Effect of Music Exposure on Online Subcortical Plasticity

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Abstract

The present study aimed to investigate influence of music exposure on the online plasticity of auditory system. The online plasticity was documented using context-dependent changes of speech evoked brainstem responses, which in turn was compared across musicians, music listeners and, non-music listeners. Speech perception in noise was recorded as a behavioral index of online plasticity. The experimental data was collected on 30 normal hearing adults. The results showed that speech perception in noise was better in musicians than that in other two groups. Whereas online plasticity was similar in the three groups. The enhanced speech perception in noise in musicians has been attributed to the training related changes in the olivocohlear bundle. The music exposure however, did not influence the online plasticity. The findings of the study support that only the active task like singing or playing an instrument is advantageous for speech perception in noise.

Keywords: *Online plasticity, speech ABR, speech perception in noise, plasticity*

Introduction

Animal experiments and human behavioral and electrophysiological studies have shown that the auditory cortex shows changes in plasticity, i.e. it is capable of reorganization as a function of experience (Tremblay, Kraus, Carrell & McGee, 1997). The term 'neural plasticity' refers to the alterations in the physiological and anatomical properties of neurons in the brain in association with sensory stimulation or deprivation. Studies have shown that both long-term and short-term experience affects the functioning of the brain (Shinn-Cunningham, 2001; Tremblay et al., 1997; Russo, Nicol, Zecker, Hayes & Kraus, 2005; Wong, Skoe, Russo, Dees & Kraus, 2007; Madhok & Maruthy, 2010). Long-term plasticity refers to the reorganization of the physiological and anatomical properties of brain neurons secondary to the training done for several months or years. Similarly, the changes that are resultant of few hours or days of training are referred as short-term plasticity.

In the past, plasticity was believed to be a phenomenon observed only in cortical structures, while the later experiments have evidenced plasticity even in the subcortical structures (Krishnan, Xu, Gandour & Cariani, 2005; Musacchia, Sams, Skoe & Kraus, 2007; Russo et al., 2005; Madhok & Maruthy, 2010).

Researches by Chandrasekaran, Hornickel, Skoe, Nicol and Kraus (2009) and, Skoe and Kraus (2010) reported the presence of a new type of plasticity which is termed as online plasticity. According to their findings, repetitive presentation of the stimulus induces online plasticity within few hours which causes the automatic sharpening of brainstem representation of speech cues related to voice pitch. This repetition induced neural fine tuning is found to be strongly associated with perception of speech in noise, suggesting that this type of plasticity is indeed functional (Chandrasekaran et al., 2009).

Skoe and Kraus (2010) demonstrated that human subcortical activity evolves in response to repetition of entire melody and repetition of a note within the melody within the ongoing stimulus stream. They found a robust enhancement to the repeated note appearing to develop monotonically over the 1.5 hour session. It was proposed by the authors that the subcortical online plasticity results from the statistical enhancement of intrinsic circuitry interacting with top-down influences such as auditory memory, musical knowledge, expectation and/or grouping via the corticofugal pathway. Hanan and Maruthy (2011) observed the presence of online plasticity only for spectrally dissimilar contextual stimulus and not for spectrally similar context.

The speech elicited ABR represents the pitch encoding (F0 & its harmonics) at the level of brainstem (Wong et al., 2007; Musacchia et al., 2007). It is shown that the encoding of pitch associated with complex sounds is due to the role of the neural phase-locked activity related to F0 (Swaminathan, Krishnan, Gandour & Xu, 2008). Bidelman, Gandour and Krishnan (2010) showed that the auditory brainstem encodes pitch irrespective of the context. Their findings also suggest that the pitch encoding is better in musicians than non-musicians for the linguistically and musically relevant features. Wong et al. (2007) found that the pitch encoding is better in musician group. They found correlation of the effect of long-term music training on linguistic pitch encoding, at the brainstem level. Hence, it could be said that the experience leads to superior representation of the pitch in native speakers and musicians. Review of literature (Musacchia et al., 2007; Wong et al., 2007) reveals that the speech ABRs are enhanced in musicians when compared to non-musicians. Furthermore, it is reported by the researchers (Parbery-Clark Skoe & Kraus, 2009; Musacchia et al., 2007; Wong et al., 2007) that there is direct relationship between the number of years of music training and the robustness of brainstem

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responses obtained, with the response being better with more years of practice.

In the real listening situations, it is very common to come across noisy situation. Thus, it becomes essential to understand the involvement of brainstem in the perception of speech in the presence of noise. Kumar and Vanaja (2004) suggested that the efferent auditory pathway plays an important role in the perception of speech in the presence of noise. Parbery-Clark et al. (2009) reported that if the brainstem responses evoked for speech in the presence of noise have early latencies, the HINT scores would also be good.

It is reported that the individuals with poor performance on HINT showed delayed latencies and lower magnitude for the formant transition in the presence of noise (Anderson, Skoe, Chandrasekaran & Kraus, 2010; Anderson, Skoe, Chandrasekaran, Zecker & Kraus, 2010). The poor temporal resolution at the brainstem is attributed to be the cause of the behavioral findings. Thus, speech ABR can be an electrophysiological index of deficits in speech perception in noise. The correlation between speech ABR and SPIN is an evidence for the role of brainstem in the SPIN.

