Influence of Musical Proficiency on Psychophysical Tuning Curves and Contralateral Suppression of DPOAEs

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This Dissertation is submitted as part of fulfillment
for the Degree of Master of Science in Audiology
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May 2015

CERTIFICATE

This is to certify that this dissertation entitled "**Influence of Musical Proficiency on Psychophysical Tuning Curves and Contralateral Suppression of DPOAEs**" is a bonafide work submitted in part of fulfillment for the Degree of Master of Science (Audiology) of the student (Registration No.: 13AUD002). This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any of the University for the award of any other Diploma or Degree.

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This is to certify that this dissertation entitled "**Influence of Musical Proficiency on Psychophysical Tuning Curves and Contralateral Suppression of DPOAEs**" has been prepared under my supervision and guidance. It is also certified that this has not been submitted earlier in other University for the award of any Diploma or Degree.

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DECLARATION

This is to certify that this dissertation entitled "**Influence of Musical Proficiency on Psychophysical Tuning Curves and Contralateral Suppression of DPOAEs**" is the result of my own study under the guidance of Mrs. Devi. N, Lecturer in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier in other University for the award of any Diploma or Degree.

Mysore Register No.: 13AUD002

May, 2015.

Abstract

Greater spectral acuity has been seen in musicians in terms of enhanced pitch and timbre discrimination and better perception of speech in adverse listening conditions which could be attributed to enhanced peripheral filtering at the level of cochlea. However, studies behaviorally estimating sharpness of tuning curves in musicians is limited. Hence current study aimed to investigate the effect of musical proficiency on psychophysical tuning curves (PTCs) which behaviorally estimates sharpness of tuning curves; and on contralateral suppression of distortion product oto-acoustic emissions (DPOAEs). Thirty participants were divided into three equal groups (non-musician, junior musician & senior musician) based on their musical proficiency. PTCs were obtained using forward and simultaneous masking paradigm at 1 KHz and 4 KHz; and contralateral suppression of DPOAEs was carried out using white noise in opposite ear at 50dBSL. Results reveal that greater sharpness of tuning curves in senior musicians across all conditions. Sharper tuning curves were obtained under forward masking condition and at 4 KHz for all the participants. Greater amount of contralateral suppression of DPOAEs were noted in senior musicians and a significant positive correlation was noted between contralateral suppression at 4 KHz and simultaneous masking at 4 KHz. The degree of correlation was greater for senior musicians. Results of the present study indicate that musical training strengthens the activity of medial olivocochlear bundles, which is reflected by increase in sharpness of auditory filters and greater suppression of OAEs. As musical training strengthens the cortico-fugal top down control; it could be advised as one of the remedial programs for individuals having difficulty to perceive speech in noise, elderly individuals and individuals with auditory processing disorders.

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Chapter 1

Introduction

The complex brain functions involving auditory memory, acoustic analysis and auditory scene analysis are employed in music perception, and hence musical training would lead to superior performance in these domains. Weiss, Bidelman, Moreno and Alain (2014) documented the first evidence on musicians' auditory recognition memory to be superior to that of non-musicians. The superiority has been reported for both musical and non-musical segments. Acoustic analysis of the incoming signal would be done under both spectral domain and temporal domain. Musicianship enhances both spectral and temporal acuity in musicians as revealed by superior performance in pitch discrimination tasks and temporal resolution tasks (Monteiro, Nascimento & Soares, 2010; Strait, Kraus, Parbery-Clark & Ashley, 2010; Kumar, Rana & Krishna, 2014). Auditory scene analysis involves segregating the sound into spectro-temporal contents and determining how many sound sources are present in the environment and from which source a particular sound is coming (Trainor, 2014) and hence, auditory scene analysis is essentially employed in music perception. Greater attention would be paid by the musicians to the acoustic stimuli when compared to non-musician peers (Strait et al., 2010). Enhanced auditory abilities have also been reported in professional musicians in tasks involving auditory memory (Boh, Herholz, Lappe & Pantev, 2011; Strait, Parbery-Clark, Hittner & Kraus, 2012), pitch discrimination (Kishon-Rabin, Amir, Vexler & Zaltz, 2001; Micheyl, Delhommeau, Perrot & Oxenham, 2006) or auditory attention (Strait et al., 2010).

Spectro-temporal acuity concerned with identification and discrimination of speech is superior in musicians (Micheyl et al., 2006; Bidelman & Krishnan, 2010).

Speech cues in adverse listening situations are better extracted by musicians compared to non-musician peers as these benefits are extended into real world perception and auditory scene analysis (Parbery-Clark, Skoe, Lam & Kraus, 2009; Bidelman & Krishnan, 2010). Although interaction of central auditory system plasticity and effect of musical training system has been reported in various studies (Hyde et al., 2009; Ellis et al., 2012; Herholz & Zatorre, 2012; Oechslin, Van De Ville, Lazeyras, Hauert & James, 2013; Strait, Parbery-Clark, O'Connell & Kraus, 2013); how peripheral auditory system is influenced by musical experience is less known.

Experimental findings over the past two decades or so, shows larger olivocochlear efferent suppression suggesting enhanced Medial olivocochlear system (MOCS) activity in musicians. As corticofugal descending auditory system (CDAS), exerts top-down control on MOCS, enhanced MOCS activity in musician could be attributed to training induced plasticity (Xavier Perrot & Lionel Collet, 2014). As Active Cochlear Micromechanics (ACMs) is modulated by MOCS, an enhanced MOCS would result in improved frequency selectivity, speech perception in noise and enhanced dynamic range. Findings from various empirical studies indicate enhanced perception of speech by musicians in challenging listening profile (Parberry-Clark et al., 2009; Bidelman & Krishnan, 2010). However, investigations documenting behavioral estimates of frequency selectivity in musicians are lacking.

Peripheral filtering at the level of the cochlea influences the auditory spectral acuity (Bidelman & Krishnan, 2010). Processing at the level of basilar membrane is conceived as a bank of overlapping band pass filters where the sound input undergoes spectral decomposition. Auditory filter's bandwidth contributes to frequency resolution of the system and thereby, the perceptual acuity to detect changes in the spectral input (Bidelman, Schug, Jennings & Bhagat, 2014). Greater spectral acuity has been seen in musicians where a large number of empirical studies have shown enhanced pitch (Strait et al., 2012) and timber discrimination (Bidelman & Krishnan, 2010), and their greater ability to extract speech cues in adverse listening situations (Parberry-Clark et al., 2009). It could be suggested that musical experience increases cochlear tuning leading to enhanced spectral sensitivity in musicians (Bidelman et al., 2014).

Soderquist (1970), reported musicians to be superior to naive listeners on frequency analysis task. The reason for the superiority could, of course, be attributed to either musical training (perceptual learning) or innate ability. It has been postulated that musician's performance to be in relation with the Critical Band (CB) concept. If one accepts the postulate that the CB determines the limits of frequency analysis for both musicians as well as non-musicians, then a logical conclusion is that CBs for musicians are both narrower and more rectangular than those of naive individuals. Using this logic and a post hoc inspection of musicians' performance, he predicted musicians' CBs to be approximately 20% smaller than the published values for normals (Zwicker, 1961).

Psychophysical tuning curves (PTCs) are a measure of critical bands in the cochlea which could behaviorally estimate the auditory filters. Through PTCs it is possible to measure pitch perception of musicians with that of non-musicians and compare the results quantifiably with a figure of PTC slope called Q10 value. However, there is dearth of studies comparing musicians and non-musicians using psychophysical tuning curves (PTCs).

PTCs in humans can be obtained using either simultaneous masking paradigm where masker and the probe signal are presented simultaneously or forward masking paradigm where probe follows the masker (Moore, 1978; Oxenhan & Shera, 2003). Sharper PTCs are obtained using forward masking than those obtained in simultaneous masking. Both these approaches provide useful measures of the auditory system's frequency selectivity (Moore, 1978; Bidelman et al., 2014).

