REAL EAR SOUND LEVELS IN VOCAL AND INSTRUMENTAL MUSICIANS

Reg. No. 02SH0014

An independent project submitted as part fulfillment for the
first year Master of Science (Speech and Hearing),
University of Mysore, Mysore

ALL INDIA INSTITUTE OF SPEECH AND HEARING
MANASAGANGOTHRI,
MYSORE - 570 006

JUNE, 2003

This is dedicated to my aunt, Sara Thomas. Even though you are not here with us............you will always be near us, always in our hearts.

Certificate

This is to certify that this Independent Project entitled **"Real Ear Sound Levels in Vocal and Instrumental Musicians"** is a bonafide work in part fulfillment for the first year Master of Science (Speech and Hearing) of the student (Register No. 02SH0014).

Mysore

June, 2003

Dr. M. Jayaram
Director
All India Institute of Speech and Hearing
Mysore-570 006

Certificate

This is to certify that this Independent Project entitled **"Real Ear Sound Levels in Vocal and Instrumental Musicians"** has been prepared under my supervision and guidance. It has also been certified that this has not been submitted earlier in any other university for the award of any diploma or degree.

Guide

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June, 2003

DECLARATION

This is to certify that this Independent Project entitled **"Real Ear Sound Levels in Vocal and Instrumental Musicians"** is the result of my own study under the guidance of Mrs. P. Manjula, Lecturer, Department of Audio logy, All India Institute of Speech and Hearing, Mysore and has not been submitted earlier in any other University for the award of any Diploma or Degree.

Mysore,

June, 2003 **Reg. No. 02SH0014**

Acknowledgements

The Lord is the tight of my tife
- whom shaft I fear?
The Lord is the stronghotd of my tife
- of whom shaft I be afraid?
(Psalm 27:1

first and foremost of all, I would like to thank the Lord for helping me throughout this year, for never letting go of my hand and for always letting his presence Be known to me.

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"I can do all things through Him who strengthens me"

phil 4:13

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

It is generally accepted today that professional jobs shouldn't result in adverse effect on health. This concern is inconsistently raised across various professions. The musical profession is highly dependent upon a good sense of hearing to match pitch, monitor vocal quality, and provide feedback and direction for voice/instrument adjustments during performance (Axelsson & Lindgren, 1981b).

The importance of good hearing has been under appreciated. While well-trained singers are usually careful to protect their voices, they may subject their ears to unnecessary damage and thereby threaten their musical career (Sataloff & Sataloff, 1993). For example, Chasin and Chong (1991) found the real ear values of Sopranos to be around 115 dBSPL. They have reported 90 to 126 dBSPL at the eardrum of musicians while playing instruments or singing. This may result in hearing loss because of which there will be impairment of self-monitoring leading to vocal abuse. Various investigations have found an increased incidence of high frequency sensori-neural hearing loss among professional musicians as compared to the general public (Sataloff & Sataloff, 1993).

Two other major changes in a musician's auditory system also may result from damage to the cochlea, and, in some sense, these are even more important than loss of hearing sensitivity. One is difficult in pitch perception and the other is the onset of tinnitus. Both of these can be career-threatening conditions for musicians, and, at the very least, will significantly reduce their enjoyment of music (Chasin, 1998).

Another problem common among singers is vocal strain, especially if they have to sing over loud background music (Chasin, 1998). The problem of occupational hearing loss among classical singers and other musicians is less obvious, but equally important. Classical music can be just as damaging as or more damaging than rock music or factory noise (Chasin, 1998). The frequent occurrence of loud pure tones and impulse sounds in the musical environment suggests the possibility of hearing loss by performance of classical music (Axelsson and Lindgren, 1981a).

Obviously, the result of occupational hearing loss would be embarrassing and musicians would prefer it not to be known that their sense of hearing, on which their performance relies, is not of class order. Hence, music or noise exposure should be reduced in order to ensure that musicians can still play and enjoy music 30-40 years later. This requires two types of information:

1. Level of noise exposure
2. Specification of optimal ear protection

It is important to be alert for hearing loss from all causes in performance, recognize it early and treat it or prevent its progression, whenever possible.

Music tends to be more "intermittent" which is thought to reduce a musician's risk for hearing loss as compared with that of industrial noise exposure. Such differences caution against generalizing the results of industrial noise induced hearing loss (NIHL) to music induced hearing loss (MIHL).

Like noise induced hearing loss, the hearing loss due to music exposure is related to factors such as intensity of music, duration of exposure, total exposure time (months, year) and personal liking for music. There are a number of studies that confirm the effect of industrial noise exposure on hearing. Literature reveals certain differences between the industrial noise exposure and exposure to music. There are only a few studies on the effect of exposure of music on hearing. There are even fewer studies on the actual amount of sound the instrumentalists and vocalists are exposed to at the ear level. The studies that have been carried out mainly involve Western musicians.

Hence, there is a dearth of literature with reference to Indian classical musicians, both instrumentalists and vocalists. Also, there is a general misconception that only rock-and-roll or pop music can cause hearing loss. Hence, keeping in mind the above speculations, this study was undertaken in order to investigate the sound pressure levels of music (instrumental and vocal) at the ears of the musicians.

REVIEW OF LITERATURE

Clients in the performing arts pose a fascinating problem for healthcare professionals. They can be subjected to music levels in excess of even the most stringent of noise regulations, or find themselves in relative quiet. A review of literature reveals that band musicians, classical musicians and rock musicians are prone to noise induced hearing loss (Axelsson & Lindgren, 1977, 1978; Ostri, Eller, Dahlin & Skylv, 1989; Royster, Royster & Killion, 1991; Berghoff, cited in Sataloff & Sataloff, 1998; Chasin, 1998).

Other than being on-site during an actual performance with an array of sound level meters, there is no definitive way to determine the musician's amount of noise/music exposure. However, fairly good estimates can be obtained from assessing the spectral output of: (1) their own instruments and (2) those around them. This can be done using real ear measurement systems like Fonix 6500C, Audioscan RM500, etc. These measurement systems can be used as a sound level meter and as a spectrum analyzer. They are ideal devices for the purposes of measuring the spectral output from the musicians' output.

Axelsson and Lindgren (1978) studied the hearing of 160 pop musicians and found, on the average, a surprisingly low percentage of hearing loss. However, an individual analysis showed a 13-30% of sensori-neural hearing loss, depending upon the definition of hearing loss. Subjects with hearing loss showed a discrete impairment in the frequency range 3-8kHz, considering the sound levels and the length of exposure.

They also found the dominant frequencies of pop music to be low; the 250-500 Hz range was maximally amplified. Since low frequency noise is less damaging to the inner ear, perhaps through the protective action of the stapedius reflex, and the presentation of loud pop music is often interrupted by pauses which offer at least some possibility of recovery and rest, they concluded these to be the reasons for the low incidence of hearing loss in pop musicians. Rintleman and Borus reported similar findings in 1968. In their study on rock-and-roll musicians who were exposed to 105 dBSPL of rock-and-roll music for an average of 5 hours a day, 2 days a week, for 2.9

years, they found only 5% of them to have incurred noise-induced hearing loss. The reason for such a finding was similar to that reported by Axelsson and Lindgren inl978, as mentioned earlier.

Palin (1994) remarked that as there is a firm association between live rock-and-roll music and hearing loss in musicians, the evidence that classical music may damage the hearing of musicians remains conflicting. However, Chasin (1998) reported that 37% of rock musicians and 52% of classical musicians have hearing loss. The higher incidence of hearing loss in classical musicians is attributed to the closer proximity of different musicians during a classical concert. Axelsson and Lindgren (1981a) reported the frequent occurrence of loud pure tones and impulse sounds in the musical environment to be one of the possibilities of hearing loss in classical musicians. They concluded from their study on 139 musicians that if the sound level measurements during musical performances and durations of exposure exceed recognized DRC (Damage Risk Criteria), then it would imply that there is a risk for sensori-neural hearing loss by music. Results of an investigation by Royster et al. (1991) showed that Leq during a musical performance varied from 79-99 dB. Janson and Karlsson, in 1983, reported the risk threshold for noise injuries to be 85 dB(A), Leq. However, they concluded from their study on symphony orchestra players that the risk criteria were difficult to apply and that measures should be taken to reduce exposure to noise when 'heavy' music was played.

Satish (2002) had done a study on twenty-five Indian classical musicians to investigate the hearing in orchestral performers. The results of his study indicated the presence of hearing loss in those individuals exposed to orchestral music and the hearing loss to be more evident in the 8 kHz and 12,500 kHz regions.

According to Westmore and Eversden (1981), many orchestral musicians, by their own admission, actually enjoyed and received a form of physical as well as aesthetic stimulation from the barrage of sound to which they were subjected. This finding was supported by Chasin's study (1998) where he reported that if the music was liked, there was less of a hearing loss.

Over the years different investigators have studied the amount of noise produced by various instruments. The values in dB(A) or dBSPL for various instruments, mainly western instruments have been recorded and published in various studies.

Folprechtova and Miksovska (as cited in Sataloff & Sataloff, 1998) measured sound levels of 92 dB(A) with variations of 87-98 dB(A) in a symphony orchestra. They reported the sound levels of various instruments, as shown in Table 1. Similar findings were also reported by Chasin in 1996.