Musicians are found to have enhanced spectral and temporal representation of the stimulus at the subcortical level. This enhancement is attributed to the presence of active top-down mechanisms, such as attention, memory, and context (Kraus, Skoe, Parebery-Clark & Ashley, 2009). Thus, based on the knowledge about these mechanisms and research support, it could be assumed that the auditory system, apart from showing long-term and short term plasticity, also shows plasticity for the stimulus presented for a very short duration known as online plasticity. Earlier, many studies have documented the longterm and short-term neuroplastic changes in musicians. However, there is a dearth of literature on the *online plasticity* in musicians. Considering that their corticofugal pathway in trained for duration of their music training, one would expect that the online plasticity is better in musicians. Furthermore, it is not clear in the previous studies whether the training related changes seen in musicians is due to formal practice of vocal or instrumental music which is an active task or, due to listening to music on a regular basis which is relatively a passive task. Therefore, to answer these questions, the present study was taken up. There were two specific objectives of the study that is to compare the online plasticity among musicians, music listeners and control individuals on an electrophysiological paradigm and, to compare the relationship between online plasticity and speech perception in noise.

Method

The present study was initiated with null hypotheses that there is no significant difference between the online plasticity among musicians, music listeners and non-music listeners. The following method was used to test the null hypothesis.

Participants

A total of 30 normal hearing (peripheral & central) adults, in the age range of 18 to 30 years participated in the present study. They were divided into three groups based on their music experience. Each group consisted of 10 participants. Group I consisted of participants who never received any formal music training and did not have the habit of listening to music on a regular basis. This group served as a control group. Group II had participants who had never received any formal music training, but would listen to music (either vocal or instrumental) at least for one hour a day and 5 days a week since last 5 years, at least. Group III had participants who had received formal music training for minimum of 5 years. The participants in this group had received either instrumental or vocal music training, and had been practicing the same everyday at least for an hour. These participants would also listen to music at least for an hour each day.

A checklist developed to profile their audiological status, and exposure in music, was administered prior to the actual testing. The interested readers can refer to the complete dissertation submitted to University of Mysore. Based on the responses obtained using this checklist, the groups were subdivided. A written consent was taken from all the participants before carrying out any of the tests.

Test Stimulus

The experimental procedure required presentation of two types of stimulus: context stimuli and a core stimulus. The contextual stimuli occurred more frequently than the core stimulus. The core stimulus was operationally termed so, as only the responses obtained for this particular stimulus was of interest in data analysis. The three stimuli used were, synthetically generated /da/, f2 filtered /da/, and the white noise. The /da/ stimulus was originally synthesized in Auditory Neuroscience lab, Northwestern University, Chicago by Professor Nina Kraus, Principal investigator, Auditory Neuroscience lab, Northwestern University, Chicago. The same stimulus was used in the present study with the consent of Prof. Kraus. The white noise of 40 ms duration was generated at Psychoacoustic Lab, All India Institute of Speech and Hearing, Mysore, using Adobe Audition (version 1.5) software.

All the three stimuli were individually normalized and then group normalized to obtain equal average RMS power of 93.4 dBSPL, using MATLAB software. They were then loaded into the personal computer with Bio-Logic Navigator Pro AEP Software (Version 7.0). The

Table 1: Mean behavioral thresholds in (dBSPL) of the synthetically generated syllables /da/, F2 filtered /da/ and, the white noise

Stimulus	Mean behavioral thresh-old(dBSPL)	Approximated mean behavioral thresh-olds(dBSPL)
Synthetically generated /da/	27.71	30
F2 filtered /da/	28.82	30
White noise	31.14	30

synthetic speech syllables /da/, and the filtered /da/ were subjected to a subjective rating of quality judgment from 15 sophisticated listeners with normal hearing. This was done for the nHL calibration. To do so, all the three stimuli were presented at a repetition rate of 10.9/s through the insert receivers of the Bio-Logic Navigator Pro AEP system. The mean behavioral thresholds obtained were as given in Table 1.

All tests were administered in acoustically treated rooms with noise levels at permissible limits (ANSI S3.1, 1991).

Test Procedure

Only the participants who fulfilled the inclusion criteria were subjected to the actual test procedure. The preliminary testing included pure tone audiometry, immittance evaluation, speech perception in noise (SPIN) test and auditory brainstem responses (ABR). The actual experimental paradigm involved recording of Speech perception in noise and speech evoked brainstem responses.

In the experimental testing, SPIN and speech evoked ABR were recorded. SPIN was assessed using the standardized English sentence speech stimuli developed by Thakur and Kumar (2008). Multi talker babble was used as the background noise, during the test administration. Target sentences were presented at 40dBHL. Speech to noise ratio (SNR) required to understand 50% of the words in sentences (SNR-50), was estimated. Level of the multi-talker babble was varied in 2dB steps using adaptive staircase procedure to yield 50% correct response. SNR was made adverse when the subject repeated all the key words in a sentence. Target sentences and noise were presented monaurally in the right ear only.

Speech evoked ABR was recorded in three different stimulus conditions. The target responses were recorded using vertex (non- inverting) and nape (inverting) while the baseline activity was recorded with ground on the left ear mastoid. The experiment involved presentation of stimuli in two stimulus paradigm that is, repetitive and odd ball paradigm. The stimulus used in the repetitive paradigm was synthetically generated /da/ stimulus, for which two recordings of 1500 sweeps each were done. This was done for establishing baseline for responses obtained in the contextual condition. In the odd ball paradigm, a core (infrequent) stimulus was presented in the presence of a contextual (frequent) stimulus. The synthetically generated /da/ was the core stimulus and was presented with the probability of 25%, against 75% for the frequent stimuli which was either white noise (in condition 2) or F2 filtered /da/ (in condition 3).

