A multitude of evidences suggests that long term musical training has benefits on sensory and cognitive processing. Music involves fine modulations of amplitude, frequency, and temporal aspects and musicians are trained to recognize these fine variations due to their extensive training. As a result of this practice a well-trained musician will have rich auditory experience. Due to their auditory experience musicians are considered as auditory experts and they are thought to have better auditory skills than non-musicians. Music performs better than non-musicians, both on music specific as well as general auditory skills.

Psychoacoustic research on musicians using behavioral measures suggests an enhancement of various psycho-acoustical skills. It has been reported that musicians perform better than non-musicians on tasks involving pitch discrimination, backward masking, forward masking and random gap detection. Micheyl et al. reported that musicians had pitch discrimination thresholds that were six times smaller than non-musicians. Similarly, Ishii et al. reported that gap detection thresholds of trained musicians were better when compared to non-musicians. Furthermore, significant enhanced performance on the backward masking and backward masking with a gap were also reported in musicians compared to non-musicians. It was also observed that there was a correlation between years of musical practice and performance on backward masking, which suggests that musical training influences temporal resolution. Furthermore, it has also been shown that long-term musical training induces both structural and functional plasticity in the auditory system. Schlau reported differences in auditory, motor and visual-spatial brain regions in trained adult musicians compared to amateur musicians or non-musicians. More specifically, professional musicians had a larger gray matter density in the pre-central gyrus, Heschl’s gyrus and right superior parietal cortex. Gaab and Schlau reported increased activations in auditory association areas of professional musicians compared to non-musicians. Music induced structural and functional plasticity changes have also been reported in the auditory brainstem.

Taken together, from the above studies, it can be concluded that long-term formal music training results in structural, functional and behavioral changes in the auditory system. It has also been shown that, positive effects of music can be transferred on auditory processing as well as speech and language. However, the positive effects of music have been demonstrated only on those musicians who have undergone long term formal training in music. It would be interesting to see whether these advantages would extend for short-term perceptual musical exposure also. Therefore, the present study was taken up to evaluate the perceptual changes in the auditory system, if any, due to short-term perceptual music training. Short-term musical training was operationally defined as non-formal perceptual listening to music for 8-10 sessions. This study measured the effect of short-term auditory perceptual training of two Carnatic Ragas on auditory system using various psycho-acoustical abilities (frequency, intensity and temporal abilities).
Materials and Methods

Participants
A total of 10 normal hearing adults (7 males, 3 females) in the age range of 18-25 years participated in the study. All the participants had their hearing thresholds less than or equal to 15 dB HL at octave frequencies from 250 Hz to 8000 Hz and A type tympanogram. It was also ascertained from a structured interview that these listeners did not have any history of neurologic or otologic disorder. All the participants did not have any complaints of difficulty in understanding speech either in quiet or in the presence of background noise and were amateur or rare listeners of music. All the listeners’ participation was voluntary and they were not paid for their participation in the study. Ethical clearance was obtained from the ethics committee of the institute prior to commencement of the experiment.

General procedure
Written consent was taken from all the participants for willingly participating in the study. The study was carried out in three phases. In first phase pre-training evaluation was done on raga identification and various psycho-acoustical measures, including frequency and intensity discrimination, duration discrimination test, gap detection test, modulation detection test, backward masking and duration pattern test. In the second phase, auditory perceptual training with music was given and in third phase post-training evaluation was done using the same tests as mentioned in the pre-training phase. The order of the psychoacoustical tests was randomized among the participants.

Phase I: Raga identification
This was assessed by determining: i) minimum number of notes required to identify a Raga; and ii) identification of Raga by listening to small excerpts of music.

Minimum number of notes required to identify Raga

Stimuli and procedure: Stimuli consisted of violin compositions from two Carnatic Ragas [Kalyani (Audio 1) and Mayamalavagola (Audio 2)]. These two are the basic ragas of South Indian classical music wherein Mayamalavagola is a shudd madhyam raga and Kalyani is a prati madhyam raga. Also Mayamalavagola is a 15th mela karta and Kalyani is 65th mela karta. A Carnatic violinist with an experience of more than 15 years, who had passed senior level examination and practices for at least 2 to 3 h daily played the two Ragas. Musical notes of two Ragas were played in the octave scale where the distance between the first note (sa) and the last note (sa) is one octave. The notes consisted of sa re ga ma pa dha ni sa played either in Kalyani or Mayamalavagola Raga. Eight stimuli were constructed using this composition for each Raga. The first stimulus had only one note, second stimulus had 2 notes, third stimulus had 3 notes and so on, 8 stimuli had all 8 notes. Testing consisted of two phases: familiarization and identification. In the familiarization phase, participants were asked to listen to violin notes played in octave notes for Kalyani Raga and were instructed that hereafter whenever they hear the excerpts from this Raga they had to identify the Raga as Kalyani. After that, the participants were asked to listen to a song played on violin in Mayamalavagola Raga for 15 min and were asked to name the Raga as Mayamalavagola. After this initial familiarization phase, the identification phase began. Presentation of stimuli and collection of the responses were controlled via the software DMDX.

