COMPARISON OF MMN AND DLF IN EXPERIENCED MUSICIANS

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CERTIFICATE

This is certify that this dissertation entitled **"*Comparison of MMN and DLF in Experienced Musicians*"** is the bonafide work submitted as part fulfillment for the Degree of Master of Science in Audiology of the student with Registration No. 13AUD007. 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.

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CERTIFICATE

This is to certify that this dissertation entitled **"*Comparison of MMN and DLF in Experienced Musicians*"** has been prepared under my supervision and guidance. It is also certified that this has not been submitted earlier to any other Universities for the award of any other Diploma or Degree.

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DECLARATION

This dissertation entitle **"*Comparison of MMN and DLF in Experienced Musicians*"** is the result of my own study under the guidance of Dr. Prawin Kumar, Lecturer in Audiology, Department of Audiology, All India Institute of Speech and Hearing, and has not been submitted earlier in any other University for the award of any Diploma or Degree.

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Abstract

Present study aimed to find out the relationship between MMN and DLF in musicians and non-musicians. There were total 50 participants, out of which experimental group had 25 adult musicians and 25 age-matched non-musicians served as control group. Experimental group participants had minimum professional music experience of 5 years. However, control group participants were not having any formal training of music. Mismatch negativity (MMN) was recorded with pair of stimuli having /1000Hz/ and /1100Hz/ with /1000Hz/ as frequent stimulus and /1100Hz/ as the infrequent stimulus. Difference Limens of frequency (DLF) was assessed at 1000 Hz with the help of MATLab software using maximum likelihood procedure technique. Out of 25 musicians and 25 non-musicians, MMN was present only in 17 (68%) musicians and 16 (64%) non-musicians. Hence, further statistical analyses were done only for 17 musicians and 16 non-musicians. MMN was analyzed for onset latency, offset latency, peak latency, peak amplitude and area under the curve parameters. Descriptive statistics shows better waveform morphology among musicians in comparison to non-musicians. Further, MANOVA was done which showed marginal significant difference for onset latency and no significant difference observed for offset and peak latency, whereas statistically significant difference for peak amplitude and area under curve was seen between two groups. Similarly, Independent t-test showed statistically significant difference in DLF between two groups. Correlation analysis showed negative relationship with DLF across all measures of MMN, though it was not statistically significant. Absence of significant difference may be due to poor reliability and high variability in latency measures of MMN. Based on MMN and DLF outcomes, present study probably points towards enhancement of pre-attentive auditory discrimination skills and enhanced active auditory discrimination skills in musicians. Lack of significant correlation between DLF and MMN in musicians could be because they represent different processes and may not be a viable option for each other.

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Chapter-1

Introduction

Electrophysiological measures are one of the objective modes of assessment to check the integrity of the auditory function. These measures complement the information provided by the behavioral measures. An auditory evoked potential is one of the electrophysiological measures which describes as series of electrical changes occurring in the peripheral and central nervous system, usually related to the sensory pathways. The auditory evoked potential is further classified as endogenous and exogenous potential. The exogenous potentials are primarily evoked by some external event related dimension of the stimulus. The endogenous potentials are responses which are due to internal events such as cognition or perception. Studies has been considered the possibility of studying auditory discrimination using a technique referred as event related potentials (Sams, Paavilainen, Alho & Naatanen, 1985; Novak, Ritter, Vaughan & Wiznitzer, 1990; Ceponinene, Kushnerenko, Fellman, Renlund, Suominen & Naatenen, 2002; Chang, Iizuka, Naruse, Ando & Maeda, 2014).

Event related potentials are virtually the only means that the current technology provides to evaluate the physiologic events of the normal brain, as it performs spectacular feats of information processing (Naatanen & Alho, 1997). The mismatch negativity (MMN) is a component of event related potential has been extensively used to study the pre-attentive auditory discrimination skill and storage of regularities in features of stimulus (Paavilainen, 2013). Mismatch Negativity is a negative component of the event related potential (ERP) elicited by any discriminable changes in auditory stimulation (Naatanen & Alho, 1997). It reflects central processing of very fine acoustics differences in acoustic stimuli. It can occur when the difference between the standard and deviant stimuli is as small as 8Hz or even when stimulus differences are near psychophysical threshold (Sams et al, 1985; Kraus et al. 1993). All acoustic features that are discriminable elicit MMN, such as change in intensity, frequency, duration, rise-time and perceived location. In addition to that, Sams et al., 1985 also showed that MMN were present, when the deviant stimuli were just discriminable from the standard stimuli even though the differences were not perceptible. It appears that MMN reflects neuronal representation of the discrimination of numerous auditory stimulus attributes. MMN is usually obtained by presenting a train of repetitive homogenous tones at a rate of around one tone per second, occasionally interspersed with a tone that differs physically (Gomes et al., 1995). If MMN reflects the ability to discriminate between the acoustic stimuli, then it may not only be of research interest but may have clinical importance because speech perception, by its nature, depends on neuronal responses to changes in stimulus (Kraus et al., 1994). MMN is shown to be an objective index of the discrimination accuracy that correlates well with the behavioural discrimination thresholds. Lang, Nyrke, Aaltonen, Raimo and Naatanen (1990) recorded MMN to a frequency deviance and correlated it to a behavioral discrimination task. They divided their participants into three groups (good, poor & intermediate) based on their performance in the behavioural discrimination task and found that MMN was present for a smaller frequency deviance in the good performers group. On the other hand, in poor performers group, MMN was elicited with a greater frequency deviance. Thus, MMN is considered as an objective neurophysiological test of auditory discrimination.

Several studies investigated MMN in musicians and non-musicians using tonal as well as speech stimuli (Peretz, 2006; Boh, Herholz, Lappe, Pantev, 2011; Kuhnis, Elmer, Meyer & Jäncke, 2013; Habibi, Wirantana, & Starr 2014; Putkinen, Tervaniemi, Saarikivi, Vent & Huotilainen, 2014). The results revealed better performance of musicians in comparison to non-musicians irrespective of stimuli. The musician’s brain is presumed to be a good and appropriate model to investigate neuroplastic changes (Munte, Altenmuller, & Jancke, 2002). Professional musicians have fine tuning of aural skills which is achieved by ear training that musical students receive during their musical training and it is considered as important component of their vocational formation (Herdener et al., 2010). A study done by Boh et al., in 2011 on 8 musicians and 13 non-musicians with sine-tones as stimulus shows enhancement of the MMN in musicians compared to non-musicians. This finding indicate that long-term musical training differentially influence the memory capacity of auditory short-term memory for sine-tones. Study done by Kuhnis et al., in 2013 investigated MMN in musicians and non-musicians using vowels and temporally manipulated consonant vowel syllables as stimuli. They found that musicians are not only advantaged in the pre- attentive encoding of temporal speech cues, but most notably also in processing vowels. A study done by Habibi et al., in 2014 recorded behavioral and event-related brain potential responses of musicians and non-musicians to discrepancies of rhythm between pairs of unfamiliar melodies based on western classical rules. They noticed that musicians could able to detect rhythm deviations significantly better than non-musicians. Musical training helps in enhancing auditory discrimination for musically central sound dimensions in pre-adolescence (Putkinen et al., 2014). A study done by Virtala, Huotilainen, Partanen, and Tervaniemi in 2014 used inverted major chord and minor chord, which were presented in the context of major chords to musicians and non-musicians. The results revealed that MMN was evoked to inverted major chord and minor chord in musicians only, and N1 amplitude was larger in musicians than non-musicians. This study also measured active discrimination task using inverted major chord and minor chord showed processing of complex musical stimuli is enhanced in musicians both neurally and behaviorally.

It has been realized for a long time that there is an importance of good pitch discrimination abilities, not only to psychoacousticians but also in musicians. Psychoacoustic measures comparing frequency discrimination thresholds, also known as difference limen for frequency (DLF), for musicians and non-musicians reported significantly smaller discrimination threshold for musicians (Rabin, Amir, Vexler, & Zaltz, 2001). Rabin et al. (2001) reported that an instrumental musician has 50% smaller DLF for pure tones than non-musicians, which suggest extensive musical training influences auditory pitch discrimination. Psychoacoustic research also showed that auditory skills may differ between musicians of different musical genres. In another study done by Bidelman and Krishnan in 2010 on musicians and non-musicians with fundamental (F0) and first formant (F1), frequency difference limens (DLs), showed that the musicians threshold of DLs which were 2-4 times better than non-musicians. Further, Bidelman, Gandour and Krishnan in 2011 compared brainstem encoding and perceptual benefit in musicians and tonal language speaker. They observed that only musicians showed connections between behavioral and neural measures. Further, lower frequency discrimination threshold discriminated by musicians could be due to cortical reorganization. However, there are very few studies explored combination of event related potentials and difference limens for frequency measures in musicians.

1.1. Need for the study

There are several studies highlighting the enhanced MMN and DLF in musicians (Bidelman & Krishnan, 2010; Boh et al., 2011; Habibi et al., 2014; Putkinen et al., 2014). However, only few studies (Tervaniemi, Just, Koelsch, Widmann & Schroger, 2005; Habibi et al., 2014; Virtala et al., 2014) have shown the relationship between active auditory discrimination and pre-attentive auditory discrimination among musicians and non-musicians. There is a dearth of literature to explore the combination of MMN and DLF measures in musicians. Further, there is need to find out the relationship between MMN and DLF measures in musicians.

A study done by Vinod in 2012, recorded BioMARK in Carnatic musicians revealed that musicians had a more enhanced representation at the sub-cortical level in Indian population. Another study done by Verma in 2012 revealed no significant difference in the latencies of P1, N1 and N2 between musicians and non-musicians for speech evoked long latency response (LLR) in Indian population. However there is a dearth of literature on abilities of MMN and DLF of musicians in Indian population. There is a need to determine whether a significant difference exists between musicians and non- musicians in DLF and MMN in Indian population. It is also a research question that whether formally trained musicians has enhanced MMN and smaller DLF.

1.2 Aim of the study

To assess the relationship between MMN and DLF in musicians and non-musicians.

1.3 Objective of the study

1. To determine the onset latency, offset latency, peak latency, peak amplitude and area under the curve of MMN in musicians and non-musicians.
2. To determine the threshold of frequency discrimination (DLF) in musicians with age matched non-musicians.
3. To determine the relationship between MMN and DLF in musicians and non-musicians.

Chapter 2

Review of Literature

2.1 Auditory evoked potential in musicians.

2.1.1 Brainstem auditory evoked potential in Musicians

Wong, Skoe, Russo, Dees and Kraus in 2007 recorded brainstem encoding of linguistic pitch. Result showed that musicians reflects more enhanced and better encoding of linguistic pitch than non-musicians. Similar study done by Lee, Skoe, Kraus and Ashley in 2009 assessed auditory brainstem responses in 10 adult musicians and 11 non-musicians. In the musicians group there were six pianists, tow vocalists and two violinists with 10 or more years of musical training. The stimuli used were two musical interval, the minor seventh and major sixth. Result showed that there was significant difference found in the spectral analysis of the frequency following response. Musicians had significantly greater amplitude for the harmonics compared to non-musicians. The other major finding of this study was that the number of years of musical exposure and training was well correlated with the amplitude of each of the frequency.