Response Analysis

The resultant averaged waveform had both transient and sustained components in it. The responses were analyzed subjectively as well as objectively. The transient responses were analyzed subjectively by two experienced audiologists to mark peak V, A, and C. The peak latency and amplitude were noted down at marked points. Marking of the peaks in a representative averaged waveform is shown in Figure 1.

Additionally, objective analysis was done for evaluating the spectral composition of sustained portions of the response using Fast Fourier transform (FFT). This was done using the MATLAB R 2009a platform and software (Brainstem toolbox) developed by Kraus (2004) at Northwestern University. Fourier analysis was performed on the 11.4 to 40.6 ms epoch of the FFR in order to assess the amount of activity occurring over three frequency ranges; (103-121Hz), (454-719Hz) and (721- 1155Hz). These frequency ranges were chosen because the neural responses at these frequencies correspond to the Fundamental frequency, first formant and higher harmonics of the stimulus /da/ respectively (Johnson et al., 2008). A 2 ms on 2 ms off Hanning ramp was applied to the waveform (to avoid the spectral splatter). Zero-padding was employed to increase the number of frequency points where spectral estimates were obtained. The raw amplitude value of the F0, F1 and higher frequency (HF) component of the FFR were then measured and noted. The FFR response in a representative spectrum is shown in Figure 2.

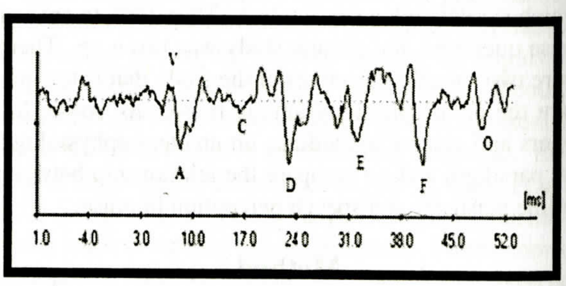

Figure 1: Representation of the marking of the peaks in a representative averaged waveform.

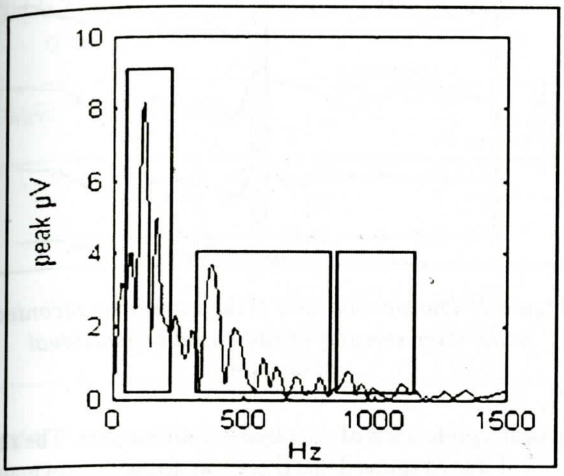

Figure 2: Representation of FFR responses in a representative spectrum.

Results

The mean latency and amplitudes derived were statistically compared to test the effect of condition and, group. The individual data of brainstem responses were also correlated with the respective speech perception in noise performance to understand the relationship between the two variables. All the statistical tests were performed using Statistical Package for Social Science software (version 16.0).

The percentage of occurrences of V, A, and C peaks among the participants of the three groups, in the three stimulus conditions is given in Table 2.

As evident from Table 2, the wave V and A were present in 100% of the participants in all three stimulus conditions, whereas this was not the casewith wave C. The absence of the peak was noticed for different conditions in different individuals, which reduced the actual number of data in Analysis of Variance (ANOVA). It was due to this reason that peak C was not included for the comparisons among the various conditions and groups.

Table 2: The percentage of occurrence of wave V, A and C among the participants of three groups, in the three stimulus conditions.

Group	Condition	Transient waves (in %)		
		V	A	C
NML	1	100	100	100
	2	100	100	100
	3	100	100	90
ML	1	100	100	80
	2	100	100	80
	3	100	100	80
MC	1	100	100	100
	2	100	100	100
	3	100	100	100

Table 3: The mean and standard deviation (SD) of peak latency (ms) of wave V, A, and C in the three stimulus conditions, for the three groups

Wave	Group	Condition 1	Condition 2	Condition 3
		Mean in ms (SD)	Mean in ms (SD)	Mean in ms (SD)
V	NML	7.49 (0.62)	7.79 (0.60)	7.78 (0.59)
	ML	7.36 (0.45)	7.66 (0.44)	7.69 (0.50)
	MC	7.23 (0.30)	7.39 (0.30)	7.33 (0.25)
A	NML	8.47 (0.64)	8.78 (0.55)	8.95 (0.58)
	ML	8.37 (0.54)	8.61 (0.50)	8.49 (0.56)
	MC	8.25 (0.37)	8.42 (0.36)	8.55 (0.38)
C	NML	17.51 (0.87)	17.81 (0.89)	17.73 (0.65)
	ML	17.64 (1.12)	17.72 (1.42)	17.91 (1.20)
	MC	16.96 (1.55)	17.27 (1.74)	17.04 (2.19)

Effect of Condition on Transient Responses

The mean and standard deviations of latency of transient responses were estimated among the three stimulus conditions (one repetitive paradigm & two oddball paradigms), using descriptive statistics. The data is as given in Table 3.

