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Review

Enhanced auditory evoked potentials in musicians: A review of recent findings

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Abstract

Auditory evoked potentials serve as an objective mode for assessment to check the functioning of the auditory system and neuroplasticity. Literature has reported enhanced electrophysiological responses in musicians, which shows neuroplasticity in musicians. Various databases including PubMed, Google, Google Scholar and Medline were searched for references related to auditory evoked potentials in musicians from 1994 till date. Different auditory evoked potentials in musicians have been summarized in the present article. The findings of various studies may support as evidences for music-induced neuroplasticity which can be used for the treatment of various clinical disorders. The search results showed enhanced auditory evoked potentials in musicians compared to non-musicians from brainstem to cortical levels. Also, the present review showed enhanced attentive and pre-attentive skills in musicians compared to non-musicians.

Keywords: Neuroplasticity; Auditory evoked potential; Review; Musicians; Electrophysiological

Contents

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1. Introduction

Electrophysiological testing is one of the objective modes of assessment to check the integrity of the auditory function and neuroplasticity (Starr et al., 1977; Golding et al., 2007). These measures complement the information provided by behavioral measures (Bruneau et al., 2003; McArthur and Bishop, 2005; Golding et al., 2007). Auditory evoked potentials are one of the electrophysiological measures which describe a series of electrical changes occurring in the peripheral and central nervous systems, usually related to the sensory pathways (Kraus and Nicol, 2008). Auditory evoked potentials can be further classified as endogenous and exogenous potentials. The exogenous potentials are primarily evoked by some external event related dimensions of the stimulus (Kraus and Nicol, 2008). The endogenous potentials are responses which are due to internal events such as cognition or perception (Sams et al., 1985; Novak et al., 1990; Čeponien et al., 2002; Chang et al., 2014). Recently, researchers showed a great interest in using auditory evoked potentials as an objective tool to assess neuroplastic changes in different populations including musicians (Bidelman and Alain, 2015; Pantev et al., 2015) and dancers (Karpati et al., 2015; Sinha et al., 2013). In the present review, auditory evoked potentials in musicians are summarized under different headings and the findings of various studies can act as an evidence for music-induced neuroplasticity and enhanced auditory evoked potentials which can be used for the treatment of various clinical disorders, i.e. dyslexia, central auditory processing disorder, schizophrenia, development language disorder, Parkinson disease, Alzheimer's disease, etc.

Music training contributes to the development of cognitive and linguistic abilities with increment in neuroplasticity along cortical and sub-cortical pathways of the auditory system as revealed by various electrophysiological studies (Bidelman and Krishnan, 2010; Musacchia et al., 2008; Okhrei et al., 2012; Nikjeh et al., 2009; Polat and Ataş, 2014). Music requires a wide range of processing mechanism which consists of encoding of sounds at a higher cognitive level involving memory, sequencing and learning. These higher cognitive skills, enhanced by music training, ultimately help improving speech and language processing.

2. Methodology

Various databases, such as PubMed, Google, Google Scholar and Medline, were searched for references related to auditory evoked potentials across musicians from 1994 to 2016.

3. Roadmap of review

1. Brainstem auditory evoked potentials in musicians
2. Cortical auditory evoked potentials in musicians
3. P300 in musicians
4. Mismatch negativity in musicians
5. Neuroplasticity in musicians
6. Clinical implication

All the above electrophysiological tests were conducted across different types of musicians by several schools of researchers.

3.1. Brainstem auditory evoked potentials in musicians

Wong et al. (2007) recorded brainstem encoding of linguistic pitch. The results showed that the musicians reflected more enhanced and better encoding of linguistic pitch compared to non-musicians. A similar study was done by Lee et al. (2009) which assessed auditory brainstem responses in 10 adult musicians and 11 non-musicians. The musicians were six pianists, two vocalists and two violinists with 10 or more years of musical training. The stimuli used were two musical intervals, the minor seventh and major sixth respectively. The results revealed that there were significant differences in the spectral analysis of the frequency following response. Musicians had significantly greater amplitudes for the harmonics compared to non-musicians. The other major finding for this study was that the number of years of musical exposure and training was well correlated with the amplitude of each of the frequency. It can be inferred that musicians have a better encoding of linguistic pitch and harmonics compared to non-musicians.