Clark, Skoe and Kraus in 2009 recorded subcortical neurophysiological response to speech in noise and quiet for experienced musicians and non-musicians. The stimuli taken was CV speech syllable /da/ of 170 ms in quiet and background noise consisted of multi-talker babble. Result showed that musicians were having higher similarity between brainstem response of speech in quiet and noise. This showed that incorporating background noise was not able to degrade brainstem responses in musicians when compared to quite condition. However, poor brainstem responses were seen in non-musicians using speech stimuli as presentation in noise. This indicates that addition of background noise, deteriorates brainstem responses in non-musicians when performance were compared to quite condition. These outcome showed that musical training and experience curb the negative effects of competing background noise, thereby giving the evidence for musicians' perceptual advantage for speech-in-noise.

Bidelman and Krishnan in 2010 investigated brainstem frequency following responses in adult musicians and age matched non-musicians in response to the vowel /i/ at different level of reverberation. Result showed that reverberation had little influence on the neural encoding of pitch but it significantly degraded neural encoding of formant-related harmonics. In other study by Bidelman, Krishnan and Gandour in 2011 recorded brainstem frequency following response in musicians and non-musicians. The stimuli taken was tuned and detuned chordal arpeggios which was differing only in pitch. Result revealed that musicians showed faster and enhanced neural synchronization and enhanced brainstem encoding for defining characteristics of musical sequences regardless of whether they were in or out of tune. Whereas, non-musicians had relatively stronger representation for minor/major chords but showed poor responses for detuned chords. A study done by Bidelman, Gandour and Krishnan in 2011 compared auditory evoked responses from brainstem among 11 English speaking musicians, 11 non-musicians and 11 native speaker of Mandarine Chinese in the age range of 21 to 25 years. The musicians were having musical experience of more than 10 years. The stimuli used were tuned and detuned musical cords. The result showed that musicians and native speaker of Mandarian Chinese had enhanced representation of defining pitches of musical sequences at brainstem level in comparison to non-musicians.

Clark, Strait and Kraus in 2011 investigated subcortical encoding of speech syllable in variable and predictable condition in adult musicians. Musicians showed enhanced neural encoding of the fundamental frequency of speech presented in the predictable condition compared to the variable condition than non-musicians. Finding showed that subcortical sensitivity to the speech regularity was modified by musical training and exposure. Clark, Tierney, Strait and Kraus in 2012 investigated the extent to which timing difference of subcortical responses with speech syllable /ba/, /da/ and /ga/ in adult musicians and non-musicians. The result showed that musicians exhibit enhanced subcortical discrimination of closely related speech sounds than non-musicians. Clark, Anderson, Hittner and Kraus in 2012 compared auditory brainstem timing in older and younger musicians and non-musicians. The stimulus taken was a CV speech sound /da/. The result showed that musicians are unsusceptible to age related slowdown in neural timing. Strait, O’Connell, Parbery, and Kraus in 2014 recorded brainstem encoding of speech syllable /ga/ and /ba/ as well as visual and auditory cognitive abilities across 3 different age range: preschoolers, school-aged children, and adults in musicians and non-musicians. The result revealed that musicians had more clearly neural encoding of stop consonants early in life (as young as age 3) and was seen in children with few years of training. It concludes that musicians had enhanced neural differentiation of stop consonants early in life and with as little as few years of musical experience.

From the above literature it can be concluded that musicians had enhanced spectral analysis of the frequency following responses. It also indicates that musicians were also having higher similarity between brainstem responses in quiet and noise. It was also observed that musicians showed rapid neural synchronization and enhanced brainstem encoding for defining characteristics of musical sequences. Above literature also highlights that musicians exhibit enhanced subcortical discrimination of closely related speech sounds than non-musicians and musicians are unsusceptible to age related slowdown in neural timing.

2.1.2. Cortical Auditory Evoked Potential in Musicians

Changes in waveform morphology of CEAPs in terms of decrease in latency and increase in amplitude are considered to indicate increases in neural synchrony and strengthened neural connections (Trembley, Kraus, McGee, Ponton & Otis, 2001). A study done by Shahin, Bosnyak, Trainor and Roberts in 2003 showed that P2 and N1c peaks of the auditory evoked potential (AEP) was sensitive to remodeling of the auditory cortex with training. In this study, highly skilled 11 violinists (24.3 ± 2.2 years of age; five males and six females) and 9 pianists (23 ± 2.5 years of age; one male and eight female) were taken as experimental. Violinists and pianists had played their instruments for an average of 17 ± 3.7 years and 16.6 ± 4.0 years, respectively, and practiced for 34.7 ± 20.8 and 17.9 ± 11.1 hr/week, respectively. Age matched individuals with no musical background was taken as control group. The stimuli taken was piano tones, violin tones and pure tones for the study. The results revealed that P2 and N1c AEP evoked by musical tones were robust in musicians compared to non-musicians. P2 and N1c responses by pure tone which were having a pitch like quality was also enhanced in musicians compared to non-musicians. They reported enhancement of N1c and P2 was significant because these AEPs have been shown to sensitive to neuroplastic remodeling (Trembley at al., 2001; Shahin, Bosnyak, Trainor, Roberts, 2003). Similarly, Trainor, Shahin and Roberts in 2003 compared auditory evoked potential in adult musicians and non-musicians as well as in 4 to 5 years old children who had extensive musical training and compared with the children who never had any musical training. The stimuli taken were pure tones, violin tones and piano tones. The result showed that P2 was enhanced in both adult and child musicians compared to non-musicians. The result also revealed that the P2 shows neuroplasticity and effect of musical training shown early in development.

Shahin, Roberts, Pantev, Trainor and Ross in 2005 investigated N1 and P2 evoked responses in pianist and non-musicians. The stimuli taken were three variant of a C4 piano tone which was equated for temporal envelop but differing in the number of harmonics. The result showed that P2 amplitude was enhanced in pianist compared to non-musicians. It was also observed that P2 amplitude increased with spectral complexity in pianist but not N1amplitude.

Musachhia, Strait and Kraus in 2008 investigated cortical encoding of speech in 26 participants (mean age 25.6 ± 4.1 years), which includes 14 musicians and 12 non-musicians. The synthesized speech syllable (Klatt Software, 1980) was 350 ms in duration with a fundamental frequency of 100 Hz. F1and F2 of the steady state were 720 Hz and 1240 Hz, respectively. The result indicates that musicians had larger F0 peak amplitude compared to non-musicians. It was also seen that overall P1 and N1 peaks were earlier in latency and larger in amplitude for musicians. Polat and Atas in 2014 evaluated cortical auditory evoked potential in adult musicians and non-musicians with different speech stimuli (/m/, /g/ & /t/) at 65 dBSPL. The results showed enhanced amplitude of P1 and P2 in adults musicians compared to non-musicians. The results revealed that musical training and experience has an effect on the nervous system and this can be seen in cortical auditory evoked potentials recorded when the subjects listen to speech sounds.

From the current literature it can be inferred that there was a shorter latency and greater amplitude (better) of CEAPs in musicians compared to non-musicians, which indicate increases in neural synchrony and strengthened neural connections in musicians. Literature also showed that P2 and N1c AEP evoked by musical tones were robust in musicians compared to non-musicians. It was also observed that neuroplasticity and effect of musical training shown early in development. It can be concluded that musical training and experience has an effect on the nervous system and this can be seen in cortical auditory evoked potentials recorded when the subjects listen to different stimuli.

2.1.3. P300 in Musicians

Crummer, Walton, Wayman, Hantz and Frisina in 1994 investigated P3 component of the event related potential between adult musicians and non-musicians. The stimuli used were the three timber series, all of which consisted the same pitch i.e. (1) flutes made of silver and wood, (2) string instruments in the same family (cello and viola),and (3) instruments of slightly different size (B-flat versus F tubas). The mean P3 amplitude for the difficult timber task were enhanced for musicians compared to non-musicians. However, P3 amplitudes were alike for the two other timber series. The other finding observed was the mean P3 latencies for the musicians and were shorter in all series than mean P3 latencies for non-musicians. A study done by Tervaniemi, Just, Koelsch, Widmannand, Schrogerin 2005 investigated P3 response in 13 professional musicians and age matched non-musicians. The study carried out in attentive and reading condition. The result showed that P3 responses found at the time of attentive listening, were having larger amplitude in musicians compared to non-musicians. Whereas, P3 responses recorded during reading condition were not able to differentiate between musicians and non-musicians.

Okhrei, Kutsenko and Makarchouk in 2012 investigated P3 in 7 musicians and 10 non-musicians using tonal stimuli showed that the peak latencies of P3 component in the left hemisphere was significantly shorter in musicians compared to non-musicians. They also observed that there was significant difference in latency between left and right hemisphere. Ungan, Berki, Erbil, Yaqcioglu, Yuksel and Utkucal in 2013 investigated to find out difference between musicians and non-musicians in their skill to identify rhythm change. The stimuli used was three consecutive and equally spaced drum beats. The results showed that P3 evoked due to rhythm change was significantly larger in amplitude and shorter in latency in musicians compared to non-musicians. The conclusion made was P3 data strongly supported the hypothesis that cognitive and/or sensory advantage of musicians seen over non-musicians in detecting rhythm changes also reflect in their P3. Rabelo, Neves, Rocha, Ubiali and Schochat in 2015 investigated P300 latency and amplitude in 30 musicians and 25 non-musicians between age range of 20 and 53 years. The result showed that there was a significant difference in amplitude and latency between musicians and non-musicians. Musicians were having shorter latency and larger amplitude than non-musicians. The conclusion made was that the central auditory nervous system of musician’s shows a special characteristic in electrophysiological responses probably due to plasticity occurred because of musical training and practice.

The above literature showed that P300 latencies were shorter (better) and amplitude was larger (better) in musicians compared to non-musicians with different stimulus and conditions. The review of literature on P300 in musicians highlights that sensory and/or cognitive advantage of musicians seen over non-musicians. It was observed that musicians were having enhanced active auditory discrimination skill compared to non-musicians.

2.1.4. Mismatch Negativity in Musicians

Mismatch negativity (MMN) was done by Koelsh, Schoger & Tervaniemi in 1999 on professional violinists and non-musicians. They considered attended and ignored conditions for the study. The stimuli taken were slightly impure chords, presented as odd ball among perfect major cord to elicit mismatch negativity. The result showed that distinct MMN was evoked in professional violinists but not in non-musicians. They concluded musicians has better pre-attentive auditory processing skills compared to non-musicians. In a study by Russeler Altenmuller, Nager, Kohlmetz & Munte in 2001 on musicians by using MMN to find out any differences in temporal integration between musicians and non-musicians. They found that the temporal window of integration seems to be more precise and longer in trained musicians, compared to non-musicians and further the long-term training effect was reflected with respect to changes in neural activity.

