EFFECT OF MUSIC EXPOSURE ON ONLINE SUBCORTICAL PLASTICITY

Mahima Gupta

Registration No: 10AUD019

A Dissertation Submitted in Part Fulfillment for the Degree of
Master of Science (Audiology)
University of Mysore, Mysore

ALL INDIA INSTITUTE OF SPEECH AND HEARING
MANASAGANGOTHRI, MYSORE – 570006
May 2012

CERTIFICATE

This is to certify that this dissertation entitled **'Effect of Music Exposure on Online Subcortical Plasticity'** is the bonafide work submitted in part fulfillment for the Degree of Master of Science (Audiology) of the student with Registration No. 10AUD019. This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysore
May, 2012

Dr. S.R. Savithri
Director
All India Institute of Speech and Hearing
Manasagangothri, Mysore-570006

CERTIFICATE

This is to certify that the dissertation entitled **‘Effect of Music Exposure on Online Subcortical Plasticity’** has been prepared under my supervision and guidance. It is also certified that this has not been submitted earlier in any other university for the award of any Diploma or Degree.

Mysore
May, 2012

Dr. Sandeep M.
Guide
Lecturer in Audiology
Department of Audiology
All India Institute of Speech and Hearing
Manasagangothri, Mysore-570006

DECLARATION

This is to certify that this Master's dissertation entitled **'Effect of Music Exposure on Online Subcortical Plasticity'** is the result of my own study under the guidance of Dr. Sandeep M., Lecturer in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysore, and has not been submitted in any other University for the award of any Diploma or Degree.

Mysore   Registration No. **10AUD019**
May, 2012

to everyone who
has taught me
something &
anything ☺

ACKNOWLEDGMENT

"The task of the excellent teacher is to stimulate 'apparently ordinary' people to unusual effort." - K. Patricia Cross.

I would like to express my gratitude to ***Dr. Sandeep M****. for being a wonderful teacher, and guide. Sir, you have always been the immense source of inspiration, knowledge, and encouragement. Thank you so much for your expert guidance and patience.*

I would like to extend my gratitude towards ***Dr. S. R. Savithri****, Director, All India Institute of Speech & Hearing, for permitting me to carry out this study.*

I would also like to thank ***Dr. P. Manjula****, and* ***Dr. Animesh Barman****, HOD Audiology for permitting me to use the department of Audiology for my study.*

I would like to thank ***Prof. Nina Kraus****, for providing and permitting me to use the stimulus and Brainstem toolbox for my study.*

I would also like to thank ***Dr. Ajith K. U.*** *for permitting me to use the stimulus.*

I would like to express my gratitude to ***Mr. Jinu Jacob****, M V Shetty College of Speech and Hearing, Mangalore for his timely help.*

Thank you ***Hemanth sir*** *for all your help.*

I would take this opportunity to thank ***Ganpathy sir****,* ***Hemanth sir, Arun sir, Antony sir,*** *and* ***Jithen sir,*** *people who would readily open the department for us on any day and any time we would request them to, so that we could finish our data collection on time.*

I would also like to acknowledge ***Nike sir****, to whom I always ran whenever I had trouble during study and he would always help me out with the same.*

A special thanx to ***Sujit sir,*** *for all his help throughout this study.*

Dakshyayni ma'am*, thank you for all the lovely times during the postings. You really are the heart of HE. ☺*

Thank you ***Ravi sir****, for giving CPR to my laptop each time it had cardiac arrest.*

Teacher's *at my school taught me how to write an 'a' and then 'audiology', the task was then taken over by the lecturer's at AIISH and they taught me that speech & hearing is not at all an alien language. Thank you, Rita Goswami ma'am, Sunil Saini sir, Savithri ma'am, Pushpa ma'am, Sreedevi ma'am, Sapna ma'am, Goswami sir, R. Manjula ma'am, Jayshree ma'am, Sangeetha ma'am, Gopishankar sir, Vasanthlakshmi ma'am, and Ajeesh sir. Also, thanx to Asha ma'am, P Manjula ma'am, Sandeep sir, Vijay sir, Animesh sir, Sujit sir, Niraj sir, Vinay sir, Sreeraj sir, Chandni ma'am, Geetha ma'am, Ajith sir, Kishore sir, Rajlakshmi ma'am, Mamatha ma'am, Devi ma'am, Praveen sir, Ramadevi ma'am, Revathi ma'am, Dhanalakshmi* *ma'am and Baba sir for teaching me abcd of Audiology and making it an interesting subject.*

This study would have never seen the day in binding press, if all those amazing people would have not cooperated with me, giving up their lunch time, movie time, sleeping time, library time and, endless other works they kept aside and became ***subjects*** *for my study. Thank you so much.*

It was only after presenting your case study for my clinical conference; I realized where my interest is, and what I want to do in the field. Thank you (my ***CC case*** *& family), and I pray to god that now you are in a much happier place than this mortal world.*

Even a kind word said when going through a nightmare means a lot, and what you gave me was more than kind words. I could never ask for the support that all of you gave me when life was throwing lemons, melons and all other kinds of fruits at me. Thank you so much, ***Roshni ma'am, Tanvi di, and Sharanya di.***

Shruti di, *love you for all the care, support and help. You were and always would be a good friend. And this is something that I would cherish forever.*

Thank you ***Sandeep sir and Deepa****. I never thought that making correction in the drafts could be this much fun and coffee-cious.*

If life was a box, people you know would be spices filled in it. So here I am, thanking all the spices aka ***Jas, Swathee, Nimmi, Vinsha, Pratibha, Anusha, and Arya (G n C). Laxme, Greeshma, Louisa, Rishitha, Nita, Shabnam, and Sweta*** *this journey would never have been this much fun without your company. Love all of you for all the trips, uno lessons, dinners, fights, 'square-walking', late night talks, gossips, sharing pain of boring classes, realizing 6 hours before the exam that we don't have majority of the drafts with us, late night coffee sessions etc etc etc, but most importantly for being there with me always. With you people around, the time just flew away (esp during tests, exams and when I had to do my presentations :D).*

Your friend is the person who knows all about you, and still likes you. And nobody would understand you better than the idiots you happen to know from the days when even a lost Tiffin box would bring tears to your eyes. Kudos to ***Gaurav, Piyush,*** *and* ***Kritika****. I would not say anything more than that, because I don't want you people to be sitting on Channe ka jhad after reading this.*

Thank you, ***Pooja*** *for being there for me, sharing all highs and lows of life.*

Sometimes we meet people with little realization that they could turn out to be the most important people in your life. Whatever I say, will never be enough, so would sum up by saying that, Love you ***Swagi****.*

Ishu, *don't know whether to thank you for being a friend or brother throughout. Words fail me here, but I hope you know that I value all the help and care that you show unconditionally.*

Thank you, all my dearest classmates especially ***Spoorthi, Giten, Deepthi, Deeps, Prasad, Prasanna, Vipin, Hemraj, Rhea, and Sahana*** *for making this journey* *an amazing and unforgettable experience.* ***Mythri*** *and* ***laxme****, thank you for being the best posting partners. I would also like to thank my amazing class, you all rock!!!*

I would also take this opportunity to thank all my seniors (especially ***Priya ma'am, Viji, Suchi ma'am, Meenakshi ma'am, Manasa ma'am, Priyanjali di, Prabhash sir, Ranjeet sir, Priyanka di, Rupali di, and Pallavi di****) for just being there. Sometimes we don't realize that a small gesture that we make, could mean a lot to others, and that's what you all did. Thank you for everything.*

I can never forget the amazing juniors I have. Though we disagreed on many things and I had seniority, I never told you that you are the loveliest bunch of people I have ever met. My loads of best wishes and love to ***Charu, Veena, Shrusti, Mitu, Praggi, Sindhu, Juhi, Dhananjay, Pavan, Saloomi, Tanvi, Rashika, Shruti and Jitu****.*

Sandhya, *I do not know what I would have done without your help. Though I felt guilty disturbing at that crucial time, but you always reassured me with a smile that it was not at all a problem. Thank you so much.*

It is very important when someone believes in you and shows the confidence in giving any responsibility to you. And if these people are your teachers, it means a world. Thank you, ***Sreeraj sir, Sandeep sir, Sreedevi ma'am*** *and,* ***Anjana ma'am****, to have that confidence in me and, to guide me through out. Also, thank you* ***Geetha ma'am, Suma di,*** *and* ***Yashomati di. Tanvi*** *and* ***Shreyank,*** *kudos to both of you for sharing all the responsibility with me and, making it all a remarkable experience. I would surely miss all the meetings, be it NSS, Hostel and most importantly mess meetings.* ☺

All my ***sisters and brothers****, you are best in whatever you do whether it is annoying me, blackmailing me, scolding me, caring for me, and fighting for or with me. Love you all (Sorry, running out of space to mention everybody's name here, and also in that case I would not have to worry about missing your names… ;)).*

I have saved the best for the last, though whatever I say for all of you would never be enough. My words would never be right, as love cannot be quantified and noted down on a piece of paper, but still it is human nature to try. Love you so much ***Papa*** *for having faith and confidence in me, to tell me that I have the potential even when I start doubting myself. You are the best father and role model.* ***Mommy****, you are just an ocean of love, care, strength, and wisdom. You really are the best friend, I could ever ask for.* ***Nanaji*** *&* ***Naniji, Mamaji's*** *&* ***Mamiji's****, for showering all your love, being the guide, mentor, and my friends. For teaching me right from wrong and always telling me that, "yes, you can to do it."* ***Amma*** *&* ***Babasaheb****, for always being there for me.*

And sorry if I have missed anybodies name here, but please consider my dementia and forgive me. Thank you so much.

P.S.: This acknowledgment would never be complete without thanking ***Mr. Page*** *and* ***Mr. Brin*** *who came up with the wonderful thing called Google…*☺ *Also, Davidoff and Bru, for ensuring that I stay awake to be able to write this acknowledgment.*

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1

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. Depending on the experience, mechanisms of plasticity can involve synaptic changes that occur rapidly or slowly over a longer period of time (Tremblay & Kraus, 2002). 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). Trainor (2005) reported that the plasticity is influenced by the extent of training done particularly in the early life.

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. Shinn-Cunningham (2001) reported that the long-term training alters the way spatial cues are integrated to form spatial percepts while short-term training appears to influence how these locations are mapped to spatial behaviors.

Although in the past plasticity was believed to be a phenomena observed only in cortical structures, recent experiments have evidenced plasticity even in the subcortical structures (Krishnan, Xu, Gandour, & Cariani, 2005; Musacchia, Sams, Skoe, & Kraus, 2007). Krishnan et al. (2005) measured the impact of long-term language experience on the frequency following response (FFR). They found that native Mandarin-speaking subjects with at least twenty years of Mandarin language exposure showed more precise linguistic pitch pattern encoding relative to native English-speaking subjects. Changes in plasticity secondary to training in music are seen not just for music stimuli but also for speech stimuli (Musacchia et al., 2007). Hannon and Trainor (2007) concluded that music training induces functional as well as structural changes in the subcortical and cortical level, apart from the improvement in cognitive domain.

Wong et al. (2007) also provided evidence for the positive effect of long-term music exposure on speech encoding at the brainstem. They found significant positive correlation between brainstem pitch tracking and formal music training. Song, Skoe, Banai, and Kraus (2011) documented a positive correlation between speech perception in noise and, neural encoding of F0 in the presence of noise. Parbery-Clark, Skoe, and Kraus (2009) on the other hand, showed that the perception of speech in the presence of noise is not correlated with the F0 representation at subcortical level. Lee, Skoe, Kraus, and Ashley (2009) found that the musicians have specialized sensory systems for processing fundamental frequency and harmonics. They also found that temporal envelope is more precisely represented in the subcortical responses of musicians. They support the notion that subcortical tuning is at least partially driven by top–down modulation of the corticofugal system.

Russo et al. (2005) evaluated effect of auditory speech discrimination training (for 8 weeks of 1 hour everyday) on brainstem responses. They found that the brainstem responses for periodic features of the stimulus in FFR are encoded precisely after training for shorter duration. Madhok and Maruthy (2010) also reported that the changes in brainstem responses could be observed within few weeks of training. Hence, it is clear from literature that the subcortical structures evidence both long and short term plasticity.

Recent researches by Chandrasekaran, Hornickel, Skoe, Nicol, and Kraus (2009) and, Skoe and Kraus (2010b) 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 (2010b) 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.

Speech perception in noise is considered as the behavioral measure of the efferent pathway functioning (Parbery-Clark, Skoe, & Kraus, 2009; Anderson, Skoe, Chandrasekaran, & Kraus, 2010; Anderson, Skoe, Chandrasekaran, Zecker, & Kraus, 2010). Studies of OCB functioning (Micheyl, Khalfa, Perrot, & Collet, 1997; Perrot, Micheyl, Khalfa, & Collet, 1999; Micheyl, Carbonnel, & Collet, 2002) and corticofugal pathway (Parbery-Clark, Skoe, Lam, & Kraus, 2009; Strait, Kraus, Parbery-Clark &, Ashley, 2010; Parbery-Clark, Strait, Anderson, Hittner, & Kraus, 2011; Anderson & Kraus, 2011; Parbery-Clark, Strait &, Kraus, 2011) have shown that the speech perception in noise was better in musicians compared to non-musicians. These differences are attributed to the training related changes in the efferent pathway of the musicians. However, the relationship between the online plasticity and speech perception in noise is not clearly established. Also, Ameen and Maruthy (2011) had related enhanced speech perception to the changes in OCB functioning. Hence, it is important to clarify whether the underlying mechanism of speech perception in noise is OCB or online plasticity. There is also no study comparing the speech perception in noise among music listeners and non-music listeners.

1.1 Justification for the Study

Using the electrophysiological results, it has been observed that the human auditory brainstem is sensitive to ongoing stimulus context and shows plastic changes (Chandrasekaran et al., 2009; Skoe & Kraus, 2010b). This online plasticity is attributed to the corticofugal pathway. Musicians possess a trained auditory system. In the process of music-training, the feedback mechanisms are actively used and in turn further trained. If corticofugal mechanism is to regulate the online plasticity, it is expected that musicians possess better online plasticity than the non musicians. To establish this relation between online plasticity and music training, a systematic scientific study was necessary.

Further, it was not clear from the literature whether the training of corticofugal modulation requires active training like in musicians or whether it can be trained with relatively passive task like music listening. A scientific study comparing the online plasticity among musicians, music listeners and control individuals could have thrown more light on the underlying mechanisms of online plasticity. Hence the present study was taken up with 2 objectives.

1.2 Objective of the Study

There were two specific objectives of the study;

1. To compare the online plasticity among musicians, music listeners and control individuals on an electrophysiological paradigm.
2. To compare the relationship between online plasticity and speech perception in noise.

Chapter 2

REVIEW OF LITERATURE

Evoked potentials represent electrical responses of the nervous system to externally presented stimuli. Auditory evoked potentials (AEP) refer to the time locked changes in EEG in response to a sound (Eggermont, 2007). Among the different type of AEPs, ABRs have been most useful for the clinical diagnosis. Although, they were first recorded by Sohmer and Feinmesser (1967), the description was given by Jewett and Williston in 1971.

ABR in its normal form has a series of five to seven, (wave I-VII) vertex-positive waves representing the passage of electrical activity evoked by auditory stimuli from cochlea to brainstem within the first 10 ms, and a slow negative-going deflection starting after wave V at about 6 ms (Levine et al., 1993; Morimoto & Sakabe, 2006). Studies have shown that the ABRs are generated as the result of neural activities from distal end of the eighth cranial nerve (wave I) to medial geniculate body (MGB) of thalamus (Moller & Jannetta, 1983; Martin, Pratt, & Schwegler, 1994; Starr, 1976; Parkkonen, Fujiki, & Ma'kela, 2009).