Generally, psychophysical tuning curve are employed to assess frequency selectivity and dead regions in hearing loss individuals. Studies estimating sharpness of auditory filter in musicians using PTCs are very much limited. Psychophysical tuning curves give a more accurate representation of critical bandwidth of basilar membrane than difference limens for frequency. By using PTC as a measurement of pitch perception, more information about physical properties of cochlea are known.

Till date, studies to empirically validate sharper auditory filters in musicians are very much limited (Bidelman et al., 2014), and so are the studies investigating whether enhancement of MOCS activities enhances in experience dependent manner.

1.1. Need of the study

- Enhanced MOCS activity in musicians has been validated with their superior performance in speech perception tasks in adverse listening conditions and larger contralateral suppression of OAEs compared to non-musicians. As enhanced MOCS activity also results in improved frequency selectivity, empirical studies behaviorally estimating frequency selectivity in musicians are limited.

- Studies to investigate whether experience dependent effect of musicianship on cochlear processing acts differently along the cochlear partition are limited.

1.2. Aim of the study

- To investigate the influence of musical proficiency on Psychophysical tuning curves and contralateral suppression of DPOAEs.

1.3. Objectives of the study

- To find out the influence of musical proficiency on psychophysical tuning curves (forward masking paradigm versus simultaneous masking paradigm).
- To find out the influence of musical proficiency on contralateral suppression of DPOAEs.
- To investigate whether proficiency dependent effect of musicianship on cochlear processing acts differently along the cochlear partition.

Chapter 2

Literature Review

The auditory system functions on a network of redundancies and checkpoints that allow a signal to reach the brain uninterrupted. Sound signals on reaching the ear, are processed by various structures, and are perceived by the listener to have a particular pitch, loudness, duration, and timbre, or quality.

Pitch perception, the psychological correlate of frequency discrimination, is one of the least understood auditory processes in humans. While research supports (Pantev, Hoke, Lutkenhoner & Lehnertz, 1989; Yamamoto, Uemura & Llinas, 1991; Bilecen, Scheffler, Schmid, Tschopp & Seelig, 1998) that tonotopic organization exists at all levels of the central auditory nervous system, including the cortex, the exact processes involved in pitch perception are largely unknown. Closely related to pitch perception is masking, which is the ability of one sound to be covered, or masked, by another sound to the point that the original sound is inaudible. Several theories regarding pitch perception and masking have been hypothesized and tested, including theories of how pitch perception is affected by timing, location of maximum displacement on the basilar membrane, and neural organization (Gelfand, 2010). One such theory explaining the dynamics of pitch perception is critical band theory, which describes the basics of masking principles as well as the limits of pitch perception (Fletcher, 1940).

Though some major landmarks in the auditory system are tonotopically organized, frequency information is also deciphered by timing differences in the neural firing of the auditory pathway. These two conditions are separated into theories of pitch perception called place theory and timing theory (Gelfand, 2010). Place theory is the idea that pitch perception is dependent on the tonotopic organization of the basilar membrane, organization of frequency-specific fibres in the vestibulocochlear nerve, and the further tonotopic organization of the auditory cortex.

Timing theory is the conjecture that pitch perception is dependent on the synchronous, organized firing of neurons in the auditory system that correlate to specific frequencies. Most hearing scientists agree that pitch perception is a result of a merging of both theories, with lower frequencies distinguished via timing, and higher frequencies starting around 5000 Hertz (Hz) relying on place, and the frequencies in between perceived via both processes (Moore, 1993).

2.1. Musicians vs. Non-musicians as listeners

Because of their exposure to sound and their use of sound as a profession, musicians in general are specialized listeners when compared to non-musicians. Experiments not specifically measuring pitch perception indicate differences between non-musicians and musicians as listeners (Chartrand & Belin, 2006; Parbery-Clark et al., 2009). These studies have compared timbre discrimination, speech discrimination in background noise, and the aging auditory system in musicians versus non-musicians. Greater spectral acuity has been seen in musicians where a large number of empirical studies have shown enhanced pitch (Strait et al., 2012; Bidelman, Hutko & Morneo, 2013) and timber discrimination (Bidelman & Krishnan, 2010), and their greater ability to extract speech cues in adverse listening situations (Parberry-Clark et al., 2009).

In an experiment by Chartrand and Belin (2006), timbre discrimination, the musical quality that distinguishes the source of a musical sound from another, was compared for musicians and non-musicians. Thirty-six participants, both male and female, were recruited for the study. The 17 musicians included a mixture of vocalists and instrumentalists who had at least three years of formal training. Two groups of stimuli, one of, sounds produced by musical instruments and the other of vocal presentations, were used in the experiment in groups of two. Participants were required to choose if both the stimuli in each trial came from the same or a different source. Results proved to be statistically significant for musicians versus non-musicians; musicians performed better at distinguishing within both groups of stimuli, suggesting that training in instrument timbre made them more advanced at distinguishing vocal differences as well, though the vocal tasks were more difficult for both the groups.

Performance of musicians and non-musicians on frequency-discrimination task was assessed by Spiegebl and Watson (1984). Auditory discrimination abilities of professional musicians were compared with those of non-musicians. 30 musicians were compared with non-musicians across frequency discrimination task and tone pattern task. The stimuli for the frequency-discrimination tasks were 300-msec sinusoidal tones, 300-msec square waves and tone patterns consisting of ten 40-msec tones played sequentially. The musicians difference threshold for single tones were between $\Delta f / f = 0.001$ and 0.0045. One-half of the non-musicians attained thresholds almost as low; the rest attained larger thresholds up to $\Delta f/f = 0.017$. The results for pattern stimuli show a clearer separation between the musicians and non-musicians whose median difference thresholds were about three times smaller. From these results it appeared that specific training on a complex auditory task would provide greater benefit for performance than previous musical experience.

Kishon-Rabin et al. (2001) measured differential limen for frequency (DLF) for non-musical pure tones in 16 musicians and 14 non-musicians using 2 & 3 interval forced choice procedure. DLF performance was related to the musical background.

DLF was obtained for .25, 1 and 1.5 kHz. Results of the present study showed that, mean DLF scores for musicians was approximately half the values of non-musicians. Classical musicians performed better than musicians with contemporary background. It could be concluded from the following study that musicianship enhances auditory abilities in terms of spectral discrimination and speech perception in adverse listening situations.

Schröger, Koelsch, Widmann and Tervaniemi (2005), studied pitch discrimination in musicians and non-musicians using behavioral and electrophysiological measures. Rare deviant sounds (0.8, 2, or 4% higher in frequency) and frequent standard sounds were presented to 13 non-musicians and thirteen professional musicians. Initially, the subjects were made to read a self-chosen book and secondly they were asked to detect the presence of deviant stimuli behaviorally. AEP evoked for both standard and deviant sounds were recorded. Pitch changes were detected faster and more accurately by musicians than non-musicians. Larger amplitude of N2b and P3 responses were recorded in musicians than in non-musicians during attentive listening. Interestingly, not only with the 0.8%, accuracy of pitch discrimination was superior in musicians, but also with the 2% frequency changes. Moreover, detection of the smallest pitch changes of 0.8% by non-musicians was also reliable. However, there was no difference between musicians and non-musicians in the P3a and mismatch negativity (MMN) recorded during a reading condition. These results suggest that effects are exerted merely at attentive levels of processing by musical expertise and not necessarily at the pre-attentive levels.

Empirical studies have shown that musical experience influences pitch discrimination abilities. Micheyl et al. (2006) reported that discrimination thresholds for pure tone and complex tone in 30 classical musicians were six times smaller to thresholds of 30 non-musicians compared.These findings supplement and qualify earlier data in the literature regarding the respective positive influence of musical and psychoacoustical training on pitch discrimination performance.