The data in Table 3, shows that the mean latencies were prolonged in condition 2 and condition 3 compared to that in condition 1. This is true for wave V, A, and C. To verify whether the observed mean differences in wave V and A are significantly different across the three stimulus conditions, repeated measure ANOVA was done taking group as between-subject variable. The results (Table 4) showed significant main effect of stimulus condition on the latency of wave V and, A. There was no significant interaction between condition and group.

Because there was significant main effect of stimulus condition on wave V and A, pair-wise comparison was

Table 4: The results of repeated measure ANOVA for wave V, and A latencies

Wave	Effect of condition		Condition X Group	
	F	df(error)	F	df(error)
V	36.18*	2 (54)	2.34	4 (54)
A	12. 83*	2 (54)	1.77	4 (54)

*Note: * - p<0.01*

Table 5: The mean and standard deviation (SD) of peak amplitude (μV) across three stimulus conditions for three participant groups

Wave	Group	Condition 1	Condition 2	Condition 3
		Mean in μV (SD)	Mean in μV (SD)	Mean in μV (SD)
V	NML	0.17 (0.05)	0.10 (0.08)	0.13 (0.05)
	ML	0.15 (0.06)	0.13 (0.06)	0.13 (0.07)
	MC	0.15 (0.06)	0.14 (0.05)	0.12 (0.12)
A	NML	-0.13 (0.06)	-0.14 (0.07)	-0.12 (0.07)
	ML	-0.17 (0.06)	-0.14 (0.05)	-0.14 (0.07)
	MC	-0.19 (0.07)	-0.14 (0.08)	-0.21 (0.09)
C	NML	-0.23 (0.29)	-0.23 (0.29)	-0.16 (0.09)
	ML	-0.07 (0.02)	-0.09 (0.04)	-0.07 (0.04)
	MC	-0.25 (0.31)	-0.29 (0.50)	-0.20 (0.35)

Note:The waves A and C were recorded in the negative polarity and hence, the peak amplitude have a negative sign

Table 6: The results of repeated measure ANOVA for wave V and A amplitude

Wave	Effect of condition		Condition X Group	
	F	df(error)	F	df(error)
V	2.61	2 (54)	0.94	4 (54)
A	1.57	2 (54)	2.36	4 (54)

done using Bonferroni Post-hoc test. The results of the Post-hoc analysis demonstrated that the mean latencies were significantly prolonged in condition 2 and 3 compared to condition 1. There was no significant difference between condition 2 and 3, in their mean latencies. This was true for wave V as well as wave A. The representative waveform showing transient response comparison in three stimulus conditions is shown in Figure 3.

Descriptive statistics was done to obtain mean and standard deviation of peak amplitude in the three stimulus conditions (Table 5). Although mean amplitude differ across three stimulus conditions, there was no definable trend in the way mean amplitude of wave A varied among the three stimulus conditions. The peak amplitude was higher for stimulus condition 1 than that in condition 2 and 3 for wave V. The mean amplitude of wave V and A were compared across the three conditions using repeated measure ANOVA to verify the statistical significance of the observed differences. The results (Table 6) showed that there was no significant main effect of condition on amplitude of transient responses. Also, there was no significant interaction between group and condition.

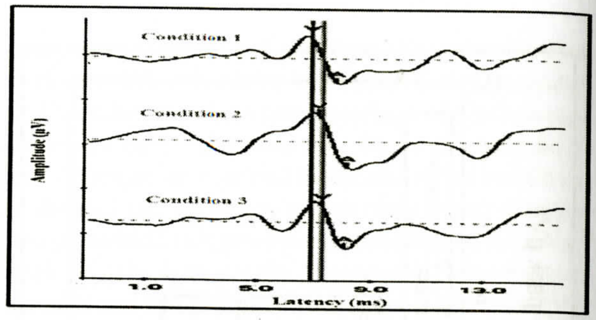

Figure 3: Transient portion of the waveforms recorded in the three stimulus conditions in an individual participant.

Effect of Condition on Sustained Responses

The peak amplitude at the frequencies corresponding to fundamental frequency (F0), first formant (F1) and, high frequency region (HF) of the stimuli was obtained from the FFT analysis (Figure 3). As apparent from Table 7, there is no general trend of the peak amplitude across the three stimulus conditions. The significance of difference in the mean amplitudes of F0, F1 and, HF was tested using repeated measure ANOVA taking group as a between-subject variable. The mean differences were however found to be statistically insignificant for F0 [$F (2, 54) = 0.302$, $p > 0.05$], F1 [$F (2, 54) = 0.103$, $p > 0.05$] and, HF [$F (2, 54) = 1.069$, $p > 0.05$].