The underlying synchronous neural firing of ABR have been documented to be generated by the onset of the stimulus (Gorga, Beauchaine, Reiland, Worthington, & Javel, 1984), and the responses are relatively independent of duration (Smith, 1977, 1979; Harris, 1977; Harris & Dallos, 1979), provided the rise/fall time of the stimulus remains constant (Gorga et al., 1984). Increase in the rise/fall time of the stimulus results in increased latency and decreased amplitude of the responses in both adults and infants. Rise time greater than 5 ms has been shown to not generate a brainstem response (Folsom & Aurich, 1987).

Although clicks and tone bursts are commonly used for the elicitation of ABR, they are considered to be poor representatives of the behaviorally relevant sounds. As a result, the use of complex sounds to evoke brainstem responses is being gradually preferred over clicks and tones for clinical diagnosis of auditory disorders (Greenberg, 1980; Greenberg, Marsh, Brown, & Smith, 1987; Skoe & Kraus, 2010).

The purpose of the present study was to understand the underlying mechanism of music induced online plasticity on a speech ABR paradigm. The review of literature in this regard has been reported under the following sections;

2.1 Speech elicited ABR

2.2 Application of speech evoked ABR

2.3 Plasticity of the auditory system

2.4 Mechanism for experience dependent plasticity

2.1. Speech Elicited ABR

2.1.1 Stimulus used for Speech ABR

A number of speech stimuli could be used to elicit speech evoked ABR. However, syllable /da/ is most commonly used among all for obtaining speech ABR (Skoe & Kraus, 2010a).

The CV syllable /da/ is the choice of stimuli because of various reasons, such as, it consists of a transient segment followed by a sustained periodic segment, giving opportunity to record both kinds of responses for one stimulus. Syllable /da/ is relatively universal syllable, present in the phonetic inventories of most languages (Maddieson, 1984). Studies (Tallal & Stark, 1981; Turner, Fabry, & Barrett, 1992; Kraus, McGee, & Carrell, 1996) have shown that the stop consonants are more challenging for the clinical populations and hence, could prove sensitive in detecting abnormalities. Syllable /da/ is also found to elicit clear and replicable ABRs (Skoe & Kraus, 2010). The time amplitude waveform of synthetically generated /da/ and the resultant ABR are shown in Figure 2.1. The output of the FFT analysis of a recorded ABR is shown in Figure 2.2.

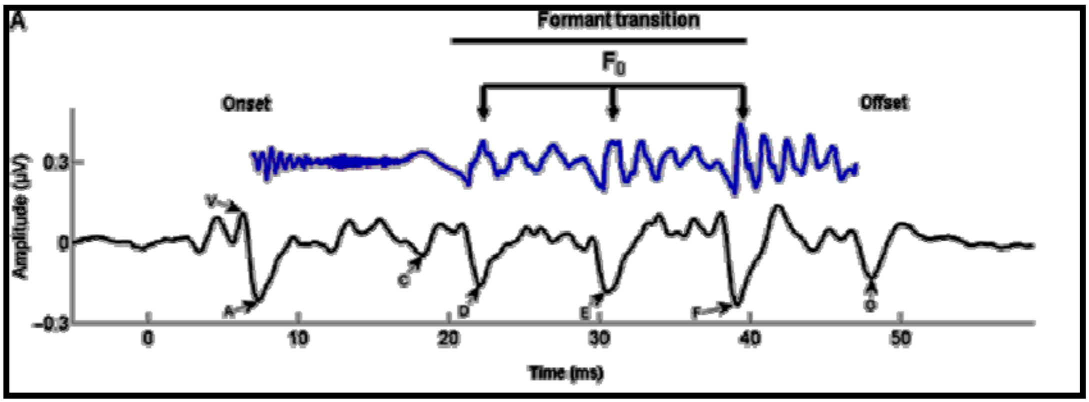

Figure 2.1 Time- amplitude waveform of a 40 ms synthesized speech stimulus /da/ and, the resultant ABR (Courtesy Chandrasekaran & Kraus, 2010).

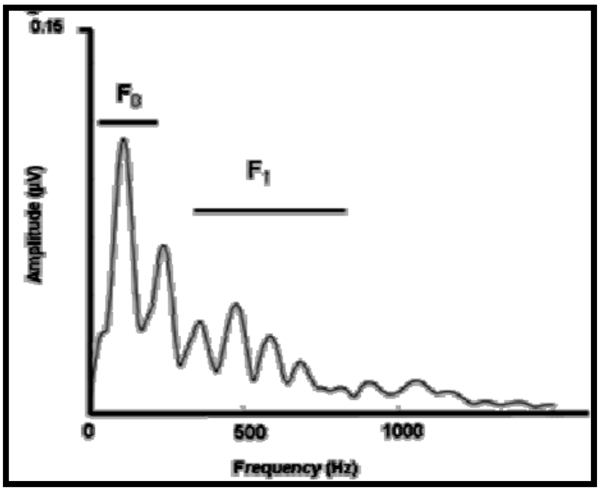

Figure 2.2 Output of the FFT analysis of the brainstem response to stimulus /da/ (Courtesy Chandrasekaran & Kraus, 2010).

The brainstem response to the syllable /da/ broadly is made up of two separate elements, the onset response and the frequency following response (FFR). Onset responses are the transient responses which are evoked by brief, non-sustained stimulus features. FFR on the other hand, is a sustained brainstem response elicited using vowel as a stimulus and, suggested to reflect synchronous neural phase locking.

In response to syllable /da/ wave V, A, C, and O are transient responses elicited. According to Russo, Nicol, Musacchia, and Kraus (2004), wave V and A are seen at the latency of 6-10 ms post-stimulus onset and the complex represents onset burst of the stop consonant. The onset of formant transition represented as the changes from burst to the vowel is suggested to be seen as wave C. Wave O is recommended as the representative of the stimulus offset. Wave D, E, and F are suggestive representatives of the periodic portion of the syllable from which the fundamental frequency of the stimulus can be extracted. To obtain sustained responses, the stimulus should have a low pitch with a fundamental frequency (F0) in the range of 80-300 Hz (Skoe & Kraus, 2010a).

2.1.2 Frequency Following Response

Worden and Marsh (1968) described FFR as those responses which accurately mimic the periodicity of the input acoustic stimulation. The onset of FFRs is reported to have a delay of 5 to 10 ms, even for simple sinusoidal tones, suggesting a rostral origin of FFRs. The amplitude of FFR is reduced under anoxic conditions and shows latency shifts with increasing rates of stimulation, indicating a neural origin. However, FFRs are reported to also demonstrate small, but noticeable amplitude and phase fluctuations with change in stimulus polarity.

The amplitude of scalp-recorded FFR is lesser than 1 μV in humans (Chandrasekaran & Kraus, 2010) and is found to be maximum (mean amplitude of 400 nV) between 320 and 380 Hz (Hoorman, Falkenstein, Hohnsbein, & Blanke, 1992).

Researchers have suggested that FFR does not have either cochlear or cortical origin (Marsh, Worden, & Smith, 1970; Hood, 1998; Krishnan, 2007; Thornton, 2007; Hoorman et al., 1992; Chandrasekaran & Kraus, 2010). In an attempt to find the generators of FFR, Batra, Kuwada, and Maher (1986) used latency measure as a tool. They concluded that the low frequency responses are generated from the inferior colliculus (IC) which is in consonance with results in cat by Smith, Marsh, and Brown (1975). Earlier studies have also evidenced the role of multiple generators in the generation of FFR (Marsh, Brown, & Smith, 1974; Worden & Marsh, 1968; Marsh et al., 1970). Gardi, Merzenich, and McKean (1979) suggested cochlear nucleus to be the primary generator of the scalp-recorded FFR, while Marsh et al. (1974) found that the FFR generators lie between the cochlear nucleus (CN) and the IC. It is also suggested that there are two parallel pathways involved in FFR generation, one from CN to contralateral IC via the lateral lemniscus (LL), and another ipsilateral pathway via the superior olivary complex (SOC) and the LL.

The sustained FFRs are synchronized in such a way that each cycle represents the transition period between the burst and the onset of the vowel, and also the vowel itself (Chandrasekaran & Kraus, 2010). FFRs represent the fundamental frequency (F0), first (F1), second (F2), and third (F3) formants of the stimuli (Krishnan, Swaminathan, & Gandour, 2008; Krishnan, Xu, Gandour, & Cariani, 2004, 2005; Song, Skoe, Wong, & Kraus, 2008; Wong et al., 2007).

2.1.3 Reliability of Speech ABR

Studies (Russo et al., 2004; Musser, 2010; Song et al., 2011) have indicated that there is good test-retest reliability between the two recording sessions for the stimulus duration of both 170 ms and 40 ms. The response fidelity is also reported to be same in both noisy and quiet background. They observed that the responses do not differ significantly for either time or spectral domain in either of the stimulus durations (40 ms or 170 ms) used. The results have been found to be reliable in case of normal children (Hornickel, Knowles, & Kraus, 2011) and also in clinical population (Musser, 2010; Goncalves, Wertzner, Samelli, & Matas, 2011; Wible, Nicol, & Kraus, 2004; Russo, Nicol, Trommer, Zecker, & Kraus, 2009).

2.2 Application of Speech Evoked ABR

Clinically, speech ABR has been shown to be a powerful tool in detecting APDs in a number of disorders. Although, majority of studies show difference in speech ABR on a group data outputs are being made to improve its sensitivity at individual levels. The following few sections give an overview of its application in different domains.

2.2.1 Speech ABR in Clinical Population

Khaladkar, Kartik, and Vanaja (2005) found that the speech ABRs in individuals with sensorineural hearing loss were prolonged in latencies and reduced in amplitude. Musser (2010) reported that the latencies were prolonged and amplitude was reduced in poorer ear of individuals with unilateral hearing loss. Prolonged latencies are also reported in children with phonological disorder (Goncalves et al., 2011) and, children with autism (Russo et al., 2009). Children with learning disability are reported to have delayed peak A latencies, and degraded morphology of wave V and A. It is reported that the children with learning disability who show delayed onset responses, also have delayed latencies for later peaks in FFR (Wible et al., 2004; King, Warrier, Hayes, & Kraus, 2002).

2.2.2 Pitch Encoding in the Auditory Brainstem

The speech elicited ABR represent 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. It is shown that, in an ABR elicited to complex sounds, the forming of the neurons in the brainstem is phase-locked to the pitch of the stimulus and the resultant sustained activities are recorded as FFR in the scalp recorded potentials (Swaminathan, Krishnan, Gandour, & Xu, 2008).

Swaminathan et al. (2008) using Mandarian monosyllables and time varying iterated rippled noise (IRN) found that the brainstem is able to encode pitch better for speech than the non speech stimuli. They concluded that the representation of pitch encoding at the brainstem level is better in the experienced neural system. Krishnan, Gandour, Bidelman, and Swaminathan (2009) compared Mandarian and English native speakers and suggested that the native language speakers show improved representation of pitch. This representation is believed to be experience dependent.

Krishnan, Gandour, and Bidelman (2010) reported that the pitch encoding in brainstem of experienced listeners is less susceptible to any degradation of stimulus. They attributed these findings to the local brainstem mechanism and top-down influence. Further, 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. However, they found musically relevant features to be dominant over linguistic features.

On comparing musician and non-musician group, 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, based on above mentioned findings it could be said that the experience leads to superior representation of the pitch in native speakers and musicians.

2.2.3 Speech Perception in Noise and Speech Evoked Brainstem Responses

It is very common to come across noisy situations in the real listening situations. Thus, it becomes essential to understand the involvement of brainstem in the perception of speech in the presence of noise. Bronkhorst and Plomp (1990) suggested that performance of normal hearing individuals for the perception of speech in the presence of noise is degraded when compared to quiet situations. 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, Skoe, and Kraus (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. However, they could not find any correlation between the brainstem responses and the QuickSIN responses.

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 credited to be the cause of the behavioral findings.

Song et al. (2011) found that the speech perception in noise as measured by QuickSIN is related to the brainstem representation of the F0 in the presence of noise. Results demonstrated that listeners with poor QuickSIN had more degradation of F0 in the presence of noise than that in controls. It is thus suggested that the perception of speech in noise could be related to the strength of F0 representation at the subcortical level.

Dewson (1968) reported that the accuracy of the speech discrimination in noise was reduced when there was lesion of olivocochlear bundle (OCB), and in instances of Olivocochlear bundle lesions the contralateral suppression of evoked oto-acoustic emission (OAE) was reduced (Giraud, Collet, Chery-Croze, Magnan, & Chays, 1995; Prasher, Ryan, & Luxon, 1994).

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.

2.2.4 Speech Evoked ABR in Musicians

Review of literature reveals that the speech ABRs is enhanced in musicians when compared to non-musicians. Musacchia et al. (2007) observed that the onset responses for the speech elicited brainstem responses are earlier in musicians in comparison to the non-musicians. The amplitude of the F0 was also observed to be higher in musicians than non-musicians. Wong et al. (2007) showed that the correlation between the F0 of the stimulus and the brainstem response is stronger in the musicians than the non-musicians. Furthermore, it is reported by the researchers (Parbery-Clark et al., 2009; Musacchia et al., 2007; Wong et al., 2007) that there is a direct relationship between the number of years of music training and the robustness of brainstem responses obtained, with the response being better with more years of practice.

Parbery-Clark et al. (2009) found that the brainstem responses obtained for speech stimulus in the presence of noise was delayed in latency when compared to quiet, in musicians. However, these delays were reported to be smaller when compared to the non-musicians.

Kraus, Skoe, Parebery- Clark, and Ashley (2010) suggested that the timbre, pitch, and timing processing in musician are highly enhanced at subcortical level. They concluded that though music training helps in obtaining a fine grained subcortical representation of pitch, timbre, and timing, it also depends on the higher level cognitive factors too.

Patel (2011) suggested an OPERA hypothesis to explain how music training enhances neural encoding of speech. OPERA hypothesis suggests that the music training has potential to cause improvement in five areas, that is, overlap, precision, emotion, repetition, and attention. It is suggested that only if musical activity meets these conditions, it would lead to adaptive enhancement of speech encoding.

The exact physiology behind music related enhancement in speech ABR is not clear. However, based on the literature it can be hypothesized that due to musical training, corticofugal pathway of the musicians is modulated in a way as to give better responses to speech and tonal stimuli, compared to non-musicians. Because the encoding of speech improves as a function of duration of music training, it would be interesting to study the effect of amount of music exposure on the subcortical structures. Also, though human auditory system could be exposed to music either actively (for example musicians) or passively (for example music listeners), based on the music listening routine, it is not well understood whether the encoding of speech would be similar among the two groups.

2.3 Plasticity of the Auditory System

Animal experiments and human behavioral and electrophysiological studies have shown that the auditory cortex is capable of reorganization as a function of experience, which is also known as plasticity (Tremblay et al., 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 (Tremblay & Kraus, 2002). These synaptic changes could be rapid or occur slowly over time depending on the experience. Studies have shown that experience, whether long-term or short-term, affects the brain functioning (Shinn-Cunningham, 2001; Tremblay et al., 1997; Russo et al., 2005; Wong et al., 2007; Madhok & Maruthy, 2010). Trainor (2005) also reported that the plasticity is influenced by the extent of training in early life.

Long-term plasticity refers to the reorganization of the physiological and anatomical properties of brain neurons after the training given for several months or years. Similarly, the changes that are resultant of few hours or days of training are referred as short- term plasticity. Shinn-Cunningham (2001) reported that the long-term training alters the way spatial cues are integrated to form spatial percepts while short-term training appears to influence how these locations are mapped to spatial behaviors.

Plasticity, among the initial researchers was believed to be a phenomena observed only in cortical structures, however recent experiments has shown that it is present even in the subcortical structures and efferent auditory pathway (Krishnan et al., 2005; Musacchia et al., 2007; Ameen & Maruthy, 2011).

Studies (Wong et al., 2007; Musacchia et al., 2007; Strait, Kraus, Skoe & Ashley, 2009) have shown that the tracking of pitch is highly correlated with the number of years of training. That is to say that longer the music training, better is the coding of speech at the brainstem level.