Stimuli were presented in a random manner using a scrambling code of DMDX. During each stimulus trial, participants were presented with 5 notes excerpt from a Raga (either Kalyani or Mayamalavagola) along with words Kalyani and Mayamalvagola on the computer screen. Participants were asked to identify the stimulus by pressing the button 1 or 2 on the keyboard of the computer, where 1 and 2 represented Kalyani and Mayamalavagola respectively. The participants were given 3 s after the stimuli to respond. Till then the letters remained on the computer screen. The accuracy in identification was measured. Hereafter, this would be referred to as a Music-test.

Psycho-acoustical assessment
This involved administration of a group of tests to assess frequency, intensity and temporal perception. All psycho acoustic tests except duration pattern test was carried out using maximum likelihood procedure (mlp) toolbox, which implements an mlp in Matlab. The maximum likelihood procedure employs a large number of candidate psychometric functions and after each trial calculates the probability (or likelihood) of obtaining the listener response to all of the stimuli that have been presented. The psychometric function yielding the highest probability is used to determine the stimulus to be presented at the next trial. Within about 12 trials, the maximum likelihood procedure usually converges on a reasonably stable approximation of the most likely psychometric function, which then can be used to estimate threshold. Stimuli were generated at 44,100 Hz sampling rate. A three-interval, alternate forced-choice method using mlp was employed to track a 79.4% correct response criterion. During each trial a stimulus was presented in each of three blocks where two blocks contained the reference stimulus and the other interval randomly chosen had the variable stimulus. The participant task was to indicate which block contained the variable stimulus. All the psycho-acoustical tests were...
administered as per procedure mentioned above and stimulus presentation and response acquisition were controlled by mlp toolbox. For all the tests 5-6 practice items were given before the commencement of the actual test.

The test stimulus for all psycho-acoustical tests was kept at 80 dB SPL. Stimuli for all the tests were presented via a laptop (Asus) connected to Sennheiser HD 449 earphones. The output of the earphones was calibrated to produce 80 dB SPL for a 1000 Hz pure tone in a 2 cc coupler.

**Difference limen of frequency**

Difference limen for frequency (DLF) for pure tones was measured using a three-block forced-choice procedure as mentioned through mlp procedure. On each trial, two of the three observation blocks contained pure tones at a reference frequency and one selected at random had a pure tone of variable frequency, which was always higher than the reference frequency. The participant’s task was to identify that block. It was done at 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz.

**Difference limen of intensity**

Difference limen of intensity (DLI) for pure tones was measured using a three-block, forced-choice procedure. It was obtained for 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz. The rest of the procedure was same as mentioned in DLF testing.

**Duration discrimination test**

Duration discrimination was done for a 1000 Hz tone at anchor duration 250 ms. The rest of the procedure was same as mentioned in DLF testing.

**Gap detection thresholds**

The participant’s ability to detect a temporal gap in the center of a 500 ms broadband noise was measured. The noise was 0.5 ms cosine ramps at the beginning and the end of the gap. In a three-block alternate forced-choice task, the standard stimulus was always a 500 ms broadband noise with no gap whereas the variable stimulus had the gap.

**Modulation detection thresholds**

A 500 ms Gaussian noise was sinusoidal amplitude modulated at modulation frequencies of 4 Hz, 8 Hz, 16 Hz, 32 Hz, 64 Hz and 128 Hz. A noise stimulus was two 10 ms raised cosine ramps at onset and offset. The participants were instructed to detect the modulation and determine which blocks had the modulated noise. Modulated and unmodulated stimuli were equated to total root mean square (rms) power. The depth of the modulated signal was varied according to the participant’s response up to a 79.4% criterion level. The modulation detection threshold was expressed in dB by using the following relationship:

\[ \text{Modulation detection thresholds in dB} = 20 \log_{10} \frac{m}{m} \]  
(1)

where \( m \) = modulation detection threshold in percentage.

**Backward masking**

A 20 ms, 1000 Hz pure tone (the signal) was presented immediately before \( i.e., \) no silent gap \( \) a band of band pass noise of 300 ms (400-1600 Hz). All sounds were onset and offset gated by means of two raised cosine onset and offset ramps of 10 ms. The participant task was to tell which block has the tone. The rest of the procedure was same as mentioned in DLF testing.