Effect of Group on Speech Perception in Noise

The mean and standard deviation of the SNR-50 was obtained for the three groups. The results are shown in Figure 4. As seen in the figure, SNR-50 was lowest (better) for the musician group followed by music listeners and non music listeners. The mean differences among the three groups were compared on one-way ANOVA

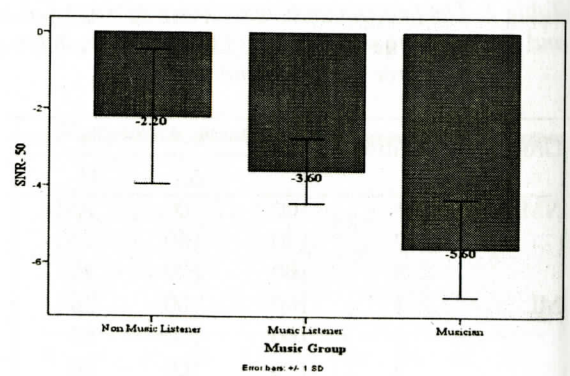

Figure 4: Graphical representation of the mean and standard deviation (SD) of SPIN in the three participant groups.

Table 7: The results of one-way ANOVA showing the effect of groups on latency of wave V and A

Wave	Condition	Effect of Group	
		F	df (error)
V	1	0.70	2 (27)
	2	1.94	2 (27)
	3	2.52	2 (27)
A	1	0.47	2 (27)
	2	0.26	2 (27)
	3	2.37	2 (27)

Table 8: The results of one-way ANOVA showing the effect of groups on amplitude of wave V and, A

Wave	Condition	Effect of Group	
		F	df (error)
V	1	0.51	2 (27)
	2	0.99	2 (27)
	3	0.08	2 (27)
A	1	2.34	2 (27)
	2	0.01	2 (27)
	3	3.48	2 (27)

taking group as an independent variable. The results revealed that there was significant main effect of group on SNR-50 [F (2, 27) = 16.289, p = 0.000]. Consequently, pair- wise comparison was done on Bonferroni post-hoc test. The results showed that the musician group had significantly better (lower) SNR-50 compared to the other two groups. There was no significant difference between mean SNR-50 of music listeners and non music listeners.

Effect of Group on Speech Evoked Brainstem Responses

When compared among the three participant groups, for wave V and A, musicians showed shorter latencies than music listeners, which in turn were shorter than the non music listener group. The mean amplitude of wave A was higher for the musician group compared to the other two groups. However, no such trend was seen in the mean amplitudes of wave V. To derive the group effect, the mean data were compared across the three groups on one-way ANOVA. This was done separately for each stimulus condition. The results of ANOVA (Table 7 & 8) showed that the group effect was absent on the latencies and amplitudes of transient response in all the three conditions.

The mean amplitudes of the F0, F1 and, HF (Table 9) were also compared across the three participant groups to study the effect of group on sustained responses. As evident from Table 9, mean was higher in musicians in contrast with music listeners and non music listeners for F0 and HF in condition 1, and F1 in all stimulus conditions. However, no such trend was seen for other responses. One-way ANOVA was done for the same and the results showed that the mean amplitude across the groups were not significantly different ($p > 0.05$). The F and degree of freedom (df) for each parameter in each condition are given in Table 10.

Effect of Group on Online Plasticity

The online plasticity was quantified by subtracting latencies and amplitude obtained in repetitive paradigm with that of latency and amplitude obtained in oddball paradigms using white noise. The resultant was termed as index of online plasticity. This was separately done for the data of each participant group. The mean and standard deviations of latency and amplitude index of online plasticity is given in Figure 5 and Figure 6, respectively. The mean results evidently show that these differences were smaller in musicians compared to non-musicians and, music listeners for amplitude index of online plasticity (except peak A). However, these differences were found to be statistically insignificant, on one-way ANOVA (Table 11).

The index of online plasticity was also computed by subtracting amplitude of sustained responses in repet-

Table 9: The mean and standard deviation (in parenthesis) of the amplitude (μV) of sustained responses across the three stimulus conditions for the three participant groups

Response	Group	Condition (μV)		
		1	2	3
		mean (SD)	mean (SD)	mean (SD)
F0	NML	5.61 (2.04)	5.42 (2.61)	6.73 (2.39)
	ML	5.49 (2.55)	6.47 (2.46)	5.83 (1.74)
	MC	6.98 (2.53)	5.48 (2.85)	6.11 (2.04)
F1	NML	0.66 (0.29)	0.65 (0.29)	0.70 (0.23)
	ML	0.65 (0.20)	0.64 (0.17)	0.67 (0.12)
	MC	0.88 (0.42)	0.87 (0.50)	0.79 (0.50)
HF	NML	0.30 (0.07)	0.32 (0.11)	0.34 (0.11)
	ML	0.31 (0.07)	0.29 (0.07)	0.31 (0.04)
	MC	0.34 (0.05)	0.31 (0.09)	0.33 (0.06)

Note: NML- Non Music Listener, ML- Music Listener, MC- Musician

Table 10: The results of one-way ANOVA showing the effect of group on FFR measures

Response	Condition	Effect of Group	
		F	df (error)
F0	1	1.20	2 (27)
	2	0.49	2 (27)
	3	0.49	2 (27)
F1	1	1.57	2 (27)
	2	1.37	2 (27)
	3	0.41	2 (27)
HF	1	1.17	2 (27)
	2	0.37	2 (27)
	3	0.39	2 (27)

Table 11: Results of one-way ANOVA showing the effect of group on online plasticity index