Table 1:

Intensity levels (dBA) of different instruments

Instrument	**dB(A)**
Violin	84-103
Cello	84-92
Piccolo	95-112
Flute	85-111
Clarinet	92-103
French Horn	90-106
Oboe	80-94
Trombone	85-114
Xylophone	90-92

Note: From "Hearing loss in singers and other musicians", by Sataloff and Sataloff, 1998, *Vocal Health and Pedagogy,* San Diego:Singular, p. 141.

Miskolczy-Fodor (1960), as cited by Axelsson and Lindgren (1981b), found the sound levels from the piano to be 90-96 dB when playing fortissimo sequences of chords with a sustaining pedal. However, the average levels of piano sound rarely reached 85 dB.

Berghoff (1968), as cited by Axelsson and Lindgren (1981b), presented sound registrations in phon for the big band; the levels were 80-120 phons. For most musicians the sound levels were similar at the external ear and at 1 meter distance. For wind instruments, however, the sound levels were 2-3 phon higher at 1 meter distances than at the ear canal.

Flach (1972), as cited in Axelsson and Lindgren (1981b), didn't find any difference in hearing for different instrument groups. According to Flach and Aschoff, as cited in Axelsson and Lindgren (1981b), musicians playing the violin have decreased hearing on the left ear when compared to the right. This implies that the sound levels produced by the violin are more for the left ear compared to the right. Chasin, in 1998, reported violinists and violists to typically have worse hearing on the left side because of how they hold their instruments. So also for drummers because of the high-hat cymbal near the left ear. However, Axelsson and Lindgren (1981b) in their study on classical musicians reported that the violinists did not show any general tendency to have less good hearing on the left ear. If there was an influence on the left ear by the violin, this apparently was only reflected by high frequency dips in the pure tone audiogram. They also reported woodwind instruments, like the flute, to be a contributing factor for sensori-neural hearing loss. Chasin, 1998, reported flute players to often have greater problems in their right ear. An earlier study by Flach (1972), as cited in Axelsson and Lindgren (1981b), found hearing loss to be most common in musicians playing string instruments (14.5%).

Chasin and Chong (1991) reported of sound levels at the eardrum of the musicians, as cited in Table 2.

Table 2:

Sound Pressure Levels (dBSPL) produced by various instruments

Instrument	Sound Pressure Level (dBSPL)
Reeded woodwinds	<100
Flute	105 in the right ear
Small String (Violin and Viola)	110-126 in the left ear
Large String (Bass, Cello)	90
Brass Instruments	>115
Vocalist (Soprano)	115

Note: From "Musicians are at a risk for noise-induced hearing loss: An in-situ ear protection program for musicians", by Chasin and Chong, 1991, *Hearing Instruments*, p.27.

Chasin (1996) made a Decibel - Loudness Comparison Chart, as cited in Table 3, for both classical and rock music, i.e., in other words, the amount of loudness an individual would hear when exposed to different type of musical instruments or music in general.

Table 3:

Intensity levels in dB(A)from classical music and rock music

Instrument	dB(A)
Normal piano practice	60-70 dB
Fortissimo singer 3 ft. away	70 dB
Chamber music in small auditorium	75-85 dB
Regular sustained exposure may cause permanent damage	90-95 dB
Piano fortissimo	92-95 dB
Timpani & bass drum rolls	106 dB
Average Walkman on 5/10 setting	94 dB
Symphonic music peak	120-137 dB
Amplified rock music at 4-6 ft.	120 dB
Rock music peak	150 dB

Note- From "Decibel Trivia", by Chasin, 1996,
http://www.hearnet.com/at_risk/risk_trivia.shtml

Chasin also recorded the following observations in this study

> The brass section playing fortissimo can drown out practically the whole orchestra.
>
> One-third of the total power of a 75-piece orchestra comes from the bass drum.
>
> High frequency sounds from 2,000 to 4,000 Hz are the most damaging. The uppermost octave of the piccolo is 2,048-4,096 Hz.

> Aging causes gradual hearing loss, mostly in the high frequencies.
>
> Speech reception is not seriously impaired until there is about 30 dB loss; by that time severe damage may have occurred.
>
> Hypertension and various psychological difficulties can be related to noise exposure.
>
> The incidence of hearing loss in classical musicians has been estimated at 4-43%, in rock musicians 13-30%.

Studies undertaken by other investigators have shown conflicting readings and, in many cases, investigators did not specify at what distance the readings were taken or what the musician was actually playing. In general, when there were several readings, the higher one was chosen.

Steurer, Simak, Denk and Kautzky (1998) did a study on choir singers and found the peak sound levels to be >110 dBSPL. However, unlike other studies, they reported the low frequency regions to be most affected. The major concentrations of energy were found below 1000 Hz and even 500 Hz, but not below 100 Hz. They put forth a hypothesis (unproven) to explain this phenomenon. They hypothesized that singing might lead to increased endolymph pressure, and thus might cause hearing loss especially in the low frequency region.

A ccording to the TNT-Audio article "What's In Your Music" (n.d), the Table 4 is a guide to the sort of sound pressure levels acoustic instruments produce unamplified. Here, again no distances were specified. It has been assumed that a couple of meters may have been the distance used.

Table 4:

Sound pressure levels produced by instruments unamplified

Instrument	**Ranee measured in dBSPL**
Bass drum	35-115
Cymbal	40-110
Organ (orchestral)	35-110
Piano	60-100
Trumpet	55-95
Violin	42-95

Note. From "What's in your music", (n.d),
http://www. tnt-audio. com/topics/frequency_e. html

In Table 5, given by the Audioscan article "Assessing Musicians"(n.d), a summary of the peak levels of various musical instruments is shown. It can be seen that some instruments are quite capable of generating sound levels that can be potentially damaging. This table can be used to estimate the exposure from the other musical instruments around the performer.

Table 5:

Peak levels of musical instruments

Instrument	*Peak (dBSPL)*
French Horn	107
Bassoon	102
Trombone	108
Tuba	110
Trumpet	111
Violin	109
Clarinet	108 ,
Cello	100
Amplified Guitar	>115
Drums	>120

Note. From "Assessing Musicians", by Chasin, (n.d), *http://www. audioscan.com/'AppNote_98-05.pdf*

Results will vary according to the individual's playing style, their reed, bow or mouthpiece; and construction of their own instrument.

In general, the Audioscan article "Assessing Musicians", has revealed the following findings with reference to different categories of instruments:

1. All stringed (violin, viola, cello, bass, etc.) and brass (trumpet, French horn, trombone, etc.) instruments perform like the violin - steady overall increase in output as playing level increases.

2. All reeded woodwinds (clarinet, saxophone, oboe, bassoon, etc) have an interesting characteristic where the high frequency output increases faster than the lower frequency output as the playing intensity is increased.

3. Treble musical instruments, such as the trumpet and flute, tend to have greater energy in the higher frequencies than fundamental energy for the lower frequencies.

Due to the variety of differences between various musical instruments and their respective sound levels, it is necessary for the musicians to take utmost care of their hearing. According to Chasin (1998), a cornerstone of any hearing loss prevention program for musicians is education. Most musicians (up to 90%) will have the beginnings of a hearing loss. So an assessment that will be used to prevent hearing loss, and in so doing, will prevent pitch perception problems and tinnitus, is very important.

But the question arising among many musicians mind would be - how to do so without it affecting their music? Research has indicated the use of earplugs as a means of protecting the hearing sensitivity of musicians. But another question that would arise would be whether ordinary earplugs are sufficient or whether any specific type of earplug is needed to benefit the musicians.

According to Westmore and Eversden (1981), many musicians discretely use earplugs to protect their ears, but often these consists only of cotton wool, which are useless. They only reduce sound by less than 7 dB.

Reports from the Hearnet article "Are You At Risk?" (n.d), have revealed conventional earplugs to have varied disadvantages. Some of these have been listed:

1. Existing earplugs attenuate more than necessary for much of the noise in industry and the environment.

2. Regardless of their exact construction, existing earplugs produce 10 to 20 dB of high frequency attenuation and the result is that people often reject them because they can't hear speech clearly.

3. Conventional earplugs make the wearer's own voice sound hollow (known as the occlusion effect).

4. Many people risk their hearing by either wearing earplugs loosely or wearing no protection at all so they will be able to hear voices, machinery or music more clearly.

Another type of protection that may be used by the musicians are the custom **fit** earplugs, which are worn by many musicians, and made from an impression of the ear canal taken by an audiologist or other hearing health professionals. The impression is then sent to a lab where the final earplug is made. Custom earplugs are comfortable, easy to insert correctly, and filter sound better than disposable plugs.

There are more specific protective devices for musicians called Musician's Earplugs. There are two types of people who could benefit from Musician's Earplugs. The first group are those exposed to 90-120 dB sound levels for various time periods and who need to hear accurately. This group includes musicians, their sound crews, recording engineers, nightclub employees, and other music industry professionals. The second group consists of people outside the music industry, including loud-music listeners, persons with tinnitus or hyperacusis, spectators at sporting events, some construction workers, motorcycle drivers, and regular airline or auto travelers. These people often have high-frequency hearing loss but refuse to wear conventional hearing protection because they need to hear more clearly.