Parbery-Clark et al. (2009) recorded subcortical neurophysiological responses to speech in noise and quiet situations for experienced musicians and non-musicians. The stimuli taken were CV speech syllable /da/ of 170 ms in quiet and background noise which consisted of multi-talker babble. The results indicated that musicians were having higher similarities between brainstem responses of speech in quiet and noisy situations thereby indicating to us that incorporating background noise was not degrading brainstem responses in musicians. However, poor brainstem responses were seen in non-musicians when speech stimuli were presented in noise. This indicates that addition of background noise deteriorates brainstem responses in non-musicians when performance was compared to quiet condition. These outcomes showed that musical training and experience curb the adverse effects of background noise, showing perceptual benefits in speech in noise conditions for musicians compared to non-musicians.

Bidelman and Krishnan (2010) investigated brainstem frequency-following responses across adult musicians and age-matched non-musicians in response to the vowel /i/ at a different level of reverberation. The outcome of the study showed that the effect of reverberation had a slight impact on neural encoding of the pitch, but at the same time the neural encoding of the formant related harmonics were significantly vulgarized. In another study, Bidelman et al. (2011b) recorded brainstem frequency-following responses for both musicians and non-musicians. The stimuli taken were tuned and detuned chordal arpeggios which were differing only in pitch. The results revealed that musicians showed faster and enhanced neural synchronization and brainstem encoding for defining characteristics of musical sequences regardless if 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. The outcome of the study suggests that salient aspects of the musical pitch are represented at brainstem level and this representation improves with expertise in music. A study conducted by Bidelman et al. (2011a) compared auditory evoked responses from brainstem among 11 English-speaking musicians, 11 non-musicians and 11 native speakers of Mandarin (tonal language, Chinese) in the age range of 21–25 years. The musicians had musical experience of more than 10 years. The stimuli used were tuned and detuned musical cords. The results showed that musicians and native speakers of Mandarin had enhanced representation of defining pitches of various musical sequences at brainstem level in comparison to non-musicians. The results of this study show that Mandarin speakers are equivalent to musicians with 10 years of musical experience in defining pitches of musical sequences. It can be inferred that a non-musician tonal language speakers will have superior brainstem encoding of auditory stimuli compared to non-musician non-tonal language speakers.

Parbery-Clark et al. (2011) investigated subcortical encoding of speech syllable in variable and predictable conditions for adult musicians. Musicians showed enhanced neural encoding for fundamental frequencies of speech presented under predictable conditions compared to variable conditions than non-musicians. Findings also pointed out that the subcortical sensitivity to speech regularity had been modified by musical training and exposure. Parbery-Clark et al. (2012b) investigated the extent to which the timing difference of subcortical responses varied with speech syllables /ba/, /da/ and /ga/ in adult musicians and non-musicians. The results showed that musicians exhibited enhanced subcortical discrimination of closely related speech sounds than non-musicians. The outcome of the study demonstrated that music training leads to superior discrimination skills. So it can act as a proof that music training leads to superior auditory discrimination skills of closely related speech sounds in clinical populations which can indirectly help in the improvement of speech perception. Parbery-Clark et al. (2012a) compared auditory brainstem timing in older and younger musicians and non-musicians. The stimulus taken was a CV speech sound /da/. The results showed that musicians are unsusceptible to an age-related regression in neural timing. Strait et al. (2014) recorded brainstem encoding of speech syllable /ga/ and /ba/ as well as visual and auditory cognitive abilities across 3 different age ranges: preschoolers, school-aged children, and adult musicians and non-musicians. The results revealed that musicians had clear neural encoding of stop consonants early in life (as young as 3 years of age) and this was seen in children with few years of training. To sum it up, musicians had improved neural differentiation of stop consonants early in life and with a little experience of musical training. In contrast to the above studies, another study done on professional pop/rock musicians, which showed diminished mean latencies of ABR (auditory brainstem response) and cognitive potentials in musicians compared to non-musicians. They concluded that rock/pop musicians are at risk for developing music-induced hearing loss (Samelli et al., 2012). It is likely due to exposure to loud music among rock musicians.