Strait et al. (2010), measured frequency discrimination in 33 adult musicians in the age range of 18-40 years. Three alternative forced choice paradigm was used where target stimulus was presented in equal probability with one of the three intervals amidst a standard tone. Enhanced frequency discrimination was seen in musicians where threshold for frequency discrimination in musicians (0.85) was almost three times smaller than non-musicians (3.12). Results were conclusive of that, musical training bring about fine tuning in auditory domain and musical training would be advocated as a remedial tool for management of central auditory processing disorder.

Temporal processing abilities have been reported to be superior in musicians compared to non-musicians. Not just fine tuning of auditory pathways takes place by musical training but also preservation of temporal resolution ability in the elderly hearing-impaired population.

Rammsayer and Altenmüller (2006) examined, whether musicians possess greater temporal information processing than non-musicians. For this purpose, set of seven different auditory temporal tasks were performed by 36 non-musicians and 36 academically trained musicians. Superior temporal acuity was shown for rhythm perception, auditory fusion, and three temporal discrimination tasks by musicians when compared to non-musicians. Two tasks tapping temporal generalization showed no difference between two groups. Musicians’ superiority in performance appeared to be limited to timing aspects which are considered to be immediately and automatically derived from temporal information’s online perceptual processing.

Extensive music training seemed not to influence temporal generalizations, unlike to that of temporal information’s immediate online processing which involve a reference memory of sorts.

Monteiro et al. (2010) measured temporal resolution abilities in musicians and non-musicians. The participants in the study were 20 musicians and equal number of non-musicians. They were subjected to gap in noise test to assess temporal resolution. Although musicians performed better in gap in noise test, it was not statistically significant. However, a significant correlation was noted among the performance of the GIN test for LE and the time of daily exposure to music, which is indicative that increased length of daily musical exposure is directly proportional to the threshold of gap detection. They concluded that, duration of exposure to music did not facilitate the performance of temporal resolution.

Thomas and Rajalakshmi (2011) studied the effect of music training on temporal resolution abilities. A total of 20 professionally trained Carnatic vocal musicians were included in the study. They were classified into 4 groups based on their years of experience. Unmodulated white noise and sinusoidally amplitude modulated white noise of 500ms duration, with a ramp of 20msec was used to measure Temporal Modulation Transfer Function (TMTF). Three alternative forced choice method was used to obtain gap detection threshold. Presentation level of the stimulus was 40dBSL. The results of temporal modulation transfer function and gap detection threshold values showed that the temporal resolution abilities become better as the years of musical experience of musicians increased.

Vijay kumar et al. (2014) studied temporal processing abilities in musicians and non-musicians. Four different psychoacoustic tests – gap detection threshold (GDT), duration pattern test (DPT), duration discrimination test (DDT) and the modulation detection threshold for sinusoidally amplitude-modulated noise (SAM) at six different modulation frequencies – were used to assess differences in temporal processing abilities among 15 trained violinists and 15 trained vocalists. The results were compared with a group of 15 non-musicians. Musicians, both violinists and vocalists, always performed significantly better ($p<0.01$) than non-musicians in all 4 psychoacoustic tests. Vocalists performed equal to or slightly better than violinists in GDT and at 5/6 modulation frequencies in modulation detection threshold for SAM noise test, although the differences were not statistically significant. Although a musician was undergoing training for vocals or instrumentals, their difference in training for sound they produce and what aspect of sound they perceive does not bring about change in their temporal processing abilities significantly.

Enhanced speech perception in adverse listening situations has been empirically validated in musicians. Parberry-Clark and Kraus (2009) administered Speech in noise performance by running Hearing in Noise Test (HINT) and QuickSIN on 16 musicians and 15 non-musicians who served as controls to investigate the effect of musical training. Better performance was shown by musicians' group in both QuickSIN and HINT-F tasks, meaning that musicians could repeat the target sentences presented at a lower level and more adverse SNR conditions than non-musicians. Musical experience appears to enhance the ability to hear speech in adverse listening environments and also provide further evidence for effect of musical training transferring to non-musical domains.

Parberry-Clark and Kraus (2009) investigated how speech in noise is neurally represented by comparing subcortical neurophysiological responses for speech in presence of noise and speech in quiet conditions. 16 musicians and 15 non-musicians were involved in the study. Auditory brainstem responses evoked by speech were obtained using speech syllable /da/ on all the subjects. Semantically anomalous but grammatically correct sentences spoken by six different speakers to create multi-talker babble which was used as the background noise. Quick SIN and HINT were also administered. In presence of background noise, speech-evoked auditory brainstem responses were more robust for musicians’ group. Greater phase-locking ability to stimulus harmonics and the temporal waveform, and response onset timing which was earlier was noted for musicians than for non-musicians. Better speech perception in noise which was evaluated using HINT was found to be related to robust auditory brainstem response for speech syllable and earlier response timing.Through these findings are provided the biological evidence for musicians’ superior advantage in perception of speech in adverse listening situations and that musical experience limits the negative effects of competing background noise.

Bidelman and Krishnan (2010), examined whether on undergoing musical training, subcortical representations of formant and pitch related harmonic information of speech is resilient to reverberation’s degradative effects. Frequency-following responses (FFRs) from brainstem were recorded for vowel /i/ from musicians and non-musician group. Response was recorded at four different reverberation levels. The same was analyzed based on their spectro-temporal composition. For both groups, Neural encoding of pitch was least affected by presence of reverberation at different levels. However, formant related harmonics, which represent vowel quality, were encoded weakly at neural level due to presence of reverberation. This finding is suggesting that the source-filter components of speech are differentially impacted. However, across different reverberation conditions tested and in quiet condition as well, more robust responses were exhibited by musicians in comparison to non-musicians. To confirm the neurophysiologic results, perceptual measures of frequency difference limens (DLs), (F0) and first formant (F1) were obtained. The behavioral responses were compared with brainstem spectral magnitudes. DLs obtained from musicians were 2-4 times better when compared to non-musicians for discrimination tasks of both type. Findings suggest that perceptually salient aspects of musical pitch are not only represented at subcortical levels but these representations are also enhanced by musical experience.

Strait et al. (2012) reported that, ‘musical training during early childhood enhances the neural encoding of speech in noise’. Thirty-one normal hearing children between in the age range of 7–13 participated in this study. SIN perception was measured using the Words in Noise Test (WIN) and the Hearing in Noise Test (HINT). Six-thousand artifact-free auditory brainstem responses were recorded to the speech sound /da/. For quiet and noise conditions, neural recordings were obtained continuously. Non-musicians were outperformed in speech perception in noise tests by children who were musically trained. Lesser degradation of auditory evoked brainstem response in presence of background noise was noted in musicians on comparing to non-musicians. However, neural enhancements were observed in both noise and quiet conditions in musicians’ group. These finding reveals benefit for speech in noise for musicians in early developmental years and this could be driven by strengthened auditory cognitive functions.

Experimental findings over the past two decades or so, shows larger olivocochlear efferent suppression suggesting enhanced Medial olivocochlear system (MOCS) activity in musicians. Micheyl and Collet (1995), measured contralateral suppression of TEOAEs in right ear for 11 musicians and 24 non-musicians. Stronger contralateral suppression in musicians was obtained on comparing to non-musicians at input level of 65dBSPL.

Micheyl, Khalfa, Perrot and Collet (1997), recorded contralateral suppression of TEOAE in right ear for 16 musicians and equal number of non-musicians. In both groups there was significant attenuation in OAE amplitude on application of contralateral suppressor. A greater stimulus equivalent attenuation in right ear was seen in musicians.

Micheyl, Perrot and Collet (1997), performed auditory intensity discrimination and contralateral suppression of TEOAEs for a group of 20 musicians. Intensity discrimination task was carried out in quiet situation and in presence of noise in contralateral ear. There was no difference found between the two conditions. Change in TEOAE growth function parameter was noted on application of contralateral broad band noise.