With Musician's Plugs, sound quality is clearer and more natural. They help to reduce fatigue associated with noise exposure. A flat-response attenuator must have a frequency response that follows the shape of the natural frequency response of the open ear, but at a reduced level. The Musician's Earplugs **ER-9, ER-15 and ER-25** use a diaphragm, similar to a passive speaker cone, to achieve the desired response curve. To reduce the occlusion effect, a deep seal of the plug in the second bend of the ear canal is necessary. Their special filter lets the listener hear music at a safe level without sacrificing quality. Instead of cutting out the high frequencies, musician's plugs attenuate all the frequencies evenly in relation to ones' hearing.

According to the Earlink article " Musician's Earplugs" (n.d), the ER-20 uses a tuned resonator and acoustic resistor. It has a comfortable ear tip designed to provide hearing protection with both a flat attenuation and a great "universal fit" for comfort. This plug provides approximately 20 dB of attenuation while preserving the natural sound quality.

As mentioned before, conventional earplugs reduce sound more in the high frequencies than in the mids and lows, making voices and music sound unclear and unnatural. The ER-20s reduce sound levels evenly across frequencies, so voices and music are clear and undistorted.

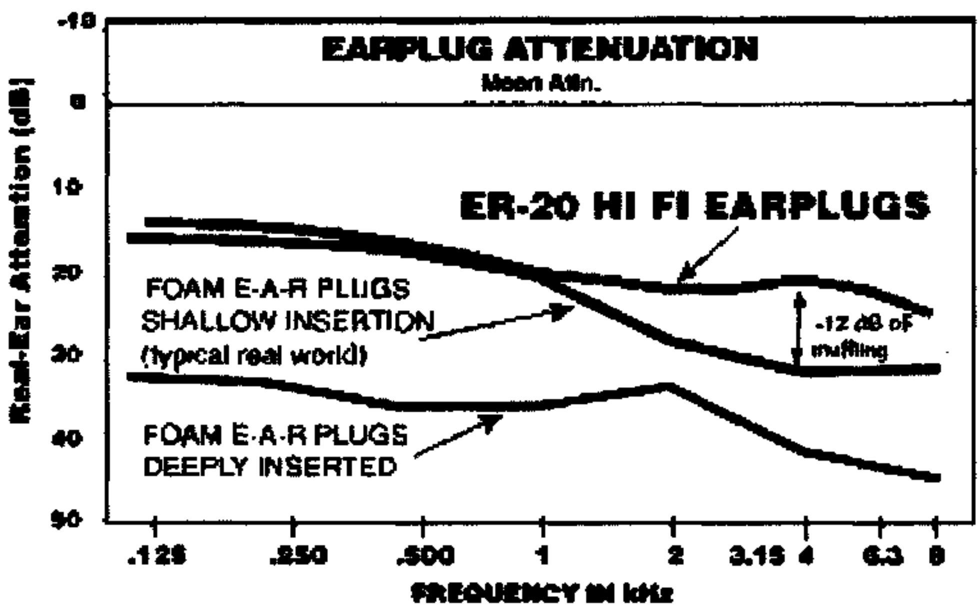

Figure 1: Earplug attenuation

Note. From "Musician's Earplugs", (n.d), *http://www.earlink.com/musicianearplugs.htm*

Chasin, in 1996, gave the following table (Table 6) showing the optimal hearing protection for musicians, with various instruments:

Table 6:

Hearing protection for musicians

Instrument	**Auditory Damage**	**Earplugs**
Reeded woodwinds	Brass section to rear	ER-15 vented/tuned
Flutes	>105dBSPL	ER-15 vented/tuned
Small strings	(>110dBSPL)	ER-15
Large strings	Brass section to rear	Vented/tuned
Brass	Brass section to rear	Vented/tuned
Percussion	Percussion (high hats)	ER-25
Vocalists: • Solo • Non-solo • Amplified instruments	Soprano (>115dBSPL) Other instruments Speakers/Monitors	Vented/tuned ER-15 ER-15

Note. From "Assessing Musicians", by Chasin, (n.d),
. *http://www. audioscan.com/AppNote_98-05 .pdf*

According to Chasin (1998), **Ear Monitors or custom-made earphones** can also be used by musicians. Depending on the manufacturer, one or two matched receivers are included in each in-the-ear shell. A cable joins the earphone directly to the electrical rack of the music group or to an FM transducer that communicates remotely with the rack. In this way, the environment of the stage is amplified. The musician can then monitor the music at a more comfortable and safer level.

Musicians can also improve the monitoring of their music by using a combination of **"Acoustic monitors"** and electrical **"Shakers".** Acoustic monitors are primarily useful for bass acoustic instruments such as the cello and string bass. It provides significant low and mid-frequency amplification for the musician. Drummers and electric bass players can derive benefit from a shaker, which is an electrical device, designed to pick up low frequency energy and extend this vibration to even lower frequencies. The enhanced vibrations improve music awareness.

Chasin also reported of changes that can be made in the environment of musicians to minimize the risk of hearing loss:

1. Placing trumpet players on risers, so that most of the damaging energy goes over the heads of the musicians in front of them.

2. Pulling the band back from the edge of the stage, if there is room available. This unoccupied space at the front will assist in reflecting the sound toward the audience. Hence, the band or orchestra won't need to play intensely to sound loud.

3. Ensuring that the stringed instruments (violins and violas) are not placed under overhangs. Absorption of high-frequency energy takes place, which leads violinists to overplay. The music will be unnecessarily intense and arm injuries may occur from overplaying.

4. Elevating all speakers. Not only will the low frequencies be able to reach the audience (rather than being absorbed by the floor) but the higher frequencies will be more audible to the musicians and to the audience.

Thus, a review of literature shows that the different categories of instruments, mentioned earlier, have proven to produce sound levels dangerous to' the human ear. Continued exposures to these levels of sound are damaging, not only affecting the hearing sensitivity, but also by causing biological and psychological problems. Hearing protection has also been shown to be effective and necessary for musicians to protect damage or sometimes further damage from these intense levels of sound.

METHOD

The present study aimed at measuring the real ear sound pressure levels for carnatic musical instruments and vocal music. In order to investigate this, the following method was used.

For this purpose, twenty-five adult carnatic vocalists and twenty-six adult carnatic instrumentalists were taken as subjects for the study. Five different categories of instruments were used with four to six subjects taken for each category of instrument.

The criteria for selecting the subjects were that they should have passed at least their junior music level or an equivalent exam.

Environment:

The tests were carried out in a sound treated room with the ambient noise within permissible levels (re: ANSI, 1991, as cited in Wilber, 1994).

Instruments Used:

i. Fonix 6500C hearing aid test system (Computer controlled real time analyzer, V-3.09)

ii. A calibrated audiometer and a calibrated immittance meter

iii. Carnatic music instruments, i.e., Veena, Mridangam, Ghatam, Violin and Flute.

The *Veena* is an important string instrument in South Indian Carnatic music. The highest quality Veenas have the entire body carved from a single block of wood, while the ordinary Veenas have the entire body carved in three sections (resonator, neck and head). The main bridge is a flat bar made of brass which has a very slight curve. It is this light curve that gives the veena its characteristic sound.

The *Mridangam* is the main rhythm instrument of Carnatic music with the Ghatam, and is made of jackwood. The body has two apertures of different sizes; one very small generating high-pitched sounds and the other, wider generating low-pitched sounds.

The *Ghatam* is the main percussion instrument, an earthenware pot played in the South Indian classical music, with the Mridangam. The percussionist uses the flat, the knuckles and the sides of both hands to hit the walls of the Ghatam, but he also uses his belly to cover the mouth of the pot, generating controlled tuning and even notes in the lower octave.

The *Violin* is a string instrument whose construction seems to be no different for its western counterpart. However, the technique used is quite different. The most refined technique is found in South Indian music, where, instead of holding the instrument under the chin, it is propped between the shoulder and the foot. This gives it a stability, which cannot be matched by North Indian techniques.

The *Flute* is one of the oldest woodwind instruments, only recently been used in Caraatic music. In this, it is possible to sustain sound for a long time. Hence, it is able to perform all kinds of delicate notes.

Test ***Procedure:***

The testing was carried out in two phases: -

Phase I: Audiological testing/screening

Phase II: Measurement of real ear SPLs

Phase I - Audiological Testing/Screening

Though the aim of the present study was to measure the real ear SPLs, the hearing testing/screening of the subjects was also conducted.

- In this phase a hearing screening, with respect to pure tone audiometry and immittance, was done.
- A detailed case history was also taken involving the following information:

Name	
Age/Sex	
Music qualification	
Years of experience	
Years of public performance	
No. of hours of practice per day or per week	
Whether solo/group performance	
Types of accompaniments	
Otological signs and symptoms	

- In case of pure tone audiometry, the intensity was kept constant at 15 dB HL, and the subject's hearing was screened at 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz and 8000 Hz. When the subject failed at any of these frequencies, the hearing thresholds were established at that particular frequency.

- With reference to immittance screening, tympanograms of each ear and screening for presence of ipsilateral acoustic reflexes at 500 Hz, 1000 Hz and 2000 Hz at 100 dBHL were done.

Phase II - Measurement of real ear SPLs

- The subject was asked to sit comfortably in his/her usual posture as in performance, i.e., either on the ground or on a chair, comfortably. He/she was then instructed to play the instrument or sing with normal effort.

- The song they played or sang depended on each subject, i.e., each subject was instructed to play or sing a carnatic piece of music with which he/she was comfortable.

- During this, the SPL of the music in each ear of the subject was measured using the probe tube microphone of the Fonix 6500C.