From the above literature, it can be concluded that musicians have enhanced spectral analysis of the frequency following responses. It also indicates that musicians also have increased similarities between brainstem responses in quiet as well as in noise. It has also been observed that musicians show rapid neural synchronization and enhanced brainstem encoding for defining characteristics of musical sequences. The 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 regression in neural timing.

3.2. Cortical auditory evoked potentials (CAEP) in musicians

Changes in waveform morphology of CAEPs (in terms of decrease in latency and increase in amplitude) are considered to indicate an increase in neural synchrony and strengthened neural connections (Tremblay et al., 2001). A study was done by Shahin et al. (2003) which showed that P2 and N1c peaks of the auditory evoked potential (AEP) were sensitive to remodeling of the auditory cortex with training. In this study, 11 highly skilled 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 the experimental group. Pianists had used the instruments for 16.6 ± 4.0 years and violinists had used their instruments for 17 ± 3.7 years and practiced for 17.9 ± 11.1 (pianists) and 34.7 ± 20.8 h/week (violinists). Age-matched individuals with no musical background were taken as the control group. The stimuli taken were piano tones, violin tones and pure tones for the study. The results revealed that P2 and N1c AEPs evoked by musical tones were robust in musicians compared to non-musicians. P2 and N1c responses to the pure tone, which had a pitch like quality, were also enhanced in musicians compared to non-musicians. They reported that the enhancement of N1c and P2 was significant because these AEPs have been shown to be sensitive to neuroplastic remodeling (Tremblay et al., 2001; Shahin et al., 2003). Similarly, Trainor et al. (2003) compared auditory evoked potentials in adult musicians and non-musicians as well as in 4–5 years old children who had extensive musical training compared to the children who never had any musical training. The stimuli taken were pure tones, violin tones and piano tones. The results showed that P2 was enhanced in both adult and child musicians compared to non-musicians. The results also revealed that the P2 indicated neuroplasticity as an effect of musical training seen early in development. It can be inferred from the study that P2 can be considered as a biological marker of neuroplasticity and more research should be done to validate it. It will help the professional to report an increment in neuroplasticity after musical therapy/training across clinical populations. Shahin et al. (2005) investigated N1 and P2 responses in pianists and non-musicians. The stimuli taken were three variants of a

C4 piano tone which was equated for temporal envelop but differing in the number of harmonics. The results highlighted that the P2 amplitude was enhanced in pianists compared to non-musicians. It was also observed that only P2 amplitudes increased with spectral complexity in pianists but not N1 amplitudes.

Musacchia et al. (2008) investigated cortical encoding of speech in 26 participants (mean age 25.6 ± 4.1 years), which included 14 musicians and 12 non-musicians. The stimulus taken for the study was a synthesized speech syllable of a total duration of 350 ms which had a fundamental frequency of 100 Hz. The first formant of steady state was 720 Hz and second formant of steady state was 1240 Hz. The results indicated 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 Ataş (2014) evaluated cortical auditory evoked potentials in adult musicians and non-musicians with different speech stimuli (/m/, /g/ & /t/) at 65 dB SPL. The results showed enhanced amplitude of P1 and P2 in musicians compared to non-musicians. The results also revealed that musical training and experience had an impact on central auditory nervous system and the outcome of the study showed enhanced cortical auditory evoked potentials in musicians compared to non-musicians with speech sounds.