Perrot, Micheyl, Khalfa and Collet (1999), compared contralateral suppression of TEOAEs in both ears for 16 professional musicians and equal number of non-musicians. Significant reduction in OAE amplitude was noted for both groups in suppressor condition. However, stimulus equivalent attenuation was larger in musicians on comparing to non-musician group.

Brashears, Morlet, Berlin and Hood (2003) measured suppression of TEOAEs in 28 musicians and 29 non-musicians matched for age and gender. Forward masking paradigm was employed where bilateral broad band noise was used as the suppressor stimulus. Result showed that musicians had significantly greater suppression in both ears when compared to non-musicians and it was possible to conclude that music and musicianship enhances suppression and would lead to improvement in auditory skills.

Greater spectral acuity has been seen in musicians where a large number of empirical studies have shown enhanced pitch (Strait et al., 2012) and timber discrimination (Bidelman & Krishnan, 2010), and their greater ability to extract speech cues in adverse listening situations (Parberry-Clark et al., 2009). Musical experience might increase cochlear tuning leading to enhanced spectral sensitivity in musicians (Bidelman et al., 2014). Behavioral estimates of the auditory filters can be obtained via psychophysical tuning curves (PTCs) measurement (Moore, 1978). PTC measurement could be carried out by using simultaneous masking paradigm, forward masking paradigm, notched noise method and fast tracking PTC method.

Moore (1978), measured PTC in 5 normal hearing individuals using simultaneous and forward masking paradigm at different level and frequency of the test tone. PTCs obtained in this form were quite similar to single neuron tuning curve when low level probe tone was used. PTCs obtained in forward masking paradigm showed sharper tip and steeper slopes when compared to simultaneous masking paradigm. Authors acknowledged that PTCs obtained using simultaneous masking paradigm could be influenced by combination tones, lateral suppression and beats, whereas, PTCs in forward masking paradigm could be influenced by off frequency listening and decaying effect of the masker.

Jennings and Strickland (2012), measured auditory filter tuning using notched noise masker which eliminated the influence of off frequency listening. Iso-level curves were obtained using short sinusoidal and notched noise masker and results were found to be consistent with studies in the literature. Results inferred that, off frequency listening could be successfully eliminated using notched noise method.

To determine psychophysical tuning curves, a Fast method was developed by Moore, Sek, Alcantara, Kluck and Wicher (2005). PTCs were obtained in 10 normal hearing subjects and 12 hearing impaired subjects using fast tracking method and traditional method. PTCs obtained in normal hearing subjects were similar in both the procedures. For subjects diagnosed having dead regions showed good repeatability in

PTCs obtained using fast tracking method. They concluded that, results obtained using fast tracking method edge frequencies could be predicted and PTCs could be constructed with less time compared to traditional methods.

However, till date empirical studies validating sharper auditory filters in musicians are limited. Bidelman et al. (2014) studied auditory filter sharpness in musicians through psychophysical tuning curves obtained using forward masking and simultaneous masking paradigm. 10 musicians and 9 non-musicians in the age range of 18-35 years were involved in the study. PTCs were measured for each listener at two characteristic frequency 1 and 4 kHz. Forward masking PTCs were measured using three interval forced choice task. Narrow band noise centered at 0.50, 0.62, 0.75, 0.87, 1.00, 1.05, 1.12, 1.25, and 1.50 relative to the probe's CF was used as masker. Narrowband noise was of 200ms duration and was gated with 5ms cos2 ramps. The masker was immediately followed by a brief probe signal (30ms, 10ms ramps). The probe signals were presented at 1 kHz and 4 kHz at fixed level of 20dBSL of participant's threshold. To quantify the filter sharpness from PTCs, Q10 factor was derived from the auditory filter. Simultaneous masked PTCs were obtained using "Fast PTC method". A narrowband noise masker (1 kHz probe: 200 Hz BW; 4 kHz probe: 320 Hz BW) 8 was used to minimize the detection of beats between the probe and the masker. Probes were 500 ms pure tones (20-ms ramps), pulsed on/off continuously at a regular rate (ISI: 200 ms) to help subjects maintain their attention to the target stimuli. The centre frequency of the masker was swept in upward direction from f-min to f-max over a time span of 4min, where f-min/f-max are frequencies 1.5 and 0.6 octaves below and above the CF, respectively. Results showed that auditory filters were sharper when obtained using forward masking paradigm and musicians had higher Q10 value at 4 kHz when compared to their non-musician peers.

It is evident from above literature that musicianship enhances performance on various auditory tasks involving spectral acuity, temporal acuity, speech perception in adverse listening conditions and so on. The benefits extended into the real world could be better explained by increased cochlear tuning in musicians. However, there is dearth of information on behavioural estimates of frequency selectivity in musicians collaborates with their enhanced ability in spectral processing and influence of musical proficiency on cochlear processing.

Chapter 3

Method

The study was aimed to investigate and compare frequency selectivity and contralateral suppression of DPOAEs in musicians and non-musicians and to find out the influence of musical proficiency on the same. Frequency selectivity was behaviorally estimated using forward masking PTCs and simultaneous masking PTCs.

Participants

Thirty young adults in the age range of 15 to 35 (Mean: 23.666, SD: 3.209) years were chosen for the study. All the participants were right handed individuals. Participants were equally divided into three groups: Group I as Non-musicians (No formal musical experience throughout their lifespan), Group II as musician-junior (should have cleared junior level exam, practicing at least 3 days weekly for >1 hour per session) and Group III as musician-senior (should have cleared senior level exam, practicing at least 3 days weekly for >1 hour per session). Their hearing sensitivity was within normal limits (audiometric thresholds within 15dB hearing level from 250Hz to 8000Hz). All the participants had normal middle ear status (‘A’ type tympanogram with acoustic reflex present bilaterally) and outer hair cells (OHCs) functioning that were confirmed through immittance evaluation and transient evoked oto-acoustic emissions (TEOAEs) evaluation. Participants reported no neurological problems or understanding of speech in noise. The three groups were age and gender matched.

Instrumentation

A calibrated clinical diagnostic audiometer (two channel Inventis Piano Plus) was used to carry out pure tone audiometry. Assessment of functioning of the middle ear system was carried out by recording tympanogram and acoustic reflex in a diagnostic immittance meter (GSI-tympstar). In order to assess the integrity of outer hair cells oto-acoustic emissions were recorded using Otodynamics Ltd, ILO v6. The experiment to obtain PTCs were run using personal computer (Intel(R) core (TM) i3-3110M, 4GB RAM, 64 bit operating system) loaded with Psychon software (1.50 version). A sound level meter (B & K 2270) was used to calibrate the output from the personal computer. Calibration was carried out for both narrow band noise and pure tones at test frequencies. The output was within ±3dB SPL of the given input. The output signal were routed through Sennheiser HDA 200 supra aural headphones.

Test environment

All the measurements were carried out in an acoustically treated room, where the level of ambient noise was well within the permissible limit (ANSI 1999).

Procedure

Before the actual procedure, a written consent was taken from all the participants for their willingness to participate in the study.

Contralateral suppression of DPOAEs

An otoscopic examination was carried out prior to measurement of DPOAEs to inspect for any debris in the external auditory meatus. DPOAEs were measured using two pure tones of frequencies f1 and f2 presented at intensities L1 and L2 respectively. The intensity level of L1 and L2 was kept constant at 65 and 55dBSPL respectively. f2/f1 ratio was maintained constant at 1.22. Probe was positioned in the test ear canal and was adjusted to maintain a flat stimulus frequency spectrum.

OAEs were recorded in 2 conditions: in the absence of noise and in presence of contralateral masker. BBN was used as the masker presented to contralateral ear at 50dBSL. Suppressor noise was presented through calibrated audiometer and was routed via ER-3A insert receiver.