Protocol for measurement of SPL in the ear of the subject:

1. From the Probe Menu of Fonix 6500C,

    a) 'SPL measurement' was selected from 'Gain (G)/SPL' measure

    b) Reference microphone and the speaker were disabled

2. The probe tube microphone (20mm) was inserted into the ear canal for SPL measurement.

3. The subject was asked to play the instrument or sing.

4. The SPL in the ear canal was measured at frequencies from 200 Hz to 8000 Hz, when the subject sang or played the instrument.

5. The 'Data' facility of Fonix 6500C was utilized to note down the levels in dB SPL at 200 Hz, 500 Hz, 1000 Hz, 1500 Hz, 2000 Hz, 2500 Hz, 3000 Hz, 3500 Hz, 4000 Hz, 4500 Hz, 5000 Hz, 5500 Hz, 6000 Hz, 6500 Hz, 7000 Hz, 7500 Hz and 8000 Hz.

6. The highest value (in dBSPLs) among two to three measurements, for each ear, for each subject were tabulated and then subjected to statistical analysis.

RESULTS AND DISCUSSION

The present study was undertaken with the aim of establishing the sound pressure levels in the ears of carnatic musicians, i.e., for both vocalists as well as instrumentalists. The results of the study are discussed under two categories:

Phase I: Audiological testing/screening

Phase II: Measurement of real ear SPLs

Results of Audiological screening:

A summary of the findings during audiological screening is given in Table 7, Table 8, Table 9, Table 10, Table 11 and Table 12. In these tables, BE stands for Both Ears, Rt stands for Right ear and Lt stands for Left ear.

Table 7: Musical experience and audiologicalfindings in veena players

S.NO.	AGE/SEX	MUSICAL QUALIFICATION	YRS. OF EXPERIENCE	HRS. OF PRACTICE HRS/WEEK OR HRS/DAY	SOLO OR GROUP	AUDIOLOGICAL FINDINGS
1.	21y/M	Senior	6 yrs	3-4 hrs/wk	Solo	Rt: <15 dBHL; 'Ad' type, reflexes present Lt: 250 Hz -35 dBHL, 500 Hz - 40 dBHL, 1 kHz - 20 dBHL, 2 kHz-45 dBHL, 4 kHz-50 dBHL, 8 kHz - 50 dBHL; 'A' type, no reflexes
2.	42y/M	Senior	20 yrs	4 hrs/day	Solo& Group	Rt: 8 kHz-30 dBHL Lt: 4 kHz - 25 dBHL, 8 kHz - 25 dBHL <15 dBHL at other frequencies in both ears Rt: 'Ad' type, reflexes present Lt: 'A' type, reflexes present
3.	47y/F	Junior	7 yrs	4 hrs/wk	Solo	Rt: <15 dBHL; Lt: <15 dBHL Immittance could not be done.
4.	56y/M	Senior	46 yrs	6-8 hrs/day	Solo& Group	Rt: <15 dBHL; Lt: <15 dBHL BE: 'A' type, reflexes present

Table 8: Musical experience and audiologicalfindings in mridangam players

S. NO.	AGE/SEX	MUSICAL QUALIFICATION	YRS. OF EXPERIENCE	HRS. OF PRACTICE HRS/WEEK OR HRS/DAY	SOLO OR GROUP	AUDIOLOGICAL FINDINGS
1.	20y/M	Senior	lOyrs	7 hrs/wk	S0I0& Group	Rt: <15 dBHL; Lt: <15 dBHL BE: 'A' type, reflexes present
2.	22y/M	Junior	9 yrs	1 hr/day	S0I0& Group	Rt: <15 dBHL; Lt: <15 dBHL BE: 'A' type, reflexes present
3.	26y/M	Senior	18 yrs	2-3 hrs/day	Group	Rt: 250 Hz & 500 Hz-35 dBHL; <15 dBHL at other frequencies. Lt: <15dB HL BE: 'A' type, reflexes present
4.	27y/M	Bachelors degree	3 yrs	3-4 hrs/wk	Group	Rt: <15 dBHL; Lt: <15 dBHL BE: 'A' type, reflexes present
5.	35y/M	Bachelors degree	10 yrs	2-3 hrs/day	S0I0& Group	Rt: <15 dBHL; Lt: <15 dBHL BE: 'A' type, reflexes present
6.	42y/M	Bachelors degree	15 yrs	3 hrs/day	S0I0& Group	Rt: <15 dBHL; Lt: <15 dBHL BE: 'A' type, reflexes present

Table 9: Musical experience and audiological findings in ghatam players

S.NO	AGE/SEX	MUSICAL QUALIFICATION	YRS. OF EXPERIENCE	HRS. OF PRACTICE HRS/WEEK OR HRS/DAY	SOLO OR GROUP	AUDIOLOGICAL FINDINGS
1.	18y/M	Senior	8yrs	7-10 hrs/wk	S0I0& Group	Rt: <15 dBHL, Lt: <15 dBHL BE: 'A' type, reflexes present
2.	25y/M	Junior	lOyrs	2-3 hrs/day	S0I0& Group	Rt: <15 dBHL; Lt: <15 dBHL BE: 'A' type, reflexes present
3.	26y/M	Junior	llyrs	3 hrs/day	S0I0& Group	Rt: <15 dBHL; Lt: <15 dBHL BE: 'A' type, reflexes present
4.	37y/M	Senior	27yrs	3 hrs/day	S0I0& Group	Rt: <15 dBHL; Lt: <15 dBHL Rt: 'A' type, reflexes present Lt: 'As' type, No reflexes

Table 10: Musical experience and audiological findings in violinists

S.NO	AGE/SEX	MUSICAL QUALIFICATION	YRS. OF EXPERIENCE	HRS. OF PRACTICE HRS/WEEK OR HRS/DAY	SOLO OR GROUP	AUDIOLOGICAL FINDINGS
1.	15y/M	Junior	11 yrs	5-6 hrs/wk	S0l0& Group	Rt: <15 dBHL; Lt: <15 dBHL BE: 'A' type, reflexes present
2.	21y/M	Vidhwath	13 yrs	3-4 hrs/day	S0I0& group	Rt: 250, 500 & 1000 Hz-25 dBHL; <15 dBHL at other frequencies Lt: <15 dBHL BE: 'A' type, reflexes present
3.	24y/M	Senior	14 yrs	7-8 hrs/wk	S0l0& group	Rt: <15 dBHL; Lt: <15 dBHL BE: 'A' type, reflexes present
4.	24y/M	Junior	12 yrs	4 hrs/wk	Solo	Rt: <15 dBHL; Lt: <15 dBHL BE: 'A' type, reflexes present
	24y/M	Junior	13 yrs	5 hrs/wk	Solo	Rt: <15 dBHL; Lt: <15 dBHL BE: 'A' type, reflexes present
6.	43y/M	Vidhwath	37 yrs	6 hrs/wk	S0I0& Group	Rt: <15 dBHL; Lt: <15 dBHL BE:'A' type, reflexes present

Table 11: Musical experience and audiological findings in flutists

S.NO.	AGE/ SEX	MUSICAL QUALIFICATION	YRS. OF EXPERIENCE	HRS. OF PRACTICE HRSAVEEKOR HRS/DAY	SOLO OR GROUP	AUDIOLOGICAL FINDINGS
1.	16y/M	Senior	8yrs	1-2 hrs/day	Group	Rt: <15 dBHL; Lt: <15 dBHL BE: 'A' type, reflexes present
2.	20y/M	Junior	4yrs	4 hrs/wk	Solo	Rt: 4 kHz-25 dBHL; <15 dBHL at other frequencies Lt: 4 kHz-25 dBHL; <15 dBHL at other frequencies BE: 'A' type, reflexes present
3.	23y/M	Junior	lOyrs	7-8 hrs/wk	Solo& group	Rt: <15 dBHL; Lt: <15 dBHL BE: 'A' type, reflexes present
4.	25y/M	Junior	6yrs	1 hr/day	Solo& Group	Rt: <15 dBHL; Lt: <15 dBHL BE: 'A' type, reflexes present
5.	26y/M	Senior	lOyrs	2-3 hrs/day	Group	Rt: <15 dBHL; Lt: <15 dBHL BE: 'A' type, reflexes present
6.	27y/M	Senior	5yrs	7-10 hrs/wk	Solo& Group	Rt: <15 dBHL, Lt: <15 dBHL BE: 'A' type, reflexes present

Table 12: Musical experience and audiological findings in Vocalists

S.NO.	AGE/SEX	MUSICAL QUALIFICATION	YRS. OF EXPERIENCE	HRS. OF PRACTICE HRS/WEEK OR HRS/DAY	SOLO OR GROUP	AUDIOLOGICAL FINDINGS
1.	18y/F	Junior	lOyrs	7hrs/wk	Solo	Rt: <15 dBHL; Lt: <15 dBHL BE: 'A' type, reflexes present
2.	19y/F	Junior	5 yrs	7hrs/wk	S0I0& Group	Rt: <15 dBHL; Lt: <15 dBHL BE: 'A' type, reflexes present
3.	19y/F	Junior	5 yrs	4hrs/wk	S0I0& Group	Rt: <15 dBHL; Lt: <15 dBHL BE: 'A' type, reflexes present
4	21y/F	Masters degree	7-8 yrs	15hrs/wk	S0I0& Group	Rt: <15 dBHL; Lt: <15 dBHL BE: 'A' type, reflexes present
5.	21y/F	Junior	5 yrs	4-5 hrs/wk	Solo	Rt: <15 dBHL; Lt: <15 dBHL BE: 'A' type, reflexes present
6.	21y/M	Vidhwath	9 yrs	3-4 hrs/day	S0I0& Group	Rt: 250 Hz - 25 dBHL, 500 Hz - 25 dBHL; <15 dBHL at other frequencies Lt: <15 dBHL BE: 'A' type, reflexes present
7.	23y/F	Junior	6-7 yrs	4-5 hrs/wk	Solo	Rt: <15 dBHL; Lt: <15 dBHL BE: 'A' type, reflexes present
8.	24y/F	Junior	6 yrs	5 hrs/wk	Solo	Rt: <15 dBHL; Lt: <15 dBHL BE: 'A' type, reflexes present