**Duration pattern test**

The duration pattern test was administered in the similar way as described by Pinheiro and Musiek. A 1000 Hz pure tone was generated at 44,100 sampling frequency with two different durations \( i.e., \) short 250 ms and long 500 ms, using Audacity software (ver. 1.3.5). By combining these two durations in three tone pattern six different patterns were generated (short short long; short long short; long long short; short short short; long long long; short long long). Following practice trails, 30 test items were administered. The participants were asked to verbally repeat the sequence.

**Phase II: Training**

After pre-training evaluations, participants received the musical training in auditory mode. During training everyday participants listened to the 15 min composition of Kalyani and Mayamalavagola Ragas with the help of a personal computer through high fidelity headphones (Sennheiser HD 449). After listening to these compositions in the end of each session, participants performed the Music-test. In this test participants were presented with 5 notes excerpt from a Raga (either Kalyani or Mayamalavagola) along with words Kalyani and Mayamalavagola on the computer screen. Participants were asked to identify the stimulus by pressing the button 1 or 2 on the keyboard of the computer, where 1 and 2 represented Kalyani and Mayamalavagola respectively. The participants were given a 5 s time after the stimuli to respond. Till then the letters remained on the computer screen. This training was given for eight sessions. Eight sessions were selected because previous studies have shown that about eight sessions of auditory perceptual training is enough to show improvement in listening skills.

**Phase III: Post-training evaluations**

All the behavioral tests mentioned in Phase I were re-administered at the end of the 8th day of the training session.

**Results**

Results are reported for raga identification and psycho-acoustical measures separately. Prior to the statistics, test of normality was performed using the Kolmogorov Smirnov test on all the parameters and it showed that ten parameters were significantly different \( P<0.05 \) from the normal distribution. Hence, non-parametric tests were used for the present study.

**Raga identification**

This was assessed by determining: i) minimum number of notes required to identify a Raga; and ii) identification of Raga by listening to small excerpts of music.

**Minimum number of notes required to identify Raga**

Figure 1 shows identification of Ragas with different number of notes in participants in pre-training condition. The y-axis represents performance and the x-axis represents the number of notes. It can be noted that the identification of Ragas even with the maximum number of notes was below chance level (0.5) for all the participants in the pre-training condition. Figure 2 shows identification of Ragas with different number of notes for participants in post-training condition and it is evident from the table that the identification scores improved following training. Highest identification scores were obtained for the stimuli that had all 8 notes.

**Identification of Raga by listening to small excerpts of music**

Mean Raga identification scores in pre-training and post-training conditions are shown in Figure 3. It can be noted that Raga identification scores improved following training. The Wilcoxon Signed Rank test was performed to see the significance of difference in identification-
tion scores of Raga in pre- and post-training conditions. Results showed that training significantly improved the identification of Ragas (Z=-2.805, P<0.01).

Psychoacoustic measures

Results are reported for each psychoacoustic test separately. Figures 4 and 5 shows the mean scores and one-standard-deviation error bars for differential limen for frequency and intensity at 500, 1000, 2000 and 4000 Hz in pre-training and post-training conditions. It can be noted that the scores showed improvement in post-training compared to pre-training across all frequencies except at 4000 Hz for the DLF task. Thus, in order to see the effect of training on DLI and DLF Wilcoxon Signed Rank test was performed between the pre-training and post-training conditions. Results showed that there was significant improvement in DLF and DLI after musical training at 1000 Hz in DLF task (Z= -2.497, P<0.01) and for 500 Hz in DLI task (Z= -2.805, P<0.01). Figure 6 shows the mean and one-standard-deviation error bars of the modulation detection scores at 4 Hz, 8 Hz, 16 Hz, 32 Hz, 64 Hz, and 128 Hz across pre-training and post-training conditions. It can be noted that there was an improvement in detection threshold post-musical training with more improvement evident at low modulation frequency. To estimate whether the improvement was significant, a Wilcoxon Signed Rank test was performed between the pre-training and post-training conditions. Results showed that there was no significant difference in the score in pre- vs post-training at all the modulation frequencies (P>0.05). Figure 7 shows the mean scores and one-standard-deviation error bars of duration discrimination, gap detection, backward masking and duration pattern in pre- vs post-training condition. It can be noted that there was an improvement in scores for all the tests after musical training except for the gap detection threshold, wherein pre-training thresholds were better than post-training thresholds. To assess the difference in performance after training Wilcoxon Signed Rank test was performed and results showed that the pre-training and post-music training scores was not significant for all the tests (P>0.05).