In contralateral suppression of DPOAEs multiple recordings were obtained where DPOAEs were measured in absence of noise and in presence of noise twice respectively. OAEs were considered present only if it was at least 6 dB above the noise floor for at least three consecutive frequencies (Wagner, Heppelmann, Vonthein & Zenner, 2008)

Contra lateral suppression of OAE was calculated from the difference between OAE amplitude with noise and without the noise condition. Amount of contralateral suppression was measured across frequencies from 1 kHz to 6 kHz.

Forward masking PTCs

Standard forward masking paradigm presented in a three interval, forced choice task was used to obtain PTC in each of the participants. Narrow band noise centered at 0.50, 0.62, 0.75, 0.87, 1.00, 1.05, 1.12, 1.25, and 1.50 relative to the probe's CF was used as masker. Narrowband noise was of 200ms duration and was gated with 5ms cos2 ramps. The masker was immediately followed by a brief probe signal (30ms, 10ms ramps). The probe signals were presented at 1 kHz and 4 kHz at fixed level of 20dBSL of participant's threshold. Instead of using all of 9 masker-probe combination to construct a listener's PTC at a given CF, 5 masker-probe combinations were used; 1 at CF and 2 each on either side of the CF.

The masker was initially set at a level -10dB below that of the probe. With probe being fixed at a low presentation level, level of the masker was varied and masked threshold was obtained. Responses were obtained via computer keyboard or mouse and visual feedback was provided after each trial. To obtain masked thresholds, a 2 down, 1 up adaptive procedure was employed. Following 2 correct responses, masker level was increased for subsequent trial and decreased following a single incorrect response. The geometric mean of last 8/12 reversals were used to compute each listener's masked threshold. A single masked threshold was obtained for each of the 5 masker-probe combination and was used to construct a listener's PTC at a given CF. Each individual was briefly familiarized regarding the procedure prior to start of the testing. From the auditory filter, Q10 factor was measured and filter sharpness was quantified from PTCs. Q10 dB value is defined as the center frequency divided by the bandwidth at the 10dB down points.

Simultaneous masking PTCs

Here simultaneous masking paradigm was used where making noise was present concurrently with the probe signal. The probe signal was placed at the center of the noise along the duration, as placing signal at the onset of the masker would influence the detection threshold due to presence of spectral splatter. Stimulus parameters remain the same. Using 2 down 1 up adaptive procedure, amount of noise just able to mask the signal was measured across same frequencies previously mentioned. PTCs were obtained at both the CFs and Q10 dB value was quantified.

Results of contralateral suppression of DPOAEs and PTCs obtained using forward masking and simultaneous masking was compared to check if correlation exists between the degree of contralateral suppression and sharpness of auditory filters.

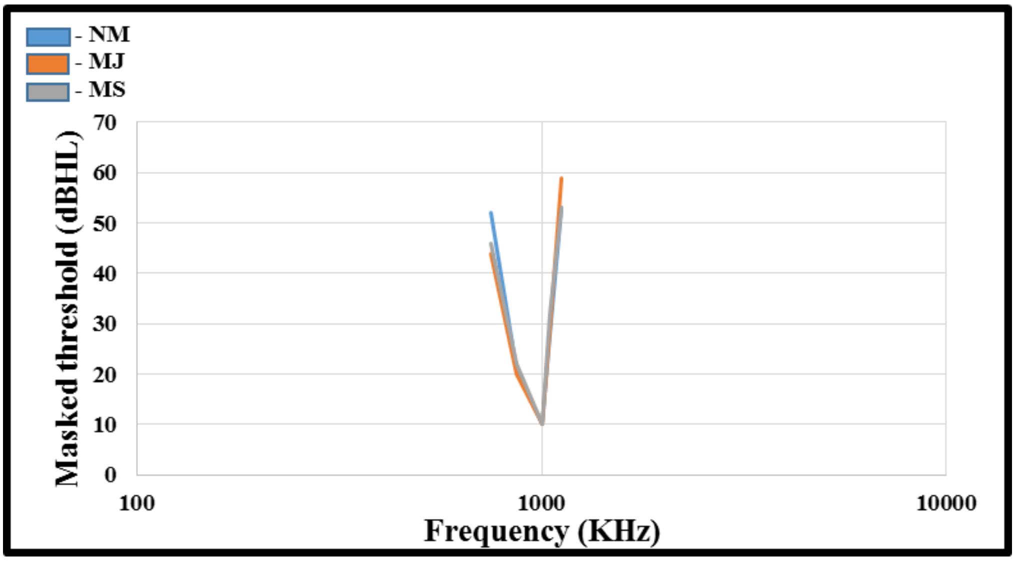
Chapter 4

Results

Data obtained inset for all conditions were tabulated. Descriptive and inferential statics were carried out using Statistical Package for Social Sciences (SPSS), version. 20. Prior to the inferential statistics, the data were subjected to check the assumptions of parametric statistics. The normality of distribution was tested using Shapiro-Wilk test. Results showed normally distributed data in all the conditions ($p>0.05$). Levene test was carried out to assess homogeneity of variance and results showed that there was no significant difference ($p>0.05$) indicating that assumption of homogeneity of variance is maintained. Hence, parametric statistics was chosen for analysis.

4.1. Effect of musical proficiency on Psychophysical tuning curves

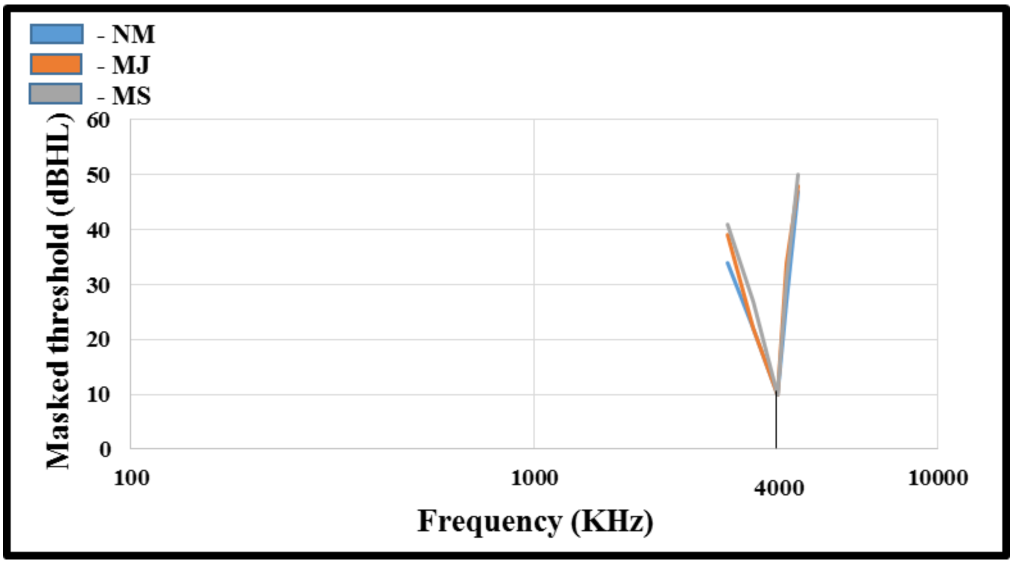
Psychophysical tuning curves (PTCs) obtained at 1 kHz and 4 kHz using forward and simultaneous masking paradigm are shown in graph (4.1-4.4). Psychophysical tuning curves showed typical “V-shape” with high frequency skirt steeper than that at low frequency. PTCs obtained using forward masking paradigm was sharper relative to that obtained using simultaneous masking.



Graph 4.1**:** Psychophysical tuning curves obtained for three groups at 1 KHz using forward masking paradigm.