9.	24y/F	Junior	8yrs	4 hrs/wk	Solo	Rt: <15 dBHL; Lt: <15 dBHL BE: 'A' type, reflexes present
10.	25y/M	Senior	8yrs	2 hrs/day	S0I0& Group	Rt: <15 dBHL; Lt: <15 dBHL BE: 'A' type, reflexes present
11.	26y/F	Masters degree	lOyrs	12 hrs/wk	S0I0& Group	Rt: <15 dBHL; Lt: <15 dBHL BE: 'A' type, reflexes present
12.	27y/F	Senior	6yrs	9 hrs/wk	S0I0& Group	Rt: <15 dBHL Lt: <15 dBHL BE: 'A' type, reflexes present
13.	31y/F	Masters degree	19 yrs	5 hrs/day	S0I0& Group	Rt: <15 dBHL Lt: <15 dBHL BE: 'A' type, reflexes present
14.	32y/F	Masters degree	6-7 yrs	30 hrs/wk	S0I0& Group	Rt: <15 dBHL; Lt: <15 dBHL BE: 'A' type, reflexes present
15.	34y/F	Senior	7 yrs	5 hrs/wk	S0I0& Group	Rt: <15 dBHL; Lt: <15 dBHL Rt: 'A' type, reflexes present Lt: 'A' type, no reflexes
16.	35y/F	Senior	13 yrs	4 hrs/day	S0I0& Group	Rt: 4kHz-25 dBHL, 8 kHz-25 dBHL Lt: 250 Hz - 25 dBHL, 8 kHz - 35 dBHL Rt: 'Ad' type, no reflexes Lt: 'A' type, no reflexes

17.	37y/M	Vidhwath	28yrs	9hrs/day	Solo& Group	Rt: 2 kHz - 40 dBHL, 4 kHz - 55 dBHL, 8 kHz - 35 dBHL; <15 dBHL at other frequencies Lt: 250 Hz - 25 dBHL, 1 kHz - 30 dBHL, 2 kHz - 65 dBHL, 4 kHz - 70 dBHL, 8 kHZ - 65 dBHL; <15 dBHL at 500 Hz BE: Immittance could not be done
18.	39y/F	Masters degree	15yrs	lhr/day	Solo	Rt: <15 dBHL; Lt: <15 dBHL BE: 'A' type, reflexes present
	39y/F	Vidhwath, Masters degree	27yrs	4-5 hrs/day	Solo& Group	Rt: <15 dBHL; Lt: <15 dBHL BE: 'A' type, reflexes present
20.	41y/M	Senior	18yrs	10 hrs/wk	Solo& Group	Rt: <15 dBHL Lt: <15 dBHL BE: 'A' type, reflexes present
21.	42y/M	Senior	20yrs	2-3 hrs/day	Solo& Group	Rt: <15 dBHL; Lt: <15 dBHL BE: 'A' type, reflexes present
22.	42y/F	Senior	20yrs	4 hrs/day	Solo& Group	Rt:8kHz-30dBHL;<15 dBHL at other frequencies Lt: 4 kHz - 25 dBHL ,8 kHz - 25 dBHL; <15 dBHL at other frequencies Rt: 'Ad' type, reflexes present Lt: 'A' type, reflexes present

23.	45y/F	Bachelors degree	23yrs	2-4 hrs/day	Solo& uroup	Rt: Ear discharge, immittance could not be done Lt: 4 kHz - 30 dBHL. 8 kHz - 20 dBHL; <15 dBHL at other frequencies, no reflexes
24.	52y/F	Senior	44 yrs	6 hrs/day	Solo& Group	Rt: <15 dBHL; Lt: <15 dBHL BE: 'A' type, reflexes present
25	52y/M	Junior	2Oyrs	lhr/day	Solo	Rt: 500 Hz - 20 dBHL, 4 kHz - 30 dBHL, 8 kHz - 25 dBHL; <15 dBHL at other frequencies Lt: 4 kHz - 55 dBHL, 8 kHz - 45 dBHL; <15 dBHL at other frequencies BE: 'A' type, reflexes present

From the Tables 7, 8, 9, 10, 11 and 12, it can be inferred that there is no systematic relationship between musical qualification/years of experience/musical exposure and hearing loss.

Phase II: Measurement of real ear SPLs

Results ofSPL measurement:

The mean real ear values of twenty-five vocalists and twenty-six instrumentalists across seventeen frequencies, for each ear, have been given in Tables 13, 14, 15, 16, 17 and 18. These tables have also been discussed alongside.

Table 13:

Mean, SD and Range of real ear sound levels (in dBSPL) at different frequencies in the right and left ears of vocalists

Frequencies	Ear	N value	Mean	**SD**	Range	t- value	Significance
200	L	25	72.62	7.89	57.8-86.5	-1.509	NS
	R	25	74.16	6.54	63.1-87		
500	L	25	77.28	6.22	68.3-90.9	0.371	
	R	25	76.9	5.93	67-91.3		
1000	L	25	72.7	8.75	59.1-85.8	-0.949	
	R	25	74.04	8.86	58.8-88.9		
1500	L	25	70.02	10.68	54.2-86.7	-0.623	
	R	25	69.08	9.93	55.8-86		
2000	L	25	67.74	9.55	53.8-87.9	-0.524	
	R	25	66.97	9.52	53.3-90.1		
2500	L	25	66.16	8.58	50.8-89.1	-0.41	
	R	25	66.67	9.7	52.6-90.9		
3000	**L**	25	63.84	8.2	50.1-79.4	-0.601	
	R	25	63.08	7.04	53.1-76.2		
3500	L	25	57.71	9.32	40.6-70.8	-1.302	
	R	25	59.52	9.61	45.2-75.1		
4000	L	25	54.17	8.96	40.9-73.9	-0.696	
	R	25	55.08	8.66	42.1-67.4		

4500	L	25	48.98	7.42	40.6-64.3	-0.232	NS
	R	25	49.22	8.43	37.9-65.1		
5000	L	25	42.98	7.21	34.2-57.5	-0.435	
	R	25	43.42	7.88	34.8-61.9		
5500	L	25	40.2	5.93	30.8-52.6	0.348	
	R	25	39.83	7.01	32.4-54.9		
6000	L	25	37.54	5.79	30.9-56.3	-1.403	
	R	25	39.38	8.42	29.3-62.3		
6500	L	25	36.8	5.01	32.1-55.2	-1.29	
	R	25	38.13	6.92	30.1-54.7		
7000	L	25	36.46	4.08	31-51.5	-1.811	
	R	25	38.09	5.61	31.3-53.1		
7500	L	25	38.74	2.8	33.6-42.7	-1.361	
	R	25	38.27	4.51	30.6-49.5		
8000	L	25	38.08	3.17	33.8-47.3	-1.763	
	R	25	39.2	4.97	30.3-50		
RMSO/P	L	25	92.34	-	80.1-106.9		
	R	25	91.31	-	80.1-103.3		

NS- Not Significant

It is clear from table 13 that the major concentration of energy is found in the low frequency regions, i.e., from 200 Hz to 1500 Hz for vocalists. Also the RMS levels of the carnatic singers, across frequencies were found to be around 91 dBSPL for the right ear and 92 dBSPL for the left ear. Chasin (1996) reported that Fortissimo singers, 3 ft. away, produced sound levels of 70 dB(A).