Numerous studies have shown that the musicians have enhanced spectral and temporal representation of complex stimulus (Lee et al., 2009; Musacchia et al., 2007; Strait et al., 2009), even in the presence of noise (Parbery-Clark et al., 2009). Interestingly, Moreno, Marques, Santos, Santos, Castro, and Besson (2009) showed that the enhancements found in the discrimination of pitch and, cognitive functions are the result of music training and not inherent.

Induced gamma-band activity (GBA) is believed to be an indicator of efficiency of top-down processes (Shahin, Roberts, Chau, Trainor, & Miller, 2008; Trainor, Shahin, & Roberts, 2009). Shahin et al. (2008) reported that the induced GBA was enhanced in children who received music training compared to control group. This was suggested to be the indicator of the enhanced top-down processing as a result of music training.

2.3.1 Effect of Long-term Training on Brainstem Malleability

Krishnan et al. (2005) measured the impact of long-term language experience on the frequency following response (FFR) using Mandarian monosyllables. They found that the native Mandarin-speaking subjects with at least twenty years of Mandarin language exposure have more precise linguistic pitch pattern encoding relative to non native language subjects. Bent, Bradlow, and Wright (2006) indicated that long-term linguistic experience influences the processing of non-speech sounds when the stimuli bear some resemblance to speech.

Krishnan et al. (2008) using IRN (iterated rippled noise) stimulus showed that the pitch strength is strongly represented by the native Mandarian language speakers when compared to the non-native speakers. This indicates that the brainstem is susceptible to the long-term experiences in responding to the spectral variations. However, they found that this sensitivity was independent of the stimulus context, and equally represented for the non-speech stimulus. Similar findings are reported by Krishnan et al. (2009). These findings suggest that language experience modifies the neural circuitry of the auditory pathway.

Johnson, Nicol, Zecker, and Kraus (2007) found that the FFR peaks in the young children have delayed latencies when compared to the older children. This again indicates that with the language exposure and phonological awareness, the neural timing and frequency representation of linguistic stimulus improves at the brainstem level.

2.3.2 Effect of Short-term Training on Brainstem Malleability

Russo et al. (2005) evaluated effect of auditory speech discrimination training for 8 weeks of 1 hour every day. The neural encoding of temporal, harmonic and periodic aspect of the linguistic stimulus was reported to improve with the training, indicating that the FFR responses are dynamic. However, the onset responses were found to show no change with the training, indicating that the mechanism for onset response and FFR responses development are different.

Song et al. (2008) carried out their study by training native English speakers using the Mandarian tones for eight sessions. They found that the subcortical representation of the pitch improved as a result of the training given to the non-native speaker. This is an indicator of the fact that the auditory system undergoes modification as a result of training for even a very small duration.

Madhok and Maruthy (2010) also reported that the changes in brainstem responses could be observed within few weeks of training. Consistent with the results obtained by Russo et al. (2005), they also reported that the training does not alter the onset responses, but improvement in the pitch coding could be seen even after the short-term training.

2.3.3 Online Plasticity

It is clear from literature that the subcortical structures evidence both long and short-term plasticity. Recent researches by Chandrasekaran et al., (2009), Skoe and Kraus (2010b) and, Hanan and Maruthy (2011) reported the presence of a new type of plasticity which is termed as online plasticity. The 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 (2010b) demonstrated that human subcortical activity evolves in response to the 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 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 that the online plasticity is evident only for spectrally dissimilar contextual stimulus, not for spectrally similar context.

Adank and Devlin (2010) studied normal and time-compressed speech intelligibility, and found that the online adaptation to the time-compressed speech occurs at an acoustic level in the right hemisphere. These findings were tested both behaviorally and through neuroimaging techniques. However, the adaptation in the left hemisphere was found to be at linguistic level. Thus, they concluded that the online adaptation takes place while comprehending the degraded speech signal.

2.4 Mechanisms of Experience Dependent Plasticity

Above mentioned studies have shown that the human brainstem is susceptible to changes over a period of time, irrespective of duration i.e., it could be seen for a longer as well as shorter period training. The mechanism involved in these changes is described based on two approaches, local reorganization mechanism and corticofugal modulation.

Local reorganization mechanism (Krishnan & Gandour, 2009) explains that once the reorganization of brainstem is complete over the critical development period, local mechanisms are sufficient to extract linguistically-relevant pitch information. That is, once the brainstem establishes tuning with the corticofugal modulation, local mechanisms can maintain plasticity and would not require corticofugal influence.

Corticofugal modulation mechanism (Suga, 2007) on the other hand, suggests that when the corticofugal pathway is repetitively stimulated, it activates the cortical neural net and the corticofugal system. This activation evokes cortical as well as subcortical plastic changes, which are conditioned by constant facilitation and inhibition.

2.4.1 Corticofugal Pathway and its Influence on Subcortical Signal Processing

It has been shown by anatomical studies (Suga, Gao, Zhang, Ma, & Olsen, 2000; Spangler & Warr, 1991; Winer & Prieto, 2001; Mulders & Robertson, 2000; Guinan, 2006) on animals that the efferent system can be divided into two parts, the corticofugal system (cortex to pons) and the olivocochlear system (pons to cochlea). In the efferent pathway, neuronal fibers originate from the deep layers of auditory cortex (AC). They innervate the medial geniculate body (MGB), superior olivary complex (SOC) and descend further to innervate the olivocochlear bundle (OCB), especially medial OCB (MOCB). These fibers then terminate in the cochlea via cochlear nucleus. Corticofugal projections are bilateral to the SOC and the CN. The olivocochlear system forms a multiple feedback loop in the auditory pathway. This pathway can be summarized as in Figure 2.3.

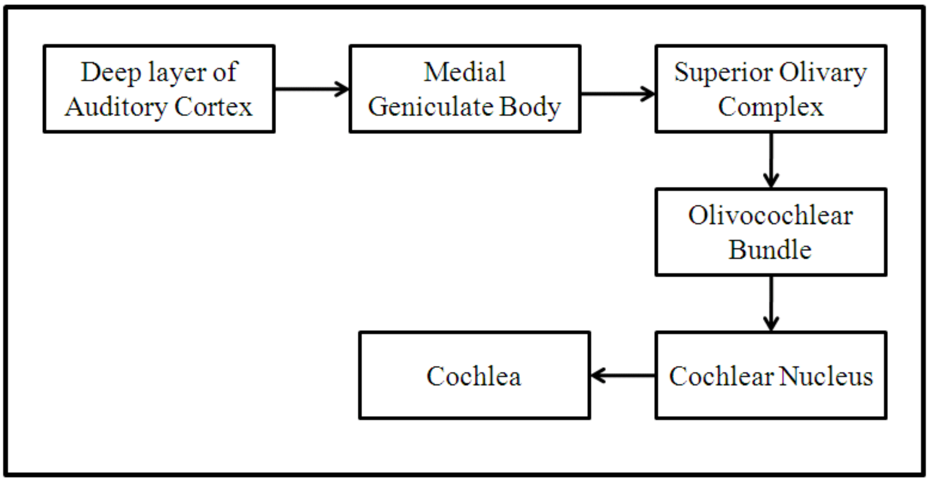

Figure 2.3 Block diagram representing efferent pathway in the auditory system.

Suga et al. (2000) provide evidence that the corticofugal system is important in shaping, creating and reorganizing frequency and computational maps. These findings are in contrast to the previous belief that corticofugal pathway is not important for auditory processing to take place.

Suga, Gao, Ma, Sakai and Chowdhury (2001) suggested that when a behaviorally irrelevant acoustic stimuli is heard, it ascends from the cochlea to the Auditory cortex (AC). This subcortical signal then undergoes modulation by the AC and, the corticofugal system. This evokes small and short-term changes in the cortex. These signals then become behaviorally relevant by the association with the amygdala. There is a positive feedback loop working which augments modulation of subcortical signal processing, making changes in the cortex larger and long-term.

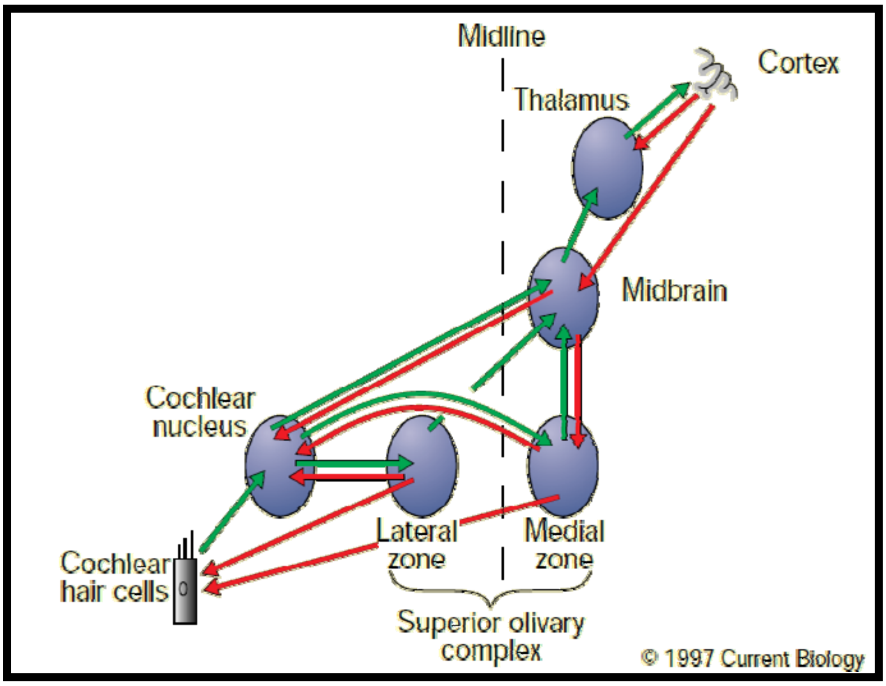

Figure 2.4 Ascending and descending auditory pathway along with parallel pathways (Courtesy King, 1997).

The use of passive oddball stimulus paradigm while evoking ABR helps in examining pre-attentive and automatic central auditory processing. It involves comparison of each auditory input with the input in the recent auditory memory. This paradigm includes presentation of two (or more) stimuli presented randomly, with one being relatively infrequent and other frequent. The subject is not required to pay attention to the stimulus. It is suggested to be an objective measure of the discrimination capability of an individual (Tanaka & Hirata, 2008; Schulte- Korne, Deimel, Bartling, & Remschmidt, 1998; Rissling & Light, 2010; Heinze, Munte, Kutas, Butler, Naatanen, Nuwer, & Goodin, 1999).

Researchers have found this paradigm to be effective in studying the effect of context on the encoding of the stimulus at the level of brainstem (Chandrasekaran et al., 2009; Hanan & Maruthy, 2011). The corticofugal modulation in human auditory system has been non-invasively derived using odd ball paradigm.

Logic of the Present Study

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 et al., 2009).

Top-down mechanisms include feedback mechanism mediated by efferent pathway between cortex and brainstem. It is suggested that the corticofugal pathway links learnt representations and the neural encoding of the acoustic features, and thus fine tunes subcortical processing of the speech sounds. Top-down mechanism is believed to be a knowledge driven mechanism and is believed to enhance the processing of the relevant sound (Kraus et al., 2009; Sarter, Givens & Bruno, 2001).

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. According to OPERA hypothesis, the adaptive plasticity in speech processing is better when there is overlap, precision, emotions, repetitions, and attention present. Earlier, many studies have documented the long-term 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. To prove this logical relationship between music training and online plasticity, the present study was taken up.

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. Hence, to get clarity about the underlying mechanisms, it was required to compare the online plasticity in musicians, and music listener.

Chapter 3

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 listener. The following method was used to test the null hypothesis.

3.1 Participants

A total of 30 normal hearing 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.

All the participants had hearing thresholds within 15dB HL at octaves between 250Hz and 8000Hz. The presence of any middle ear pathology was ruled out using immittance evaluation. All the participants had type ‘A’ tympanogram with acoustic reflexes present bilaterally, indicative of normal middle ear system. The presence of central auditory processing disorder was screened out using speech perception in noise test, in which the participants of the study had more than 60% score at 0dB SNR. They also had normal click-evoked ABR, which ensured normal functioning of the auditory brainstem pathway.

A checklist developed to profile their audiological status, and exposure in music (Annexure 1), was administered prior to the actual testing. 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.

3.2 Stimuli for the Experiment

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 total duration of synthetically generated /da/ stimulus was 40 ms, with rise and fall-time of 5 ms. The consonant contained an initial 10 ms burst, the center frequencies of which were around the beginning of formants 3-5, thus in the range of 2580-4500 Hz. The spectrum of stimulus was such that the onset burst frication at $F3$, $F4$, and $F5$ during the first 10 ms was included, followed by 30 ms $F1$ and $F2$ transitions stopping immediately before the steady-state portion of the vowel (King et al., 2002; Russo et al., 2004; Johnson, Nicol, & Kraus, 2005). The time-amplitude waveform and spectrogram of 40 ms synthesized /da/ stimulus was as shown in Figure 3.1 (A). For the purpose of the present study, the /da/ was further passed through a high pass filter of 1700Hz to prepare the F2 filtered /da/. The time-amplitude waveform and the spectrogram of F2 filtered /da/ and the white noise is shown in Figure 3.1 (B) and (C) respectively. 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 Dr. 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 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 3.1.

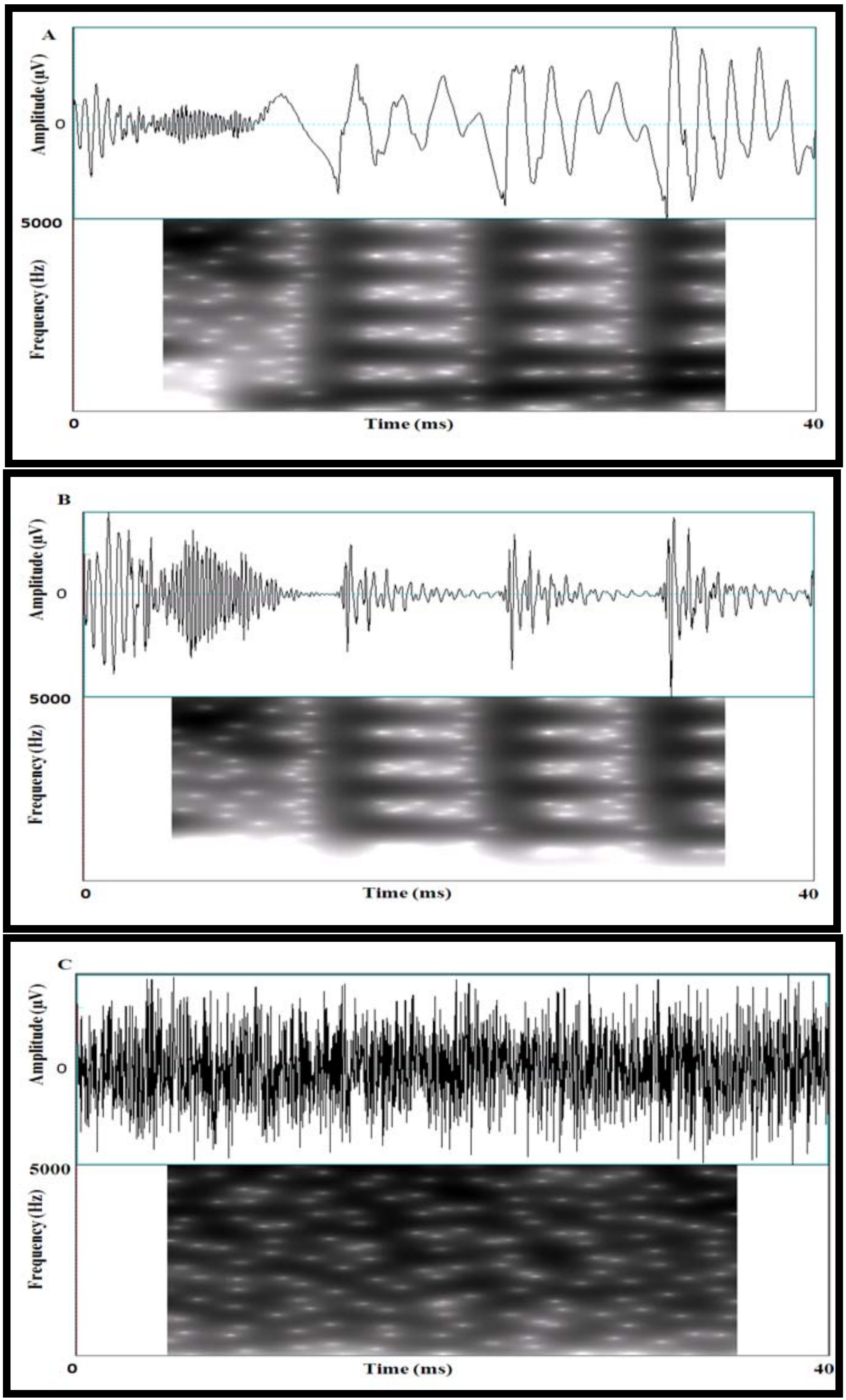

Figure 3.1 *Time- amplitude waveform and the spectrogram of a (A) synthetically generated /da/ (B) F2 filtered /da/ (C) white noise stimulus.*