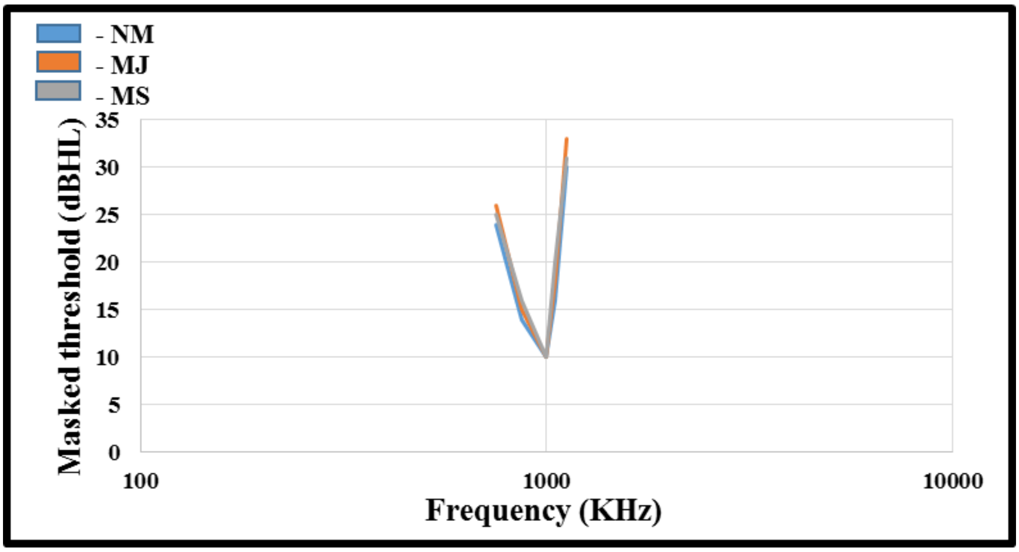
Note: **NM-** non-musician, **MJ-** musician junior, **MS-** musician senior.

It can be seen from the above graph (4.1.) that, the tuning curves obtained under forward masking condition at 1 KHz did not differ across 3 groups of participants. Thresholds nearly overlapped for three groups at the tip of the curve, whereas minimal difference was noted at end frequencies.



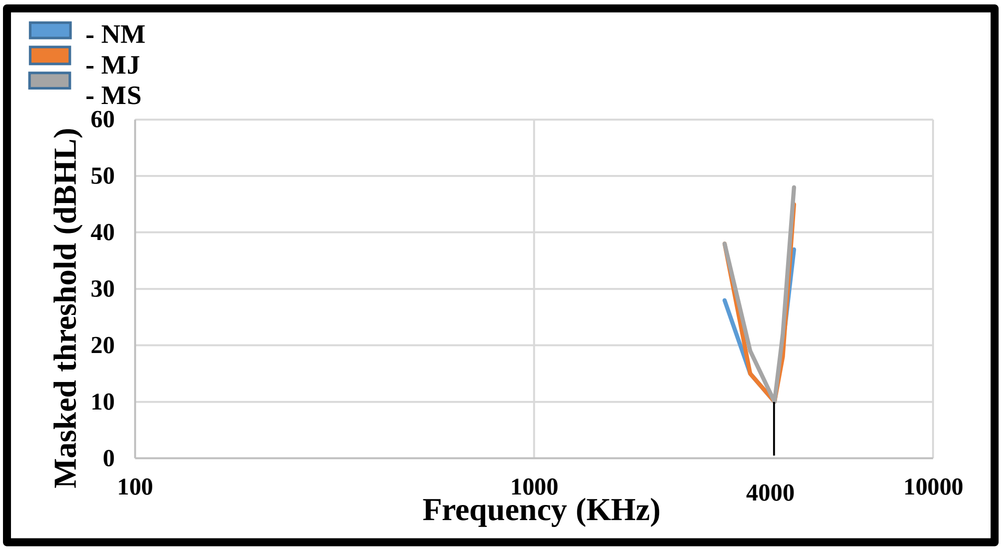
Graph 4.2**:** Psychophysical tuning curves obtained for three groups at 4 KHz using forward masking paradigm.

From the above graph (4.2.) it could be noted that, tuning curves are relatively broader to that obtained at 1 KHz using forward masking; indicative of broader filters at high frequencies. Narrower tuning curves were obtained for MS group, and in NM group broadest tuning curves were noted suggestive of relatively poor spectral resolution in non-musicians compared to musicians.



Graph 4.3**:** Psychophysical tuning curves obtained for three groups at 1 KHz using simultaneous masking paradigm.

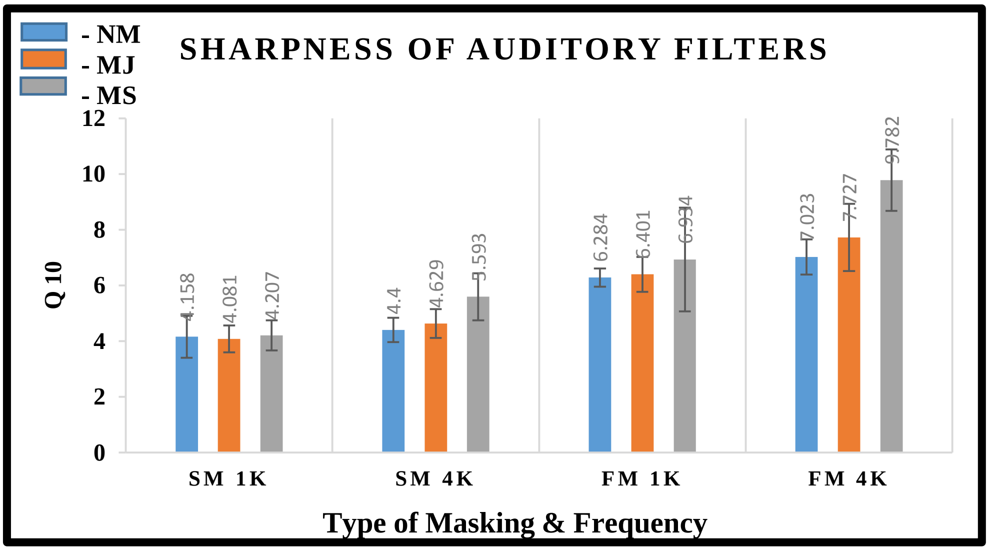
It could be inferred from the above graph (4.3.) that, tip of the tuning curves obtained under simultaneous masking condition is relatively broader compared to that obtained under forward masking. Similar performance was noted in all three groups.



Graph 4.4**:** Psychophysical tuning curves obtained for three groups at 4 KHz using simultaneous masking paradigm.

Tuning curves obtained in the above condition was broader compared to that obtained at 4 KHz using forward masking. Narrower tuning curves were obtained in MS group as level of noise needed to mask the signal was higher. Broadest tuning curves were seen in NM group.

Q10 values used to quantify sharpness of auditory filter are shown for three groups in Graph 4.5. Q10 values are depicted for each group, obtained at 1 kHz and 4 kHz using forward and simultaneous masking paradigm. It can be seen that higher Q10 values were obtained on forward masking, relative to that of simultaneous masking. Better tuning was noted for all 3 groups at higher frequency (4 KHz) relative to low frequency (1 kHz). Higher Q10 values were obtained for musicians in comparison to non-musicians across all conditions.



Graph 4.5**:** Mean and SD of Q10 for three groups of participants.

Note: **SM1K**- simultaneous masking at 1 KHz, **SM 4K**- simultaneous masking at 4 KHz, **FM 1K**- forward masking at 1 KHz and **FM 4K**- forward masking at 4 KHz.

Mixed analysis of variance (MANOVA) conducted with probe frequency and type of masking as within subject variables and group as between subject variable revealed a significant main effect of probe frequency [*F*(1,27)=51.568.*p*<0.05], type of masking [*F*(1,27)=334.038. *p*<0.05] and group [*F*(2,27)=18.251. *p*<0.05].

Results also revealed significant interaction effect between probe frequency and type of masking [*F*(1,27)=8.429. *p*<0.05], probe frequency and group [*F*(2,27)=8.696. *p*<0.05] and type of masking and group [*F*(2,27)=4.228. *p*<0.05]. No significant interaction effect was noted for probe frequency, type of masking and population [*F*(2,27)=0.832. *p*>0.05].