Nager, Kohlmetz, Altenmuller, Rodriquez and Munte in 2003 also investigated Mismatch Negativity in professional pianists, conductors and non-musicians. The stimuli used to evoke MMN were noise-bursts which were presented from six speaker in a random order. Three speakers were located in front and other three to the right of the subjects. In different runs, participants either attended the centermost or the most peripheral speaker to detect even slightly deviants noise bursts. Mismatch Negativity was used to monitor entire auditory scene. It was found that MMN was larger in amplitude in musicians compared to non-musicians. A study done by Zuijen, Sussman, Winkler, Naatanen and Tervaniemi in 2005 investigated encoding of complex regularities in musicians and non-musicians. The stimuli used were tone sequences which contained either a temporal or numerical regularity. Auditory encoding of the regularity was investigated using Mismatch Negativity, whether an occasional segment lengthening, either in time or by number elicited the MMN. The result revealed that in both groups, MMN was elicited on the violation of temporal regularity but with the violation of numerical regularity, MMN was elicited only in musicians. This study showed superior pre attentive skill in musicians compared to non-musicians. Similar finding showed by Zuijen, Sussman, Winkler, Naatanen and Tervaniemi in 2004 investigated ability to pre-attentively group consecutive sound among musicians and non-musicians. They recorded MMN using four consecutive tones in a sequence could be grouped according to either good continuation or pitch similarity of pitch. Occasionally, the tone-group length was violated by a deviant tone. The result showed that MMN was evoked in both groups when sounds were grouped based on patch similarity whereas MMN was elicited only in musicians when sounds were grouped according to good continuation of pitch. They concluded that some form of auditory grouping enhanced with musical training and experience and not all aspects of auditory grouping is universal.

Tervaniemi et al., in 2005 used MMN on 13 professional musicians and 13 non musicians. Stimuli used were frequent standard sounds and rare deviant sounds at 0.8%, 2% and 4% higher in frequency. There was no significant difference noticed in peak amplitude between musicians and non-musicians, when MMN was recorded in reading condition. They reported that musical expertise may show its effects merely at attentive levels of processing but not at the pre attentive level. Nikjeh in 2006 recorded MMN in 21 formally trained instrumental musicians and age matched non musicians using harmonic tones. The result showed no significant difference in latency of MMN between instrumental musicians and non-musicians. According to a study done by Tervaniemi, Castaneda, Knoll & Uther in 2006 recorded MMN to change in acoustic features (gap, duration, frequency, location and intensity) and abstract features (interval size and melodic contour) on non-musicians with amateur band musicians. Result showed that musicians were having larger amplitude of MMN and greater area under curve compared to non-musicians for location change, whereas no statistically significant group difference was seen in response to other feature changes or in abstract-feature in mismatch negativity. This study showed that even amateur musicians have neural sound processing advantage, when compared with non-musicians.

Nikjeh, Lister and Frisch in 2009, assessed mismatch negativity on 67 trained musicians and 35 non musicians. Three stimulus condition were taken (1) pure tones, (2) harmonic tones, and (3) speech syllable. For the pure tone condition, standard tone was taken as 1000 Hz and deviant were 1015 Hz and 1060 Hz. For the harmonic tone condition the standard tone was G4 (F0=392Hz), and the two deviant tone were F0=386Hz and F0=370Hz. For the speech syllable, /ba/ was used as standard and /da/ as deviant. The results showed that musicians had shorter MMN latencies to frequency changes in pure tones than non-musicians. Further in both groups, they observed as the frequency difference between standard and deviant increases, MMN latency decreased (better). They also observed that mismatch negativity latencies for harmonic tone and speech syllable were significantly lesser (better) for musicians when compared to non-musicians. Marie, Kujala and Besson in 2012 investigated pre-attentive skill in musicians and non-musicians using mismatch negativity. The stimuli were presented on odd ball paradigm, in which deviant tone was different from standard in terms of frequency. The results revealed that mismatch negativity peak amplitude was significantly larger in musicians compared to non-musicians for frequency deviants. This showed enhancement in pre-attentive auditory discrimination skill in musicians. Vuust et al., in 2012 administered MMN on musicians using fast, novel and musical sounding multi-feature paradigm, to six types of musical feature change in musicians playing three distinct styles of music (classical, jazz & rock/pop) and in non-musicians. Result revealed that jazz musicians had larger amplitude than rock, classical and non-musicians across the six different sound features.

Boh et al., in 2011 recorded MMN on 8 musicians and 13 non-musicians with sine tones as stimulus shows larger amplitude of MMN in musicians compared to non-musicians showed that long-term musical training differentially affects the memory capacity of auditory short-term memory for sine tones. Similar study done by Kuhnis et al., in 2013 investigated MMN in musicians and non-musicians using vowels and temporally manipulated consonant vowel syllables as stimuli. They found that musicians were not only advantaged in the pre- attentive encoding of temporal speech cues than non-musicians, but most notably also in processing vowels. Habibi et al., in 2014 recorded event-related brain potential responses of musicians and non-musicians to discrepancies of rhythm between pairs of unfamiliar melodies based on western classical rules. They noticed that musicians could able to detect rhythm deviations significantly better than non-musicians. Putkinen et al., in 2014 recorded MMN for changes in melody, rhythm, musical key, timbre, tuning and timing in musically trained children. When compared to non-trained children, the musically trained children showed significantly larger amplitude of MMN for all changes in stimuli. Musical training helps in enhancing auditory discrimination for musically central sound dimensions in pre-adolescence.

From the above literature it can inferred that musicians has higher amplitude (better) and greater area under the curve (better) of MMN compared to non-musicians. This indicates that musicians has better pre-attentive auditory processing skills compared to non-musicians. Further the long-term musical training effect were reflected with respect to changes in neural activity. The current literature also showed that that even amateur musicians have neural sound processing advantage, when compared with non-musicians.

2.2. Psychoacoustic Tests in Musicians

2.2.1. Gap detection threshold in Musicians

Several studies carried out to check whether musical training improved temporal resolution abilities using Gap Detection Threshold (GDT)(Monteiro, Nascimento, Soares & Ferreira, 2010; Zendel & Alain, 2012; Sangamanatha, Fernandes, Bhat, Srivastava & Prakrithi, 2012; Mishra & Panda, 2014; Kuman, Rana & Krishna, 2014; Mishra, Panda & Herbert, 2014). However, few studies did not show any changes due to musical training

(Monteiro, Nascimento, Soares & Ferreira, 2010). Monteiro et al., 2010 investigated gap in noise on 20 violinists and 20 non musicians. The result showed no significant difference in gap detection threshold between musicians and non-musicians. Zendel and Alain in 2012 compared gap detection threshold in 74 musicians and 89 non-musicians in the age range of 18 to 91 years. The result showed that musicians demonstrated less age related decline in GDT compared to non-musicians.

Sangamanatha et al., in 2012 investigated gap detection threshold in three groups with 15 participants in each: children with musical training (mean age 12.66 years), children without any musical training (mean age 12.89 years), and adults (mean age 24.30 years) without any musical training. The results showed mean gap detection thresholds were significantly lower for children with musical training and adult with musical training, when compared to children without any musical training. This study showed that children with musical training performed at par with adults without musical training, and better than children with no musical training. Similar investigation done by Mishra and Panda in 2014 investigated temporal resolution in Carnatic musicians and non-musicians. Result revealed that the Carnatic musical training has significant effect on temporal resolution ability in musicians assessed by gap detection threshold. A study done by Kuman et al., in 2014 showed significant difference in gap detection threshold between violinists and non-musicians. The same study also showed significant difference in gap detection threshold between vocalist and non-musicians, but there was no significant difference between vocalist and violinists. Similar study done by Mishra, Panda and Herbert in 2014 investigated gap detection threshold in Carnatic musicians and non-musicians. Result showed significant difference in gap detection threshold between musicians and non-musicians. Musicians was having significantly better gap detection thresholds compared to non-musicians.

From the above literature it can be concluded that musical training has significant effect on temporal resolution ability in musicians. Further, musicians demonstrated less age related decline in GDT compared to non-musicians. In addition to that, musicians has better temporal resolution skill irrespective of their nature of musical training and experience.

2.2.2. Temporal Modulation Transfer Function in Musicians

Sangamanatha et al., 2012 obtained modulation detection threshold at 8, 20, 60, and 200 Hz modulation frequency in three groups with 15 participants in each: children with musical training (mean age 12.66 years), children without any musical training (mean age 12.89 years), and adults (mean age 24.30 years) without any musical training. The result showed children underwent musical training performed significantly better that children without any musical training at all modulation frequencies.

Kuman et al., in 2014 investigated modulation detection threshold in vocalist, violinists and non-musicians. The result revealed that there was a significant difference in modulation detection threshold in musicians compared to non-musicians. Both, vocalist and violinists had significantly better modulation detection threshold compared to non-musicians. In this study, they also observed that there was no significant difference in the modulation detection threshold between vocalist and violinists.

2.2.3. Speech Perception in Noise in Musicians

Parbery, Skoe, Lam and Kraus in 2009 compared Quick SIN and Hearing in Noise Test (HINT) between musicians and non-musicians of the range in between 19 to 31 years. The results showed that musicians performed significantly better compared to non-musicians in both Quick SIN and HINT. Similar study done by Clark, Strait, Anderson, Hittner and Kraus in 2011 on 17 musicians and 18 non-musicians in the age range of 45 to 65 years. The result showed that musicians demonstrated lower (better) thresholds than non-musicians for all three speech-in-noise tests. This showed that speech in noise perception is enhanced in musicians compared to non-musicians. According to study done by Strait, Clark, Hittner and Kraus in 2012 on 15 musicians and 16 non musicians in the age range of 7-13 years, compared speech in noise perception using word in noise test and HINT. The result showed that musically trained children outperformed non-musicians on speech in noise perception tests. A study done by Jain, Mohamed and Kumar in 2014 investigated speech perception in noise before and after musical training in normal hearing individuals of 18 to 25 years. The results showed that 8 sessions of short term musical training enhanced speech perception in noise significantly in experimental group. There was a significant improvement in speech perception in noise after training when compared with pre-training. From the current research indicates that speech in noise perception is enhanced in musicians compared to non-musicians further short term musical training can improve speech perception in noise.

2.2.4. Duration Discrimination Test

Guclu, Sevinc and Canbeyli in 2011 investigated duration discrimination threshold in 17 adults musicians and age matched 22 non-musicians. The standard durations tested were 0.5 and 3.0 seconds. Participants were asked to discriminate comparison stimuli which were having durations slightly shorter and longer than the standard durations. The result showed that musicians had better duration discrimination threshold compared to non-musicians. Sangamanatha et al., in 2012 also did a study on duration discrimination in three groups with 15 participants. The result showed that mean duration discrimination thresholds were significantly lower (better) for children with musical training and adult with musical training, when compared to children without any musical training. This study showed that children with musical training performed at par with adults without musical training, and better than children with no musical training.