Table 14:

Mean, SD and Range of real ear sound levels (in dBSPL) at different frequencies in the right and left ears ofveena players

Frequencies	Ear	N value	Mean	SD	Range	t- value	Significance
200	L	4	64.5	6.3	58.3-73.3	-1.040	NS
	R	4	68.7	2.39	66.4-71.4		
500	L	4	65.85	2.39	64-69.1	-0.627	
	R	4	67.35	4.94	62.2-72.3		

1000	L	4	60.8	5.04	57-68.1	-1.481	NS
	R	4	64.37	.25	64.1-64.7		
1500	L	4	58.13	6.74	52.6-66.6	-1.404	
	R	4	62.3	1.16	60.8-63.6		
2000	L	4	61.02	1.37	60-63	-1.642	
	R	4	62.95	2.08	61.4-66		
2500	L	4	65.93	3.48	63.1-71	-8.466	
	R	4	71.25	3.07	69.1-75.8		
3000	L	4	63.75	5.58	55.4-67.6	0.186	
	R	4	63.25	5.67	56.9-70.7		
3500	L	4	58.45	9.1	44.8-63.6	-0.015	
	R	4	59.73	5.87	53.7-67.1		
4000	L	4	55.07	10.87	39.7-65.2	0.186	
	R	4	54.03	5.65	49.4-61.5		
4500	**L**	4	52.88	6.66	44.3-59.3	1.882	
	R	4	48.67	3.6	43.5-51.2		
5000	L	4	47.55	4.75	42-51.9	0.889	
	R	4	43.85	7.03	37.7-52.9		
5500	L	4	44.2	5.42	39.2-50.7	0.685	
	R	4	40.35	7.8	33.6-50.7		
6000	L	4	41.15	4.67	35.2-46.4	0.799	
	R	4	37.78	4.39	31.7-41.1		
6500	L	4	37.67	2.15	34.6-39.6	0.846	
	R	4	35.77	3.28	31-38.5		
7000	**L**	4	37.5	3.17	34.2-41.8	1.696	
	R	4	36.57	2.17	34.1-39.4		
7500	L	4	38.37	5.72	31.8-44.6	0.404	
	R	4	37.92	4.26	32.9-43.3		
8000	L	4	39.53	4.25	35.1-43.6	0.538	
	R	4	40.17	4.37	35-45.7		
RMSO/P	L	4	80.55	-	76.6-84.2		
	R	4	82.88	-	80.1-86.2		

NS-Not Significant

Table 15:

Mean, SD and Range of real ear sound levels (in dBSPL) at different frequencies in the right and left ears ofmridangam players

Frequencies	Ear	N value	Mean	SD	Range	t- value	Significance
200	L	6	81.32	9.38	71.8-95.2	0.649	NS
	R	6	79.97	5.79	72.1-87.2		
500	L	6	75.48	5.08	69.8-83.1	-1.389	
	R	6	77.12	4.46	71.8-82.6		
1000	L	6	56.55	2.62	53.5-60.9	-3.431	
	R	6	62.06	2.75	60.2-67.5		
1500	L	6	51.77	3.28	47.8-57	-2.333	
	R	6	56.33	3.75	51.6-60.9		
2000	L	6	48.33	3.11	43.4-52.2	-7.367	
	R	6	55.75	1.3	53.7-57.2		
2500	L	6	47.67	7.29	35-56.3	-5.226	
	R	6	57.48	4.43	52.3-63.5		
3000	L	6	46.22	3.39	42.5-49.8	-9.356	
	R	6	55.22	3.95	50.9-61.7		
3500	L	6	42.92	3.49	38.6-48.3	-1.511	
	R	6	48.5	7.76	39.1-61.4		
4000	L	6	40.38	5.17	35.3-46.7	-1.679	
	R	6	44.2	3.64	39.7-48.8		
4500	L	6	41.68	3.77	36.2-44.6	-0.462	
	R	6	42.77	4.61	38.1-49.1		
5000	L	6	39.22	3.68	36-44.8	-0.727	
	R	6	40.9	4.95	35.5-46.4		
5500	L	6	36.28	4.21	29.7-42.8	-2.770	
	R	6	41.82	6.71	33.3-48.4		
6000	L	6	36.57	4.61	30.5-44.7	-3.519	
	R	6	40.93	6.49	33-50.4		

6500	L	6	3643	402	32.2-43.2	-2.196	NS
	R	6	40.22	644	31.2-48.3		
7000	L	6	36.68	3.02	34.8-42.5	-1.350	
	R	6	38 92	5.21	31.2-44.3		
7500	L	6	36 12	3.27	33.3-42.3	-2.390	
	R	6	39.33	2.99	36-42.8		
8000	L	6	362	1.55	33.8-38.6	-4.447	
	R	6	4103	2.69	37.8-44.5		
RMSO/P	L	6	88 6	-	76.6-84.2		
	R	6	85.8	-	80.1-86.2		

NS-Not Significant

Table 16:

Mean, SD and Range of real ear sound levels (in dBSPL) at different frequencies in the right and left ears of ghatam players

Frequencies	Ear	N value	Mean	SD	Range	t- value	Significance
200	L	4	63.58	13.41	46.6-79.4	1.106	NS
	R	4	59.17	13.65	42.7-70.4		
500	L	4	65.6	20.06	38.5-85.4	1.831	
	R	4	61.33	20.39	33.8-76.8		
1000	L	4	55.47	8.58	44-64.3	1.582	
	R	4	48.47	12.07	31.6-60.2		
1500	L	4	59.1	9.73	45.5-68.6	0.613	
	R	4	56.95	12.88	38.7-69		
2000	L	4	73.37	18.28	46.2-85.7	0.218	
	R	4	72.1	14.41	53.9-84.4		
2500	L	4	78.23	14.77	56.2-86.8	0.283	
	R	4	76.8	13.15	61.2-87.7		
3000	L	4	70.07	13.51	50.3-80.3	0.652	
	R	4	68.05	14.06	47.6-77.3		
3500	L	4	63.15	11.38	46.3-70.4	-0.247	
	R	4	62.4	14.84	40.9-72.3		

4000	L	4	57.85	11.38	41.4-67.5	-0.5	NS
	R	4	59.1	13.15	39.5-66.7		
4500	L	4	55.95	11.02	41.4-68.2	-0.067	
	R	4	56.1	11.31	39.2-63.2		
5000	L	4	52.73	8.95	41.9-63.8	7.406	
	R	4	54.35	10.94	38-61.2		
5500	L	4	48.65	8.84	38.1-59	-0.895	
	R	4	51.47	9.65	37-56.6		
6000	L	4	47.05	9.13	35.4-56.3	-1.672	
	R	4	50.87	9.21	37.1-56.6		
6500	L	4	46.9	8.7	37.8-57.5	1.357	
	R	4	51.7	9.87	36.9-57.1		
7000	L	4	45.6	7.48	38.2-55.5	-1.462	
	R	4	54.03	12.02	37.1-62.6		
7500	L	4	46.83	7.46	38.8-56.7	-1.307	
	R	4	54.35	11.51	39-63.2		
8000	L	4	46.75	6.1	40.9-55.3	-1.280	
	R	4	54.33	11.52	39-63.2		
RMSO/P	L	4	89.45	-	65.4-99.6		
	R	4	90.18	-	70.6-100.4		

NS-Not Significant

Table 17:

Mean, SD and Range of real ear sound levels (in dBSPL) at different frequencies in the right and left ears of violinists

Frequencies	Ear	N value	Mean	SD	Range	t- value	Significance
200	L	6	73.65	9	56.8-82.5	-1.663	NS
	R	6	78.73	5.22	71.2-84.6		
500	L	6	80.42	8.14	73.5-91.7	-0.294	
	R	6	81.33	6.11	73-91.6		
1000	L	6	75.62	5.56	69.2-85.3	1.636	
	R	6	72.36	6.34	66.8-84.1		
1500	L	6	75.1	5.47	68.2-84.5	4.353	
	R	6	67.71	6.51	63.8-80.9		

2000	L	6	71.83	1.95	69-74.7	0.514	NS
	R	6	70.8	5.07	64.2-77.9		
2500	L	6	72.32	3.13	68.7-77	0.469	
	R	6	70.5	10.07	52-79.5		
3000	L	6	68.68	5.16	61.2-74.5	0.561	
	R	6	66.26	8.46	52.1-74.4		
3500	**L**	6	67.2	6.33	60.6-79.1	-0.015	
	R	6	67.25	8.61	64.1-76.9		
4000	L	6	59.35	7.25	51.9-72.9	0.471	
	R	6	61.58	9.13	46.8-71.8		
4500	L	6	56.48	6.99	48.6-68.7	-0.182	
	R	6	57.22	7.89	43.9-65.4		
5000	**L**	6	52.96	5.56	47.4-62.1	0.399	
	R	6	51.55	7.83	40.1-58.6		
5500	**L**	6	47.95	4.24	42.4-55.2	0.245	
	R	6	47.23	6.03	37.2-52.9		
6000	**L**	**6**	46.22	7.07	37.2-54	1.809	
	R	6	41.82	5.15	35.3-43.5		
6500	**L**	6	42.35	5.83	37.5-50.9	-1.206	
	R	6	38.45	3.44	34.2-42.5		
7000	**L**	6	41.6	5.93	35.2-50.3	1.253	
	R	6	38.12	3.78	34.4-43.5		
7500	**L**	6	41.7	5.21	36.2-51.2	2.510	
	R	6	37.62	2.4	34.6-41.2		
8000	**L**	6	42.06	6.38	38-54.9	1.966	
	R	6	37.65	2.59	34.4-40.4		
RMSO/P	**L**	6	93.7	-	81.66-99.9		
	R	6	91.85	-	83-98.4		

NS- Not Significant

Table 18:

Real ear measurements and values (in dBSPL) at different frequencies in the right and left ears of flutists