Measure	Wave	Effect of Group	
		F	df (error)
Latency	V	2.29	2 (27)
	A	0.64	2 (27)
Amplitude	V	1.85	2 (27)
	A	1.86	2 (27)

Table 12: The main effect of group for amplitude of FFR responses

FFR	Effect of Group	
	F	df (error)
F0	2.34	2 (27)
F1	0.01	2 (27)
HF	1.11	2 (27)

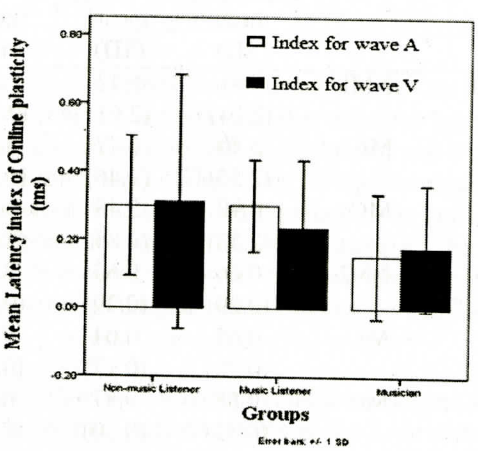

Figure 5: Graphical representation of the mean and standard deviation of online plasticity derived from latency of transient responses in the three participant groups.

itive paradigm from the odd-ball paradigm using white noise as context. The mean and standard deviations

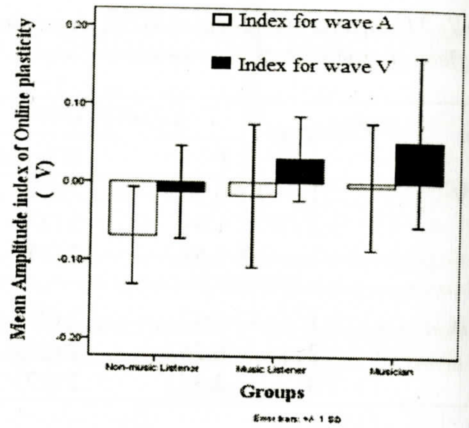

Figure 6: Graphical representation of the mean and standard deviation of online plasticity derived from amplitude of transient responses in the three participant groups.

are represented in Figure 7 (A to C). The mean amplitude differences of sustained responses were found to be consistently lower in musician group, when compared against non-music listener and, music listener group. One-way ANOVA however showed no significant variation in the amplitude values across groups ($p > 0.05$). The F and degree of freedom (df) for each parameter are given in Table 12.

Correlation of Music Training and SPIN

The analysis of group effect on SPIN showed that speech perception in noise in musicians was better compared to other two groups. Hence, it was of interest to study the relation between the years of training and SPIN scores. Figure 8 represent the scatter plot depicting the relation between SNR-50 and years of music training. The data of the two variables (SNR-50 &, years of training) in musician group were correlated using Pearson correlation. However, no correlation was found between the two variables ($r = -0.06$, $p > 0.05$).

Correlation between Online Plasticity and SPIN

The correlation between the SPIN performance and the index of online plasticity was established using Pearson correlation. The results showed that there was a positive moderate correlation between the SNR-50 and the wave V latency index of online plasticity ($r = 0.479$, $p < 0.01$). However, no correlation ($p > 0.05$) was found on the wave A latency index of online plasticity. This relation between online plasticity and SPIN is shown in Figure 9.

Discussion

Based on the knowledge about the mechanisms of training related neural plasticity and previous research reports, it is logical to assume that musicians have trained corticofugal pathway. The corticofugal pathway has been found to be moderating a newly proposed plas-

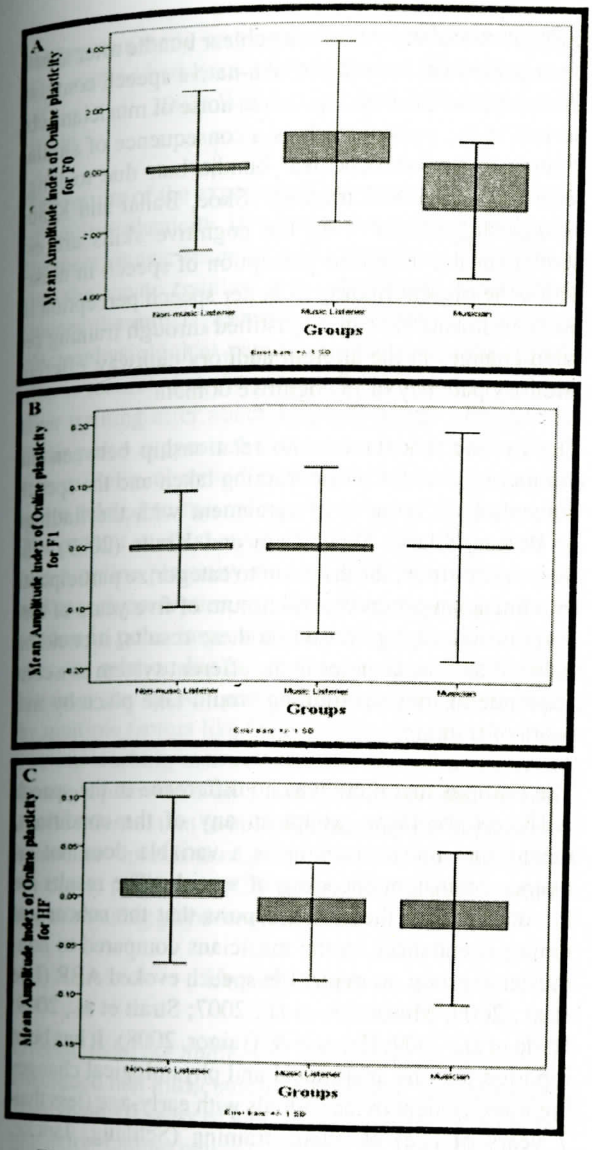

Figure 7: Graphical representation of mean and standard deviation (SD) of amplitude index of online plasticity for A) F0, B) F1, and C) HF across participant groups.

