Griha of the deity Sri Venkateswara and the corresponding main hall. The details of Ardha-Mantapa and Garbha-Griha of the deities of Sri Lakshmi and Sri Narayana and the corresponding main hall are shown in Fig. 5(b). In both temples there are many other deities. In both temples the sound pressure level recordings were made outside but near the Ardha-Mantapa in the main hall. The priest chanted in the Ardha-Mantapa and also the conch-shell, bell and gong sounds were produced in the Ardha-Mantapa. Similarly sound recordings were made in a community hall environment and an anechoic chamber. The sound pressure level increases at the position outside the Ardha-Mantapa of each temple. This is due to reverberation effects of combined Garbha-Griha and Ardha-Mantapa in comparison with the corresponding position in the free field. The increase in sound pressure level can be predicted using the following room acoustic equations.

(a) if we model the entire Garbha-Griha and Ardha-Mantapa space as highly reflective and diffuse field then the sound pressure level (SPL) at any given point,

$$L_{P1} = L_w + 10\log\left[\frac{4}{R}\right] \quad (1)$$

(b) However, If we assume the room (such as Garbha-Griha and Ardha-Mantapa) space as entirely free field then the sound pressure level at the corresponding point, close to Ardha-Mantapa for a given source of sound power level (L_w) can be written as,

$$L_{P2} = L_w + 10\log\left[\frac{1}{4\pi r^2}\right] \quad (2)$$

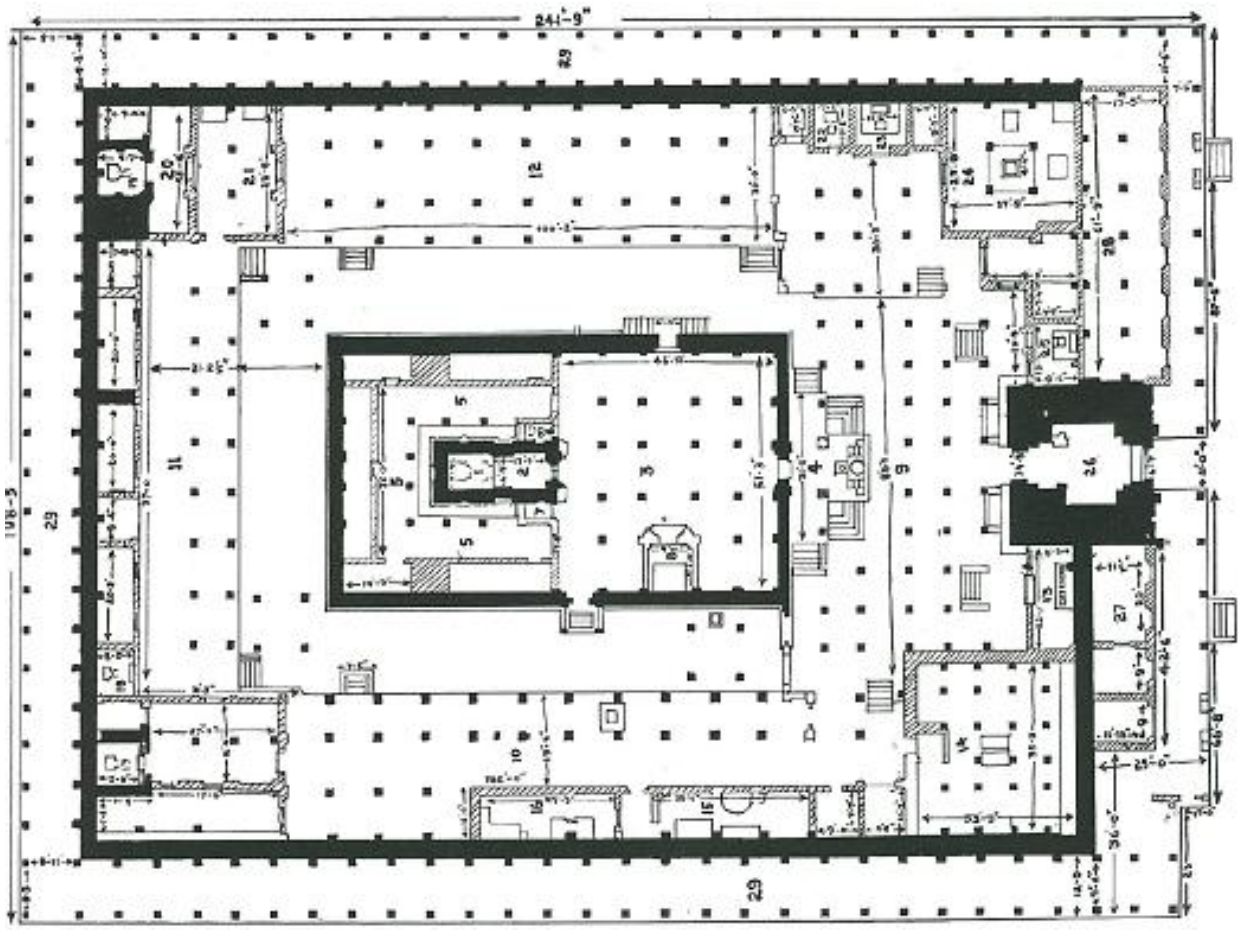

Figure 3. Floor plan of The Narayanaswami Temple at Melkote, Karnataka, India.

Subtracting Eqn. (2) from (1), we can obtain the increase in SPL of the room space as,

$$\Delta L = L_{P1} - L_{P2} = 10\log\left[\frac{16\pi r^2}{R}\right] \quad (3)$$

Where, $R = S\bar{\alpha}/(1-\bar{\alpha})$ is the room constant, S is the surface area of the room and $\bar{\alpha}$ is the average absorption coefficient of the room. Here, '*room*' represents Ardha-Mantapa, Garbha-Griha as well as combined space of Ardha-Mantapa and Garbha-Griha. The volume (m^3), theoretical estimation of reverberation time T_{60} (in sec) and increased sound pressure level (ΔL in dB) calculated using the Eqn. 3 for all these three temples are given in Table. 2. The estimated theoretical reverberation times (T_{60}) for the combined Ardha-Mantapa and Garbha-Griha for the Sri Venkateswara temple, Bridgewater, NJ, USA and the Sri Lakshmi - Sri Narayana temple, Albany, NY, USA are 1.12 sec and 0.63 sec respectively. The theoretically estimated reverberation times for the Maha-Mantapa for the above two temples are 1.25 sec and 1.1 sec respectively. The theoretically estimated reverberation time (T_{60}) as in Table 2 for the combined Garbha-Griha and

Ardha-Mantapa for the Sri Narayanaswami temple in Melkote, Mysore, India is 0.76 sec. The reverberant field in this highly reflective combined space and its propagation to the Maha-Mantapa can be pictorially represented in Figs. 6(a) and (b) for the cases of sound sources in Garbha-Griha and Ardha-Mantapa respectively.