Table 3.1: *Mean behavioral thresholds in (dBSPL) of the synthetically generated syllables /da/, F2 filtered /da/ and, the white noise*

Stimulus	**Mean behavioral threshold**	**Approximated mean behavioral thresholds**
Synthetically generated /da/	27.71 dBSPL	30 dBSPL
F2 filtered /da/	28.82 dBSPL	30 dBSPL
White noise	31.14 dBSPL	30 dBSPL

3.3 Test Environment

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

3.4 Instrumentation

Several technical instruments were necessary for the signal generation, preliminary evaluation of participants and, for the actual experiment. To estimate the air- and bone-conduction thresholds on pure tone audiometry, Madsen Orbiter-922 type I diagnostic audiometer with prescribed transducer was used. Telephonics TDH-39 headphone in Orbiter-922 audiometer was used to estimate speech perception in noise. A calibrated Grason Stadler Inc-Tympstar clinical immittance meter was used to rule out middle ear pathology, while a Biologic Navigator Pro EP (version 7.0) system was used to record the electrophysiological responses. A laptop with Adobe audition (version 1.5) and MATLAB R 2009a software’s was used to edit the stimuli and for response analysis.

3.5 Test Procedure

Only the participants who fulfilled the inclusion criteria were subjected to the actual test procedure. The actual experimental paradigm involved recording of Speech perception in noise and speech evoked brainstem responses

3.5.1 Procedure of the Preliminary Testing

3.5.1.a Pure tone audiometry

Behavioral air conduction and bone conduction thresholds were estimated using modified Hughson and Westlake procedure (Carhart & Jerger, 1959). The estimation of air conduction thresholds was done at octave frequencies in the 250 to 8000 Hz frequency range while the bone conduction thresholds were estimated only up to 4000 Hz.

3.5.1.b Immittance evaluation

Using a probe tone of 226Hz, tympanogram was obtained by sweeping the pressure from +200 to -400 daPa. The type of tympanogram was considered for the screening of middle ear as normal or pathological. The acoustic reflex thresholds were obtained for both ipsilateral and contralateral pure tone stimulus at 500, 1000, 2000, and 4000Hz.

3.5.1.c Speech perception in noise (SPIN) test

Standardized monosyllabic-words in English developed by Rout and Yathiraj, (1996) were presented at 40dBSL (ref. Pure tone Average of 500Hz, 1000Hz and 2000Hz) and 0dB SNR, monaurally for both the ears. The speech identification scores were then used as the measure of speech perception in noise and rule out (C)APD.

3.5.1.d Auditory brainstem responses (ABR)

Threshold estimation was done using click evoked auditory brainstem response. These responses were obtained in a single channel using vertical ipsilateral montage.

3.5.2 Procedure of the Experimental Testing

3.5.2.a Recording of SPIN

The speech perception in noise 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.

3.5.2.b Speech evoked ABR

The experiment involved recording brainstem responses in three different stimulus conditions. To do this, the participants were made to sit on a reclining chair and instructed to relax and avoid any body movements. The skin surface at the vertex (Cz), nape of the neck and the mastoid of the left ear was cleaned using the skin preparing gel. 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. Gold plated disc electrodes along with the conduction paste were placed over the cleaned skin surface and were secured at its place using a tape. This ensured an impedance of less than 5kOhms at each electrode site. Single-channel vertical ipsilateral montage was used for recording the response.

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 recorded. 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). The different test paradigms used during the experiment were as given in Figure 3.2.

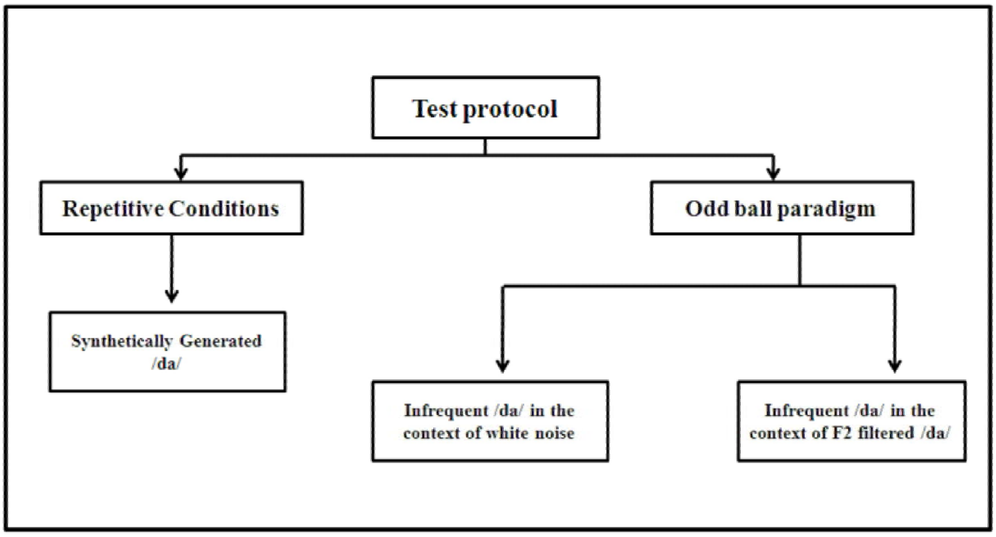

Fig 3.2 Representation of different stimulus conditions used.

Brainstem responses for each of the three stimulus conditions were collected using the parameters as given in Table 3.2.

Table 3.2: Stimulus and recording parameters for the brainstem responses elicitation

Stimulus Parameters	
Stimulus	*Repetitive condition*: /da/ *Contextual condition:* Frequent stimuli (75%): a) white noise b) f2 filtered /da/ Infrequent stimuli (25%): a) /da/
Transducer	Insert ER 3 earphone
Ear	Right
Insert delay	0.80 ms
Repetition Rate	10.9/s
Frequent/ Infrequent ratio	3:1
Polarity	Alternating
Intensity	80 dBSPL
Number of sweeps	1500
Recording Parameters	
Epoch time	-10 to 64 ms
Data points	512
Electrode montage	Vertical (Non inverting: Vertex; Inverting: nape; Ground: mastoid)
Artifact rejection	± 23.8 μV
Amplification	1,00,000

3.6 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.

The right end of the wave with the largest amplitude around 6 ms following the stimulus onset was marked as wave V. The immediate negative trough following the wave V was marked as wave A. V to A amplitude was obtained from the voltage difference between the wave V and wave A. The replicable negative wave occurring at around 18 ms with large amplitude was marked as wave C. Marking of the peaks in a representative averaged waveform is shown in Figure 3.3.

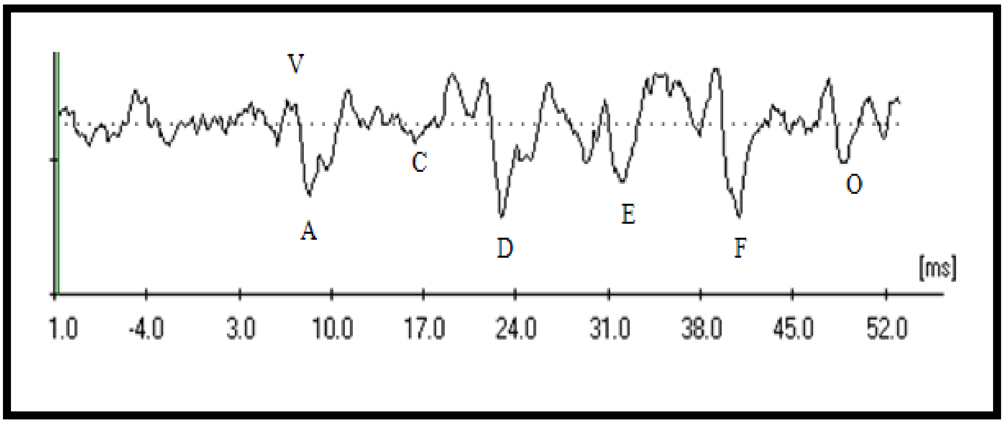

Figure 3.3 Representation of the marking of the peaks in a representative averaged waveform.

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 11.4–40.6 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, Nicol, Zecker, Bradlow, Skoe, & Kraus, 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 3.4.

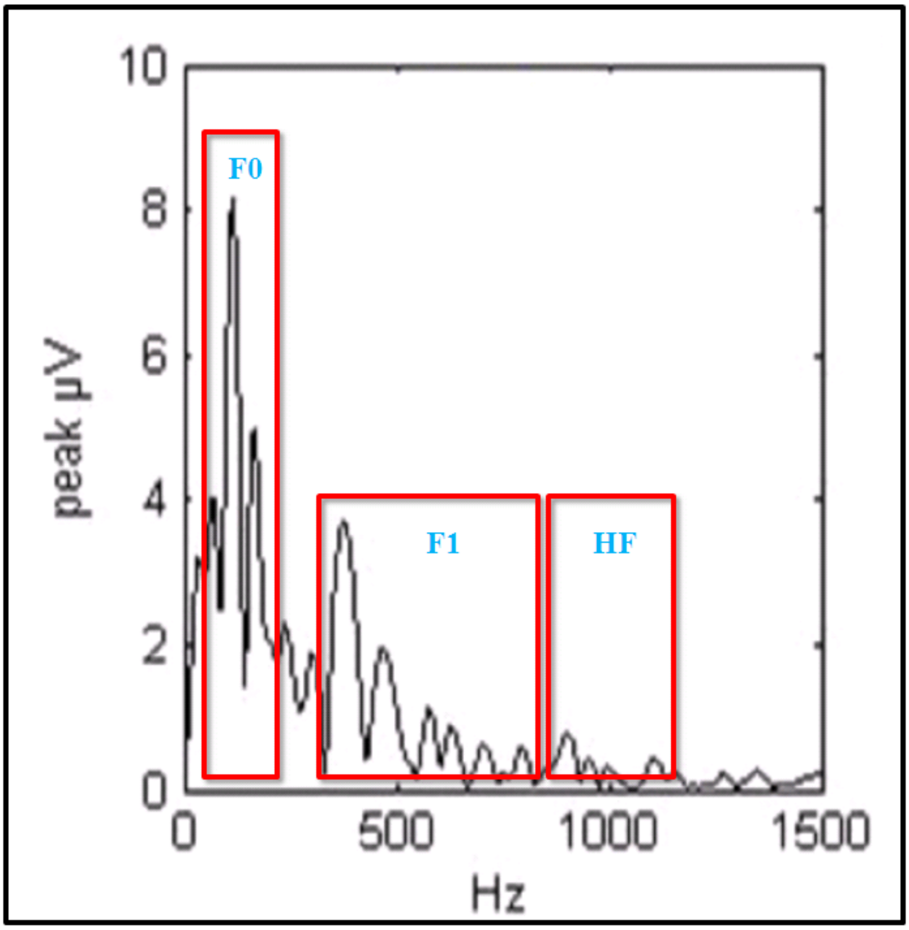

Figure 3.4 Representation of FFR responses in a representative spectrum.

3.7 Data Analysis

The following comparison were done in the group data,

1. The responses in the repetitive stimulus paradigm were compared with the response in the odd ball paradigm.
2. The responses in the three stimulus condition of the odd ball paradigm were compared among the three groups of subjects.
3. The responses in the three stimulus condition of the odd ball paradigm were compared with each other.

4. The correlation between the brainstem responses and the speech perception in noise test results obtained.

Chapter 4

RESULTS

The primary objective of the present study was to compare the online plasticity among musicians, music listeners and non music listeners, based on context dependent encoding of speech. The additional research question addressed in the study was to establish the relationship between online plasticity and speech perception in noise. The context dependent encoding of speech was assessed using speech evoked brainstem potentials.

Transient and sustained portions of brainstem responses were independently analyzed for their latency and amplitude parameters. 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 results obtained in study are detailed under the following headings;

4.1 Occurrence of transient responses
4.2 Effect of condition on transient responses
4.3 Effect of condition on sustained responses
4.4 Effect of group on Speech perception in noise (SPIN)
4.5 Effect of group on speech evoked brainstem responses
4.6 Effect of group on online plasticity
4.7 Correlation of years of music training and SPIN
4.8 Correlation between online plasticity and SPIN

4.1 Occurrence of Transient Responses

The two experienced audiologists visually inspected the transient responses and marked the peaks V, A and C. The percentage of occurrences of these peaks among the participants of the three groups, in the three stimulus conditions is given in Table 4.1.

Table 4.1 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**		
		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 %

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

As evident from Table 4.1, the wave V and A were present in 100% of the participants in all three stimulus conditions, whereas this was not the case with 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.

4.2 Effect of Condition on Transient Responses

The latency and amplitude measures of the transient responses were analyzed subjectively. The results are reported separately for latency and amplitude.

4.2.1 Latency Measures of Transient Responses

The mean and standard deviations of latency of transient responses were estimated among the three stimulus conditions (one repetitive paradigm & two odd-ball paradigms), using descriptive statistics. The data is as given in Table 4.2.

Table 4.2 The mean and standard deviation (SD) of peak latency (ms) of wave V, A, and C in the three stimulus conditions, for the three participant groups

		Condition 1		**Condition 2**		**Condition 3**	
Wave	**Group**	**Mean (ms)**	**SD**	**Mean (ms)**	**SD**	**Mean (ms)**	**SD**
	NML	7.49	0.62	7.79	0.60	7.78	0.59
V	**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
	NML	8.47	0.64	8.78	0.55	8.95	0.58
A	**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
	NML	17.51	0.87	17.81	0.89	17.73	0.65
C	**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

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

The data in Table 4.2, 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 obtained are summarized in Table 4.3. The results showed significant main effect of stimulus condition on the latency of wave V and, A. There was no significant interaction between condition and group.

Table 4.3 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*

Because there was significant main effect of stimulus condition on wave V and A, pair-wise comparison was 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 4.1.

