Influence of musical proficiency on psychophysical tuning curves and contralateral suppression of DPOAEs

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Abstract

Musicians have enhanced pitch and timber discrimination, which helps to extract speech cues in adverse listening situations. It could be hypothesised 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 and on contralateral suppression of otoacoustic emissions (OAEs). Thirty participants were divided into three equal groups 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 at 50 dB SL. The results revealed, that the estimates of tuning curves were significantly sharper in senior musicians compared to junior musicians and non-musicians, significantly sharper tuning curves were obtained under forward masking condition for all the participant., The tuning curves obtained at 4 kHz was significantly sharper compared that obtained at 1 kHz, significantly greater amount of suppression of DPOAEs were noted in 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.

Key words: *Psychophysical tuning curves (PTCs), contralateral suppression of DPOAEs, musical proficiency, auditory filters.*

Introduction

The complex brain functions involving auditory memory, acoustic analysis and auditory scene analysis are reported to have direct relationship with musical training. 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 from (Trainor, 2015) 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.

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

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& 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, 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.

Enhanced MOC 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 results in improved frequency selectivity, empirical studies on behavioral estimation of 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. The present study aimed toinvestigate the influence of musical proficiency on psychophysical tuning curves and contralateral suppression of DPOAEs.

The objectives were *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 and also to investigate whether proficiency dependent effect of musicianship on cochlear processing acts differently along the cochlear partition.*

Method

Participants

Thirty young adolescents and adults in the age range of 15 to 35 (Mean: 23.7, 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.

Test Environment

All tests were carried out in an acoustically treated room where noise levels were within the permissible limits. (ANSI S3.1; 1999).

Instrumentation

A calibrated two channel Inventis Piano Plus audiometer coupled to impedance matched TDH 39 earphones housed with MX-41/ AR cushions and a bone vibrator

(Radio ear B-71) were used to carry out pure tone audiometry, speech audiometry and MLD testing. A calibrated two channel GSI Audio Star Pro audiometer was used to carry out Quick –SIN testing. A calibrated GSI Tympstar (Grason Stadler Inc.) middle ear analyzer was used for tympanometry and reflexometry. Otodynamics Ltd, ILO v6 was used for measuring DPOAEs. Contralateral noise was presented using calibrated two channel Inventis Piano Plus audiometer through insert receiver. A personal computer (Intel(R) core (TM) i3-3110M, 4GB RAM, 64 bit operating system) loaded with Psychon software (1.50 version) was used to obtain PTCs. 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 was routed through Sennheiser HDA 200 supra aural headphones.

Procedure

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

Pure tone and speech audiometry: Pure tone audiometry was carried out using modified Hughson and Westlake method (Carhart & Jerger, 1959) for obtaining air conduction thresholds at octave frequencies from 250 Hz- 8000 Hz using TDH 39 earphones and bone conduction thresholds for octave frequencies from 250 Hz- 4000 Hz using Radio ear B-71. Speech identification scores were obtained using phonemically balanced word list developed by Yathiraj and Vijayalakshmi (2005).

Immittance audiometry: Tympanometry was administered using 226 Hz probe tone and ipsilateral and contralateral reflexes were obtained at 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz to rule out the middle ear pathology.

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 20 dB SL 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, Q_{10} factor was measured and filter sharpness was quantified from PTCs. Q_{10} 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 Q_{10} 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.

Results

Data obtained inset for all conditions were tabulated. Descriptive and inferential statistics 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. Descriptive statistics was applied on the obtained data for all the parameters.

Effect of musical proficiency on psychophysical tuning curves

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. Q_{10} values were derived for each participant. Q_{10} values used to quantify sharpness of auditory filter are shown for three groups in Figure 1. Q_{10} 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 Q_{10} 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 Q_{10} values were obtained for musicians in comparison to non-musicians across all conditions.

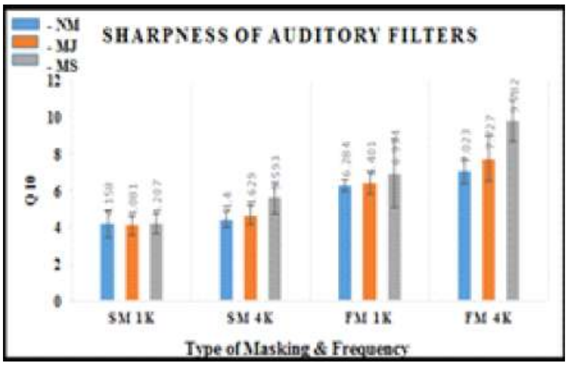

Figure 1: *Mean and standard deviation for Q_{10} for three groups of participants.*

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, Q_{10} 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 Q_{10} values compared to non-musician group (higher Q_{10} values for senior musicians followed by junior musician and non-musicians) and the difference between the groups were pronounced at 4 kHz.

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 Q_{10} values compared to junior musicians and non-musicians and the difference among the group was greater under forward masking condition.

Effect of musical proficiency on contralateral suppressionof DPOAEs

Mean and standard deviation of contralateral suppression of DPOAEs across frequencies obtained from the 3 groups are shown in Figure 2. 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.

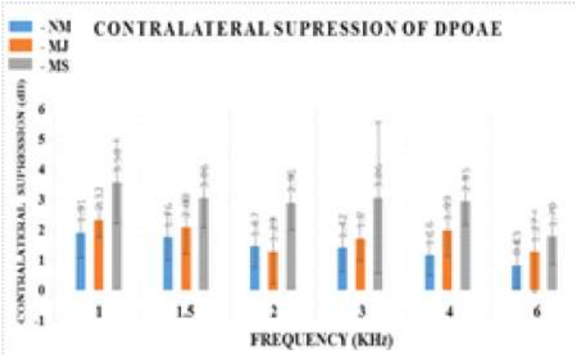

Figure 2: Mean and standard deviation for Q_{10} for three groups of participants.

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

It could be noted from the above figure 2, 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 1 and 2. It revealed that amount of contralateral suppression of DPOAEs were positively correlated to Q_{10} 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 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*)	0.3	0.2	0.6	0.5	0.2	0.19
	p value	0.3	0.4	0.5	0.1	0.4	0.4

It could be inferred from the above table 1 that, the correlation between degree of contralateral suppression at 1 kHz and Q_{10} values obtained at 1 kHz under forward and simultaneous masking paradigm is weak; and greater contralateral suppression at 1 KHz need not indicate higher Q_{10} values in any masking condition. Mixed ANOVA (Repeated measures ANOVA for comparison of frequency with participant group as between factor) was carried out. Mixed ANOVA revealed significant main effect of CAS frequency [$F(5, 140)= 11.751$, $p< 0.01$] and significant main effect of groups [$F(1, 28)= 96.477$, $p< 0.01$]. However, there was no interaction between the frequency and groups [$F(5, 140)= 0.664$, $p> 0.01$]. Hence pairwise comparison of mean suppression amplitudes across CAS frequencies were carried out. Results of the pairwise comparison are shown in the Table 2.

Table 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*)	0.7*	0.6*	0.8*	0.2	0.5	0.1
	p value	0.02	0.03	0.03	0.568	0.09	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 Q_{10} values obtained under forward masking paradigm.

Discussion

Greater spectral acuity has been seen in musicians where a large number of empirical studies have shown enhanced pitch (Spiegel & 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 naive 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.

Summary and conclusions

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.

Conclusion

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.

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