Main effect of probe frequency indicates that tuning was better at high frequency (4 KHz) than at low frequency (1 KHz) whereas, main effect of type of making suggests that forward masking provides higher estimates of filter tuning.

Musicians had better tuning of filters as indicated by main effect of group. However, difference between the filter sharpness of non-musicians and musicians junior was not statistically significant (p>0.05), whereas musicians senior group's estimate of filter sharpness was significantly higher than other two groups (p<0.05).

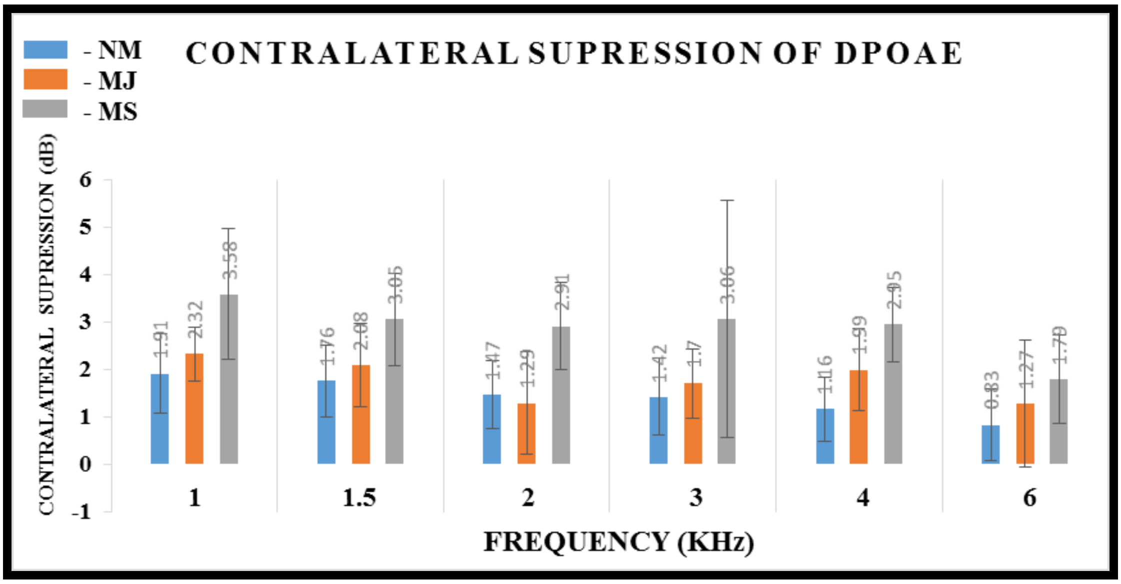
Given the interaction between probe frequency and type of masking, *post hoc* Bonferroni test was administered to further investigate type of masking difference at each probe frequencies. Results revealed that, pooled across all participants, Q10 values were higher obtained using forward masking and the difference was pronounced at higher frequency (4 KHz).

Group differences were investigated at each probe frequency using Bonferroni post hoc test as there was interaction between effect of probe frequency and group. Results revealed that both groups of musicians had higher Q10 values compared to non-musician group (higher Q10 values for senior musicians followed by junior musician and non-musicians) and the difference between the groups were pronounced at 4KHz.

As there was interaction between type of masking and group, Bonferroni post hoc analysis was carried out and the results revealed that, senior musicians had higher Q10 values compared to junior musicians and non-musicians and the difference among the group was greater under forward masking condition.

4.2. Effect of musical proficiency on contralateral suppression of DPOAEs

Mean and standard deviation of contralateral suppression of DPOAEs across frequencies obtained from the 3 groups are shown in Graph 4.6. Pooled across listeners it can be seen that greater amount of suppression was obtained at lower frequencies (1 KHz & 1.5 KHz). Similar amount of suppression was noted across 2 KHz, 3 KHz and 4 KHz which was relatively less compared to that obtained at lower frequencies. Least amount of suppression was noted at 6 KHz.



Graph 4.6: Mean and SD of contralateral suppression of DPOAEs for three groups of participants

Note: **NM-** non-musician, **MJ-** musician junior and **MS-** musician senior

It could be noted from the above graph 4.6 that, greater amount of suppression was noted at low frequencies and amount of suppression was comparatively lesser at high frequencies. Greater amount of suppression was seen in musician group and so was the amount of variation.

A repeated measure of variance (ANOVA) conducted with frequencies as within subject variable and group as between subject variable revealed a significant effect of frequency [$F(5,135)=5.608$. $p<0.05$] and group [$F(1,27)=34.35$. $p<0.05$] with no interaction [$F(10,27)=0.947$. $p>0.05$].

The simple main effect of frequency suggests that greater amount of suppression was obtained at low frequencies 1 KHz & 1.5 KHz. Amount of suppression at mid-high (2 KHz, 3 KHz & 4 KHz) were comparatively lesser. Least amount of suppression was noted at 6 KHz. Main effect of group suggests that greater amount of suppression was noted in group of musicians with senior musicians having greater suppression followed by junior musicians and non-musicians. However, difference in amount of suppression between non-musicians and musicians junior was not statistically significant ($p>0.05$), whereas, amount of suppression was significantly higher ($p<0.05$) in musicians senior when compared to other two groups.

Correlational analysis was carried out using *Pearson correlation* to find out whether an individuals' degree of contralateral suppression predicted sharpness of their auditory filter. Results are represented in Table 3 and 4. It revealed that amount of contralateral suppression of DPOAEs were positively correlated to Q10 values at 4 KHz obtained under simultaneous masking condition for non-musicians, $r=0.713$, $p<0.05$, junior musicians, $r=0.680$, $p<0.05$ and for senior musicians. The degree of correlation was highly significant for senior musicians, $r=0.837$, $p<0.05$.

Table 4.1. *Results of correlation analysis for contralateral suppression at 1 KHz with simultaneous masking at 1 KHz and forward masking at 1 KHz.*

		SM-1 KHz			NSM-1 KHz		
		NM	MJ	MS	NM	MJ	MS
CS-1 KHz	Pearson correlation (*r*)	0.348	0.264	0.619	0.517	0.290	0.192
	p value	0.324	0.460	0.56	0.126	0.417	0.496

It could be inferred from the above table 4.1. that, the correlation between degree of contralateral suppression at 1 KHz and Q10 values obtained at 1 KHz under forward and simultaneous masking paradigm is weak; and greater contralateral suppression at 1 KHz need not indicate higher Q10 values in any masking condition.

Table 4.2. *Results of correlation analysis for contralateral suppression at 4 KHz with simultaneous masking at 4 KHz and forward masking at 4 KHz.*

		SM-4 KHz			NSM-4 KHz		
		NM	MJ	MS	NM	MJ	MS
CS-4 KHz	Pearson correlation (*r*)	0.713*	0.680*	0.837*	0.206	0.555	0.050
	p value	0.021	0.030	0.003	0.568	0.096	0.890

Note: Significant difference * $p < 0.05$

Results from above table 4.2. suggests that, there exists a correlation between amount of contralateral suppression at 4 KHz and sharpness of tuning curves at 4 KHz obtained using nonsimultaneous masking; implying that greater amount of suppression is generally indicative of sharper tuning curve. However, this correlation was not found for Q10 values obtained under forward masking paradigm.

Chapter 5

Discussion

Greater spectral acuity has been seen in musicians where a large number of empirical studies have shown enhanced pitch (Spiegebl & Watson, 1984; Kishon-Rabin et al., 2001; Schroger et al., 2005; Micheyl et al., 2006; Strait et al., 2010) and timber discrimination (Bidelman & Krishnan, 2010; Chartrand & Belin, 2006). Enhanced spectral acuity in musicians suggests that musical training might improve the selectivity of the auditory filters. Although it had been postulated by Soderquist (1970) as musicians to be having narrower auditory filters compared to naïve listeners, it was empirically validated only by Bidelman et al. (2014). By estimating the sharpness of auditory filters, results of the present study provide evidence for enhanced cochlear tuning in musicians.