From the current literature, it can be inferred that there is a shorter latency and greater amplitude (better) of CEAPs in musicians compared to non-musicians, which indicates an increase in neural synchrony and strengthened neural connections in musicians. Literature also shows that P2 and N1c AEP evoked by musical tones are robust in musicians compared to non-musicians. It has also been observed that neuroplasticity and effects of musical training are early in development. It can be concluded that musical training and experience have a positive effect on the central auditory nervous system and this can be inferred by superior cortical auditory evoked potentials in musicians compared to non-musicians by different auditory stimuli.

3.3. P300 in musicians

P300 is an event-related or endogenous evoked response that is highly dependent on subject attention to certain auditory stimuli (Polich, 2007). The P3 wave is elicited by a task known as the odd-ball paradigm. During this task, a series of one type of frequent stimuli (standard stimulus) is presented along with a different type of non-frequent (target) stimulus. The task of the experimental subject is to react to the presence of target stimulus by a given motor response. If a person attends to target stimuli, P300 is produced and if not other potentials are produced. Crummer et al. (1994) investigated P3 component of an event-related potential between adult musicians and non-musicians. The stimulus used were 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 tasks was enhanced for musicians compared to non-musicians. However, P3 amplitudes were alike for the two other timber series. The other finding was that mean P3 latencies for the musicians were shorter in all series than mean P3 latencies for non-musicians. A study was done by Tervaniemi et al. (2005) which investigated P3 responses in 13 professional musicians and age-matched non-musicians. The study was carried out in attentive and reading conditions. The results showed that P3 responses found at the time of attentive listening were of a larger amplitude in musicians compared to non-musicians. In contrast, P3 responses recorded in the reading condition could not be differentiated between musicians and non-musicians.

Okhrei et al. (2012) investigated P3 in 7 musicians and 10 non-musicians using tonal stimuli which showed that the peak latency of P3 component in the left hemisphere was significantly shorter in musicians compared to non-musicians. This reveals the superior attentive auditory discrimination skills in musicians compared to non-musicians. They also observed that there was a significant difference in latency between the left and the right hemispheres. Ungan et al. (2013) found a difference between musicians and non-musicians in their skills to identify changes in rhythm. The stimuli used were three consecutive and equally spaced drum beats. The results showed that P3 evoked via rhythm change was significantly larger in amplitude and shorter in latency in musicians compared to non-musicians. They concluded that P3 data strongly supported the hypothesis that cognitive and/or sensory advantage of musicians over non-musicians in detecting rhythm changes is also reflected in their P3. Rabelo et al. (2015) investigated P300 latency and amplitude in 30 musicians and 25 non-musicians between the age of 20 and 53 years. The results showed that musicians had shorter latency and larger amplitude than non-musicians. The central auditory nervous system of musicians shows a special characteristic in electrophysiological responses probably due to plasticity from musical training and practice.

The above literature shows that P300 latencies are shorter (better) and amplitudes larger (better) in musicians compared to non-musicians in various stimuli and conditions. The review of the literature on P300 in musicians highlights the sensory and/or cognitive advantage of musicians over non-musicians. It has been observed that musicians have enhanced attentive auditory discrimination skills compared to non-musicians. Auditory discrimination abilities are important for speech perception (Reed, 1989). Musical training can be provided to individuals with poor auditory discrimination skills (CAPD, dyslexia, developmental disorder, cochlear implantees, Schizophrenia, etc.) and enhancement can be assessed through P300.