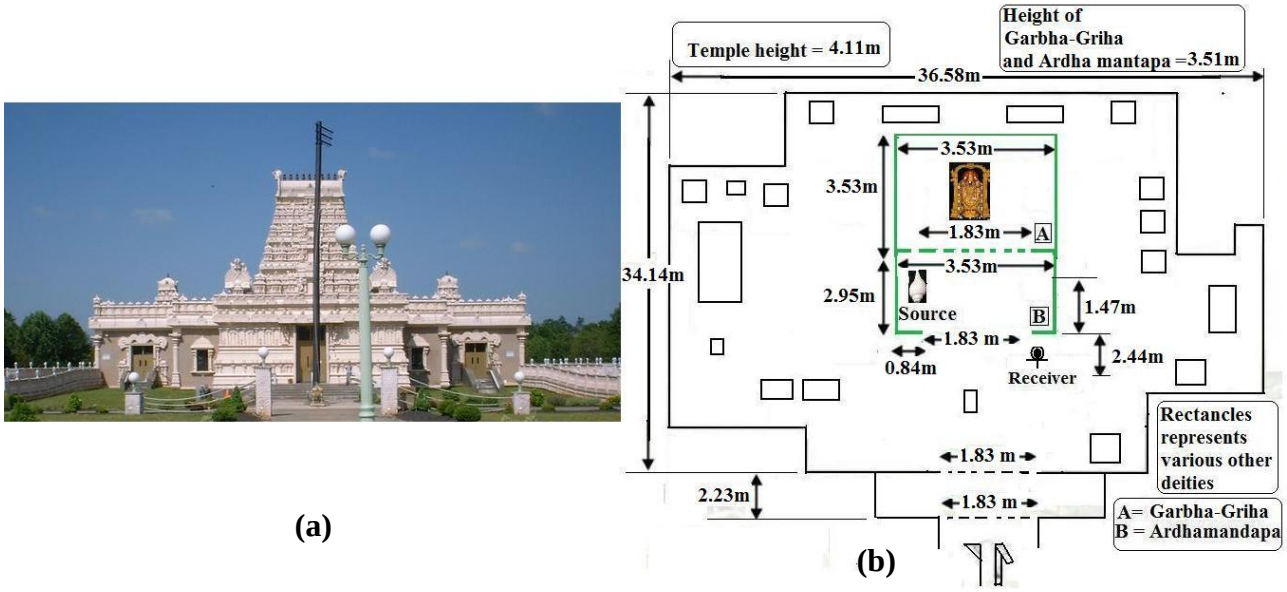

Figure 4. (a) Sri Venkateswara Temple, Bridgewater, NJ, USA (b) Floor Sketch View.

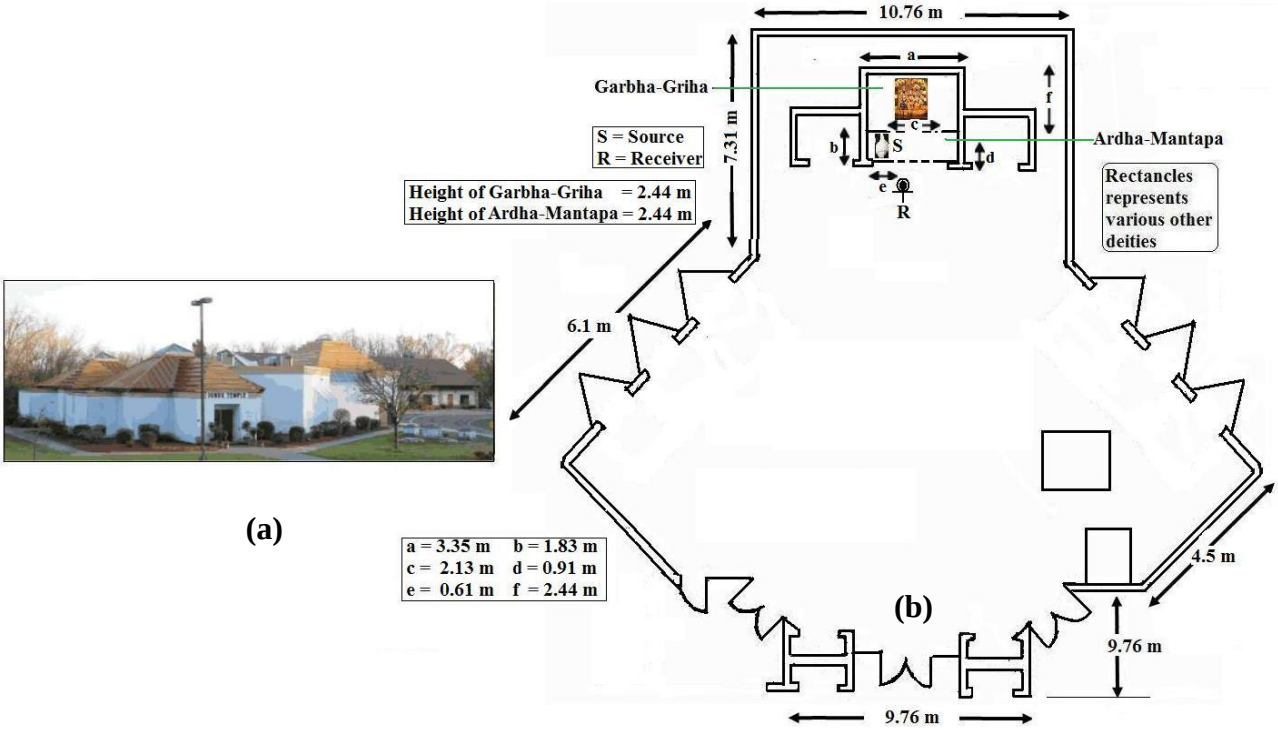

Figure 5. (a) The Hindu Temple Society of Capital District, Albany, NY, USA (b) Floor Sketch View.

Table 2. Estimated reverberation time and sound pressure level of various Hindu temples

	Temple (Bridgewater, NJ)			Temple (Albany, NY)			Temple (Melkote, India)		
	Volume	T_{60}	ΔL	Volume	T_{60}	ΔL	Volume	T_{60}	ΔL
Ardha-Mantapa	36.18	1.09	22.93	10.87	0.58	13.9	24.84	0.92	21.9
Garbha-Griha	43.86	1.14	22.32	19.93	0.68	14.5	18.11	0.61	21.5
Combined	80.02	1.12	19.62	30.80	0.63	11.2	42.95	0.76	18.7

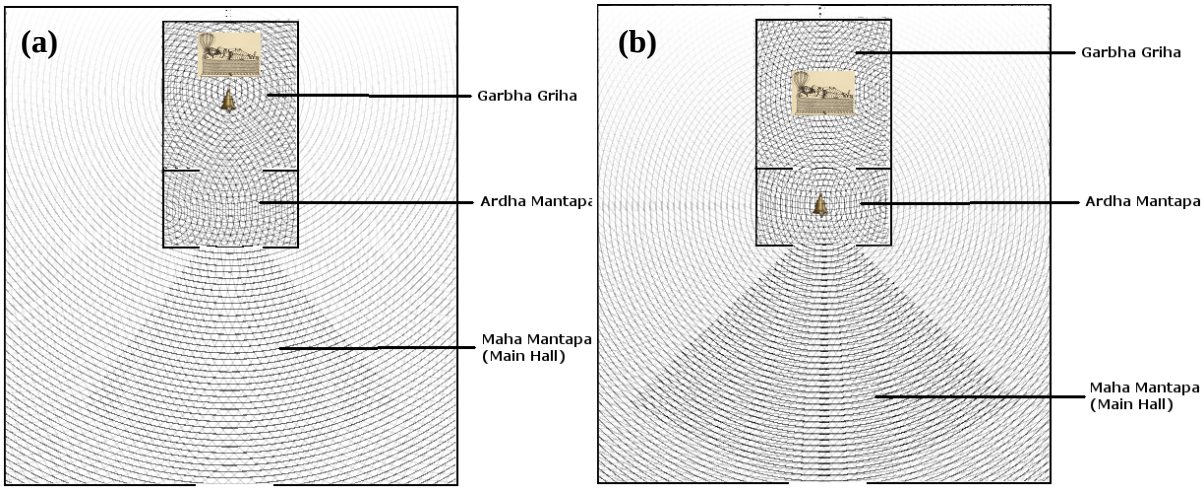

Figure 6. Reverberant sound fields with sound source in (a) Garbha-Griha and in (b) Ardha-Mantapa.

4. Chanting the mantras in Hindu worship spaces

Vedas, the foundational literature of Hinduism refers to infinitely large collection of mantras. These mantras describe the various facets of knowledge dealing with life and cosmos [4]. The chants from Vedas are extensively used in worship and sacrament rituals at homes and temples. Sounds of the Veda mantras chanted in Hindu worship spaces would carry the listeners to spiritual experiences. The acoustical characteristics, in addition to the clear phonetic articulation of chants, have deep impact on the devotees [4, 16, 17]. The Vedas are recited by a single priest or a number of priests collectively throughout the rituals or worship. Sometimes devotees also join the recitation of Vedas. In this study, a single priest recitation is measured and sound spectral analysis is carried out for an anechoic room, a community hall and an Ardha-Mantapa of a temple. The observed frequencies are given in Table 3. The measured sound spectra of the vocal (Vedic chanting) are given in Fig. 7. It is noted that the observed fundamental frequency of the Vedic chanting spectra (V1) is 147 Hz. The recoded audio (.mp3) files of typical Vedic chanting recorded in anechoic room, community hall and Ardha-Mantapa of temple (Bridgewater,NJ) are also embedded in Fig. 7.