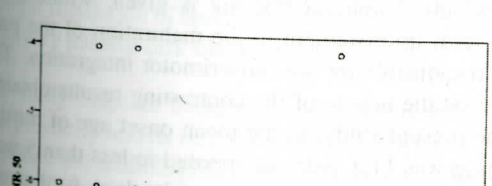

Figure 8: Relation between SNR-50 and years of music training.

ticity called online plasticity, which in turn is functional in enhancing speech perception in noise. In the present study, it was hypothesized that trained musicians have

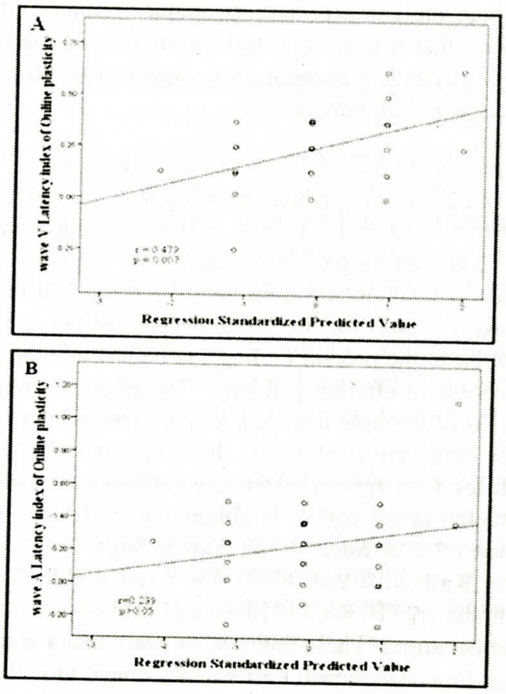

Figure 9: The correlation between Online plasticity and Speech perception in noise A) wave V latency and B) wave A latency.

better online plasticity and speech perception in noise compared to non-musicians. To further understand its mechanisms the online plasticity was compared among non-music listeners, music listeners and, musicians.

The wave C was identifiable in 100% of the musicians, which was not true for non-musicians (NMLs & MLs). Earlier studies have shown on electrophysiological studies that the encoding of speech is better among musicians when compared to age matched non-musician groups (Kraus, Skoe, Parbery-Clark & Ashley, 2010; Musacchia et al., 2007; Wong et al., 2007). These findings further strengthen the notion of neural synchrony being the determining factor for the occurrence of wave C. The lower occurrence of wave C in non-musician groups hence may be justified through reduced neural synchrony. The finding is also supported by the trend observed in the mean amplitude of wave C which was higher in musician group compared to non-musician groups.

The findings that the responses were better in the repetitive paradigm compared to that in the odd-ball paradigm is in consonance with the earlier findings (Chandrasekaran et al., 2009; Hanan & Maruthy, 2011). These are indicative of enhanced coding of the speech stimulus at the level of brainstem, when the stimulus is presented repetitively. This relative enhancement in the brainstem responses consequent to the repeating stimulus has been termed online plasticity (Chandrasekaran et al., 2009). As both the stimuli used as context (white noise & F2 filtered /da/) in the present study differed in the spectrum compared to the target /da/, the findings that both the contexts induced similar change further supports that it is the spectral difference that cues for context-dependent encoding and supports the inference of Hanan and Maruthy (2011).

The present finding of delayed transient responses in the contextual encoding is in contradiction to the earlier reports by Chandresekaran et al. (2009). Chandrasekaran et al. had seen a significant change only in the HF amplitude but not in the transient responses. Although the exact reason for the difference in the two studies is not clear, the present finding can be justified through the course of efferent pathway. The efferent pathway consists of multiple feedback loop system, which helps in the brainstem modulation. It is suggested that these feedback loop system selectively enhances relevant information in the signal, inhibiting the irrelevant information (Gao & Suga, 1998; Yan & Suga, 1998; Luo, Wang, Kashani & Yan, 2008). The result also duplicates the findings of Hanan and Maruthy (2011) who used the same paradigm. These findings are preliminary electrophysiological evidence for the corticofugal modulation of transient responses which may have implications for the perception of consonantal cues.

In Chandrasekaran et al. (2009), the context dependent effect on FFR was found at discreet intermediate frequencies (H2 & H4), while the effect was absent at F0, H3, H5 and H6. The absence of the context dependent effects in FFR in the present study may be because the analysis was over a wider range of frequencies (F0, F1, & HF), due to which the effect at some of the discreet frequencies might have got nullified.