2.2.5. Differential Limen of Frequency in musicians

It has been realized for a long time that there is an importance of good pitch discrimination abilities not only in psychoacoustics but also for musicians. Psychoacoustic measures comparing frequency discrimination thresholds, known as difference limen for frequency (DLF). Spiegel & Watson in 1984 assessed performance on frequency discrimination tasks on musicians and non-musicians by using 300-msec sinusoidal tones, 300-msec square waves, and tone patterns consisting of ten 40-msec tones played sequentially. The result for the pattern stimuli show a clearer separation between the non-musicians and musicians, whose median difference thresholds were about three times smaller. DLF for musicians and non-musicians report significantly smaller discrimination threshold for musicians (Rabin et al., 2001). Rabin et al. (2001) reported that an instrumental musicians has 50% smaller DLF for pure tones than non-musicians which suggest extensive musical training influences auditory pitch discrimination. Psychoacoustic research showed that auditory skills may differ between musicians of different musical genres.

A study done by Nikjeh, Lister & Frisch in 2008 in which DLF were investigated in 61 young adult women, which includes 21 instrumentalists, 20 vocalists and 20 non-musicians. The result showed that musicians detected pitch changes earlier and DLFs were 50% smaller than non-musicians. Both instrumental and vocal musicians had superior sensory-memory representations for acoustic parameters. Clark, Skoe, Lam and Kraus in 2009 compared frequency discrimination in 16 musicians and 15 non musicians. The result showed that musicians was having more fine-grained frequency discrimination compared to non-musicians. A study done by Nikjeh et al. in 2009 on difference limens frequency (DLFs) and pitch production accuracy (PPA) among 20 vocalist, 21 instrumentalists and 21non-musicians. They reported that DLF and PPA were significantly correlated with each other only for musicians with instrumental training; however, PPA was most consistent with minimal variance for vocalists.

In another study done by Bidelman and Krishnan in 2010 on musicians and non-musicians with fundamental (F0) and first formant (F1) frequency difference limens (DLs), showed musicians obtained DLs which were 2–4 times better in musicians than non-musicians. Further, Bidelman et al., in 2011 compared brainstem encoding and perceptual benefit in musicians and tonal language speaker. They observed that only musicians showed connections between behavioral and neural measures. A study done by

Bidelman, Hutka and Moreno in 2013 on three groups of population. First one was, English speaking trained musicians (M), second group was English speaking non-musicians (NM) and third group was Cantonese (tonal language) speaking individuals. Fundamental frequency discrimination limen were measured on all participants. The result showed, English speaking trained musicians was having significantly better fundamental frequency differential limen when compared to English speaking non-musicians. In the same study, it was also observed that, there was no significant difference in fundamental frequency differential limen in between Cantonese speaking participants and English speaking musicians. This study showed that tonal language speaker have similar perceptual abilities in terms of frequency like of musicians.

The recent literature reports that DLFs for musicians were 50% smaller than non-musicians, which showed improvement in active auditory discrimination skill in musicians compared to non-musicians. Literature also indicates that musicians was having more fine-grained frequency discrimination compared to non-musicians. It was also reported that musicians showed connections between neural and behavioral measures. Further, tonal language speaker have similar perceptual abilities in terms of frequency like of musicians. Additionally, it is observed that musicians has better active auditory discrimination skill irrespective of their nature of musical training and experience.

2.3. Music and neuroplasticity

The term ‘neuroplasticity’ indicate any change or modification in the central nervous system as a result of adaptation or experience to environmental demands. Neuroplasticity can denote change in functional or structural at either system or cellular level. Modification of gross anatomy of the brain, structural change in individual brain cell and reorganization of the neural network that subserve complex cognitive processes are all example of neuroplasticity (Merrett & Wilson, 2012). Music is one of the most demanding cognitive and neural challenges, which requires very precise and accurate timing of many actions, exact interval control of pitch not involved in language, and many different way of producing sound. Enhanced auditory perception in musicians is likely to result from auditory perceptual learning during several years of training and practice. In recent literature of plasticity dependent on experience, Kleim and Jones (2008); Green and Bavelier (2008) explained some of the prerequisites for inducing neuroplasticity, which include complexity, intensity, and repetition of training. Most trained and professional musicians are involved in intensive practice from many years in terms of both intense and repetitive to attain a high level of expertise. So, musicians are best group to research changes or modification in brain structures and functions across multiple information processing systems. According to Schneider et al., in 2002 reported that both the neurophysiology and morphology of Heschl's gyrus have a strong effect on musical aptitude. A study done by Ragert et al., in 2004 on pianist showed that despite high-level performance in pianists, the effect of Hebbian learning was more in musicians than in controls. This shows stronger capability for plastic reorganization and points to enhanced learning abilities implicating a form of meta-plasticity in professional pianists.

A study done by Hoenig et al., in 2011 show using functional magnetic resonance imaging (fMRI) that conceptual processing of visually presented musical instruments activates auditory association cortex encompassing adjacent areas in the superior temporal sulcus, as well as right posterior superior temporal gyrus and the upper part of middle temporal gyrus only in musicians, but similar activation was absent in non-musicians. Hence, intensive experience and training of musicians with variety of musical instruments provide a link between conceptual brain systems and auditory perceptual skills. Abdul, Stancak, Parkes and Sluming in 2011 done a voxel based morphometric study showed significantly increased grey matter volume in musicians compared to non-musicians. Results were positively correlated with the years of experience of music. This study also showed the change due to musical training in middle and superior cerebellar peduncle in trained musicians. Result reveled that musicians have significantly larger right superior cerebellar peduncle volume and number of streamlines, right middle cerebellar peduncle volume and total white matter volume of the right cerebellum.

A study done by Zendel and Alain in 2012 showed that musicians experience less age-related degradation in central auditory processing. Zendel, Willoughby and Rovet in 2013 have taken 4 groups of subjects, children with congenital hypothyroidism with and without music training, and healthy control with and without music training. They showed that volume of the right hippocampus was comparable between children with congenital hypothyroidism who had taken music training and the healthy controls. Children with congenital hypothyroidism who had not taken music training had reduced hippocampal volumes compared with the other three groups. These results suggest that music training may provide structural neuroplasticity in children with atypical hippocampal development because of early thyroid hormone deficiencies. A study done by White et al., in 2013 on geriatrics with a whole life of music training indicated that a moderate amount of music training of 4 to 14 years early in life was associated with faster neural timing in response to speech later in life, long after training stopped (>40 years). This study also showed that early music training sets the stage for subsequent interactions with sound and these experiences may interact over time to sustain sharpened neural processing in central auditory nuclei well into older age. A study done by Hoenig et al., in 2011 show using functional magnetic resonance imaging (fMRI) that conceptual processing of visually presented musical instruments activates auditory association cortex encompassing adjacent areas in the superior temporal sulcus, as well as right posterior superior temporal gyrus and the upper part of middle temporal gyrus only in musicians, but similar activation was absent in non-musicians. Hence, intensive training and experience of musicians with different musical instruments provide a link between conceptual brain systems and auditory perceptual skills. Abdul, Stancak, Parkes and Sluming in 2011 done a voxel based morphometric study showed significantly increased grey matter volume in musicians compared to non-musicians. Results were positively correlated with the years of experience of music. This study also showed the change due to musical training in middle and superior cerebellar peduncle in trained musicians. Result reveled that musicians have significantly larger right superior cerebellar peduncle volume and number of streamlines, right middle cerebellar peduncle volume and total white matter volume of the right cerebellum. They also observed that musicians significantly shows larger weighted clustering coefficient in the right olfactory cortex, the left supramarginal gyrus, the right gyrus rectus, the left medial superior frontal gyrus, the left lingual gyrus, and the right pallidum compared to non-musicians. Bidelman & Alain in 2015 done a study on geriatric with and without modest musical training. They recorded both cortical neuroelectric and brainstem responses in geriatric with and without modest musical training as they differentiate speech sounds as an acoustic-phonetic continuum. Results revealed that good temporal precision in speech-evoked responses at various levels of the auditory system in older musicians who were also good at differentiating phonetic categories. Older musicians also showed a closer correspondence between perceptual performance and neural activity. Pantev et al., in 2015 studied the influence of long term and short term musical training. They showed that long-term musical training is related to a significantly different way of processing multisensory information within the auditory cortex, whereas the short-term training infer that multisensory music reading training affects the multimodal processing within the auditory cortex.

2.4. Knowledge of music

Music is recognized as a universal characteristic in all human societies, both past and present. Cross-cultural evidence showed the innateness of music and its certain characteristics of music, such as interval scales, are universal regardless of the musical genre or style (Hauser & McDermott, 2003; Tillman, Bharucha, & Bigand, 2000). Some acoustic stimuli are considered as music by most members of a given culture, even if these sounds have never been heard before; and conversely, there are acoustic stimuli which humans recognize as nonmusical or dissonant (Hauser & McDermott, 2003). Therefore, even if a particular melody has never been heard, a dissonant tone may be detected based on an internal musical representation (Tervaniemi & Brattico, 2004). This representation may correspond to a neural template hardwired in the brainor may become automatic secondary to implicit neuronal models that develop from exposure to music in the environment (Tervaniemi & Brattico, 2004).

Few studies showed young infants prefer consonant musical intervals rather than dissonant intervals (Schellenberg & Trehub, 1996; Trainor & Heinmiller, 1998) and they are capable of detecting the smallest differences that are musically meaningful in any culture (Trehub, Schneider, & Henderson, 1995). However, the fetus can hear a filtered version of sounds in the external environment by the third trimester of pregnancy (DeCaspar & Fifer, 1980). Learning also occurs during the fetal period and the nature of this learning with respect to music depends on the musical sound environment before birth (Tervaniemi & Huotilainen, 2003). Thus, it is possible that seemingly *innate* traits are actually the result of early exposure to music.

2.5. Musical meaning

Musical meaning is understood within the context of an arrangement of acoustic events, such as a scale or melody. The melody, referred to as the musical structure, which has two components, rhythm and pitch (Pantev et al., 2003). Rhythm refers to timing and/or beat. Pitch is perceived as a tone's highness or lowness. It is the perceptual correlate of frequency which pertains to the sound's physical structure (i.e., the number of cycles per second) (Patel & Balaban, 2001). The pitch produced by a person's voice is measured as the fundamental frequency (F0). Pitch structure has contour and an interval code. Contour refers to the up and down pattern of pitch changes in speech prosody and music. Interval code is the distance between two sounds on a musical scale. The perception of pitch along musical scales is central to pitch organization. A musical scale refers to the use of a small subset of pitches in a given musical piece. Scale tones are not equivalent and are organized around a central tone, called the tonic. This tonic hierarchy of pitch facilitates perception, memory and performance of music by creating expectancies (Peretz & Coltheart, 2003). Although the commonly used scales differ from culture to culture, most musical scales use pitches of unequal intervals organized around five to seven focal pitches (Tillman et al., 2000). The seven tones above or below in a given tone form an octave scale. In Western culture, speech intonation contours use variations in pitch that are larger than ½ an octave to convey relevant information. In contrast, musical melodies of Western culture use smaller pitch intervals approximately 1/6th to 1/12th of an octave (Ayotte, Peretz, & Hyde, 2002). In other cultures, such as Arabic, Indian, and Chinese, the musical pitch intervals are even smaller (Tervaniemi & Brattico, 2004). Thus, the auditory processing of pitch for music is necessarily more sensitive than for speech. When a person sings, plays an instrument or speaks a sentence, a succession of acoustic events constitutes a context which is understood by others. To understand a musical context, listeners extract a tonal center by perceiving the musical relations between notes; that is, the interval (Krumhansl & Kessler, 1982). The mental representation of tonality and musical context is quickly established by the listener; thus, there is an expectancy of what tone comes next. The dominant tonic progression at the end of a harmonic sequence is considered a basic syntactic structure for major-minor tonal music. For listeners, the sound of a chord that violates musical regularities of major-minor tonal music is perceived as unexpected (Bharucha & Krumhansl, 1983; Koelsch, Schmidt, & Kansok, 2002; Tillman et al., 2000). Similar to language, culturally specific aspects of music are dependent on knowledge acquired through prior experience. Music perception is molded by implicit and/or explicit experience and is founded on early automatic functions of the auditory system that dynamically organize and store separated sounds (Tervaniemi & Brattico, 2004). Thus, in theory, ‘knowledge of music’ including musical meaning and syntax, may be acquired through exposure to music within a culture without training just as linguistic knowledge is acquired through exposure independent of education.