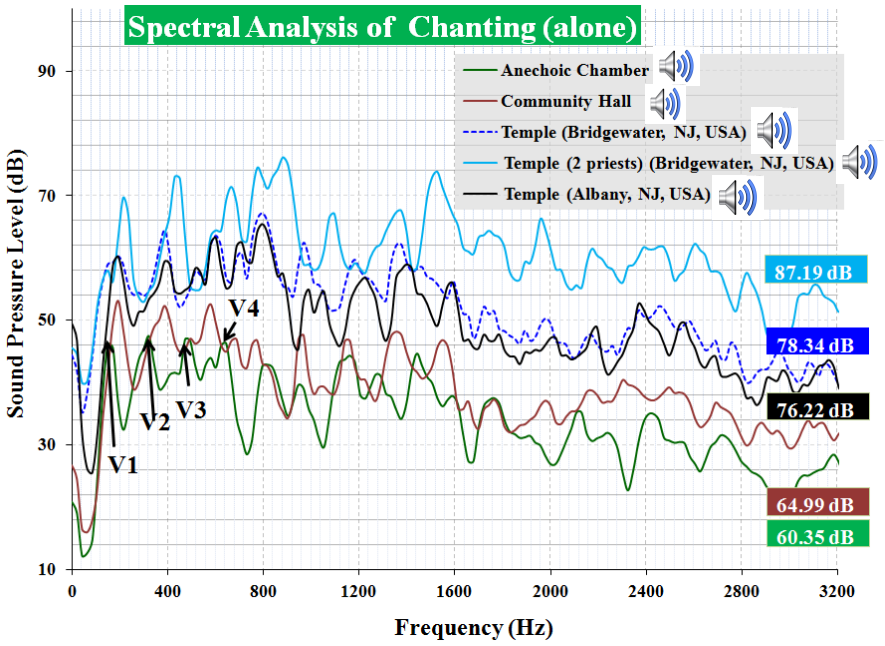

Figure 7. Spectra of Vedic-chanting (V) alone. *(**Note**: All the audio recordings were made at a distance of 2 ft (0.61m) in the anechoic chamber, community hall; 15 ft (4.6m) in Temple (Bridgewater) and 5 ft (1.52m) in Temple (Albany). However, all the graphs have been corrected for the distance of 15 ft (4.6m).)*

5. Sounding of *Conch-shells* in Hindu worship spaces

Conch-shell (*Turbinella pyrum or Indian Conch*) is a musical wind instrument that is made from a seashell, one of several different kinds of very large sea snail. It is also sometimes referred to as "conch-shell trumpet" and it is thought to have been the original horn-trumpet. The clear and hauntingly beautiful sound when blowing the conch-shell trumpet was an integral part of daily life in many societies, where it was used for communication and religious rituals. The recent excavation of twenty conch-shells (Strombus Galeatus marine shell trumpets) referred as chavin pututus in Peru was reported [18]. In Hindu religion, conch-shell is of great importance and symbolizes luster, brilliance, purity. Its tonal sound provides auspicious beginning of an event. In many Hindu temple rituals, conch-shells are sounded to announce the beginning and the ending of a worship and also arrival of the deity. It is used both as a musical instrument and as a container for holy water. It is also used to drive away the evil spirits [13]. It is interesting to note that sound from conch-shell has a loud and sharp tonal quality that can be recognized while listening. Figure 8 (a) shows the X-ray tomography view of the conch-shell. The Fig. 8(b) shows the equivalent horn of the conch-shell based on unwinding it with reference to the major and minor axes of the elliptical cavity. It is seen from Fig. 9 that the conch-shell has a very high Q-factor.

It is not possible to sound or play the naturally available conch-shell in their original form. In order to play the conch-shell, a pointed tip of its closed end is cut off to open the cavity, and then it is played by blowing into that end through vibrating lips. When the frequency of the lip vibrations matches a resonance frequency of the conch shell cavity, a clear tone is produced. By adjusting lip tension and blowing speed, different frequencies can be produced by skilled players, as like on any brass wind instruments. The spectrum of sound produced on an end blown Indian conch-shell trumpet was studied initially by Bhat et al [19, 20]. Recent studies of acoustical characteristics of conch-shell have been carried out by Rath et al [21] and Prasad et al [22]. In this study a conch-shell was blown in an anechoic chamber, a community hall that can be used as a worship space and in the Ardha-Mantapa of the two Hindu temples. The corresponding spectral analyses were carried out. The measurement was carried out using LabView Sound and Vibration software suite. The measurement was carried out for conch-shell alone and also along with other musical instruments. The observed fundamental tones of conch shell are given in Table 3 and in Fig. 9. The measured frequencies of conch-shell in an anechoic chamber are 327.5 Hz as fundamental and its harmonics. *(Note: click on the audio symbol which is embedded in Fig. 9 to listen to the sound of a conch-shell).*

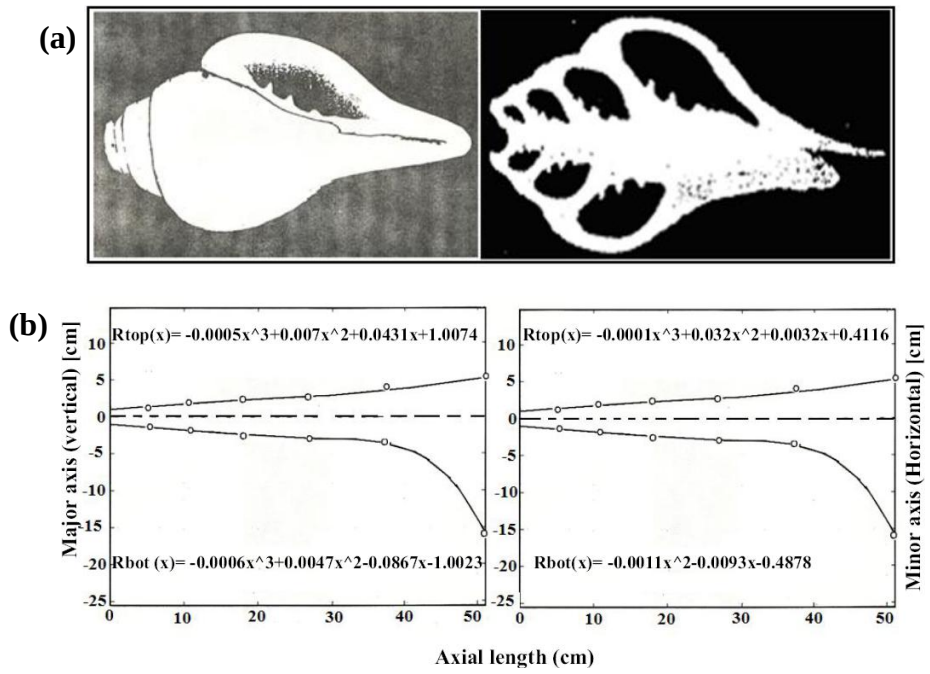

Figure 8. (a) X-Ray tomography and **(b)** Straightened conch-shell cavity profile (major and minor axis) [20]

Table 3. Observed frequencies of Vedic chants, Conch-Shell, Bell and Gong.