Discussion

Perceptual learning can be defined as the improvement in the ability to perform a particular task after continuous practice. Ragas in Carnatic music have specific note sequences which can be identified by trained musicians. The results of the present study showed that with short-term perceptual training even non-musicians can learn to identify these Ragas. The main purpose of the present study was to document the differences in psycho-acoustical abilities in individuals after short-term musical training. To the best of our knowledge, the effect of short term music training on psycho-acoustical abilities has not been studied using a group of tests, including frequency and intensity discrimination, duration discrimination, gap detection, modulation detection, backward masking and duration pattern test.

The results of the present study show that there was an improvement in all the psycho-acoustical measures, including frequency, inten-
sity and temporal measures, but it was not significant. The frequency discrimination abilities did not show a significant change after training which is in contrary to the studies done in the past. Speigel and Watson,30 compared pitch discrimination ability in musicians and non-musicians and the results showed a clear separation between both the groups with a median threshold difference three times smaller for musicians. However, there are no studies examining the effect of music on intensity perception. The findings of the present study related to temporal perception also showed that with training scores improved in all temporal abilities, though it was not significant. Similar results have been reported by Monteiro et al.,31 where they compared the temporal resolution ability using gaps in noise test in musicians and non-musicians. Results revealed that there was no difference between those groups on the performance of the gaps in noise test. On the contrary, some studies have shown that the temporal processing abilities of musicians are superior to non-musicians. Ishii et al.32 in their study reported that the gap detection thresholds were better in trained musicians when compared to non-musicians. They also reported that the random gap detection threshold was not sensitive enough to differentiate the temporal resolution abilities. However, all the above mentioned studies have taken trained musicians to compare various auditory abilities and it has been reported that temporal resolution abilities improve as the experience in music increases.32 In a study by Sangamatha et al.,23 they reported that children with one to two years of musical training were able to perform like adults on all the temporal resolution tasks measured, except modulation detection at 200 Hz. This
is in accordance with the present study where the improvement in the modulation detection task was more evident at low modulation frequencies (2 Hz, 4 Hz, 8 Hz and 16 Hz) compared to higher modulation frequencies. This result could be because music contains fine frequency and amplitude fluctuations and thus individuals with musical training are expected to have better performance on such tasks. Thus, the findings of the present study showed that with short-term musical training there was an improvement in the raga identification, but this was not generalized to the various psycho-acoustical measures. Studies done in the past have shown that with short term musical training participants exhibit superior music related perception. Flohr reported that children performed well on standardized rhythmic discrimination task after receiving training for 25 min twice a week across 12 weeks. Thus, it can be concluded that short term musical training shows an improvement in music perception skills; however the same improvement is not evident in various psycho-acoustical measures.

Conclusions

Short-term perceptual musical training shows an improvement in the identification of ragas but does not show a significant improvement in frequency, intensity or temporal resolution abilities. This could be because short-term music training is not resulting in an efficient neural mechanism for performing various auditory tasks. Further research is needed to explore the effect of duration of music training which can show enhancement in various auditory abilities. Moreover, whether any other type of listening training (non-music based) would also influence the psycho-acoustical abilities was not assessed as the part of the present study. Future research may aim to study pre- and post-pyschoacoustic abilities in participants after receiving non-music based listening training.