From review of literature, it is well documented that musicians are widely evaluated using electrophysiological and psychoacoustic measures. As reported in literature using AEP studies, musicians had enhanced spectral analysis of the frequency following responses as well as their performance alike in quiet and noise. They posses increase in neural synchrony and strengthened neural connections, which provides the sensory and/or cognitive advantage. In a similar way, psychoacoustic measures assess temporal resolution abilities in musicians. From various studies it is seen that musical training has significant effect on temporal resolution ability. They reflect better speech perception in noise in spite of short duration musical training. Further, these musicians showed better active auditory discrimination skill irrespective of their nature of musical training and experience. Even though there are many advantages observed among musicians, there is dearth of literature to explore how the pre-attentive discrimination abilities and temporal resolution abilities using MMN and DLF task.

Chapter-3

Method

3.1. Participants

Two groups of participant (Experimental & control group) in the age range of 18-40 years were involved in the study. Experimental group includes 25 musicians (Mean age of 24.52 years) who had minimum professional experience of 5 years of music exposure. Further age matched 25 participants (Means age of 24.8 years) who were not having any formal training of music served as non-musicians, in the control group.

3.2. Participant selection Criteria

All the participants were having normal hearing thresholds as defined by pure tone thresholds of <15dBHL at 250 Hz to 8000Hz. Further, they were having normal middle ear function as revealed by middle ear analyzer. Those participants who were having any other otological, neuromuscular and neurological problem were excluded from the study.

3.3. Testing environment

All the behavioural as well as electrophysiological tests were carried out in a sound treated room where the noise level was as per the guidelines in ANSI S3.1 (1999). The testing rooms were well illuminated and air conditioned for the comfort of the experimenter as well as participant.

3.4. Instrumentation

Calibrated double channel clinical audiometer (Orbitor-922) was used for pure tone audiometry. Calibrated GSI-Tympstar Immittance meter was used for tympanometry and reflexometry. Intelligent Hearing System with smart EP was used to record Mismatch Negativity. A personal computer loaded with MATLab software was used for difference limens of frequency (DLF).

3.5. Procedure

Pure tone thresholds were obtained using modified version of Hughson and Westlake procedure (Carhart & Jerger, 1959) across octave frequencies from 250 Hz to 8000 Hz for air conduction and frequencies from 500, 1000, 2000 and 4000Hz for bone conduction. Middle ear analyzer (GSI-Tympstar) was used to carry out tympanometry using a probe tone frequency of 226 Hz and to obtain ipsilateral and contralateral acoustic reflexes thresholds at 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz.

Psychoacoustic measure (difference limens for frequency) was performed on all the participants (musicians & non-musicians). Differential limens of frequency was assessed at 1000 Hz with the help of MATLab software using maximum likelihood procedure technique. Three number of blocks were taken for differential limen of frequency. Each block contained 35 trials. Three alternative forced choice procedure was adopted for response. The clients were instructed to discriminate highest pitch among 3 tones (250 ms) presented one after the other. Feedback was given after every response as correct or wrong on computer screen. The average of three blocks were considered as threshold. This procedure was adopted to obtain more precise and reliable thresholds.

MMN was recorded with pair of stimuli. The pair was having /1000Hz/ and /1100Hz/ with /1000Hz/ as frequent stimulus and /1100Hz/ as the infrequent stimulus. The total duration of the stimuli was 200 ms with 30 ms rise-fall time with plateau of 140 ms. The stimuli was made with the help of Aux Viewer program. The wave file was then converted to stimulus file for AEPs using the software “Stimconv” provided by Intelligent Hearing System. MMN was recorded in vertical montage with ‘Fz’ as the positive electrodes referenced to the nape of the neck. The ground electrode was placed on the lower forehead. A second channel was used to record the eye blink response. The sweeps with large eye blink artifacts were eliminated from the averaging. Stimuli were presented in the odd ball paradigm with the probability of standard and deviant stimulus as 80% and 20 % at 70 dBnHL respectively. The stimuli were presented in the rarefaction polarity with a repetition rate of 1.1/second. The response were averaged for 150 sweeps (150 infrequent stimuli + the corresponding number of frequent stimuli) from -50 to 500 ms (with reference to stimulus onset). The band pass filter was set to frequency between of 0.1 to 30 Hz, while it was amplified upto 50,000 times. Stimuli were presented binaurally. The participants were seated comfortably in order to avoid muscular artifacts and was made to watch a silent movie in order to promote passive listening. The subjects were instructed not to pay attention to the auditory stimuli. The skin surface of the target electrode sites was cleaned and disc electrodes was placed. The absolute impedance was less than 5 kΩ and inter-electrode impedance was less than 2 kΩ while recording MMN. Apart from recording MMN in the conventional paradigm for each stimulus pair, LLRs was also recorded for the infrequent stimulus for 150 presentations keeping the same recording parameter as it was for MMN.

3.6. Response Analysis

Conventional MMN recording was obtained in the odd ball paradigm which consisted waveform for frequent and infrequent stimulus. This was followed by a second recording which was the conventional LLR for the infrequent stimulus at the rate of

1.1/second, averaged for 150 sweeps. The LLR obtained for infrequent stimulus was later used to analyze MMN by comparing it with the infrequent waveform of the conventional odd ball paradigm. This paradigm was adopted to rule out any chance of error marking in MMN parameters due to difference in LLR elicited by the two stimuli of the odd ball paradigm and also reduces the N1 affect (Martin, Tremblay & Korczak, 2008). MMN was located in the difference wave to obtain its onset latency, peak latency, offset latency, peak amplitude and the area under curve.

3.6.1. Waveform Analysis

For the identification of the MMN true response through visual detection following criterion have been used:

(a.) MMN should be the first negative trough in the latency range of N_1-P_2 or P_2-N_2 complex of LLR of amplitude more than -0.3µV and positive peak should follow the negative peak.

(b.) If the extra negativity occurred in the P_1 area, it was ignored.

To analyze the data collected from musicians and non-musicians, following response measures were extracted from the MMN for each participants:

i. Onset Latency:-It is the time in millisecond at which the negativity started in the subtracted waveform.

ii. Offset Latency:-It is time in milliseconds at which the negativity reached the baseline activity in the subtracted waveform.

iii. Peak Latency:-It is the time in millisecond at which negativity reached its peak in the subtracted waveform.

iv. Peak Amplitude:-It is the maximum amplitude of the peak of the negativity with respect to the baseline.

v. Area under curve:-It is area under the negativity trough, derived from multiplying the peak amplitude with MMN duration.

3.7. Statistical Analysis

Descriptive statistics was done to find out mean and standard deviation (SD) for all the parameters of MMN (onset latency, offset latency, peak latency, peak amplitude and area under the curve). MANOVA was done to compare between musicians and non-musicians for each measures of MMN. Independent t-test was done to compare between musicians and non-musicians for DLF measures. Pearson's correlation test was done to compare between different measures of MMN and DLF.

Chapter 4

Results

To analyze the data collected from musicians and non-musicians, descriptive statistics and MANOVA was done. Out of 25 musicians and 25 non-musicians, MMN was present only in 17 (68%) musicians and 16 (64%) non-musicians. Hence, further statistical analysis was done only for 17 musicians and 16 non-musicians. The different measures of MMN i.e. onset latency, offset latency, peak latency, peak amplitude and area under curve was extracted from the MMN waveform through visual inspection for each participant. Sample waveform of MMN in musicians and non-musicians are represented in figure 4.1 and 4.2 respectively.

Descriptive statistics was done to find out mean and standard deviation (SD) for all the parameters of MMN (onset latency, offset latency, peak latency, peak amplitude and area under the curve) for 17 musicians and 16 non-musicians (Table 4.1). MANOVA was done to compare between musicians and non-musicians for each measures of MMN. Independent t-test was done to compare between musicians and non-musicians for DLF measures. Pearson’s correlation test was done to compare between different measures of MMN and DLF.

4.1. Onset latency, Offset latency and Peak latency

Descriptive statistics was done to find out mean and standard deviation (SD) for onset latency, offset latency and peak latency for the musicians and non-musicians. From Table 4.1, it is observed that, the standard deviation for onset and peak latency was lesser for musicians in comparison to non-musicians. The mean value of onset and peak latency for musicians were lesser (better) in comparison to non-musicians. However, the mean values of offset latency was almost similar between two groups. Figure 4.3 shows error bar graph for onset, offset and peak latency in musicians and non-musicians.

Table 4.1 Mean and standard deviation (SD) of onset latency, offset latency and peak latency for the musicians and non-musicians.

Parameters	**Onset Latency (ms)**		**Offset Latency(ms)**		**Peak Latency(ms)**	
	Mean	SD	Mean	SD	Mean	SD
Non-musicians	172.37	35.66	266.25	38.48	217.43	39.62
Musicians	152.82	22.67	266.52	36.51	206.05	23.98

MANOVA was carried out to compare significant differences between musicians and non-musicians for onset latency, offset latency and peak latency. Result of MANOVA showed marginal significant difference for onset latency [F (1, 31) = 3.57; p= 0.06; η_p^2=0.103], whereas no significant difference observed for offset latency [F (1, 31) = 0.00; p= 0.98; η_p^2= 0.00] and peak latency [F (1, 31) = 1.01; p=0.32; η_p^2=0.032] between musicians and non-musicians in spite of higher mean (better) observed for peak latency in musicians.