Type of Instrument	Observed Frequency (Hz)
Vedic chant (alone) (V)	147.5, 302, 440
Conch-Shell (sounding alone) (C)	327.5, 655, 980, 1302.5, 1637, 1965, 2292.5
Bell (sounding alone) (B)	1262.5, 2877.5
Gong (sounding alone) (G)	392, 762, 1437, 1792, 2070, 2350, 2675, 3002
Simultaneous sounding of Vedic chant, Conch-Shell, Bell and Gong	327.5, 392, 440, 655, 762, 980, 1262.5, 1437, 1792, 2070, 2350, 2675, 2877.5, 3002

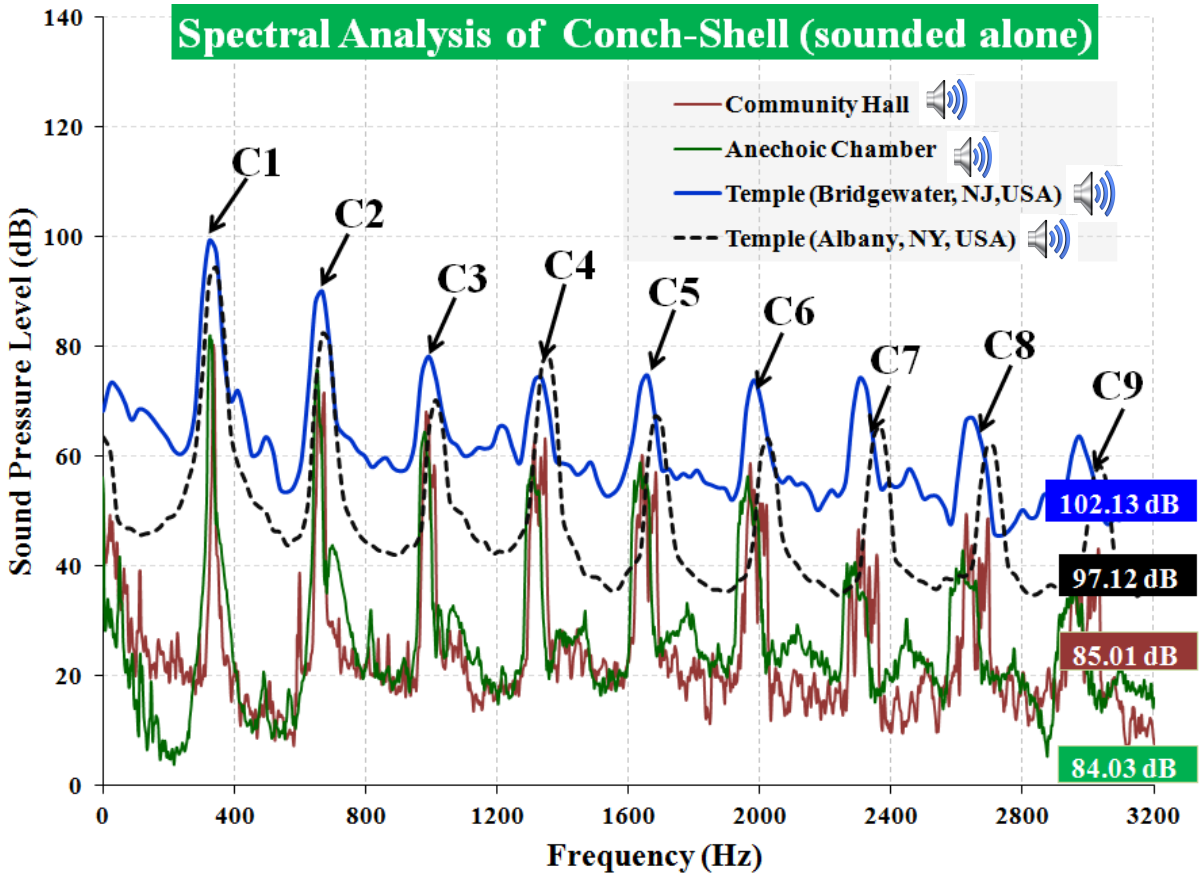

Figure 9. Spectra of a conch-shell sounded alone.

5.1 Finger-in effect of sound spectrum in Conch-shell

Measurements were also carried out to study the effect of player inserting the fingers at the mouth (large open end) of the cavity of a conch-shell as similar to hand-in condition of French horn. The measured spectra of with maximum finger-in and no finger-in conditions in an anechoic chamber are shown in Fig. 10. It is observed from the measured spectra that inserting the finger in mouth of conch-shell shifts the fundamental frequency to lower value as expected [20]. The shifting of fundamental frequency is due to increase of effective duct length of the cavity of conch shell. The recorded audio (.mp3) files of no finger-in, with maximum finger-in and gradual finger-in conditions of conch-shell blown in an anechoic room are embedded in Fig. 10.

6. Sounding of *Bells* in Hindu worship spaces

According to *Agama-Shastra* [23] which is the text for temple design and rituals, ringing of *bells* in temples and in other Hindu worship spaces during rituals is to ward off evil spirits. A verse in Sanskrit is recited when ringing the bell at the beginning of the worship. The meaning of the verse is that the bell is rung to invite the sacred vibrations and to drive away the evil vibrations.

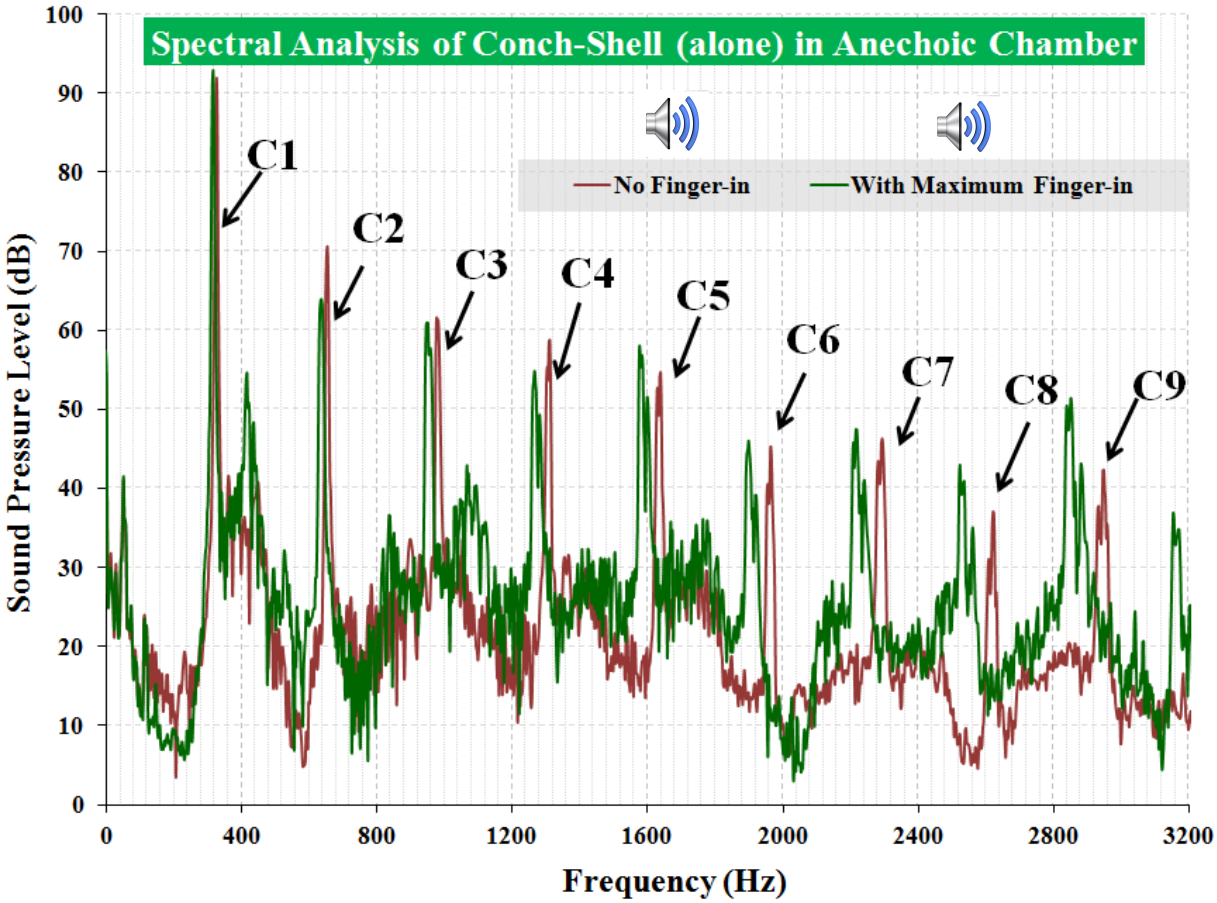

Figure 10. Finger-in effect for a conch-shell (C) sounded in an anechoic chamber.

A well designed bell is an indispensable and an important part in most Hindu worship (pooja) and prayers. It is also observed that a well-designed bell would produce long strains of the sound 'OM.' Usually the bell is sounded before the actual pooja begins. A bell is also rung in a Hindu worship, during the waving of camphor light in front of the deity, while bathing the deity and while offering food.