Frequencies	Ear	N value	**Mean**	**SD**	**Range**	t- value	**Significance**
200	L	6	50.86	6.79	41.3-60.8	-3.56	NS
	R	6	58.48	3.85	53.7-65		
500	L	6	61.73	12.09	45-78	-2.375	
	R	6	69.25	13.82	51.8-82.3		
1000	L	6	85	7.79	72-95.7	1.232	
	R	6	76.76	13.22	60-90		
1500	L	6	67.98	7.76	57.6-77.7	-4.607	
	R	6	86.32	12.23	68-102.9		
2000	L	6	65.51	5.47	58.5-73.7	-3.442	
	R	6	72.75	6.58	64.3-82.1		
2500	L	6	69.83	7.78	59.8-80.7	-1.145	
	R	6	74.78	8.01	66.3-86.5		
3000	L	6	63.78	3.69	57.5-68.1	-3.348	
	R	6	73.23	8.65	57.8-82.3		
3500	L	6	56.03	7.26	48.6-66.5	-3.459	
	R	6	63.03	6.01	51.6-68.8		
4000	**L**	6	52.82	3.62	45.8-55.8	-4.445	
	R	6	58.02	4.04	51.1-62.3		
4500	**L**	6	48.28	6.57	40.3-55.6	-2.216	
	R	6	54.26	7.58	44.9-65.2		
5000	**L**	6	46.12	2.64	42.4-48.5	-2.157	
	R	6	51.56	6.3	43.8-58.8		
5500	**L**	6	42.05	3.59	37.6-45.2	-3.195	
	R	6	48.56	6.53	40.4-56.3		
6000	**L**	6	40.12	3.81	36.6-46.6	-1.750	
	R	6	46.32	6.92	37.2-55.6		
6500	**L**	6	40.33	3.61	37-45.9	-1.206	
	R	6	44.1	6.47	36.5-54.5		
7000	**L**	6	38.6	3.06	34.5-42.1	-1.989	
	R	6	43.8	6.38	35.5-54.2		
7500	L	6	38.05	3.29-	34.6-43.4	-1.601	
	R	6	42.73	6.29	35.2-52.8		
8000	L	6	37.18	2.14	35.2-39.7	-2.509	
	R	6	43.16	5.76	35.7-52.3		
RMSO/P	L	6	100.88	-	93-111.8		
	R	6	102.66	-	98.4-107.6		

NS- Not Significant

Tables 14, 15, 16, 17 and 18 clearly show a greater concentration of energy in the low frequency regions for all the instruments. For the mridangam and the ghatam, the real ear sound levels are not expected to be different for the left and right ears. The mean values in Tables 16 conform to this expectation, in the case of ghatam. However, for the mridangam it was found that the left ear value (88.6 dBSPL) was higher than the right ear value (85.8 dBSPL). This may probably be due to the way in which the instrument was held or the playing style.

The veena, flute and violin are supposed to show differences between the left and right real ear sound levels, owing to the relative location of the sound with respect to the affected ear. The variations of dBSPL values in the left and right ears are reported in literature for the flute and violin (Flach & Aschoff, cited in Axelsson & Lindgren, 198lb: Axelsson & Lindgren, 1981b; Chasin, 1998).

In the case of veena, the sound levels are expected to be louder in the right ear compared to the left, as the source of sound is closer to the right ear. The results tabulated in Table 14 clearly show higher levels of sound in the low frequency regions. The greater concentrations of energy was found in the right ear (82.88 dBSPL) compared to the left ear (80.55 dBSPL).

Literature has also reported higher sound levels in the left ear of violinists compared to the right ear (Flach & Aschoff, cited in Axelsson & Lindgren, 1981b; Chasin, 1998), since here, the source of sound is closer to the left ear. Readings from Table 17 corroborates with literature. The RMS levels are also found to be higher in the left ear (93.7 dBSPL) compared to the right ear (91.85 dBSPL).

Since the source of sound is closer to the right ear, again, in the case of flute, literature reports the sound levels to be higher in the right ear compared to the left (Chasin & Chong, 1991). The RMS levels obtained, hence corroborates with the existing literature (i.e. 102.66 dBSPL in the right ear and 100.88 dBSPL in the left ear).

T-test was carried out to find if there was any significant difference between the right and left ear values in each frequency for both vocalists and the instrumentalists.

Results revealed no significant difference and hence, the data from the right and left, i.e. both mean and RMS values, were combined to form a single value for each frequency, as given in Tables 19, 20, 21, 22, 23 and 24.

Table 19:

Real ear dBSPLs at different frequencies and RMS values in veena players (After t-test)

Veena (N=4)	*Frequency (In Hz)*	200	500	1000	1500	2000	2500
	Mean SPL	66.6	66.6	62.6	60.2	61.9	68.5
	Frequency (In Hz)	3000	3500	4000	4500	5000	5500
	Mean SPL	63.5	59	54.5	50.8	45.7	42.3
	Frequency (In Hz)	6000	6500	7000	7500	8000	**RMSO/P (dBSPL)**
	Mean SPL	39.5	36.7	37	38.1	39.8	**81.71**

Looking at Table 19, it is obvious that the concentration of energy is in the low frequency regions. A graphical representation of these levels has been shown later in Figure 2. The RMS O/P shows that the veena produces sound much lower than the vocalists or the other instruments.

Table 20:

Real ear dBSPLs at different frequencies and RMS values in mridangam players (After t-test)

Mridangam (N=6)	*Frequency (In Hz)*	200	500	1000	1500	2000	2500
	Mean SPL	80.6	76.3	59.3	54	52	52.5
	Frequency (In Hz)	3000	3500	4000	4500	5000	5500
	Mean SPL	50.7	45.7	42.3	42.2	40	39
	Frequency (In Hz)	6000	6500	7000	7500	8000	RMS O/P (dBSPL)
	Mean SPL	38.7	38.3	37.8	37.7	38.6	**87.2**

Table 20 shows the combined mean values after t-test, which is graphically represented later in Figure 2. Here again, it is seen that the major concentration of energy is in the low frequency regions. The RMS O/P level is higher than that of the veena.

Table 21:

Real ear dBSPLs at different frequencies and RMS values in ghatam players (After t-test)

Ghatam (N=4)	*Frequency (In Hz)*	200	500	1000	1500	2000	2500
	Mean SPL	61.3	63.5	51.9	58	72.7	77.5
	Frequency (In Hz)	3000	3500	4000	4500	5000	5500
	Mean SPL	69	62.8	58.5	56	**53.5**	50
	Frequency (In Hz)	6000	6500	7000	7500	8000	RMSO/P (dBSPL)
	Mean SPL	48.9	49.3	49.8	50.6	50.5	**89.81**

Table 21 shows the concentration of energy being more in the low frequency regions. This is graphically represented later in Figure 2. The RMS O/P level has also been found to be higher than that of the veena and the mridangam. Literature on the sound levels is not available for these carnatic instruments, i.e., for the veena, ghatam and the mridangam.

Table 22:

Real ear dBSPLs at different frequencies and RMS values in violinists (After t-test)

Violin (N=6)	*Frequency (In Hz)*	200	500	1000	1500	2000	2500
	Mean SPL	76.2	80.9	73.9	71.4	71.3	71.4
	Frequency (In Hz)	3000	3500	4000	4500	5000	5500
	Mean SPL	67.5	67.2	60.5	56.9	52.3	47.6
	Frequency (In Hz)	6000	6500	7000	7500	8000	**RMSO/P (dBSPL)**
	Mean SPL	44	40.4	39.9	39.7	39.9	**92.78**

From Table 22, the RMS level of the violin corroborates with the findings as reported by the TNT-Audio article, "What's in your music", (n.d), where the unamplified instrument levels were measured in dBSPL and it was reported to be 42-95 dBSPL. This value might not corroborate with other investigations probably because of variations such as unspecified distances the readings were taken or what the musician was actually playing. In general, when there were several readings, the higher one was chosen. The levels obtained from this study are found to be higher in the lower frequency regions and greater even when the measurement was done for unamplified instruments. Hence, this implies that the levels produced by the violin are damaging to the ear. These levels have been represented graphically in Figure 2.

Table 23:

Real ear dBSPLs at different frequencies and RMS values in flutists (After t-test)

Flute (N=6)	*Frequency (In Hz)*	200	500	1000	1500	2000	2500
	Mean SPL	54.7	65.5	80.9	77.2	69.1	72.3
	Frequency (In Hz)	3000	3500	4000	4500	5000	5500
	Mean SPL	68.5	59.5	55.4	51.3	48.8	45.3
	Frequency (In Hz)	6000	6500	7000	7500	8000	**RMSO/P (dBSPL)**
	Mean SPL	43.2	42.2	41.2	40.4	40.2	**101.77**

Here again, the lower frequencies have been found to have more energy. These levels are graphically represented later in Figure 2. The RMS level obtained from the flute is seen to conform to literature, as reported by Chasin and Chong (1991). Since this RMS level was found for unamplified flutes, it implies that the sound levels produced by the flute are damaging to the ear. Amplified sounds would be even more damaging to the flute players.

Table 24:

Real ear dBSPLs at different frequencies and RMS levels in vocalists (After t-test)

Vocalists (N=25)	*Frequency (In Hz)*	200	500	1000	1500	2000	2500
	Mean SPL	73.4	77	73.4	69.5	67.4	66.4
	Frequency (In Hz)	3000	3500	4000	4500	5000	5500
	Mean SPL	63.5	58.6	54.6	49.1	43.2	40
	Frequency (In Hz)	6000	6500	7000	7500	8000	RMSO/P fdBSPL)
	Mean SPL	38.5	37.5	37.3	37.8	38.6	**91.82**

Table 24 shows that for vocalists, the greater concentration of energy to be in the lower frequency regions and the RMS O/P level to be relatively high, and most probably damaging to the human ear. This level does not corroborate with literature probably because of reasons like individual-to-individual variation, style of singing or the song that they sang.