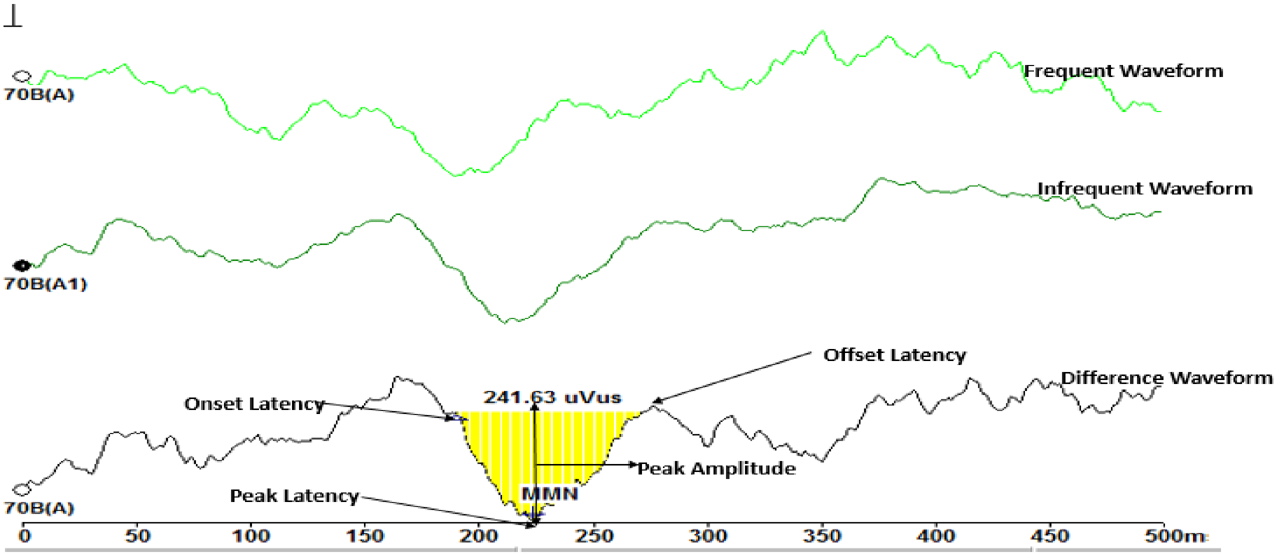

Figure 4.1 A sample waveform of Mismatch negativity in Musicians along with the response measures.

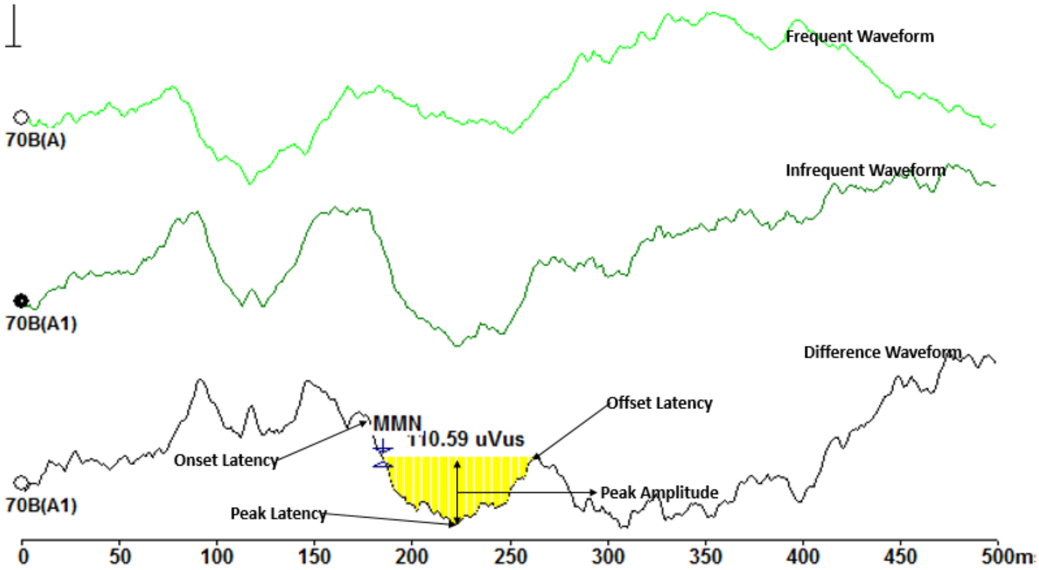

Figure 4.2 A sample waveform of Mismatch negativity in Non-musicians along with the response measures.

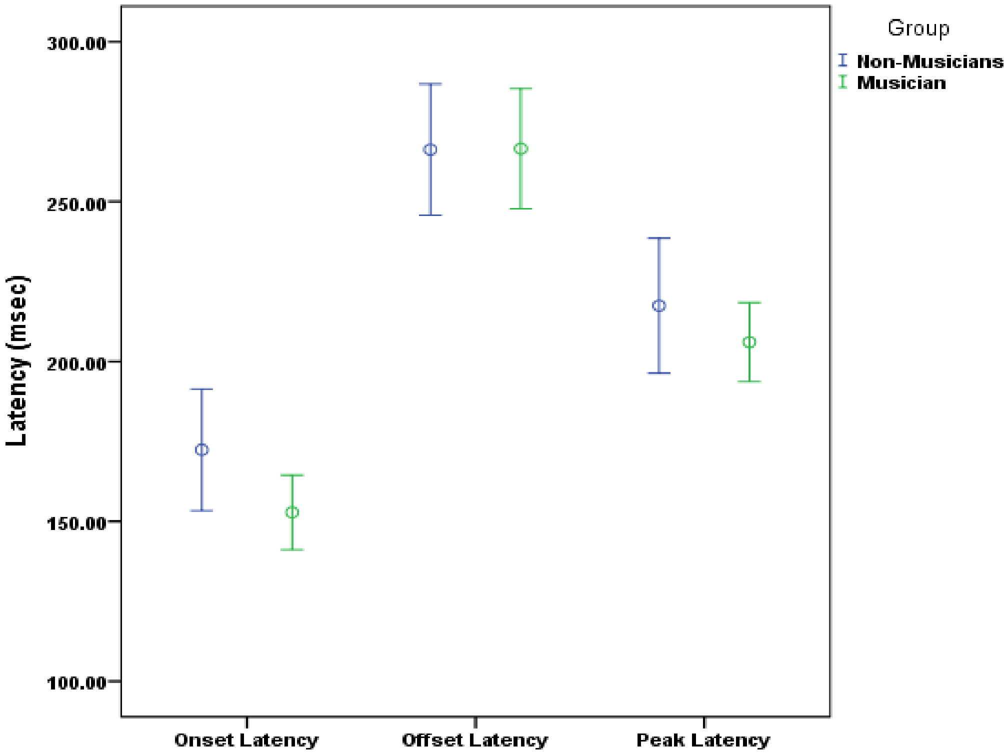

Figure 4.3 Error bar graph of onset latency, offset latency and peak latency for the musicians and non-musicians.

4.2 Peak amplitude and area under curve

Descriptive statistics was done to find out mean and standard deviation (SD) of peak amplitude and area under curve for the musicians and non-musicians. From table 4.2, it is observed that the mean of peak amplitude and area under the curve is higher (better) for musicians in comparison to non-musicians. However, standard deviation (SD) was noticed to be lesser for non-musicians in comparison to musicians (Table 4.2). Figure 4.4 and 4.5 shows error bar graph for peak amplitude and area under curve in musicians and non-musicians respectively.

Table 4.2 Mean and standard deviation (SD) of peak amplitude and area under curve for the musicians and non-musicians.

Parameters	**Peak Amplitude(µv)**		**Area under Curve (µVµsec)**	
Groups	Mean	SD	Mean	SD
Non-Musicians	2.78	0.80	131.75	39.68
Musicians	4.02	1.24	214.73	113.58

MANOVA was carried out to compare between musicians and non-musicians for peak amplitude and area under curve. Result showed statistically significant difference for peak amplitude [F (1, 31) = 11.32; p=0.00; η_p^2 = 0.267] and area under curve [F (1, 31) = 7.64; p=0.00; η_p^2=0.198] between musicians and non-musicians.

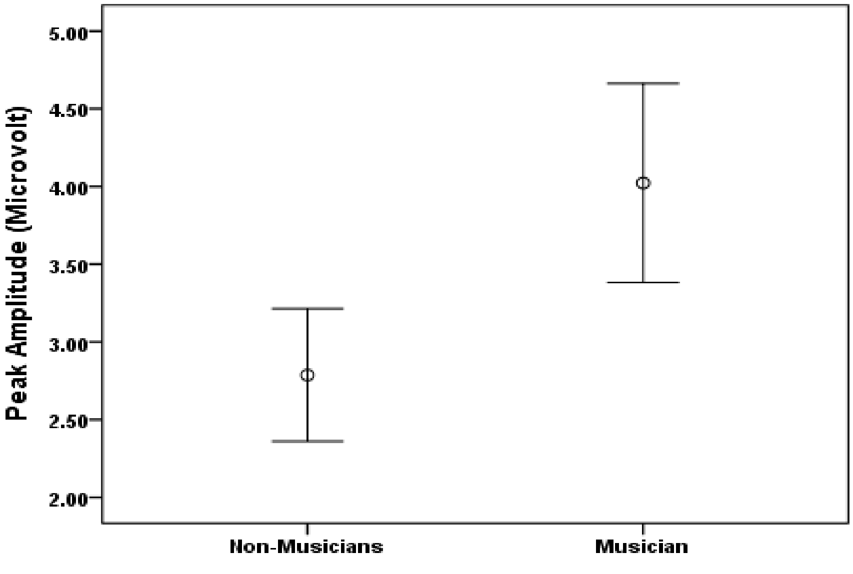

Figure 4.4 Error bar graph of peak amplitude for the musicians and non-musicians.

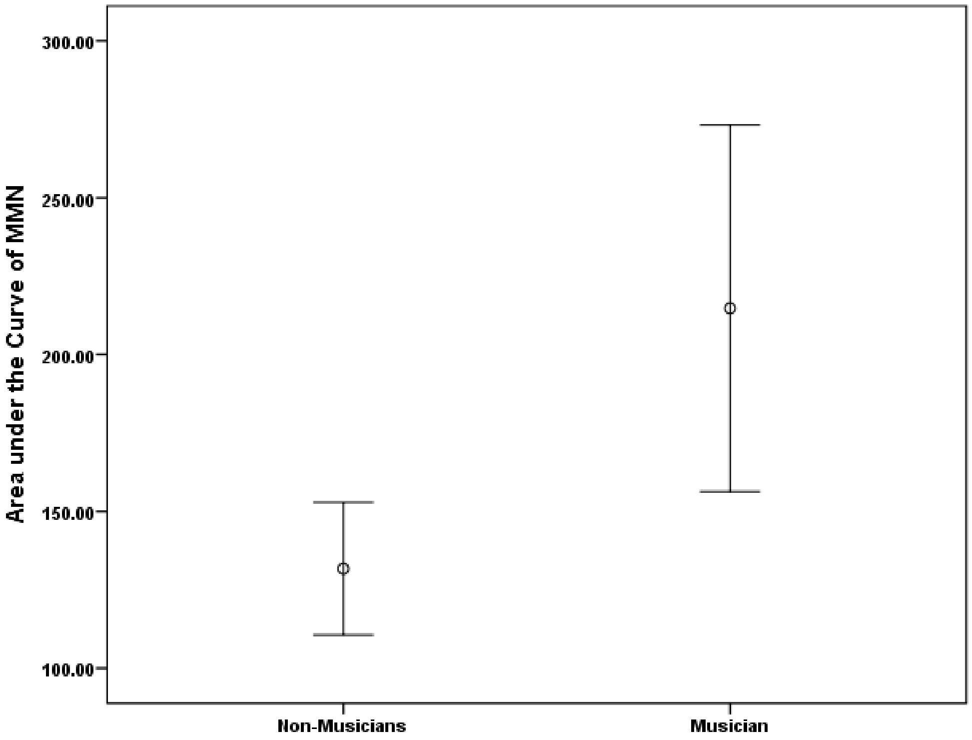

Figure 4.5 Error bar graph of area under the curve for the musicians and non-musicians.