The sound made from a well-designed bell is uninterrupted, reverberating, deep and sonorous. The bells used in Hindu temples are usually made of five metal alloys or panchaloha. The five metals used are gold (Au), silver (Ag), copper (Cu), iron (Fe) and lead (Pb). A typical hand-bell used in Hindu worship rituals is shown in Fig. 1. The spectra of the hand-bell are shown in Fig. 11 and the observed frequencies of the bell are given in Table. 3. It is noted that the fundamental frequency of the bell analysed for the study is 1292 Hz and it also noted that the second higher tone is not an integer multiple unlike conch-shell. The recorded audio (.mp3) file of ringing a hand bell in anechoic chamber, community hall and temple (Bridgewater, NJ) is also embedded in Fig. 11.

6.1 Comparison of Hand-Bell and Hanging-Bell

In Hindu worship spaces especially in temples, there are large bells suspended at the entrance and in some temples also inside the Ardha-Mantapa. When the devotees enter or leave the temple premises they ring the bell. Also in temples, hanging (suspended) bells are rung when the pooja is offered. In this study the sound spectrum of hanging-bell (the same hand-bell was suspended) is measured and analysed in an Anechoic chamber. The frequency spectrum shown in Fig. 12 indicates that fundamental and second higher tones are coincides with the hand bell spectra. However, the measured sound pressure level of hand-bell is higher than the hanging-bell. The observed higher value in hand-bell is due to the pendulum striking at two places in very short time period compared to the hanging-bell. The recorded audio (.mp3) files of striking the hand-bell and hanging-bell are embedded in Fig. 12. The spectral plot of time-decay of a hand-bell is shown in

Fig. 13. The audio file of the time-decay is also embedded in Fig. 13. The time decay sound indicates that the bell analysed for the spectrum studies is well made because the resonance tone amplitude gradually reduces than a sudden stop.

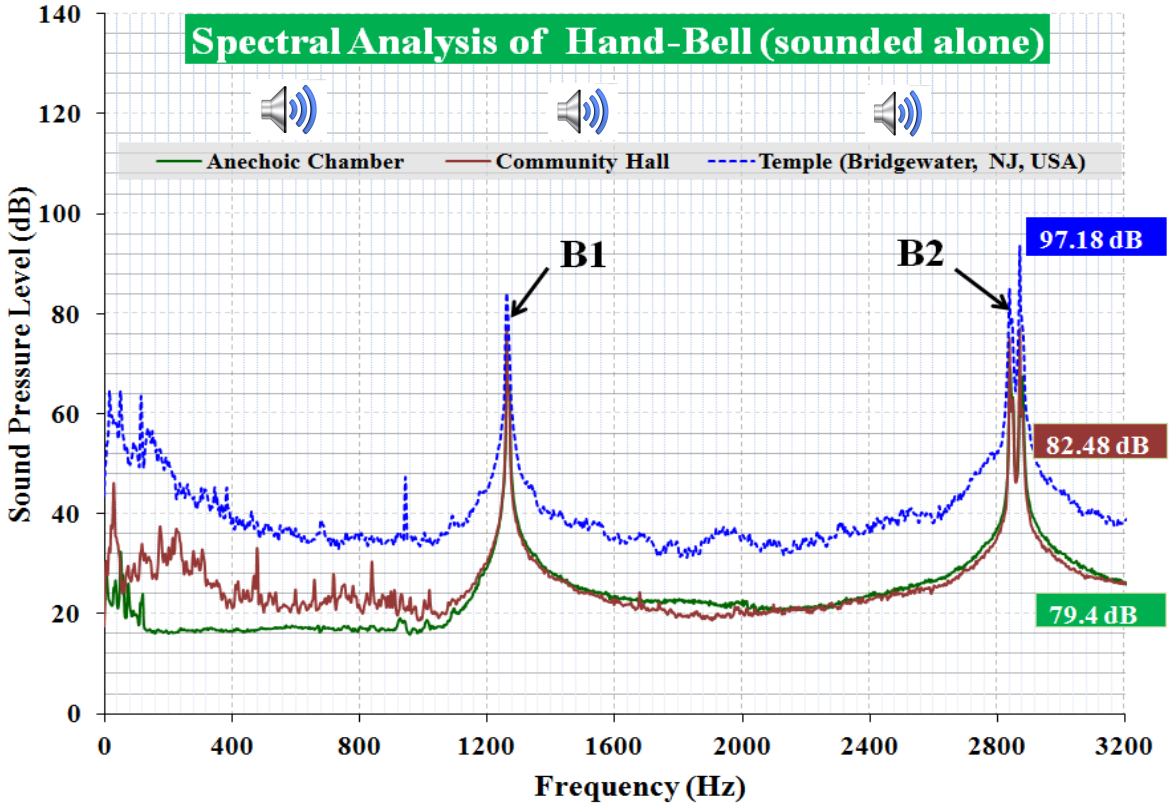

Figure 11. Spectra of a hand-bell (B) sounded alone.

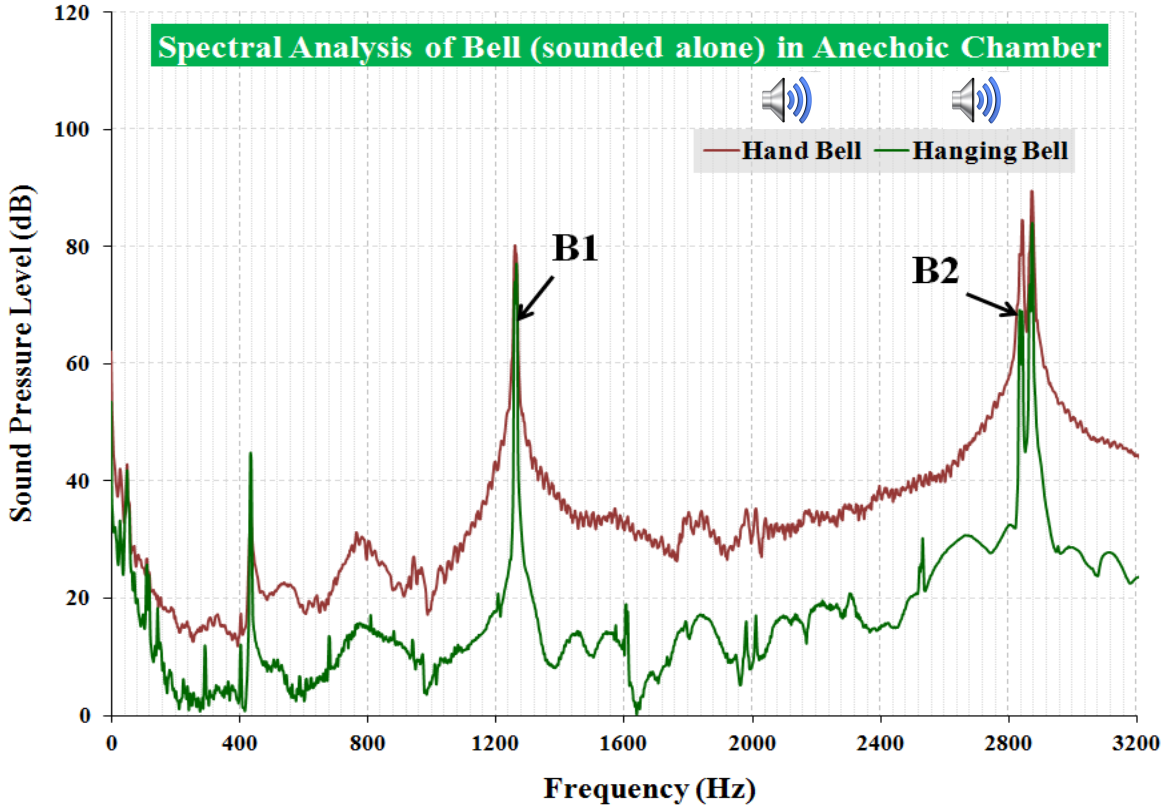

Figure 12. Spectra of hand and hanging-bells.