Hence, in each of the findings, i.e., for both vocalists and instrumentalists, variations in sound levels are seen when compared with existing literature. Other than the above reasons, these variations may also be due to differences between western classical music and classical carnatic music.

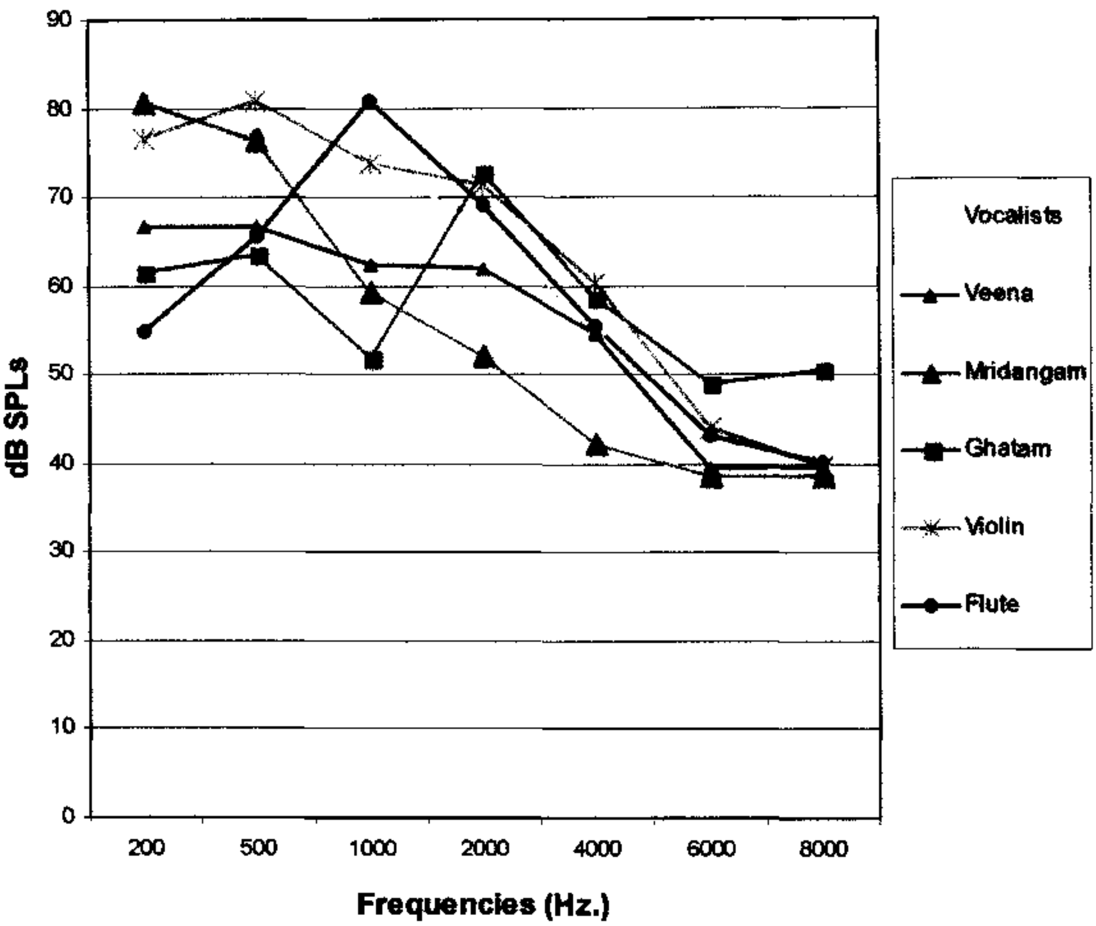

Figure 2: Real ear RMS dBSPLs of vocalists and instrumentalists

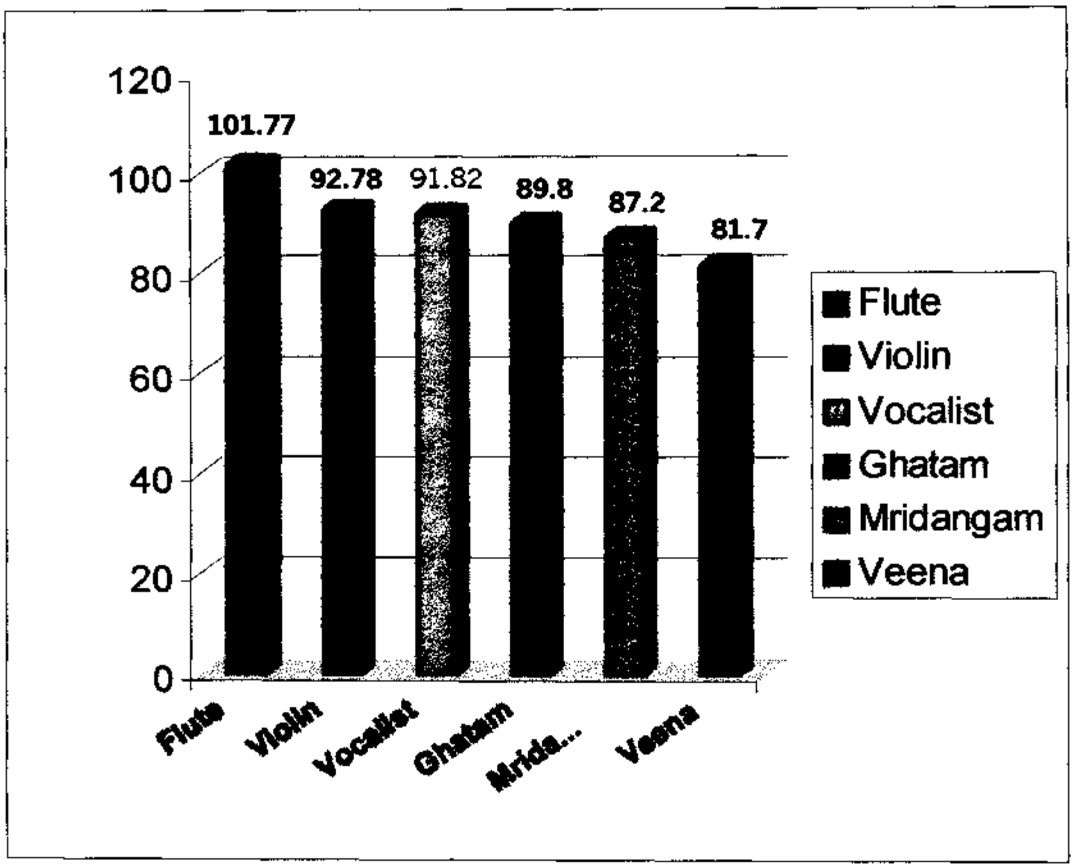

Figure 3: Overall RMS values (dBSPL)for vocalists and different instruments

From Figure 3, it is evident that the overall RMS values are highest for the flute (101.77 dBSPL), followed by the violin (92.78 dBSPL), the vocalists (91.82 dBSPL), the ghatam (89.8 dBSPL), the mridangam (87.2 dBSPL) and finally the veena (81.7 dBSPL).

SUMMARY AND CONCLUSION

Hearing is one of the most important senses. There are various causes leading to hearing loss, one of the preventable causes being exposure to loud noise/music. In the case of musicians, the hearing should be more sensitive, accurate and discriminative than that of non-musicians. Literature has reported of hearing loss in rock-and-roll performers (Rintleman & Borus, 1968; Axelsson & Lindgren, 1978). The frequent occurrence of loud pure tones and impulse sounds in the musical environment suggests the possibility of hearing loss by performance of classical music (Axelsson & Lindgren, 1981a; Chasin, 1998). This loss would consequently lead to the risk for occupational hearing loss among musicians.

Hence, the present study sought to establish the real ear sound pressure levels in carnatic musicians. Twenty-five carnatic vocalists and twenty-six instrumentalists (four veena players, 6 mridangam players, 4 ghatam players, 6 violinists and 6 flutists) served as subjects for the present study. The subjects were evaluated using a computerized real time analyzer, Fonix 6500 (V-3.09).

The results indicated that there was a major concentration of energy in the low frequency regions. For the veena, the concentration of energy was majorly between 400 Hz to 1100 Hz; for mridangam and violin, between 200 Hz to 600 Hz; for ghatam, between 600 Hz to 700 Hz; and for flute, between 700 Hz to 1000 Hz. In the case of vocalists also, the greater concentration of energy was found in the low frequency regions, i.e., between 200 Hz to 1500 Hz. Results also indicated that, though there was no statistically significant difference between the right and left ear sound pressure levels, greater levels of sound were found in the right ear of veena players (82.88 dBSPL in right ear and 80.55 dBSPL in the left ear) and flutists (102.66 dBSPL in the right ear and 100.88 dBSPL); and in the left ear for violinists (93.7 dBSPL in the left ear and) 91.85 dBSPL in the right ear) and mridangam players (88.6 dBSPL in left ear and 85.8 dBSPL in the right ear). Such findings were not observed in the case of ghatam players. For them, the overall real ear level was found to be 89.8 dBSPL. These findings conform to those in literature for violinists and flutists; and conform to the expectations for veena players.

Hence, it can be concluded that the musicians are exposed to damaging levels of music.

The implications for the present study were:

1. Establishment of real ear sound pressure levels for musicians.
2. This information would be useful for public education, in order to prevent the increase in incidence of music induced hearing loss.
3. Recommendation of hearing conservation measures to prevent hearing damage for musicians.

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