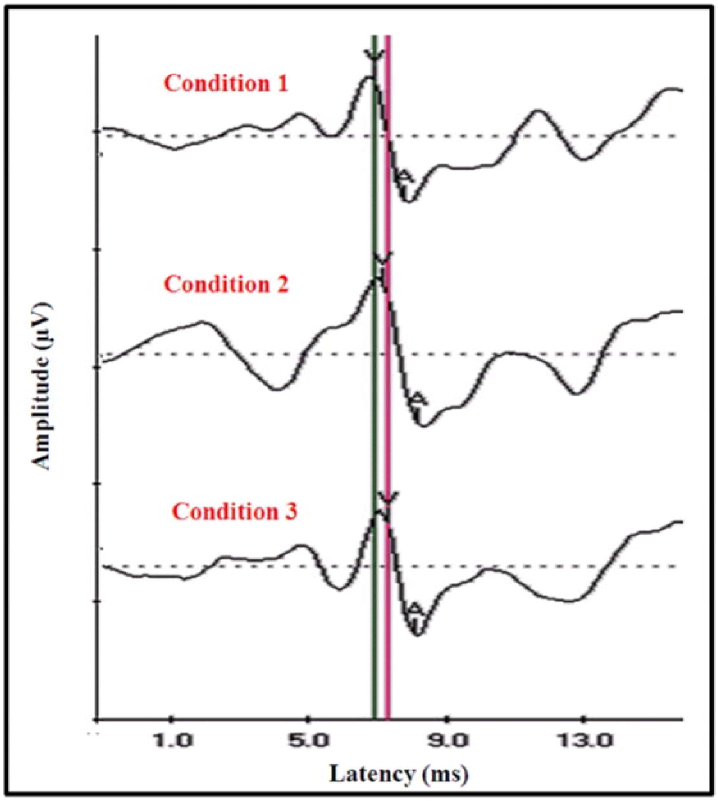

Figure 4.1 Transient portion of the waveforms recorded in the three stimulus conditions in an individual participant.

4.2.2 Amplitude Measures of Transient Responses

Descriptive statistics was done to obtain mean and standard deviation values of peak amplitude in three stimulus conditions (Table 4.4). 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 4.5) 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.

Table 4.4 The mean and standard deviation (SD) of peak amplitude (µV) across three stimulus conditions for three participant groups

		Condition 1		**Condition 2**		**Condition 3**	
Wave	**Group**	**Mean (µV)**	**SD**	**Mean (µV)**	**SD**	**Mean (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:1. NML- non music listener, ML- Music listener, MC- Musicians

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

Table 4.5 The results of repeated measure ANOVA for wave V, and A amplitude

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

4.3 Effect of Conditions on Sustained Responses

Brainstem Toolbox was used to carry out Fast Fourier Transformation (FFT) of the sustained responses for the objective analysis. 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 4.2). As apparent from Table 4.6, 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].

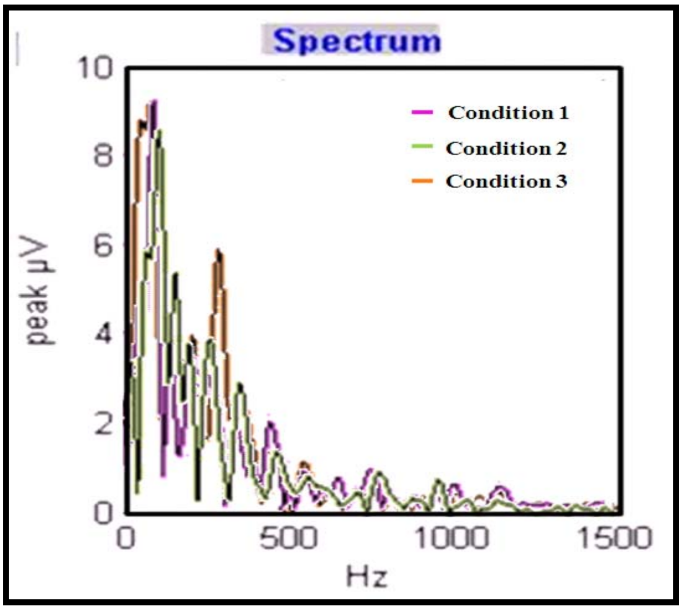

Figure 4.2 Representative spectrum of F0, F1 and, HF obtained from the FFT analysis.

Table 4.6 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 1**	**Condition 2**	**Condition 3**
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

4.4 Effect of Group on Speech Perception in Noise (SPIN)

The mean and standard deviation of the SNR-50 was obtained for the three groups. The results are shown in Figure 4.3. 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 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.

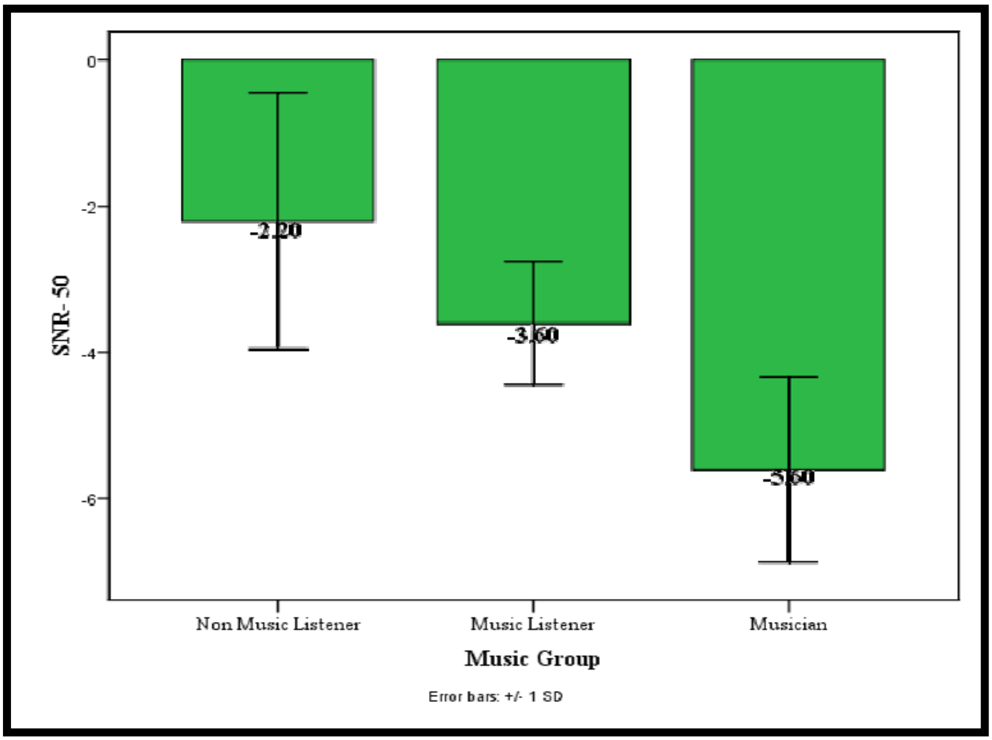

Figure 4.3 Graphical representation of the mean and standard deviation (SD) of SPIN in the three participant groups.

4.5 Effect of Group on Speech Evoked Brainstem Responses

The averaged transient and sustained responses were compared among the three participant groups for their latencies and amplitudes. The results of the same are reported separately for transient and sustained responses.

4.5.1 Effect of Group on Transient Responses

The mean and standard deviations of latencies and amplitude are given in Table 4.2 and 4.4 respectively (Section 4.2). 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 4.7 & Table 4.8) showed that the group effect was absent on the latencies and amplitudes of transient response in all the three conditions.

Table 4.7 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 4.8 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)**
	1	0.51	2 (27)
V	**2**	0.99	2 (27)
	3	0.08	2 (27)
	1	2.34	2 (27)
A	**2**	0.01	2 (27)
	3	3.48	2 (27)

4.5.2 Effect of Group on Sustained Responses

The mean amplitude of the F0, F1 and, HF (Table 4.6) was compared across the three participant groups to study the effect of group on sustained responses. As evident from Table 4.6, mean was higher in musicians in contrast with music listeners and non music listeners for F0 in condition 1, F1 in all stimulus condition and, condition 1 for HF. 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 4.9.

Table 4.9 The results of one-way ANOVA showing the effect of group on FFR measures

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

4.6 Effect of Group on Online Plasticity

The effect of groups on online plasticity was tested separately on transient and sustained responses.

4.6.1 Effect of Group on Transient Response

The online plasticity was quantified by subtracting latencies and amplitude obtained in repetitive paradigm with that of latency and amplitude obtained in odd-ball paradigms using white noise. This difference gives the 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 4.4 and Figure 4.5, 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).

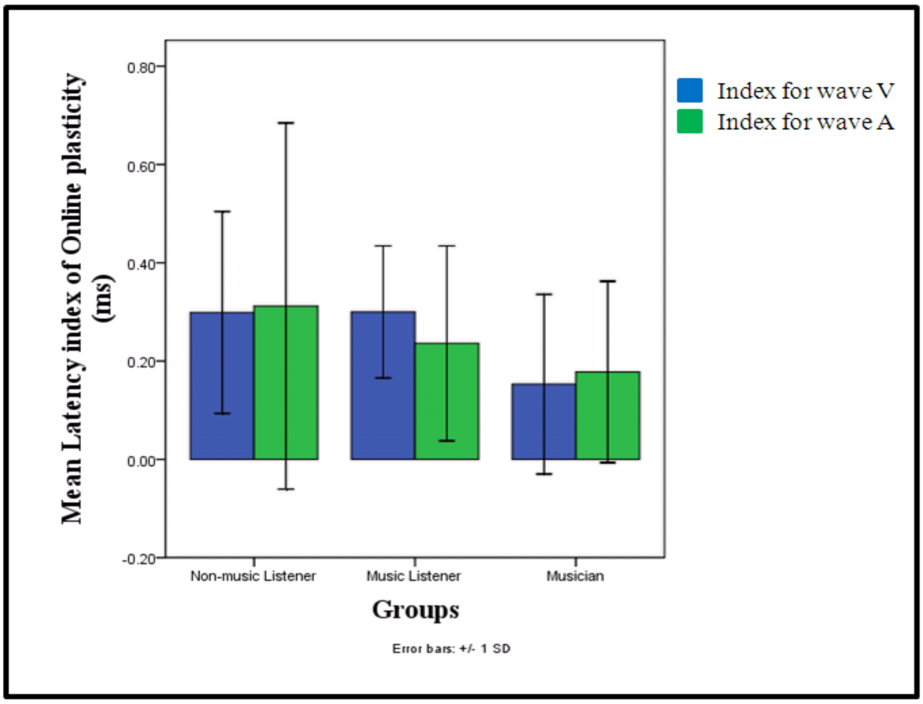

Figure 4.4 Graphical representation of the mean and standard deviation of online plasticity derived from latency of transient responses in the three participant groups.

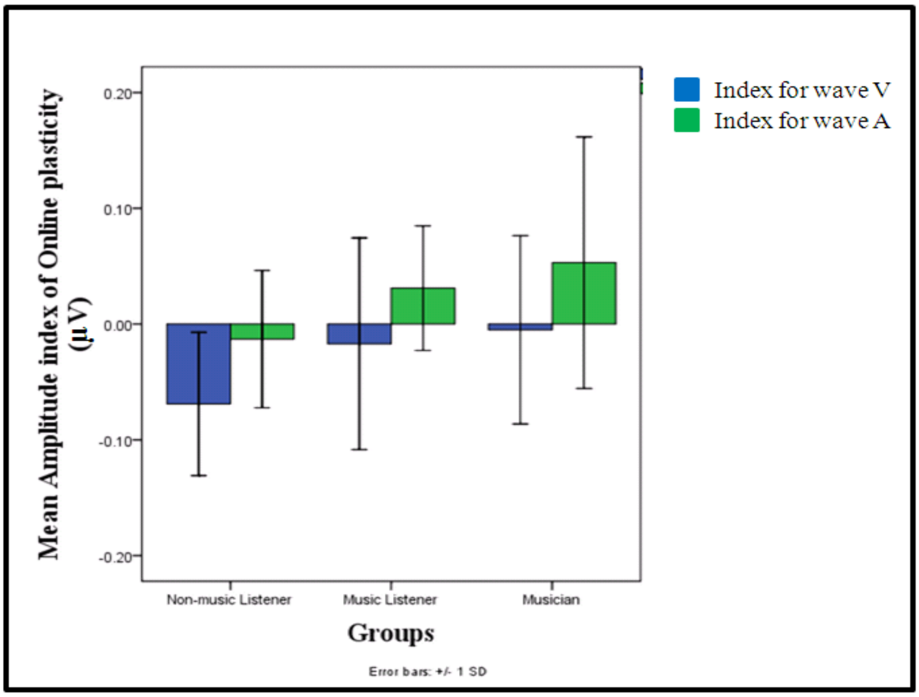

Figure 4.5 Graphical representation of the mean and standard deviation of online plasticity derived from amplitude of transient responses in the three participant groups.

However, these differences were found to be statistically insignificant, on one-way ANOVA (Table 4.10).

Table 4.10 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)

4.6.2. Effect of Groups on Online Plasticity Evidenced by Sustained Responses

The index of online plasticity was computed by subtracting amplitude of sustained responses in repetitive paradigm from the odd-ball paradigm using white noise as context. The mean and standard deviations are represented in Figure 4.6.

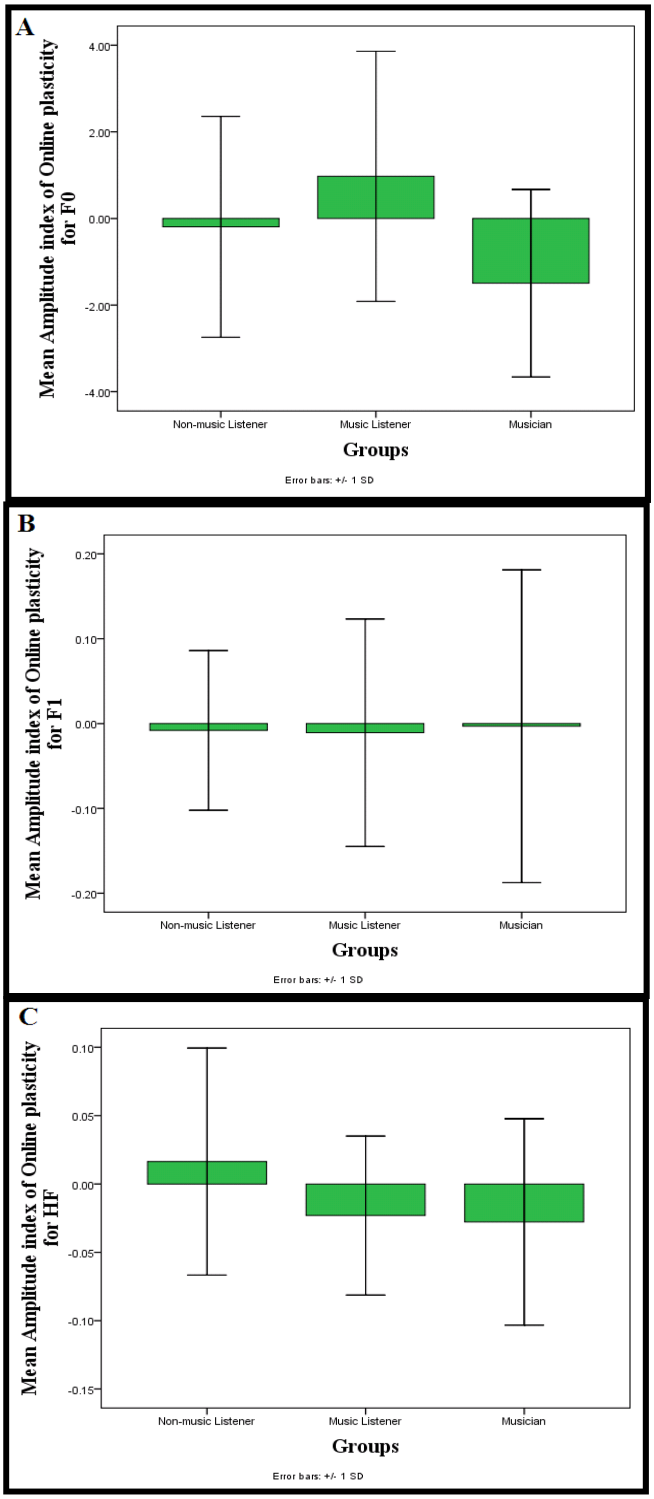

Figure 4.6 Graphical representation of mean and standard deviation (SD) of amplitude index of online plasticity for A) F0, B) F1, and C) HF across participant groups.