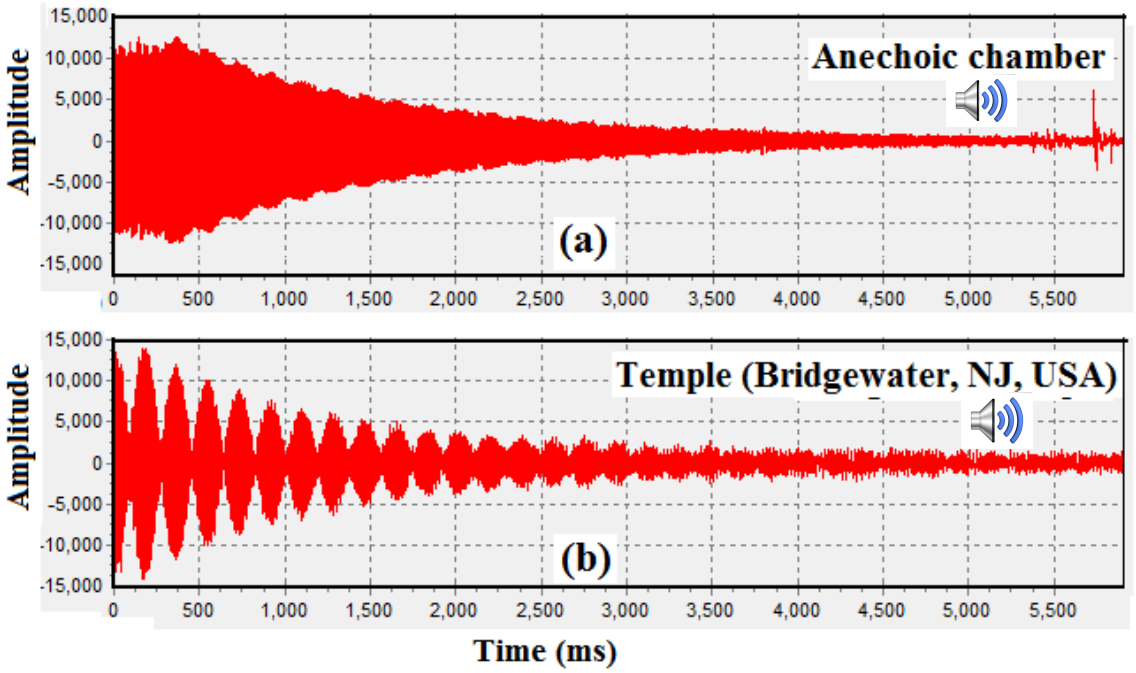

Figure 13. Impulse response of (a) Anechoic chamber and (b) Ardha-Mantapa.

7. Sounding of *Gongs* in Hindu worship spaces

A *gong* is a musical instrument that takes the form of a flat, circular metal disc which is struck with a mallet. Gongs are broadly of three types. Suspended gongs are more or less flat, circular discs of metal suspended vertically by means of a cord passing through holes near to the top rim. Bossed or nipple gongs have a raised centre boss and are often suspended and played horizontally. Gongs are made mainly from bronze or brass but there are many other alloys also in use. Gongs are fabricated by a metal (iron) or wooden hammer after repeated intervals to get sound of same pitch. Sharavage et al [24] studied in detail the vibrational properties and the modes of vibration of the gong. They [24] carried out the spectral analysis and time-average holography on the gong. They also [24] observed that the vibrational properties of gongs will depend on the point of actuation and found the modes of vibration and its mathematical equation. In Hindu temples, gongs are sounded during the worship and they are sounded along with other musical instruments such as conch shells and bells. The sizes of the gongs are usually small and they are sounded using wooden mallets. They are made of brass and circular in nature. A typical gong used in Hindu worship spaces is shown in Fig. 1. For this study the gong is excited at the center and spectral analysis is carried out. The measured fundamental frequency is 392 Hz. It is noted that unlike the conch-shell, the higher frequencies observed in gong are not exact integer multiples. The measured sound spectra are shown in Fig. 14. It is also observed that the fundamental frequency and its higher tones are not shifted when the measurement is taken at reflective room which is similar to the observation made for Bell ringing. The recorded audio (.mp3) files of gong struck at center in an anechoic chamber, community hall and in Ardha-Mantapa of Hindu temple are also embedded in Fig. 14.

7.1 Effect of striking the Gong at different places

In this study the gong is hit at three different places and the corresponding sound spectra are analysed. The spectral analysis are carried out for striking the gong at the center (r=0), middle (r=R/2) and at the edge (r=R). The spectra are shown in Fig. 15. The spectra indicate that the striking at three different places does not have any effect on the fundamental frequency. The audio (.mp3) files of striking the gong at three different places recorded in anechoic room are also embedded in Fig. 15.

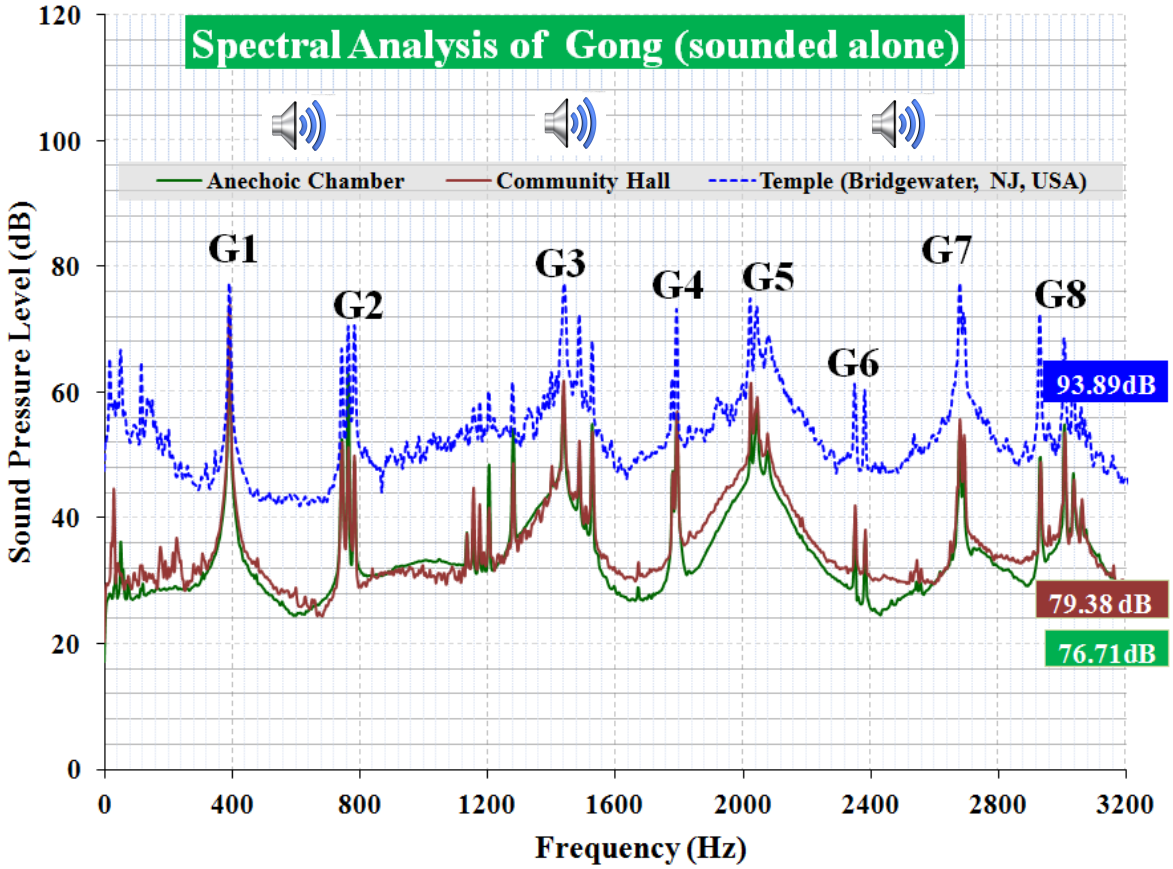

Figure 14. Spectra of a gong sounded alone.