The enhanced SPIN in musicians could be due to single or multiple underlying mechanisms (pertaining to afferent & efferent auditory pathway). The differences exist with respect to anatomical differences (Gaser & Schlaug, 2003; Ozturk, Tascioglu, Aktekin, Kurtoglu & Erden, 2002; Hyde et al, 2009; Bengtsson et al., 2005) and, enhanced encoding of spectral and temporal cues (Kraus & Chandrasekaran, 2010) in musicians when compared with non-musicians. The efferent pathway shows generation of the templates as a result of continuous representation of the ongoing stimulus (Haenschel, Vernon, Dwivedi, Gruzelier & Baldeweg, 2005; Strait, Kraus, Parbery-Clark & Ashley, 2010; Parbery-Clark, Strait & Kraus, 2011). These templates are especially essential for the exclusion of noise thus enhancing speech perception in noise (Chandrasekaran & Kraus, 2009). SPIN, in the past, also has been reported to be regulated by the OCB (Kumar & Vanaja, 2004). Deriving evidences from OCB studies (Micheyl, Khalfa, Perrot & Collet., 1997; Perrot, Micheyl, Khalfa & Collet, 1999; Ameen & Maruthy, 2011; Micheyl, Carbonnel & Collet, 2002) it could be concluded that the olivocochlear pathway is stronger in musician group compared to the non-musicians. Kumar, Hegde and Mayaleela (2010) provided evidence for changes in corticofugal modulation of olivocochlear bundle after short-term perceptual learning of non-native speech contrast. Probably, the enhanced speech in noise of musicians observed in the present study is a consequence of similar change in the olivocochlear bundle but, due to long-term formal musical training. Skoe, Banai and Kraus (2012) suggest that even the cognitive skills are essential for the improved perception of speech in noise. Thus, the present finding of better speech perception in noise in musicians can be justified through training related changes in the afferent auditory pathway, efferent auditory pathway or in cognitive domain.

The finding that there is no relationship between the number of years of music training taken and the speech perception in noise is in agreement with the findings of Parbery-Clark, Skoe, Lam and Kraus (2009). In the present study, the criterion to categorize participants into musician group was minimum of five years of formal music training. Based on these results, it could be inferred that the changes in the efferent system as a consequence of musical training would take place by five years of training.

The findings that there was no difference in the speech ABRs of the three groups in any of the conditions, means that music training as a variable does not influence brainstem encoding of speech. The results are in contrast with the earlier reports that the subcortical tuning is enhanced in the musicians compared to non-musician group, as evident in speech evoked ABR (Lee et al., 2009; Musacchia et al., 2007; Strait et al., 2009; Hyde et al., 2009; Hannon & Trainor, 2008). It has been reported that the anatomical and physiological changes are more evident in individuals with early-age (less than 7 years of age) of music training (Schlaug, Jancke, Huang, Staiger & Steinmetz, 1995; Pantev et al., 1998; Watanabe, Savion-Lemieux and Penhune, 2007). It was further concluded by Bailey and Penhune (2010) and, Penhune (2011) that there exist a sensitivity period, during which if musical training is given, would cause long-term improvement in the maturation of the pathway responsible for the sensorimotor integration. This could be the reason of the contrasting results obtained in the present study, as the mean onset age of musical training was 11;1 years as opposed to less than 5 years in other studies. The current results draw further support from the findings of Strait et al. (2009), where they reported that the musicians show distinct results from the non-musicians when compared with respect to the age of onset of music training or number of years of music training and, not when musicians with early-onset and late onset of training were grouped together.

The absence of group effect on FFT can also be attributed to the differences in methods of FFR analysis. In the previous studies the amplitude on FFT output (Lee et al., 2009; Musacchia et al., 2009) was measured at discreet frequencies. However, the analysis in the present study was over two ranges of frequencies. The method had been adopted from earlier publication (King et al., 2002; Wible et al., 2004; Werff & Burns, 2011).

The results of the experiment suggested that the amount of online plasticity is comparable among non-music listeners, music listeners and, musicians. This means that the music training or music listening did not influence the online plasticity as measured in the current electrophysiological paradigm. However, the conclusion is restricted to the group of musicians who started their training after about 11 years of age. Further, the finding also supports that the enhanced speech perception in noise observed in the musicians of this study is not related to the online plasticity of the brainstem. The present study showed a low positive correlation between online plasticity derived from wave V latencies and speech perception in noise. That means speech perception in noise improves with online plasticity. However, the relationship is not a strong one. This could be because; the speech perception in noise is determined by multiple factors like OCB functioning, binaural integration, working memory etc, and the influence of corticofugal pathway is only one of those factors. Hence, it can be inferred that to objectively study the correlates of behavioral speech perception in noise, one must study the online plasticity, OCB functioning, and binaural integration using physiological tests.

Conclusions

Overall, from the findings of the present study, it can be concluded that musicians who start their formal training after about 10 years of age do not have enhanced online plasticity. Online plasticity can be reliably documented using context-dependent encoding and is functional as it regulates speech perception in noise. The findings also demonstrated that only active tasks like singing and playing a musical instrument is advantageous for corticofugal regulation of speech perception in noise, not the relatively passive task like listening to music.

The study helps in understanding mechanisms of online plasticity and its role in speech perception in noise. It guides the audiologist in setting a protocol for evaluating context-dependent encoding of brainstem responses. It also guides clinical audiologists in the assessment of speech perception in noise and, understanding probable reasons for its deficits. Based on these findings audiologist can recommend music training to individuals with deficits in speech perception in noise.

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