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 in the two condition are given in Table 4.11.

Table 4.11 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)

4.7 Correlation of Years 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 4.7 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).

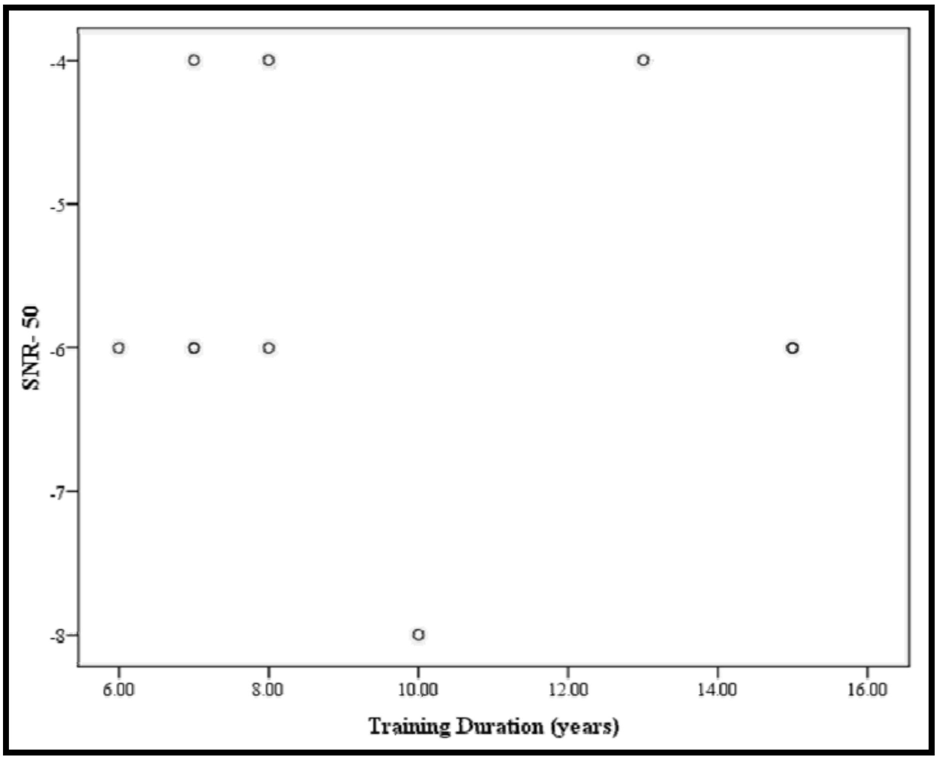

Figure 4.7 Relation between SNR-50 and years of music training.

4.8 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 4.8.

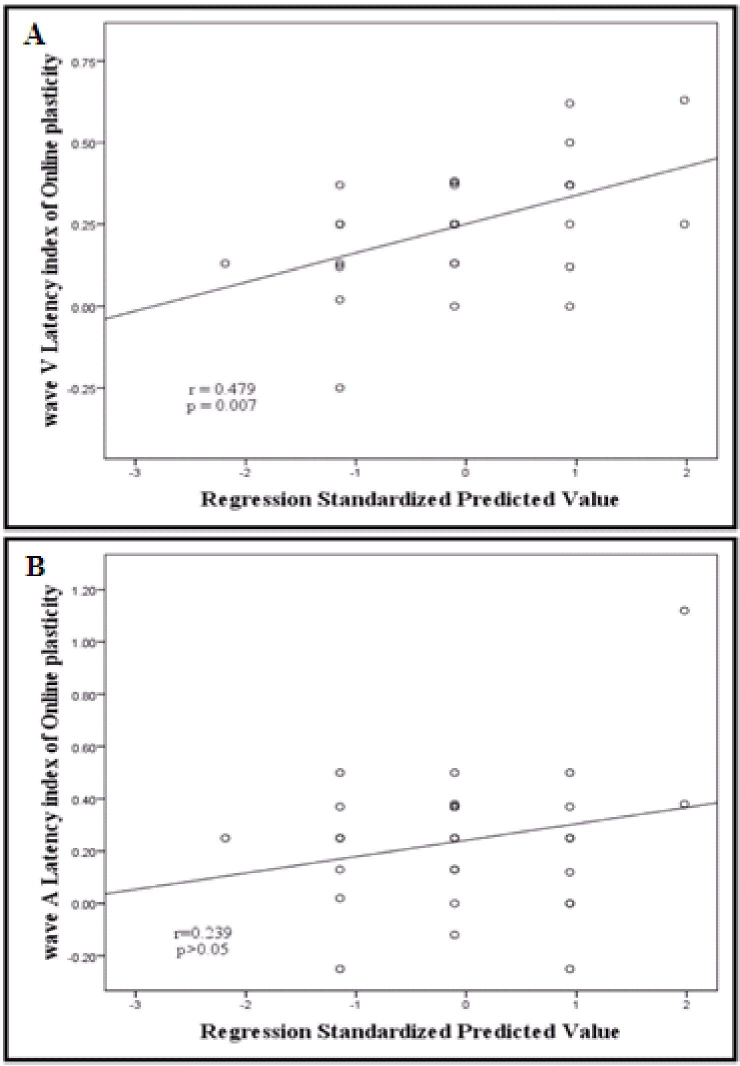

Figure 4.8 The correlation between Online plasticity and Speech perception in noise A) wave V latency and B) wave A latency.

Summary of the Results

Overall, the results of the study can be summarized as follow;

1. The transient responses (wave V & A) were elicited earlier in the repetitive paradigm, for all the participant groups.
2. The mean amplitude of the transient responses did not vary among different stimulus conditions, in any of the participant group.
3. There was no significant effect of stimulus condition on sustained responses.

4. The speech perception of noise was better in the musician group, compared to music listener and, non-music listener.
5. The mean latencies and amplitudes of the speech evoked ABR did not vary across the three participant groups.
6. The context-dependent electrophysiological findings did not differ significantly among the participant groups.
7. The speech perception of noise did not have any correlation with the number of year’s music training, but correlated with some of the context-dependent electrophysiological findings.

Chapter 5

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 plasticity 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 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 behavioral and electrophysiological data of 30 participants showed sum of the interesting findings which are discussed under the following heading;

5.1 Occurrence of speech evoked brainstem responses
5.2 Effect of Condition on Speech Evoked ABR
5.3 Effect of Group on SPIN
5.4 Correlation of Training Duration and SPIN
5.5 Effect of Group on Speech ABR
5.6 Effect of Group on Online Plasticity
5.7 Relation between Online Plasticity and SPIN

5.1 Occurrence of Speech Evoked Brainstem Responses

The transient peaks V, A and, C were marked subjectively and, the results showed that the wave C was absent in few of the participants in few of the stimulus condition. The results showed that the occurrence of wave C was lower when compared to other waves obtained from the same participants. The wave C has been reported to code for the onset of voicing in the stimulus (Kraus & Nicol, 2005). The lower occurrence of wave C may be because of the relatively lesser synchrony of the neurons involved in its generation compared to that of other waves. However, this is only an assumption and requires controlled experimental studies before concluding. The present observation is however supported by the earlier reports (Hanan & Maruthy, 2011; Werff & Burns, 2011) where in wave C was identifiable in less than 70% of their participants.

On comparing the occurrence across groups, it was further observed that wave C was identifiable in 100% of the musicians, while was not identifiable in the non-musician groups (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, Parebery-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. The mean amplitude of wave C was higher in musician group compared to non-musician groups.

In general it is well known that neural synchrony is one of the primary determining factors for the amplitude of electrophysiological response. Because, the wave V and A were already present in 100% of the participant in non-musician groups, the trend seen in wave C (higher percentage of occurrence in musicians than non-musicians) could not be observed for wave V and A due to ceiling effect.

5.2 Effect of Condition on Speech Evoked ABR

There were three stimulus conditions used in the study of which one was a repetitive paradigm and the other two were odd-ball paradigms. The speech evoked responses recorded in the three stimulus conditions were compared in order to derive the underlying mechanisms of online plasticity proposed by Skoe and, Kraus (2010).

The results of the present study showed that the responses were better in the repetitive paradigm compared to that in the odd-ball paradigm. This is in consonance with the earlier findings (Chandrasekaran et al., 2009; Hanan & Maruthy, 2011). The findings indicate that the coding of the speech stimulus at the level of brainstem is enhanced when the stimuli is presented repetitively. This stimulus-paradigm-related-difference is true although the number of averages were same in the two paradigms. This is an electrophysiological evidence to infer that the brainstem encodes speech depending on the context. If the ongoing stimulus is repetitive, the representation in the brainstem becomes better. Such context-dependent encoding has been attributed to the participation of corticofugal pathway in the brainstem encoding (Chandrasekaran et al., 2009; Hanan & Maruthy, 2011). The relative enhancement in the brainstem responses consequent to the repeating stimulus has been termed online plasticity (Chandrasekaran et al., 2009).

In the present study, there were two odd-ball paradigms used; one, with white noise as the context and the other with F2 filtered /da/ as the context. These two stimuli were chosen based on the findings of Hanan and Maruthy (2011). Hanan and Maruthy, using white noise as the context had concluded that the difference in the spectrum (between the target & the context stimuli) is the cue for differentiating between the two stimuli and the context dependent encoding.

Both the stimuli used as context (white noise & F2 filtered /da/) in the present study differed in the spectrum compared to the target /da/. While the white noise differed both in spectral content and the envelope, F2 filtered /da/ had similar envelope but differed only in the harmonic structure. The finding 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. Considering that the course of the efferent pathway extends up to cochlear nucleus, one may expect the changes to be present right in the transient responses which are generated by LL and IC. The efferent pathway is reported to be originating from the auditory cortex and terminating at cochlea via cochlear nucleus (Suga et al., 2000; Spangler & Warr, 1991; Winer & Prieto, 2001; Mulders & Robertson, 2000; Guinan, 2007). The efferent system also consists of multiple feedback loop system, which helps in the brainstem modulation. It is suggested that these feedback loop system selectively enhance relevant information in the signal, inhibiting the irrelevant information (Gao, & Suga, 1998; Yan, & Suga, 1998; Luo, Wang, Kashani, & Yan, 2008). These enhancements are then represented at the cortical level and are demonstrated in the form of plasticity, either long term or short term depending on the duration of repetition.

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 wide range of frequencies (F0, F1, & HF), due to which the effect at some of the discreet frequencies might have got nullified.

There was absence of interaction between condition and group in both transient responses and sustained responses. This shows that trend of the results of condition effect was same in all three groups.

5.3 Effect of Group on SPIN

The hypothesis was that there is a correlation between the music exposure and SPIN. Speech perception in noise (SPIN) was taken as a behavioral measure in the present study as SPIN in the past, has been shown to enhance with musical training (Parbery-Clark, Skoe, Lam, & Kraus, 2009; Strait, Kraus, Parbery-Clark &, Ashley, 2010; Ameen & Maruthy, 2011; Parbery-Clark, Strait, Anderson, Hittner, & Kraus, 2011; Anderson & Kraus, 2011; Parbery-Clark, Strait &, Kraus, 2011). Further, SPIN has also been shown to correlate well with the online plasticity as evidenced through electrophysiological findings (Chandrasekaran & Kraus, 2009). Hence, in order to understand the behavioral consequences of online plasticity secondary to music listening and formal music training, speech in noise was measured.

In the present study, it was found that the musicians have better SPIN compared to non-musicians. As music training was the differing variable among this group, the better SPIN shall be attributed to the training undergone by the musicians. There could be single or multiple underlying mechanisms (pertaining to afferent & efferent auditory pathway) for the observed enhanced SPIN in musicians.

With respect to the afferent pathway, at the level of cortex, anatomical studies have shown changes secondary to the musical training. These changes were evident as greater volume of gray-matter (Gaser & Schlaug, 2003), larger area of corpus callosum (Ozturk, Tascioglu, Aktekin, Kurtoglu, & Erden, 2002; Hyde, Lerch, Norton, Forgeard, Winner, Evans, & Schlaug, 2009) and, more structured white matter (Bengtsson, Nagy, Skare, Forsman, Forssberg &, Ullen, 2005) in musicians compared to non-musicians. Further, at the subcortical level Kraus and Chandrasekaran (2010), based on the results of speech evoked brainstem responses reported that encoding of both spectral and temporal cues is enhanced by musical training.

SPIN has also been linked to efferent auditory pathways (corticofugal pathway & OCB). With respect to the corticofugal pathway, the efferent pathway shows generation of the templates as a result of continuous representation of the ongoing stimulus. This template is then taken as the reference for the incoming signal. If the template is similar to ongoing stimulus, only then it results in enhanced sensory processing (Haenschel, Vernon, Dwivedi, Gruzelier, & Baldeweg, 2005; Strait et al., 2010; Parbery-Clark, Strait, & Kraus, 2011). This ability to categorize the ongoing signal into similar or different as the internal template is especially essential for the exclusion of noise thus enhancing speech perception in noise (Chandrasekaran & Kraus, 2009). Also, the induced GBA is evidenced to be enhanced in musicians compared to non-musicians (Shahin et al., 2008) suggesting a stronger efferent pathway in musicians.

SPIN, in the past, also has been reported to be regulated by the OCB (Kumar & Vanaja, 2004). Deriving evidences from OCB studies that showed enhanced contralateral suppression of OAEs (Micheyl et al., 1997; Perrot et al., 1999; Ameen & Maruthy, 2011), and studies on loudness adaptation (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.

Patel (2011) further hypothesized that due to the frequent repetition, focused attention and precision involved in music activity apart from the physiological overlap of structures responsible for music and speech perception, the perception of speech is superior in musicians compared to non-musicians. This along with the findings of Song, Skoe, Banai, & 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. However, from the method adopted in the present study, it can not be inferred as to which of these domains played role in the participant of the present study.

It was also found in the present study that SPIN of music listener was same as that of the non-music listeners and as already stated it was poorer than that in musicians. From this finding, it can be inferred that only the active tasks like in music training triggers the training related changes in SPIN. The findings of the present study evidence absence of neuroplastic changes secondary to music listening. This means that the passive listening is not advantageous like active, formal training, at least for speech perception in noise. Ameen and Maruthy (2011) used contralateral suppression of OAEs as the index for functioning of corticofugal pathway in musicians, music listeners and, non-music listeners. They found that though musicians showed superior efferent pathway (OCB) functioning compared to the non-music listeners, there is no difference between the music listeners and non-music listeners. Hence, it may be inferred that SPIN is primarily regulated by the OCB and the changes seen in musicians is due to the training related changes in the corticofugal modulation of OCB.

However, there are no studies, to the best of author's knowledge, comparing the performance of speech perception in noise of music listeners with that of non-music listener.

5.4 Correlation of Training Duration and SPIN

It was found that there is no relationship between the number of year music training taken and the speech perception in noise. The measure of speech perception in noise in the present study was SNR-50. These findings were similar to the findings of Parbery-Clark, Skoe, Lam and, Kraus (2009), where HINT was used as measure of speech in noise performance. 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 within five years of training.

5.5 Effect of Group on Speech ABR

The hypothesis of this experiment was that the increased music exposure would enhance speech ABR. However, the findings showed that there was no difference in the speech ABRs of the three groups in any of the conditions. This 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 had also been demonstrated by Moreno et al. (2009) that this enhanced encoding is exclusively due to the music training and not because of inherent characteristic of musicians.

It has been documented that the onset age of music training is crucial for the music training induced changes in the anatomical and physiological characteristics of the brain. The anatomical evidences point out that the individuals with early-age (less than 7 years of age) of music training have more anterior corpus callosum volume (Schlaug, Jancke, Huang, Staiger, & Steinmetz, 1995) and, increased representation of auditory signals at cortical level (Pantev, Oostenveld, Engelien, Ross, Roberts, & Hoke, 1998). Watanabe, Savion- Lemieux, and Penhune (2007) showed that the anatomical and physiological changes are seen even when the number of training years were matched. 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. It could be assumed that this sensitivity period also results in the changes at subcortical level, for the processing of the speech. 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;). It is a possibility that if compared at discreet frequencies, the differences among the participant groups may be evident. However, this is only an assumption and need a systematic study before concluding.