References

1. Tervaniemi M, Knuck S, deBaene W, Schroger E, Alter K, Friederici AD. Top-down modulation of auditory processing: Effects of sound context, musical expertise and attentional focus. Eur J Neurosci 2008;30:1636-42.
2. Zatorre RJ, Belin B, Benhune VB. Structure and function of auditory cortex: music and speech. Trends Cogn Sci 2002;6:37-46.
3. Kraus N, Chandrasekaran B. Music training for the development of auditory skills. Nat Rev Neurosci 2010;11:599-605.
4. Banai K, Fisher S, Granot R. The effects of context and musical training on auditory temporal interval discrimination. Hear Res 2012;284:59-66.
5. Barry JG, Weiss B, Sabisch B. Psychophysical estimates of frequency modulation of auditory brainstem responses. J Acoust Soc Am 2006;119:1076-81.
6. Ishii C, Arashiro FM, Pereira LD. Ordenação e resolução temporal em cantores profissionais e amadores afinados e desafinados. Pré-Fono 2006;18:285-92.
7. Nikhef DA, Liester JJ, Frisch SA. Hearing of note: an electrophysiologic and psychoacoustic comparison of pitch discrimination between vocal and instrumental musicians. Psychophysiol 2008;45:994-1007.
8. Parbery-Clark A, Skoe E, Lam C, Kraus N. Musician enhancement for speech in noise. Ear Hear 2009;30:653-61.
9. Rammsayer T, Altenmüller E. Temporal information processing in musicians and nonmusicians. Music Perc 2006;24:37-47.
10. Michely C, Delhommeau K, Perrot X, Qwenham AJ. Influence of musical and psychoacoustical training on pitch perception. Hear Res 2006;219:36-47.
11. Parbery-Clark A, Strait DL, Kraus N. Context-dependent encoding in the auditory brainstem subserves enhanced speech in noise perception in musicians. Neuropsychologia 2011;49:3338-45.
12. Strait DL, Kraus N, Parbery-Clark A, Ashley R. Musical experience shapes down-up auditory mechanisms: evidence from masking and auditory attention performance. Hear Res 2010;261:22-9.
13. Gaser C, Schlaug G. Brain structures differ between musicians and non-musicians. J Neurosci 2003;23:9240-5.
14. Schlaug G. The brain of musicians; a model for functional and structural adaptation. Ann N Y Acad Sci 2001;930:281-99.
15. Gaab N, Schlaug G. The effect of musicianship on pitch memory in performance match group. Neuro Rep 2003;14:2291-5.
16. Chandrasekaran B, Krishnan A, Gandour JT. Relative influence of musical and linguistic experience on early cortical processing of pitch contours. Brain Lang 2009;108:1-9.
17. Srikantan RR, Srinivas IMJ, Sharade T, Rudrapatna SV, Vasantha M. Sarvajanik shiksha ilalke. Bangalore: Government of Karnataka; 2002.
18. Foster KL, Foster JC. DMDX: A window display program with millisecond accuracy. Behav Res Methods Instrum Comput 2003;35:116-24.
19. Grassi M, Soranzo A. MLP: a MATLAB toolbox for rapid and reliable auditory threshold estimation. Beh Res Meth 2009;41:20-8.
20. Green DM. A maximum-likelihood method for estimating thresholds in a yes-no task. J Acoust Soc Am 1993:93:2096-105.
21. He N, Dubno JR, Mills JH. Frequency and intensity discrimination measured in a maximum-likelihood procedure from young and aged normal hearing participants. J Acoust Soc Am 1998;103:553-65.
22. Abel SM. Duration discrimination of noise and tone bursts. J Acoust Soc Am 1972;51:1210-23.
23. Sangamanatha AV, Fernandes J, Bhat J, Srivastava M, Prakrithi SU. Temporal resolution in individuals with and without musical training. J Ind Speech Hear Assoc 2012;26:27-35.
24. Harris KC, Eckert MA, Ahlstrom JB, Dubno JR. Age-related differences in gap detection: Effects of task difficulty and cognitive ability. Hear Res 2010;264:21-9.
25. Desloge JG, Reed CM, Braida LD, Perez ZD, Delhorne IA. Temporal modulation transfer functions for listeners with real and simulated hearing loss. J Acoust Soc Am 2011;129:3884-96.
26. Roth DA, Kishon-Rabin L, Hildesheimer M. Auditory backward masking and the effect of training in normal hearing adults. J Basic Clin Physiol Pharmacol 2001;12:145-59.
27. Pinheiro ML, Musiek FE. Sequencing and temporal ordering in the auditory system. In: Musiek FE and Pinheiro ML, eds. Assessment of central auditory dysfunction: foundations and clinical correlates. Baltimore: Williams and Wilkins; 1985, pp 219-38.
28. Stock JH, Skoe E, Wong PCM, Kraus N. Plasticity in the adult human auditory brainstem following short-term linguistic training. J Cog Neurosci 2008;20:1892-902.
29. Lappe C, Trairin J, Herholz SC, Pantev C. Cortical plasticity induced by short-term multimodal musical rhythm training. PloS One 2011;6:e21493.
30. Spiegel MF, Watson CS. Performance on frequency discrimination tasks by musicians and non musicians. J Acoust Soc Am 1984;76:1690-95.
31. Monteiro RM, Nascimento FM, Soares CD, Ferreira MD. Temporal resolution abilities in musicians and no musicians violinists. Int Arch Otorhinolaryngol 2010;14:302-08.
32. Ohnishi T, Matsuda H, Asada T, Aruga M, Hirakata M, Nishikawa M, et al. Functional anatomy of musical perception in musicians. Cereb Cortex 2009;11:754-60.
33. Flohr JW. Short-term music instruction and young children's developmental musical aptitude. J Res Mus Educ 1981;29:219-23.