4.3. Differential Limen of Frequency (DLF)

Descriptive statistics was done to find out mean and standard deviation (SD) of differential limen of frequency for the musicians and non-musicians. The differential limen of frequency for non-musicians was 10.62 Hz (SD=1.96 Hz), whereas differential limen of frequency for musicians was 5.76 Hz (SD=1.60 Hz). The DLF for musicians was much lesser (better) in comparison to non-musicians. Further, Independent t-test was carried out to compare differences between musicians and non-musicians for DLF. Result showed statistically significant difference in differential limen of frequency [t (31) =7.816, p=0.000] between musicians and non-musicians.

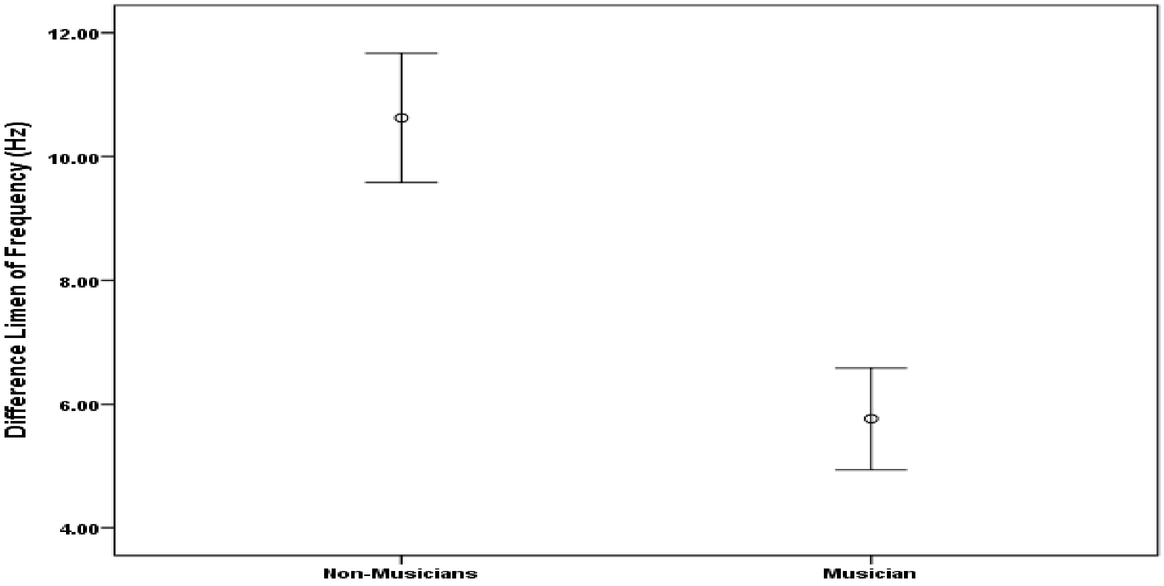

Figure 4.6 Error bar graph of differential limen of frequency for the musicians and non-musicians.

4.4 Correlation between Mismatch Negativity (MMN) and Differential Limen of Frequency (DLF) among musicians

Correlation analysis shows negative relationship with DLF across all measures of MMN (onset latency, offset latency, peak latency, peak amplitude and area under curve), though it was not statistically significant. The correlation coefficient for onset latency (r= -0.06, n=17, p=0.79); offset latency (r=-0.15, n=17, p=0.55); peak latency (r=-0.23, n=17, p=0.37); peak amplitude (r= -0.20, n=17, p=0.43) and area under the curve (r=-0.21, n=17, p=0.41) between MMN and DLF are mention in table 4.3.

Table 4.3 Correlation of DLF with onset latency, offset latency, peak latency, peak amplitude and area under curve in musicians.

With DLF	**r-value**	**p-Value**
Onset Latency	-0.68	0.79
Offset Latency	-0.15	0.55
Peak Latency	-0.23	0.37
Peak Amplitude	-0.20	0.43
Area under curve	-0.21	0.41

Note: r- correlation coefficient

Chapter 5

Discussion

Pre-attentive and active auditory discrimination should be enhanced in musicians compared to non-musicians was the hypothesis of the present study. MMN was recorded with tonal stimuli to assess the pre-attentive auditory discrimination skills and DLF was done to assess active auditory discrimination skill in musicians and non-musicians. To assess pre-attentive auditory discrimination skill, the different response measures of MMN (onset latency, offset latency, peak latency, peak amplitude & area under the curve) were obtained for both the groups. Further, the result of the same are discussed under following headings:

1. Findings in onset, offset and peak latency of MMN
2. Findings in peak amplitude and area under curve of MMN
3. Findings in DLF
4. Correlation between DLF and MMN in Musicians.

5.1. Findings in onset, offset and peak latency of MMN

Present study showed marginal significant difference in onset latency between musicians and non-musicians, and no significant difference seen in offset and peak latency between musicians in comparison to non-musicians. The present study outcomes is in consonance with previous literature (Nikjeh, 2006). In addition, there are studies done on different population and obtained similar outcomes (Gurpreet, 2003; Vinni, 2013; Lonka, Relander-Syrjänen, Johansson, Näätänen, Alho & Kujala, 2013; Jansson-Verkasalo, Eggers, Järvenpää, Suominen, Van den Bergh, De Nil, & Kujala, 2014).

However, there are few studies not in agreement with present findings (Nikjeh, Lister & Frisch, 2009; Holdefer, Oliveira & Venosa, 2013).

Nikjeh in 2006 compared MMN in formally trained instrumental musicians and age matched non-musicians using harmonic tones. The result showed no significant difference in latency of MMN between instrumental musicians and non-musicians. Since, there are not many researchers explored in the area of music. Studies done on MMN in different population considered for the support of present study. Gurpreet in 2003 recorded MMN in children with specific language impairment and compared with typically developing children. The result reveled that peak latency and onset latency measures of MMN showed alike performance between two groups. In another study, Vinni in 2013 investigated perceptual difference between native and non-native speakers using three nasal contrast of Malayalam language. The result revealed no significant difference in onset latency, offset latency and peak latency between native and non-native speakers for three nasal contrast. Lonka et al., in 2013 measured MMN in cochlear implant individual and they reported that MMN latencies to frequency deviance did not show any changes over time or difference between frequency changes. Similarly a study done by Jansson et al. in 2014 compared MMN in children with and without stuttering. The result showed no significant difference in peak latency of MMN between two groups.

The finding of the current study is in contrast with the finding of study done by Nikjeh et al., in 2009. They assessed MMN on trained musicians and non-musicians. The results showed that musicians had shorter (better) MMN latencies to frequency changes in pure tones than non-musicians; and for both groups, as the frequency difference between standard and deviant increases, MMN latency decreased (better). They also observed that mismatch negativity latencies for harmonic tone and speech syllable were significantly lesser (better) for musicians when compared to non-musicians. Similarly, Holdefer et al., in 2013 investigated MMN in subjects with tinnitus and without tinnitus with normal hearing. They reported significant difference in MMN latency between two groups.

Bishop in 2007 reported that latency measures are not reliable in MMN. They also reported that amplitude measures are more reliable than latency and most studies (Nager et al., 2003; Tervaniemi et al., 2006; Marie et al., 2012) in this area have reported only amplitude measures. The reason of not getting significant difference in latency between musicians and non-musicians in present study may be due to poor reliability and high variability in latency measures of MMN. Similar study can be replicated on large number of subjects to validate the present findings.

5.2. Findings in peak amplitude and area under curve of MMN

Result of the present study showed, peak amplitude and area under the curve was significantly higher (better) in musicians compared to non-musicians. The result of the current study showed enhanced pre-attentive auditory discrimination skill when it measured in terms of peak amplitude and area under the curve. The present study outcome is well supported by other researchers (Koelsh et al., 1999; Russeler et al., 2001; Nager et al., 2003; Zuijen et al., 2004; Tervaniemi et al., 2006; Marie et al., 2012; Boh et al., 2011; Kuhnis et al., 2013; Habibi et al., 2014; Putkinen et al., 2014). However, finding of the current study is in contrast with few studies (Tervaniemi et al., 2005; Nikjeh et al., 2009) reported in literature.

MMN was recorded by Koelsh et al., in 1999 on professional violinists and non-musicians. Attended and ignored conditions were taken for the study. The stimuli taken were slightly impure chords, presented as odd ball among perfect major cord to elicit mismatch negativity. The result showed that distinct MMN was elicited in professional violinists but not in non-musicians. This showed that musicians has better pre-attentive auditory processing skills compared to non-musicians. A study done by Russeler et al., in 2001 on musicians by using MMN to find out any differences in temporal integration between musicians and non-musicians. The result showed that the temporal window of integration seems to be more precise and longer in trained musicians, compared to non-musicians and that the long-term training effect was reflected with respect to changes in neural activity. Similarly, Nager et al., 2003 also investigated MMN in professional pianists, conductors and non-musicians. It was found that MMN was larger in amplitude in musicians compared to non-musicians. Zuijen et al., in 2005 investigated encoding of complex regularities in musicians and non-musicians. The stimuli used was tone sequences which contains either a temporal or numerical regularity. The result revealed that in both groups, MMN was elicited on the violation of temporal regularity but with the violation of numerical regularity, MMN was elicited only in musicians. This study showed superior pre-attentive skill in musicians compared to non-musicians. Similar finding reported by Zuijen et al., in 2004 among musicians and non-musicians. They recorded MMN using four consecutive tones in a sequence which could be grouped according to either pitch similarity or good continuation of pitch. The result showed that MMN was evoked in both groups when sounds were grouped based on pitch similarity whereas MMN was elicited only in musicians when sounds were grouped according to good continuation of pitch. They concluded that some form of auditory grouping enhanced with musical training and experience and not all aspects of auditory grouping is universal. The above study finding also in support with the present study.

According to a study done by Tervaniemi et al., in 2006 recorded MMN to change in acoustic features (gap, duration, frequency, location and intensity) and abstract features (interval size and melodic contour) on non-musicians with amateur band musicians. Result showed that musicians were having larger amplitude (better) of MMN and greater area under curve (better) compared to non-musicians for location change, whereas no statistically significant group difference was observed in response to other feature changes or in abstract-feature in mismatch negativity. This study showed that even amateur musicians have neural sound processing advantage, when compared with non-musicians. Marie et al., 2012 investigated pre-attentive skill in musicians and non-musicians using MMN. The results revealed that mismatch negativity peak amplitude was significantly larger (better) in musicians compared to non-musicians for frequency deviants. Similar study done by Kuhnis et al., in 2013 investigated MMN in musicians and non-musicians using vowels and temporally manipulated consonant vowel syllables as stimuli. They found that musicians were not only advantaged in the pre-attentive encoding of temporal speech cues than non-musicians, but most notably also in processing vowels. Habibi et al., 2014 recorded event-related brain potential responses of musicians and non-musicians to discrepancies of rhythm between pairs of unfamiliar melodies based on western classical rules. They noticed that musicians could able to detect rhythm deviations significantly better than non-musicians. Putkinen et al., 2014 recorded MMN for changes in melody, rhythm, musical key, timbre, tuning and timing in musically trained children. When compared to non-trained children, the musically trained children showed significantly larger amplitude of MMN for all changes in stimuli. So, musical training helps in enhancing auditory discrimination for musically central sound dimensions in pre-adolescence.