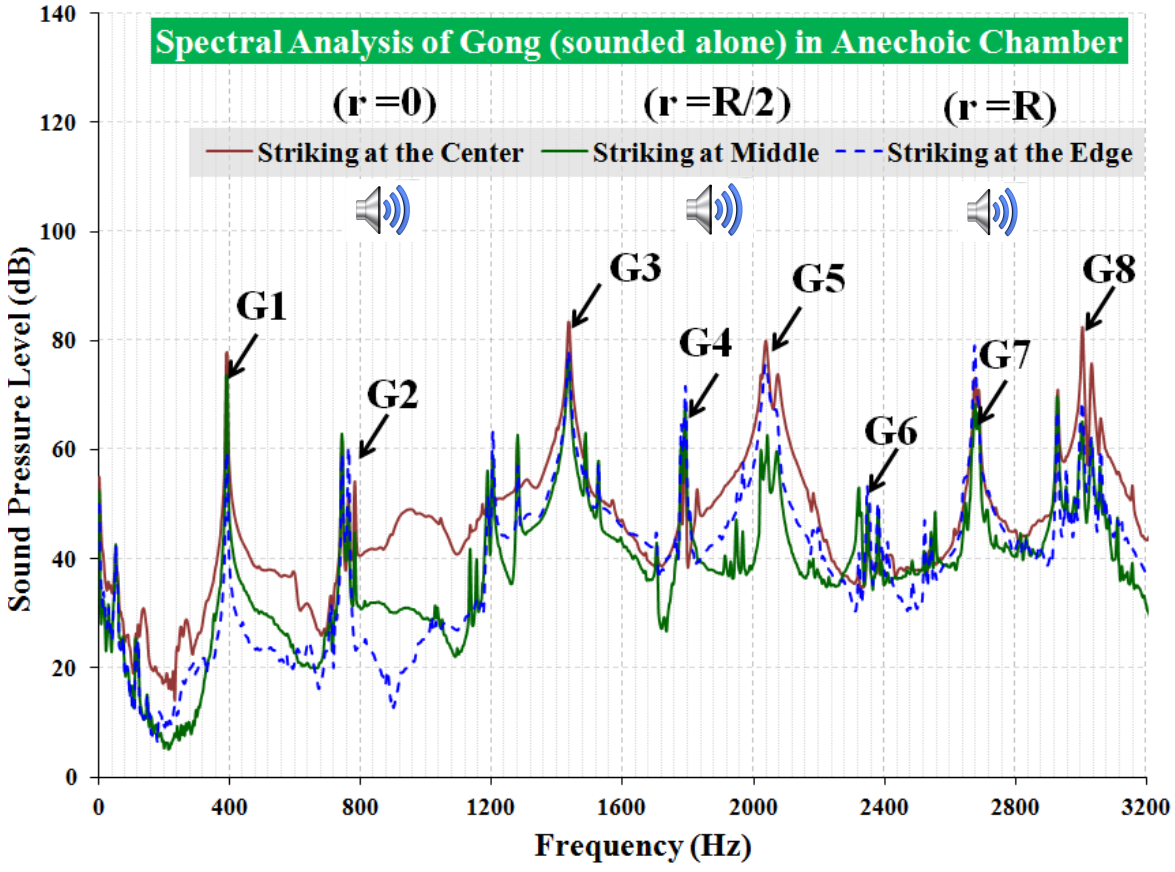

Figure 15. Spectra of a gong when stroked at different places.

8. Simultaneous sounding of conch-bell-gong and chanting in Hindu worship spaces

In worship rituals at a Hindu temple, in a community hall and in a worship room at individual homes, usually all the instruments described above are simultaneously sounded along with Vedic chanting during the pooja. In this study we have measured the sound spectra of all the three instruments played along with Vedic chanting. The measurement was carried out in anechoic chamber, community hall and Ardha-Mantapa of a temple. The measured frequencies are given in Table 3 and the sound spectra are shown in Fig. 16. It is observed that the measured spectra of all the three instruments and vocal chanting are combination of individual frequencies of the Conch-Shell, Bell, Gong and Chanting frequencies. The recorded audio (.mp3) files of playing three instruments and Vedic chanting simultaneously in an anechoic chamber, Ardha-Mantapa and community hall are also embedded in Fig. 16.

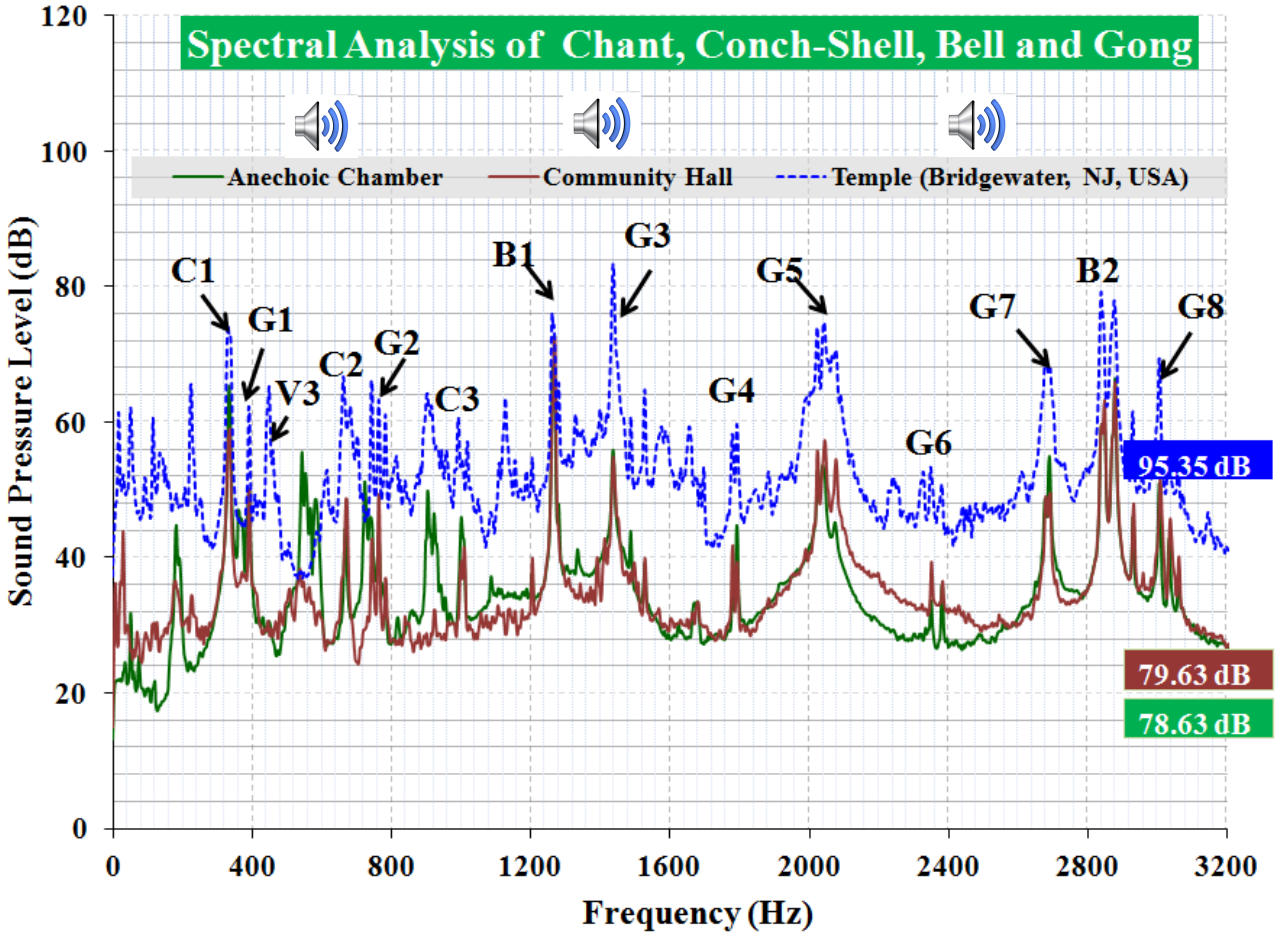

Figure 16. Spectra of Chant (V), Conch-Shell (C), Bell (B) and Gong (G) when simultaneously sounded.

9. Results and Discussions

It is seen from the Table 2 that both theoretically estimated and measured increase in sound pressure levels in the main hall outside the Ardha-Mantapa agree well for the temples in USA. Generally a traditional Hindu temple has both a Garbha-Griha and an Ardha-Mantapa. Thus the acoustically reverberant environment in the Garbha-Griha and the Ardha-Mantapa not only enhances the spiritual experiences for the devotees but also adds to the devotional environment of the temple. Figures 6(a) and 6(b) show the sound propagations due to the placement of the acoustical source in Garbha-Griha and Ardha-Mantapa respectively. The acoustical enhancement of the environment is seen clearly in both cases. However during the celebrations of the festivals in a

temple, the priests will be in both Garbha-Griha and Ardha-Mantapa. This will further amplify and enhance the acoustical environment in the temples.