In the present study, PTCs were obtained under simultaneous masking and forward masking paradigm. Pooling the result across participants, it was noted that sharper tuning curves were obtained using forward masking paradigm. Tuning curves estimated under simultaneous masking condition were relatively broader as suppression plays a major role in this condition (Moore, 1978; Oxenhan & Shera, 2003). This is consistent with findings of previous psychoacoustic studies (Moore, 1978; Oxenhan & Shera, 2003; Bidelman et al., 2014). However, greater tuning of auditory filters in musicians obtained under both types of masking paradigm is indicative of increased selectivity of peripheral auditory filters even in presence of cochlear nonlinearities like suppression.

In the current study, sharpness of tuning curves were measured as a function of musical proficiency. It was found that, as musical proficiency increases, greater is the selectivity of the auditory filters. Sharper tuning curves were noted in senior musicians followed by juniors and non-musicians. Similar findings were reported by Bidelman et al. (2014) that the sharpness of tuning curves in musicians and naïve listeners. Sharpness of tuning curves estimated in musicians were larger compared to non-musicians and the sharpness of tuning curves increased with duration of musical training. As in the present the senior musicians had greater sharpness followed by junior musicians and non-musicians; it could be attributed to longer duration of musical training in seniors and their greater proficiency in exploiting spectral cues. These results are consistent with the notion that musical training improves peripheral filtering at the level of cochlea and increases peripheral spectral resolution in an experience dependent manner (Bidelman, Hutka & Moreno, 2013).

It was noted that, although musicians obtained sharper tuning curves across frequencies and masking conditions, the group differences was more pronounced for PTCs obtained at higher frequency (4 KHz). Similar findings were reported by Bidelman et al. (2014). Micheyl & Collet (1995) and Perrot et al. (1999) reports enhanced activity of medial olivocochlear (MOC) system in musicians. From the neuroanatomical studies it could be noted that greater density of MOC fiber innervates at basal part of the cochlea (Liberman, Dodds & Pierce, 1999). Hence, the modulatory gain given by these fibers would be great at basal region of cochlea leading to better resolution at 4 KHz (Guinan, 2006). Musician’s greater performance in perceiving changes in spectral timbre and speech perception in degraded situations which relies on high frequency spectral coding (Amos & Humes, 2007) could be attributed to their sharper tuning curves at high frequencies.

Findings in the present study demonstrates greater amount of contralateral suppression in musicians. The results are comparable to those reported by earlier researches on musicians (Micheyl & Collet, 1995; Micheyl et al., 1997; Perrot et al., 1999). Greater suppression in musician group could be attributed to training related enhancement of MOCS activity in musicians. Exposure to moderate loud music sounds may serve as a sound conditioning stimulus and thereby strengthen central auditory pathway which in turn exerts its effect on olivocochlear pathway (Brashears et al., 2003).

However, it was noted that, amount of reduction in DPOAE amplitude in presence of noise was greatest for low frequencies (1 KHz-2 KHz) and least for high frequencies (beyond 4 KHz). Results are comparable to those reported by Collet et al. (1994), where larger amount of suppression was noted at 1 KHz and 2 KHz and the amount of suppression was very small for high frequencies.

It should be noted that greater amount of variability was seen in musicians group compared to non-musicians. This could be attributed to various factors like difference in the age at which musical training was started, difference in terms of musical format, listening biography and musical environment at home (Elbert, Pantev, Wienbruch, Rockstroh & Taub,1995; Margulis, Mlsna, L. Uppunda, Parrish & Wong, 2009; Schlaug, Jancke, Huang & Steinmetz, 1995).

From the above discussion we have seen that, modulatory activity of MOC and cochlear processing are strengthened by musical training. Evidences are provided from these studies for music related plasticity at auditory sensory processing’s initial stages which is mediated by strengthened top-down feedback to cochlea from the caudal brainstem.

The role of MOC fibers in humans is speculated to improve signal detection in noise by providing an antimasking effect (De Boer, Thornton & Krumbholz, 2012). By this, it could be accounted that greater MOC activity in musicians might provide greater antimasking at probe frequency and increasing the contrast with noise when both tone and noise presented together as in simultaneous masking paradigm, thus providing sharper estimates of filter tuning. This accounts for correlation between degree of contralateral suppression and sharpness of auditory filters obtained using simultaneous masking in musicians.

However, this correlation was noted only at high frequency (4 KHz). This could again be attributed to greater density of MOC fibers supplying basal portions of cochlea and greater modulatory gain provided in these regions (Liberman et al., 1999); hence greater would be the training related changes in the basal portions of the cochlea.

Thus it could be speculated that, strengthening of MOC activity by musical proficiency results in larger contralateral suppression and higher antimasking effect at signal frequency when noise and signal are presented together. However the correlation between contralateral suppression and simultaneous masking was not limited to musical group. The presence of this correlation in non-musicians as well could imply that generally, greater contralateral suppression would lead to sharper tuning curves derived using simultaneous masking, which could be innate in nature; and this degree of correlation would increase as the musical proficiency increases due to increased strength of MOC activity as seen in the results of present study where greater degree of correlation was seen in senior musician group.

Chapter 6

Summary and Conclusion

Peripheral filtering at the level of the cochlea influences the auditory spectral acuity. Auditory filter's bandwidth contributes to frequency resolution of the system and thereby, the perceptual acuity to detect changes in the spectral input. Greater spectral acuity has been seen in musicians where a large number of empirical studies have shown enhanced pitch and timber discrimination, and their greater ability to extract speech cues in adverse listening situations. It could be suggested that musical experience increases cochlear tuning leading to enhanced spectral sensitivity in musicians. Psychophysical tuning curves (PTCs) could be used to behaviorally estimate the sharpness of auditory filters.

Hence, the current study aimed at investigating the effect of musical proficiency on PTCs. Effect of musical training on contralateral suppression of OAEs was also investigated. 30 participants were divided into three equal groups (non-musician, junior musician & senior musician) based on their musical proficiency. PTCs were obtained using forward masking and simultaneous masking paradigm at 1 KHz and 4 KHz; and contralateral suppression of DPOAEs was carried out using white noise in opposite ear at 50dBSL.

Appropriate statistical analysis was carried out and the study revealed the following:

(i) Estimates of tuning curves were significantly sharper in senior musicians compared to junior musicians and non-musicians.

(ii) Significantly sharper tuning curves were obtained under forward masking condition for all the participants.

(iii) Tuning curves obtained at 4 KHz was significantly sharper compared to that obtained at 1 KHz.

(iv) Significantly greater amount of suppression of DPOAEs were noted in group of senior musicians.

(v) Significant positive correlation was noted between contralateral suppression at 4 KHz and simultaneous masking at 4 KHz. The degree of correlation was greater for senior musicians.

Results of the present study indicate that musical training strengthens the activity of medial olivocochlear bundles, which is reflected by increase in sharpness of auditory filters and greater suppression of OAEs. Increased filter sharpness indicates greater resolution of filters at peripheral level which could account for superior performance shown by musicians across various tasks in spectral domain.

Clinical implication of the study

As musical training strengthens the cortico-fugal top down control; it could be advised as one of the remedial programs for:

(i) Individuals having difficulty in perceiving speech in presence of noise.

(ii) Individuals with auditory processing disorders and in aging process.

Future direction

Group of musicians considered in the study was heterogeneous. Participants were classified solely based on their musical proficiency ignoring their style of music (vocal v/s instrumental) and the age at which musical training was started which could have brought about the greater variation seen in musicians. Studies could be carried out controlling these factors.

Future studies could be carried out to find out effect of different forms of music on PTCs and contralateral suppression.

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