Similar study done by Nikjeh et al., in 2009 using mismatch negativity on trained musicians. In this study they reported amplitude was significantly higher (better) for musicians with pure tone as stimuli, but there was no significant difference seen in terms of amplitude of MMN elicited by harmonic tones and speech syllables. Current study is in contrast with the study done by Tervaniemi et al., in 2005 using MMN on professional musicians. They were presented with frequent standard sounds and rare deviant sounds at 0.8%, 2% and 4% higher in frequency. They reported no significant difference in peak amplitude between musicians and non-musicians, when MMN was recorded in reading condition. They reported probably musical expertise may exert its effects merely at attentive levels of processing but not at the pre-attentive level. The present study showed enhanced peak amplitude and area under the curve of MMN in musicians compared to non-musicians, indicates better pre-attentive auditory discrimination skill in musicians compared to non-musicians. It can also be stated that musical training has an effect on pre-attentive auditory discrimination skill in musicians, leads to higher peak amplitude and area under the curve.

5.3. Findings in DLF

The current study showed that musicians performed significantly better than non-musicians in differential limen frequency. Threshold of differential limen of frequency for musicians was significantly lower (better) than non-musicians. The finding revealed that musicians have better “active auditory discrimination skill” than non-musicians. Similar, finding was seen in previous literatures (Rabin et al., 2001; Spiegel & Watson, 1984; Nikjeh, 2006; Nikjeh et al., 2008; Nikjeh et al., 2009; Parbery et al. 2009; Bidelman & Krishnan, 2010; Bidelman et al., 2013).

DLF in musicians and non-musicians reported significantly smaller discrimination threshold by Rabin et al. in 2001. They reported that an instrumental musician has 50% smaller DLF (better) for pure tones than non-musicians which suggest extensive musical training influences auditory pitch discrimination. Similarly, study done by Spiegel & Watson in 1984 assess performance on frequency discrimination tasks on musicians and non-musicians by using sinusoidal tones, square waves, and tone patterns consisting of ten 40-msec tones played sequentially. The result for the pattern stimuli show a clearer separation between the non-musicians and musicians, whose median difference thresholds were about three times smaller. Psychoacoustic research showed that auditory skills may differ between musicians of different musical genres.

Nikjeh in 2006 administered DLF on vocalist, instrumentalists and non-musicians. DLF was significantly smaller (better) for musicians compared to non-musicians, while DLF for vocalists and instrumentalists were similar. On similar groups, Nikjeh et al., in 2008 investigated DLF and result showed that musicians detected pitch changes earlier and were 50% smaller (better) than non-musicians. Same group of authors in 2009 examined DLFs and pitch production accuracy (PPA) in musicians. They reported that DLF and PPA were significantly correlated with each other only for musicians with instrumental training. However, PPA was most consistent with minimal variance for vocalists. They concluded stating both vocal and instrumental musicians possess superior sensory-memory representations for acoustic parameters.

Parbery et al., in 2009 compared frequency discrimination in musicians and non-musicians. They reported that musicians are having more fine-grained frequency discrimination. In a similar line, Bidelman and Krishnan in 2010 measured fundamental (F0) and first formant (F1) frequency difference limens (DLs) in musicians and showed DLs 2–4 times better than non-musicians. In another study, Bidelman et al., in 2013 assessed fundamental frequency discrimination limen between musicians and non-musicians. They reported trained musicians was having significantly better fundamental frequency differential limen when compared to non-musicians. Finding of the current study showed, mean DLF for musician was almost half of the DLF of non-musicians. It indicates that musical training and experience has influenced and enhanced active auditory discrimination skills in musicians.

5.4.Correlation between DLF and different response measures of MMN in Musician

The finding of the present study showed that there was a negative relationship between DLF and different response measures of MMN (onset latency, offset latency, peak latency, peak amplitude & area under the curve), though it was not statistically significant. It indicates as DLF reduces (better), the peak amplitude and area under the curve increases. However, similar relation does not hold good for onset, offset and peak latency in relation to DLF. The current finding is consonance with the previous studies (Bertoli, Heimberg, Smurzynski & Probst, 2001; Novitski, Tervaniemi, Huotilainen & Naatanen, 2004; Nikjeh, 2006). However few studies have shown significant correlation between MMN and psychoacoustic measures in different population (Todd, Michie & Jablensky, 2003; Pakarinen, Takegata, Rinne, Houtilainen & Naatanen, 2006).

Bertoli et al., in 2001 investigated relationship between gap-detection threshold and MMN, the result showed no correlation between GDT and MMN. Similar studies (Novitski et al., 2004; Lang et al., 1995) have investigated relationship between neural and behavioural responses to pitch deviance by comparing MMN amplitude and latency to hit rate (HR) and reaction time (RT) for auditory discrimination between two frequencies. They showed correlation between HR and MMN amplitude. However, correlation between HR, RT, and MMN latency were inconsistent. Nikjeh, Lister and Frish in 2006 showed no relationship between psychoacoustic measures (DLF) and electrophysiological variables (MMN amplitude and latency) among musicians.

However, study done by Todd et al., in 2003 tried to explore the relationship between reduced MMN in schizophrenia and behavioural measures of temporal discrimination. The result showed that the patients who had higher discrimination threshold, also have smaller amplitude of MMN to temporally deviant stimuli. It can be concluded from the above study that imprecise representations of the temporal properties of auditory stimuli can leads to reduction in amplitude of mismatch negativity. Another study done by Pakarinen et al., in 2006 recorded MMN elicited by change in stimulus frequency, duration, location and intensity. In addition, behavioural discrimination skill was also assessed to know the relationship between behavioural performance and MMN. The result showed strong relation between behavioural performance and MMN parameters (amplitude and latency).

Present study indicates that the music training and experience affects psychoacoustic ability (DLF) as well as electrophysiological response (peak amplitude of MMN and area under curve); yet, finding did not support significant relationship between these measures for musicians. Lack of significant correlation between DLF and MMN in musicians could be because they represent different processes. MMN reflect automatic neurophysiological memory based sensory response to change detection. Whereas, DLF is measure of active behavioural choices influenced by attention and short-term memory in addition to subjective motivation cooperation. Thus, the electrophysiological variable may represent only a subset of process underlying behavioural discrimination.

Chapter 6

Summary and Conclusions

Present study aimed to find out the relationship between MMN and DLF in musicians and non-musicians. The objective of the study was determine the onset latency, offset latency, peak latency, peak amplitude and area under the curve of MMN in musicians and non-musicians. Similarly, the other objective was to measure DLF in musicians and non-musicians.

Two groups of participant (Experimental & control group) in the age range of 18-40 years were involved in the study. Experimental group includes 25 musicians (Mean age of 24.52 years) who had minimum professional experience of 5 years of music exposure. Further age matched 25 participants (Means age of 24.8 years) who were not having any formal training of music served as non-musicians, in the control group. MMN was recorded with pair of stimuli. The pair was having /1000Hz/ and /1100Hz/ with /1000Hz/ as frequent stimulus and /1100Hz/ as the infrequent stimulus in vertical montage with 'Fz' as the positive electrodes referenced to the nape of the neck. Stimuli were presented in the odd ball paradigm with the probability of standard and deviant stimulus as 80% and 20 % at 70 dBnHL respectively. For the identification of the MMN visual detection following criterion have been used. Psychoacoustic measure (difference limens for frequency) was performed on all the participants (musicians & non-musicians). Differential limens of frequency was assessed at 1000 Hz with the help of MATLab software using maximum likelihood procedure technique.

To analyze the data collected from musicians and non-musicians, descriptive statistics and MANOVA was done. Out of 50 participants, MMN was present only in 17 (68%) musicians and 16 (64%) non-musicians. The different measures of MMN i.e. onset latency, Offset latency, peak latency, peak amplitude and area under curve was extracted from the MMN waveform through visual inspection for each participant. Descriptive statistics was done to find out mean and standard deviation (SD) for all the parameters of MMN. MANOVA showed marginal significant difference for onset latency whereas no significant difference observed for offset and peak latency between musicians and non-musicians. MANOVA also showed statistically significant difference for peak amplitude and area under curve between musicians and non-musicians. Similarly, Independent t-test was carried out to compare differences between musicians and non-musicians for DLF. Result showed statistically significant difference in DLF between musicians and non-musicians. Correlation analysis was carried out to find out relationship between DLF measures and MMN. Result showed negative relationship with DLF across all measures of MMN (onset latency, offset latency, peak latency, peak amplitude and area under curve), though it was not statistically significant.

Present study showed marginal significant difference in onset latency between musicians and non-musicians, and no significant difference seen in offset latency and peak latency between musicians in comparison to non-musicians. The reason of not getting significant difference in latency between musicians and non-musicians in present study may be due to poor reliability and high variability in latency measures of mismatch negativity. Result of the present study showed, peak amplitude and area under the curve was significantly higher (better) in musicians compared to non-musicians. It indicates that that musical training enhances the pre-attentive auditory discrimination skill in musicians, leads to higher peak amplitude and greater area under the curve compared to non-musicians. The current study also showed that mean DLF for musician was almost half (better) of the DLF of non-musicians. It indicates that musical training and experience has influenced and enhanced active auditory discrimination skills in musicians.

Lack of significant correlation between DLF and MMN in musicians could be because they represent different processes. MMN reflect automatic neurophysiological memory based sensory response to change detection. Whereas, DLF is measure of active behavioural choices influenced by attention and short-term memory in addition to subjective motivation cooperation.

6.1. Implication of the study

Present study showed that musical training has enhanced pre-attentive and active auditory discrimination skills in musicians. Musical training can be used to enhance pre-attentive and active auditory discrimination skills in clinical population i.e. central auditory processing disorder, Learning Disability, Parkinson’s disease, schizophrenia, Alzheimer’s disease, children with developmental language disorder and children with cochlear implant. Enhancement of pre-attentive and active auditory discrimination skills due to musical training in these populations may results in improvement in speech perception.

6.2. Future direction

Although several important inferences were derived from the present study, future studies in this direction can be strengthened by considering the following suggestions:-

1. MMN can be compared among musicians and non-musicians using different stimuli i.e. harmonic tones, speech syllables, musical tones and pure tones.

2. MMN and psychoacoustic measures can be measured among musicians of different genera.
3. MMN can be recorded from various scalp regions in musicians to observe the effect of musical training from different sites of brain.

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