Figures 7, 9, 11 and 14 show the spectra respectively of the four sources namely chants, conch-shell, hand-bell and gong sounded individually. In each figure is also shown the spectra in three spaces namely a temple, a community hall and an anechoic chamber. The spectra details of sounds from these sources and the various spaces clearly show that various dominant resonance frequencies are spread out in the active hearing range. In particular, the high amplitude sharp tonal frequencies of conch-shell, bell and gong are distinct. The Fig. 16 and the embedded audio of the combined sounds of all sources show this effect clearly.

The perception of pitch is known to depend on both spectral and temporal characteristics [25]. The presence of tones in chants and various musical instruments have deep impact on devotees in Hindu worship spaces. It is to be noted that chants and musical instruments are also commonly used in worship spaces of other religions [26-29]. Although it is observed that there are positive and beneficial effects of chants and music on human beings [30-32], further research is needed in this interesting field.

10. Conclusions

In Vedic Hinduism sound has received major emphasis through mantras, music, religion and spirituality. It is well known that sound plays a very important role in Hindu worship spaces both at homes, community halls and temples. It is observed that both Garbha-Griha and Ardha-Mantapa significantly contribute to the acoustical enhancement of the spiritual experience of the devotees. The effects of Vedic chants in Hindu worship are well known. In addition to Vedic chants musical instruments such as conch-shells, bells and gongs are also very commonly used to enhance the spiritual experience of the devotees during the worship. It is known that sounds of these instruments along with Vedic chanting during the prayer would enable the wandering mind of the devotees to focus on the worship rituals. In this study, evaluations of acoustical characteristics of these instruments have been carried out by sounding individually as well as collectively. Measurements are carried out in an anechoic chamber, community worship hall and temple. The observed sound spectra indicate that the measured frequencies are collection of all individual frequencies. Also the frequencies are distinct and are spread across from low to high frequencies in the active hearing range, which contribute to the spiritual experience of the devotees.

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REFERENCES

[1] M. Kleiner, D. L. Klepper and R. R. Torees, 2010. *Worship Space Acoustics*, J. Ross Publishing, USA.
[2] M. G. Prasad and L. B. Weiss, 2012. *Sacred Spaces*, An inter-faith journey, *Taranga*, New Jersey.
[3] G. L. Beck, 2010. *Sacred Sound: Experiencing music in world religions*, Motilal Banarsidass, New Delhi.
[4] M. G. Prasad, 2004. Mantras to Music: Acoustics in Hinduism, *147th Acoustical Society of America Meeting*, New York, USA. (www.acoustics.org/press/147th/prasad.htm)

[5] M.G. Prasad, 2009, Vedic Perspectives on Acoustics, *Workshop on Exploring Vedic Sciences organized by the Center for Indic Studies*, The Center for Indic Studies, The University of Massachusetts at Dartmouth. http://vimeo.com/32063009.
[6] T.V.Ananthapadmanabha, K. Silverman and M.G. Prasad, 1989. Vedic Chanting and Vowel Intrinsic Pitch Evidence from an Ancient Source", *117th meeting of the Acoustical Society of America*, Syracuse, NY, USA.
[7] M. G. Prasad, 2013, Oral Tradition in Indian Civilization, Chapter 6, Perspectives on the Origin of Indian Civilization, edited by A. Marcantonio and G. N. Jha, Center for Indic Studies and D K Printworld, New Delhi.
[8] C.V. Raman, 1922, *The Acoustical Knowledge of the Ancient Hindus*, Ashutosha Mukherji Silver Jubilee Volume, **2**, 179-185.
[9] Sangita and Stotra, 1991. Lectures of Sriranga Sadguru, *Ashtanga Yoga Vijnana Mandiram*, Volume 7 of Amaravani, (http://www.ayvm.in), Mysore, India.
[10] M.G. Prasad, 2012, *Four Fold Description of Sound: A Vedic view*, Chapter 4, Science and technology in Ancient Indian Texts, Edited by Bal Ram Singh, Girish nath Jha, Umesh Kumar Singh and Diwakar Mishra, D K Printworld, New Delhi, India.
[11] B. Saraswati, 1999. Thinking About Sound in Traditional Science, in *Dhvani: Nature and Culture of Sound*, (editor: S.C. Malik), Indira Gandhi national Centre for the Arts, New Delhi.
[12] S. K. Ramachandrarao, 2010. *Art and Architecture of Indian Temples*, Kalpataru Research Academy, Bengalooru, India.
[13] Sadhu Shantipriyadas, 1995. *Mandir: Traditions and Beliefs*, Swaminaryayan Aksharpith, Amdavad, India.
[14] K. R. Srinivasan, 1985, *Temples of South India*, National Book Trust, New Delhi, India.
[15] R. Vasantha, 1991. *The Narayanaswami Temple at Melkote: An Archaeological and Historical Study*, Directorate of Archaeology and Museums, Karnataka, India.
[16] S. Mukhopadhyaya, 1999. Importance of Sound in the Tradition of Vedic Chanting, in *Dhvani: Nature and Culture of Sound*, (editor: S.C. Malik), Indira Gandhi national Centre for the Arts, New Delhi.
[17] M. G. Prasad, and B. Rajavel, 2010. On the Role of Acoustics in the Vedic Hindu Tradition and Philosophy, *The Journal of Acoustical Society of America*, **127** (3), 1983.
[18] P. R. Cook, J. S. Abel, M. A. Kolar, P. Huang, J. Huopaniemi, J. W. Rick, C. Chafe, and J. M. Chowning, 2010. Acoustic Analysis of the Chavín Pututus (*Strombus Galeatus* Marine Shell Trumpets), *The Acoustical Society of America*, 128 (4), 2359.
[19] R. B. Bhat, 1992. Acoustics of conch shells, *Journal of Sound and Vibration*, **157** (1), 190–191.
[20] L. R. Taylor, M. G. Prasad, and R. B. Bhat, 1994. Acoustical characteristics of a conch shell trumpet, *The Journal of Acoustical Society of America*, **95,** 2912.
[21] S. K. Rath, S. K. and P. C. Naik, 2009. A study on acoustics of conch shell, *Current Science*, **97**, 521-528.
[22] M. G. Prasad, and B. Rajavel, 2010. Acoustical Studies on Conch-Shells, *The Journal of Acoustical Society of America***, 127** (3), 1983.
[23] C .V. S. Sarma, 2009. *The Temple Pooja Rituals as per Agama Shastras*, Narmadha Pathippagam, Chennai, India.
[24] P. Shravage, S. Parmeswaran, and Keith deSa, 2005. Vibration study of Indian Gong hung at One Point Near the Edge, *The Journal of Acoustical Society of America*, **117**(4), 2567.
[25] W. A. Yost, 2009. Pitch Perception, Attention, *Perception and Psychophysics*, **71** (8), 1701-1715.
[26] T. Irvine, 2007. Shofar Acoustics, *Newsletter of Vibration data* (www.vibrationdata.com).
[27] E. Yonnetti, 2011. Like the Roar of Thousand Thunders: Instrumental Music and Creativity in Tibetan Buddhist Ritual, Independent Study Project Collection, 1065, (http://digitalcollections.sit.edu/isp_collection/1065).
[28] J. Jackson, 1978. On Good Health and Gregorian Chant; An Interview With Dr.Alfred Tomatis, Colorado, USA. (www.saintpeterorthodox.org/files/gregorian-health.pdf)
[29] M. R. Ismail, 2013. A Parametric Investigation of the Acoustical Performance of Contemporary Mosques, *Frontiers of Architectural Research*, **2**, 30-41.
[30] B. M. Thompson and S. R. Andrews, 2000. An Historical Commentary on the Physiological Effects of Music: Tomatis, Mozart and Neuropsychology, *Integrative Physiological and Behaviorial Sciences*.
[31] A. Bennet and D. Bennet, 2009. The Human Knowledge System : Music and Brain Coherence, *The Journal of the Monroe Institute*, Virginia, USA.
[32] J. J. Pilch, 2004. Music and Trance, *Music Therapy Today*, **V** (2), 1-19. (http://musictherapyworld.net).