This could be the explanation applied to inability to see any correlation between the years of music training and speech evoked ABR.

5.6 Effect of Group on Online Plasticity

The online plasticity is better as the music exposure increases, was the hypothesis for the experiment. This was the primary

To quantify the online plasticity the latency and amplitude measures obtained in the repetitive paradigm was subtracted from the latency and amplitude measures in the odd-ball paradigm. The difference values were used to test the group effect on online plasticity.

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. These findings suggest that the musicians were not advantageous in strengthening of the online plasticity. In the earlier studies (Lee et al., 2009; Musacchia et al., 2007; Strait et al., 2009; Hyde et al., 2009; Hannon & Trainor, 2008) evidences were shown for the long-term and short-term plasticity in the musicians, based on which it was hypothesized in the present study that online plasticity could also be better in these individuals. The present findings reject the hypothesis of the study. However, the conclusion is restricted to the group of musicians who started their training after about 11 years.

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. Thereby, taking the findings of the study of OCB (Micheyl et al., 1997; Perrot et al., 1999; Ameen & Maruthy, 2011) it may be inferred that the training related changes in OCB is the underlining mechanism of enhanced speech perception in noise in the present study.

5.7 Relation between Online Plasticity and SPIN

Physiologically, the online plasticity has been attributed to the corticofugal pathway. The training related changes in the corticofugal pathway is reported to be in the form of enhanced template formation for an ongoing stimulus (Haenschel et al., 2005; Parbery-Clark et al., 2011; Strait, et al., 2010). These template formations are reported to be important for the speech perception in noise (Chandrasekaran & Kraus, 2009). A recent electrophysiological study had documented a correlation between online plasticity and SPIN (Chandrasekaran & Kraus, 2009).

In agreement with the earlier study, 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.

Chapter 6

SUMMARY AND CONCLUSIONS

Music has pervasive effects on the auditory system. Consequent to music training, positive changes in the auditory neural system have been shown both at cortical and subcortical level. In addition to the universally accepted training related long-term and short-term plasticity changes, a recent research proposed the presence of a new type of plasticity called online plasticity. According to the proponents, these plastic changes occur within a very short duration (minutes or hours), due to repetitive presentation of any stimuli and have been attributed to the corticofugal modulations. Functionally, such modulations are reported to regulate speech perception in noise.

Because musicians have a trained corticofugal pathway, it was of interest to study whether, in addition to the long-term and short-term plasticity, musicians have better online plasticity. Hence, the primary objective of the present study was to compare the online plasticity and speech perception in noise among musicians and non-musicians. Further, it was not clear from the past research whether the evidenced training related changes in musicians is because of active task of music training or due to listening to music on a regular basis which is relatively a passive task . A comparison of plasticity across musicians, music listeners and controls would have thrown more light into the underlying mechanisms of observed plasticity. Hence, a second purpose of the study was to compare the online plasticity and speech perception in noise between musicians and music listeners.

The experiment was carried out on 30 normal hearing adults. The participants were categorized as musicians, music listeners and non-music listeners based on their kind and duration of music exposure. The musicians were undergoing formal training for at least past 5 years.

The three groups were compared with each other for their speech perception in noise and online plasticity. The online plasticity in these participants was measured through context-dependent encoding of speech evoked brainstem responses. The speech evoked ABRs were recorded for two types of stimulus paradigms a repetitive paradigm and the odd-ball paradigm. In the repetitive paradigm, brainstem responses were recorded for repetitive presentation of syllable /da/ while in the oddball paradigm, brainstem responses to /da/ were recorded in the context of either white noise or F2 filtered /da/. Speech perception in noise was behaviorally measured using SNR-50.

The transient brainstem responses were subjectively analyzed (to obtain latency and amplitude of wave V, A and C). The sustained responses were objectively analyzed on FFT to measure the amplitude of F0, F1 and HF.

In the results, it was seen that the transient responses (wave V & A) were elicited earlier in the repetitive paradigm compared to the odd-ball paradigms, for all the participant groups. However, the mean amplitude of the transient responses and sustained responses did not vary among different stimulus conditions, in any of the participant groups. Based on these results, it could be inferred that the brainstem undergoes selective enhancement of relevant information depending on the context, which could be attributed to the online plasticity. Also, it can be concluded based on the results that the spectrum and not envelope is the cue for context-dependent encoding.

The speech perception in noise was better in the musician group, compared to music listeners and, non-music listeners. These findings suggested that the enhanced corticofugal modulation of the OCB as a consequence of training is due to active music exposure like formal music training and not for passive exposure.

Unlike in some of the earlier studies, the present study did not evidence enhanced brainstem encoding of speech in musicians. Also, the online plasticity, as indexed in context-dependent encoding of brainstem responses was comparable among the three groups of participants. These findings refuted the hypothesis of the present study. The finding can be attributed either to the absence of enhanced online plasticity in musicians or to the late onset of training in the musicians of the present study.

The speech perception of noise partially correlated with the index of online plasticity but not with the number of years of music training. Based on these findings it could be concluded that, 5 years of music training would be sufficient to derive the maximum advantage in the modulation of corticofugal pathway. But, corticofugal pathway is not exclusively responsible for the perception of speech in the presence of noise. The other mechanisms involved may be the OCB, binaural integration etc.

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. Finally, it is concluded from these findings that only active tasks like singing and playing a musical instrument is advantageous for corticofugal regulation, not the relatively passive task like listening to music.

Implication of the Study

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.

Limitation of the Study

1. The musician group consisted of participants who received training after 11 years of age. Hence, the possible neuroplastic changes that occur only in the sensitive period (< 7 years) might have got missed in the present study.
2. In addition to the FFT analysis at frequency ranges corresponding to F0, F1 and HF, analysis at discreet frequencies would have facilitated better comparisons with the earlier studies where similar paradigm was used.

Future Direction

1. The online plasticity could be compared among the musicians who had early or late onset of training, probably keeping seven years as the cut-off age. This would derive the sensitivity period for changes in online plasticity.
2. The online plasticity could be studied in the clinical population such as dyslexia to understand the physiology of auditory brainstem and, mechanisms of poor speech perception in noise in these populations.

REFERENCES

American National Standards Institute. (1991). *American National Standard Maximum Permissible Ambient Noise Levels for Audiometric Test Rooms.* ANSI S3.1- (1991). New York: American National Standards Institute.

Adank, P., & Devlin, J. T. (2010). On-line plasticity in spoken sentence comprehension: Adapting to time-compressed speech. *Neuroimage,* 49(1), 1124- 1132.

Ameen, Md., & Maruthy, S. (2011). *Effect of music on neural plasticity of efferent auditory system.* Unpublished dissertation, University of Mysore, India.

Anderson, S., Skoe, E., Chandrasekaran, B., & Kraus, N. (2010). Neural Timing Is Linked to Speech Perception in Noise. *The Journal of Neuroscience*, 30(14), 4922– 4926.

Anderson, S., & Kraus, N. (2011). Neural encoding of speech and music: Implications for hearing speech in noise. *Seminars in Hearing.* 32, 129-141.

Anderson, S., Skoe, E., Chandrasekaran, B., Zecker, S., & Kraus, N. (2010). Brainstem correlates of speech-in-noise perception in children. *Hearing Research*. doi:10.1016/j.heares.2010.08.001.

Bailey, J., & Penhune, V. (2010) Rhythm synchronization performance and auditory working memory in early- and late-trained musicians. *Experimental Brain Research*, 204: 91e101.

Batra, R., Kuwada, S., & Maher, V. L. (1986). The frequency- following response to continuous tones in humans. *Hearing research*, 21, 167- 177.

Bengtsson, S. L., Nagy, Z., Skare, S., Forsman, L., Forssberg, H., & Ullen, F. (2005). Extensive piano practicing has regionally specific effects on white matter development. *Nature Neuroscience*, 8(9), 1148-1150.

Bent, T., Bradlow, A. R., & Wright, B. A. (2006). The Influence of Linguistic Experience on the Cognitive Processing of Pitch in Speech and Nonspeech Sounds. *Journal of Experimental Psychology: Human Perception and Performance*, 32(1), 97–103.

Bidelman, G. M., Gandour, J. T., & Krishnan, A. (2010). Cross-domain Effects of Music and Language Experiencee on the Representation of Pitch in the Human Auditory Brainstem. *Journal of Cognitive Neuroscience,* 23(2), 425–434.

Bronkhorst, A. W., & Plomp, R. (1990). A clinical test for the assessment of binaural speech perception in noise. *Audiology*, 29, 275- 285.

Chandrasekaran, B., & Kraus, N. (2010). The scalp-recorded brainstem response to speech: Neural origins and plasticity. *Psychophysiology*, 47, 236–246.

Chandrasekaran, B., Hornickel, J., Skoe, E., Nicol, T., & Kraus, N. (2009). Context-dependent encoding in the human auditory brainstem relates to hearing speech in noise: Implications for developmental dyslexia. *Neuron.* 64, 311-319.

Dewson, J.H., III. (1968). Efferent olivocochlear bundle: Some relationships to stimulus discrimination in noise. *Journal of neurophysiology*, 31, 122- 130.

Eggermont, J. J. (2007). Correlated neural activity as the driving force for functional changes in auditory cortex. *Hearing research*, 229(1-2), 69-80.

Folsom, R. C., & Aurich, C. D. (1987). Auditory brainstem responses from human adults and infants: influences of stimulus onset. *Audiology*, 26, 117-122.

Gao, E., & Suga, N. (1998). Experience-dependent corticofugal adjustment of midbrain frequency may in bat auditory system. *Proc Natl Acad Sci USA* 95, 12663-70.

Gardi, J., Merzenich, M., & McKean, C. (1979). Origins of the scalp recorded frequency- following response in the cat. *Audiology*, 18, 358–381.

Gaser, C., & Schlaug, G. (2003). Brain structure differ between musicians and non-musicians. *The Journal of Neuroscience*. 23(27), 9240-9245.

Giraud, A. L., Collet, L., Chery- Croze, S., Magnan, J., & Chays, A. (1995). Evidence of a medial olivocochlear involvement in contralteral suppression of otoacoustic emissions in humans. *Brain Research*, 705 (1-2), 15- 23.

Goncalves, I. C., Wertzner, H. F., Samelli, A. G., & Matas, C. G. (2011). Speech and non-speech processing in children with phonological disorders: an electrophysiological study. *Clinical Science*, 66 (2), 293-298.

Gorga, M. P., Beauchaine, K. A., Reiland, J. K., Worthington, D. W., & Javel, E. (1984). The effects of stimulus duration on ABR and behavioral thresholds. *Journal of Acoustic Society of America*. 76(2).

Guinan, J. J. (2006) Olivocochlear efferents: anatomy, physiology, function, and the measurement of efferent effects in humans. *Ear Hearing,* 27(6): 589-607.

Haenschel, C., Vernon, J. D., Dwivedi, P., Gruzelier, J. H., & Baldeweg, T. (2005). Event- Related Brain Potential Correlates of Human Auditory Sensory Memory-Trace Formation. *J. Neurosci*. 25: 10494-10501

Hanan, T., & Maruthy, S. (2011). *Effect of context on brainstem encoding of speech*. Unpublished dissertation. University of Mysore, Mysore.

Hannon, E. E. & Trainor, L. J. (2008). Music acquisition: effects of enculturation and formal training on development. *Trends Cogn. Sci.* 11, 466–472.

Harris, D. M. (1977). *Forward masking and recovery from short-term adaptation in single auditory-nerve fibers.* Doctoral dissertation, Northwestern University, Evanston, IL.

Harris, D. M., & Dallos, P. J. (1979). Forward masking of auditory nerve fiber responses. *Neurophysiology,* 42 , 1083-1107.

Heinze, H. J., Munte, T. F., Kutas, M., Butler, S. R., Naatanen, R., Nuwer, M. R., & Goodin, D.S. (1999). Cognitive event- related potentials. Guidelines of the International Federation of Clinical Physiology. *EEG*, 52.

Hornickel, J., Knowles, E., & Kraus, N. (2011). Test-retest consistency of speech-evoked auditory brainstem responses in typically-developing children. *Hearing Research*. 284, 52-58.

Hood, L. (1998). Clinical applications of the auditory brainstem response. San Diego: Singular.

Hoormann, J., Falkenstein, M., Hohnsbein, J., & Blanke, L. (1992). The human frequency-following response (FFR): Normal variability and relation to the click-evoked brainstem response. Hearing Research, 59, 179–188.

Hyde, K. L., Lerch, J., Norton, A., Forgeard, M., Winner, E., Evans, A. C., & Schlaug, G. (2009). Musical Training Shapes Structural Brain Development. *The Journal of Neuroscience*, 29(10), 3019 –3025.

Jewett, D. L. & Williston, J. S. (1971). Auditory evoked far-fields averaged from the scalp of humans. *Brain*, 94, 681-96.

Johnson, K., Nicol, T., Zecker, S., & Kraus, N. (2007) Auditory brainstem correlates of perceptual timing deficits. *Journal of Cognitive Neuroscience* 19: 376-385.

Johnson, K. L., Nicol, T. G., Zecker, S. G., Bradlow, A., Skoe, E., & Kraus, N. (2008). Brainstem encoding of voiced consonant-vowel stop syllables. *Clinical Neurophysiology,* 119, 2623–2635.

King, A. J. (1997). Sensory processing: Signal selection by cortical feedback. *Current Biology.* 7(2), 85-88.

King, C., Warrier, C. M., Hayes, E., & Kraus, N. (2002). Deficits in auditory brainstem pathway encoding of speech sounds in children with learning problems. *Neuroscience Letters,* 319, 111–115.

Kraus, N., & Nicol, T. (2005). Brainstem origins for cortical "what" and "where" pathways in the auditory system. *Trends in Neurosciences,* 28, 176-181.

Kraus, N., McGee, T. J., & Carrell, T. D. (1996). Auditory neurophysiologic responses and discrimination deficits in children with learning problems. *Science*, 273, 971–973.

Kraus, N., Skoe,E., Parebery-Clark, A., & Ashley, R. (2009). Experience-induced Malleability in Neural Encoding of *Pitch*, *Timbre*, and *Timing*: Implications for Language and Music. *The Neuroscience and Music III- Disorders and Plasticity: Ann N Y Acad Sci*, 1169, 543–557.

Krishnan, A. (2007). Frequency-Following Response. In R. F. Burkard, J. J. Eggermont, M. Don (Eds.). *Auditory Evoked Potentials: Basic Principles and Clinical Application* (pp, 313–335). Philadelphia, PA: Lippincott Williams & Wilkins.

Krishnan, A., & Gandour, J. T. (2009). The role of the auditory brainstem in processing linguistically-relevant pitch patterns. *Brain & Language,* 110, 135–148.

Krishnan, A., Swaminathan, J., & Gandour, J. T. (2008). Experience-dependent enhancement of Linguistic Pitch Representation in the Brainstem Is Not Specific to a Speech Context. *Journal of Cognitive Neuroscience*, 21(6), 1092–1105.

Krishnan, A., Gandour, J. T., & Bidelman, G. M. (2010). Brainstem pitch representation in native speakers of Mandarin is less susceptible to degradation of stimulus temporal regularity. *Brain Research*, 1313, 124–133.

Krishnan, A., Gandour, J. T., Bidelman, G. M., & Swaminathan, J. (2009). Experience dependent neural representation of dynamic pitch in the brainstem. *Neuroreport*, 20(4), 408–413.

Krishnan, A., Xu, Y., Gandour, J. T., & Cariani, P. A. (2004). Human frequency-following response: Representation of pitch contours in Chinese tones. *Hearing Research*, 189, 1–12.

Krishnan, A., Xu, Y., Gandour, J., & Cariani, P. (2005). Encoding of pitch in the human brainstem is sensitive to language experience. *Cognitive Brain Research*. 25, 161 – 168.

Kumar, U. A., Hegde, M., & Mayaleela. (2010). Perceptual learning of non-native speech contrast and functioning of the olivocochlear bundle. *International Journal of Audiology,* 49(7), 488-96(9).

Kumar, U. A., & Vanaja, C. S. (2004). Functioning of Olivocochlear Bundle and Speech Perception in Noise. *Ear & Hearing,* 25(2), 142-146.

Lee, K. M., Skoe, E., Kraus, N., and Ashley, R. (2009). Selective subcortical enhancement of musical intervals in musicians. *The Journal of Neuroscience,* 29(18), 5832–5840.

Levine, R. A., Gardner, J. C., Fullerton, B. C., Stufflebeam, S. M., Carlisle, E. W., Furst, M., Rosen, B. R., & Kiang, N. Y. S. (1993). Effects of multiple sclerosis brainstem lesions on sound lateralization and brainstem auditory evoked potentials. *Hearing Research*, 68(1), 73-88.

Luo, F.,Wang, Q., Kashani, A., & Yan, J. (2008). Corticofugal modulation of initial sound processing in the brain. *Journal of Neuroscience, 28*, 11615-21.

Maddieson, I. (1984). *Patterns of Sounds.* Cambridge [Cambridgeshire], NY: Cambridge University Press.

Madhok, P., & Sandeep, M. (2010). *Neurophysiological consequence of auditory training: Subcortical and cortical structures.* Unpublished dissertation, University of Mysore, India.

Marsh, J. T., Brown, W. S., & Smith, J. C. (1974). Differential brainstem pathways for the conduction of auditory frequency-following responses. *Electroencephalogr. Clinical Neurophysiology*, 38, 415-422.

Marsh, J. T., Worden, F. G., & Smith, J. C. (1970). Auditory frequency-following responses in the central auditory pathway: Neural or artifact? *Science,* 169, 1222-1223.

Martin, W. H., Pratt, H., & Schwegler, J. W. (1995). The origin of the human auditory brain-stem response wave II. *Electroencephalography and Clinical Neurophysiology/Evoked Potentials Section,* 96(4), 357-370.

Micheyl, C., Carbonnel, O. & Collet, L. (1995). Medial olivocochlear system and loudness adaptation: differences between musicians and non-musicians, *Brain Cognit.*, 29, 127–136.

Micheyl, C., Khalfa, S., Perrot, X., & Collet, L. (1997). Difference in cochlear efferent activity between musicians and nonmusicians. *NeuroReport*, 8, 1047–1050.

Møller, A. R., & Jannetta, P. J. (1985). Neural generators of the auditory brainstem response. In J.T. Jacobson, (Ed.), *The Auditory Brainstem Response.* (pp. 13–31). San Diego: College Hill Press.

Moreno, S., Marques, C., Santos, A., Santos, M., Castro, S. L., & Besson, M. (2009). Musical training influences linguistic abilities in 8-year-old-children: More evidence from brain plasticity. *Cerebral Cortex*, 19(3), 712-23.

Morimoto, Y., & Sakabe, T. M.. (2006). *Auditory evoked potentials,* 55(3), 314-21.

Mulders, W.H.A.M., & Robertson, D. (2000). Evidence for direct cortical innervation of medial olivocochlear neurons in rats. *Hearing Res*earch. 144, 65–72.

Musacchia, G., Sams, M., Skoe, E., & Kraus, N. (2007). Musicians have enhanced subcortical auditory and audiovisual processing of speech and music. *PNAS*, 104(40), 15894–15898.

Musser, K. E. (2010). Effect of unilateral hearing loss on the speech evoked auditory brainstem response in the presence of noise. *Independent Studies and Capstones.* Paper 602. Program in Audiology and Communication Sciences, Washington University School of Medicine.

Ozturk, A.H., Tascioglu, B., Aktekin, M., Kurtoglu, Z., & Erden, I. (2002). Morphometric comparison of the human corpus callosum in professional musicians and non-musicians by using in vivo magnetic resonance imaging. *J Neuroradiol* 29:29 –34.

Pantev, C., Oostenveld, R., Engelien, A., Ross, B., Roberts, L. E. & Hoke, M. (1998). Increased auditory cortical representation in musicians. *Nature*, 392, 811-13.

Parbery-Clark, A., Skoe, E., & Kraus, N. (2009). Musical Experience Limits the Degradative Effects of Background Noise on the Neural Processing of Sound. *The Journal of Neuroscience*, 29(45), 14100 –14107.

Parbery-Clark, A., Skoe, E., Lam, C., & Kraus, N. (2009). Musician enhancement for speech in noise. *Ear and Hearing*. 30(6), 653-661.

Parbery-Clark, A., Strait, D. L., & Kraus, N. (2011). Context-dependent encoding in the auditory brainstem subserves enhanced speech-in-noise perception in musicians. *Neuropsychologia*. 49, 3338–3345.

Parbery-Clark, A., Strait D. L., Anderson, S., Hittner, E., & Kraus, N. (2011). Musical Experience and the Aging Auditory System: Implications for Cognitive Abilities and Hearing Speech in Noise. *PLoSONE*. 6(5), e18082. doi:10.1371/journal.pone.0018082.

Parkkonen, L., Fujiki, N., & Makela, J. P. (2009). Sources of Auditory Brainstem Responses Revisited: Contribution by Magnetoencephalography. *Human Brain Mapping,* 30, 1772–1782.

Patel, A. D., Why would musical training benefit the neural encoding of speech? The OPERA hypothesis. *Frontiers in psychology*, 142 (2), doi: 10.3389/fpsyg.2011.00142.

Penhune, V. B. (2011). Sensitive periods in human development: Evidence from musical training. *Cortex*, 47. 1126-37.

Perrot, X., Micheyl, C., Khalfa, S., & Collet, L. (1999). Stronger bilateral efferent influences on cochlear biomechanical activity in musicians than in non-musicians. *Neuroscience Letters*. 262, 167–170.

Prasher, D., Ryan, S., & Luxon, L. (1994). Contralateral suppression of transient evoked otoacoustic emissions and neuro-otology. *British Journal of Audiology*, 28, 247- 254.

Rissling, A. J., & Light, G. A. (2010). Neurophysiological measures of sensory registration, stimulus discrimination, and selection in Schizophrenia patients. In Swerdlow, N. R. (Ed.). *Behavioral neurobiology of Schizophrenia and its treatment* (pp 284- 303).

Russo, N., Nicol, T., Musacchia, G., & Kraus, N. (2004). Brainstem responses to speech syllables. *Clinical Neurophysiology*, 115(9), 2021–2030.

Russo, N. M., Nicol, T. G., Zecker, S. G., Hayes, E. A., & Kraus, N. (2005). Auditory training improves neural timing in the human brainstem. *Behavioural Brain Research*, 156, 95–103.

Russo, N., Nicol, T., Trommer, B., Zecker, S., & Kraus, N. (2009). Brainstem transcription of speech is disrupted in children with autism spectrum disorders. *Developmental Science*, 12(4): 557– 567. doi:10.1111/j.1467-7687.2008.00790.x.

Sarter, M., Givens, B., & Bruno, J. P. (2001). The cognitive neuroscience of sustained attention: where top-down meets bottom-up. *Brain Research Reviews*, 35, 146–160.

Schlaug, G., Jancke, L., Huang, Y., Staiger, J. F., & Steinmetz, H. (1995). Increased corpus callosum size in musicians. Neurophysiologia, 33(8), 1047-1055.

Schulte-Körne, G., Deimel, W., Bartling, J., & Remschmidt, H. (1998). Auditory processing and dyslexia: evidence for a specific speech processing deficit. *NeuroReport*, 9, 337–340.

Shahin, D., Roberts, L.E., Chau, W., Trainor, L.J., & Miller, L.M. (2008). Music training leads to the development of timber- specific gamma band activity. *Neuroimage*, 41, 113- 122.

Shinn-Cunningham, B. (2001). Models of Plasticity in Spatial Auditory Processing. To appear in the Proceedings of the IUPS-EARSAT, a special issue of Audiology and Neuro-Otology, R. Rajan, P. Thorne and G. Housley (eds.) , Aukland, New Zealand.

Skoe, E., & Kraus, N. (2010a). Auditory Brain Stem Response to Complex Sounds: *A Tutorial. Ear & Hearing*, 31(3), 302-324.

Skoe, E., & Kraus, N.(2010b). Hearing it again and again: On-line subcortical plasticity in humans. *PlosONE.* 5(10): e13645, doi:10.1371/journal.pone.0013645.

Smith, R. L. (1977). Short-term adaptation in single auditory nerve fibers: Some post stimulatory effects. *Neurophysiology*. 40, 1098-1112.

Smith, R. L. (1979). Adaptation, saturation and physiological masking in single auditory- nerve fibers. *Journal of Acoustic Society America.* 65, 166-178.

Smith, J. C., Marsh, J. T., & Brown, W. S. (1975). Far-field recorded frequency-following responses: Evidence for the locus of brainstem sources. *Electroencephalogram. Clinical Neurophysiol,* 39, 465-472.

Spangler, K. M., & Warr, W. B. (1991). The descending auditory system. In Altschuler, R. A., Bobbin, R. P., Clopton, D.W., & Hoffman (Ed.); Neurobiology of Hearing: The central auditory system (pp 27-45), Raven Press, New York.

Sohmer, H. & Feinmesser, M. (1967). Cochlear action potentials recorded from the external ear in man. *Ann. Als. Of Otology, Rhinology & Laryngology*, 76, 427-35.

Song, J. H., Skoe, E., Wong, P. C. M., & Kraus, N. (2008). Plasticity in the Adult Human Auditory Brainstem following Short-term Linguistic Training. *Journal of Cognitive Neuroscience,* 20(10), 1892–1902.

Song, J. H., Skoe, E., Banai, K., & Kraus, N. (2011). Perception of speech in noise: neural correlates. *Journal of Cognitive Neuroscience,* 23(9), 2268–2279.

Song, J., Skoe, E., Banai, K., & Kraus, N. (2012) Training to improve hearing speech in noise: Biological mechanisms. *Cerebral Cortex.* 22:1180--1190.

Starr, A. (1976). Correlation between confirmed sites of neurological lesions and abnormalities of far-field auditory brainstem responses. *Electroencephalography and Clinical Neurophysiology,* 41(6), 595-608.

Strait, D. L., Kraus, N., Skoe, E., & Ashley, R. (2009). Musical experience and neural efficiency – effects of training on subcortical processing of vocal expressions of emotion. *European Journal of Neuroscience*, 29, 661–668.

Strait, D.L., Kraus, N., Parbery-Clark, A.,, & Ashley R. (2010). Musical experience shapes top-down auditory mechanisms: evidence from masking and auditory attention performance. *Hearing Research.* 261, 22-29.

Suga, N., Gao, E., Ma, X., Sakai, M., & Chowdhury, S. A. (2001). Corticofugal system and processing of behaviorally relevant sounds: perspective. *Acoustic. Sci & Tech,* 22(2), 85- 91.

Suga, N., Gao, E., Zhang, Y., Ma, X., & Olsen, J. F. (2000). The corticofugal system for hearing: Recent progress. *PNAS*, 97(22), 11807–11814.

Suga, N. (2007). Role of corticofugal feedback in hearing. *Journal of Comparative Physiology A: Neuroethology, Sensory, Neural, and Behavioral Physiology,* 194(2), 169-183.

Swaminathan, J., Krishnan, A., Gandour, J. T., & Xu (2008). Applications of Static and Dynamic Iterated Rippled Noise to Evaluate Pitch Encoding in the Human Auditory Brainstem. *IEEE Transactions on Biomedical Engineering*, 55(1), 281- 287.

Tallal, P., & Stark, R. E. (1981). Speech acoustic-cue discrimination abilities of normally developing and language-impaired children. *Journal of Acoustic Society of America*, 69, 568–574.

Tanaka, H. & Hirata, K. (2008). Methodological aspects of ERP: integration approach from temporal and spatial domain. In Ikeda, A., & Inoue, Y. (Ed.). *Event-related potentials in patients with epilepsy: from current state to future prospects* (pp 219-232). John Libbey Eurotext.

Thakur, A. & Kumar, A. U. (2008). *Development of Quick speech in noise test for English speaking Indian children.* Unpublished dissertation, Mangalore University, Mangalore.

Thornton, A. R. D. (2007). Instrumentation and Recording Parameters. In R. F. Burkard, J. J. Eggermont, M. Don (Eds). *Auditory Evoked Potentials: Basic Principles and Clinical Application* (pp, 42–72). Philadelphia, PA: Lippincott Williams & Wilkins.

Trainor, L.J. (2005). Are there critical periods for musical development? *Developmental Psychobiology, 46*, 262–278.

Trainor, L.J., Shahin, A.j., & Roberts, L.E. (2009). Understanding the benefits of music training: Effect on oscillatory brain activity. *Annuals of the New York Academy of Science*, 1169, 133- 142.

Tremblay, K., & Kraus, N. (2002). Beyond the ear: central auditory plasticity. *Otorinolaringology*. 52: 93- 100.

Tremblay, K., Kraus, N., Carrell, T. D., & McGee, T. (1997). Central auditory system plasticity: Generalization to novel stimuli following listening training. *Journal of Acoustic Society of America.* 102 (6).

Turner, C. W., Fabry, D. A., & Barrett, S. (1992). Detection and recognition of stop consonants by normal hearing and hearing impaired listeners. *Journal of Speech and Hearing Research*, 35, 942–949.

Watanabe, D., Savion-Lemieux, T., & Penhune, V. (2007). The effect of early musical training on adult motor performance: evidence for a sensitive period in motor learning. Exp Brain Res, 176(2), 332–340

Wible, B., Nicol, T., & Kraus, N. (2004). Atypical brainstem representation of onset and formant structure of speech sounds in children with language-based learning problems. *Biological Psychology*, 67, 299–317.

Winer, J.A., & Prieto, J.J. (2001). Layer V in cat primary auditory cortex (AI): cellular architecture and identification of projection neurons. *J.Comp. Neurol.* 434, 379–412.

Wong, P. C. M., Skoe, E., Russo, N. M., Dees, T., & Kraus, N. (2007). Musical experience shapes human brainstem encoding of linguistic pitch patterns. *Nature Neuroscience.* 10 (4), 420- 422.

Worden, F. G., & Marsh, J. T. (1968). Frequency-following (microphonic-like) neural responses evoked by sound. *Electroencephalograp. Clin. Neurophysiol*, 25, 45-52.

Yan, W., & Suga, N. (1998). Corticofugal modulation of the midbrain frequency mapin the bat auditory system. *Nature Neurosci* 1, 54–58.

Annexure I

Checklist

Name of participant: Age/ Gender:

Section	Questions	Responses
A	***Otological and Audiological History***	
	Do you have problem in understanding speech in the presence of noise?	
	Do you have history/ complaint of any middle ear infections?	
	Do you have history/ complaint of ear pain?	
	Do you have history/complaint of ear discharge?	
	Do you have history of any middle ear surgery?	
	Do you have complaint/ history of tinnitus?	
	Do you have history/ complaint of vertigo/ giddiness?	
	Do you have complaint of blocking sensation in your ears?	
B	***Music Training***	
	Have you taken formal music training? (if no, please go to 10.a)	
	Since how many years have you been receiving the training?	
	At what age did you start the training?	
	What type of training have you received? Vocal/Instrumental?	
	Have you ever discontinued the training? (if yes, elaborate)	
	Can you attend to other task while listening to music?	
C	***Music Exposure***	
	Do you listen to music regularly?	
	For what duration do you listen to music (per day & per week)?	
	What type of music do you prefer? Instrumental/ vocal?	
	Since how many years have you been listening to music?	
	You prefer speaker or headphone (or earphone) for listening music?	
	Can you attend to other task while listening to music?	