3.4. Mismatch negativity in musicians

The mismatch negativity (MMN) is an auditory evoked potential which comes under event-related potentials (endogenous potentials) and has been greatly used by researchers to assess pre-attentive auditory discrimination skills and storage of regularities in features of stimulus (Paavilainen, 2013). Pre-attentive processing is the unconscious collection of auditory stimuli from the environment. All available information is pre-attentively processed by our brain. Then, our brain filters and processes important information. Information that stands out the most or is relevant to what a person is thinking about is selected for further and more complete analysis by conscious (attentive) processing (Atienza et al., 2001). Our auditory system has an important role in gathering sound information for pre-attentive processing. At the point when auditory stimuli or sound waves strike the tympanic membrane, message is sent to the brain by means of the auditory nerve for pre-attentive processing. The proficiency to appropriately filter information from pre-attentive auditory processing to attentive auditory processing is crucial for normal development (Seri et al., 2007). For acoustic pre-attentive processing, the temporal cortex is the primary site of activation, but research has additionally demonstrated the association with the frontal cortex (Habermeyer et al., 2009; Klamer et al., 2011). It is hypothesized that musicians have superior pre-attentive auditory discrimination compared to non-musicians. MMN was done by Koelsch et al. (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 results showed that distinct MMN was evoked in professional violinists but not in non-musicians. They concluded musicians had better pre-attentive auditory processing skills compared to non-musicians. Another study by Russeler et al. (2001) was conducted 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 seemed to be more precise and longer in trained musicians, compared to non-musicians and that a long-term training effect was reflected with respect to changes in neural activity.

Nager et al. (2003) also investigated MMN in professional pianists, conductors and non-musicians. The stimuli used to evoke MMN were noise-bursts which were presented from six speakers in a random order. Three speakers were located in the front and other three to the right of the subject. In different runs, participants either attended the centermost or the most peripheral speaker to detect even slight deviant noise bursts. Mismatch negativity was used to monitor the entire auditory scene. It was found that MMN was larger in amplitude in musicians compared to non-musicians, showing better pre-attentive auditory discrimination skills in musicians compared to individuals who did not practice music. A study was done by Zuijen et al. (2005) which 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 by occasional segment lengthening, either in number or time evoking the MMN. The results 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 skills in musicians compared to non-musicians. A similar study by Zuijen et al. (2004) investigated ability to pre-attentively group consecutive sounds among musicians and non-musicians. They recorded MMN using four consecutive tones in a sequence which could be grouped according to either good continuation or similarity of the pitch. Occasionally, the tone-group length was violated by a deviant tone. The outcome of the study revealed that MMN was elicited in musicians as well as non-musicians when grouping of sound was established on pitch similarity. In the same study, the researchers found that when the sound was grouped, based on the good continuation of the pitch, MMN was evoked only in musicians. They summed up that not all form of auditory grouping was enhanced with musical experience.

Tervaniemi et al. (2005) studied 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 the 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 (2006) recorded MMN in 21 formally trained instrumental musicians and age-matched non-musicians using harmonic tones. The results showed no significant difference in latency of MMN between instrumental musicians and non-musicians. According to a study which was done by Tervaniemi et al. (2006) which recorded MMN to changes in acoustic features (gap, duration, frequency, location and intensity) and abstract features (interval size and melodic contour) in non-musicians and amateur band musicians. The results showed that musicians had a larger amplitude of MMN and a greater area under curve compared to non-musicians for a 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 et al. (2009) assessed mismatch negativity on 67 trained musicians and 35 non-musicians. Three stimulus conditions were taken (1) pure tones, (2) harmonic tones, and (3) speech syllables. For the pure tone condition, the standard tone was at 1000 Hz and deviant at 1015 Hz and 1060 Hz. For the harmonic tone condition, the standard tone was G4 ($F0 = 392$ Hz), and the two deviant tones were $F0 = 386$ Hz and $F0 = 370$ Hz. For the speech syllable, /ba/ was used as the standard and /da/ as the 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 the frequency difference between standard and deviant increasing and MMN latency decreasing (better) respectively. They also observed that mismatch negativity latencies for harmonic tones and speech syllables were significantly lesser (better) for musicians when compared to non-musicians. This study showed that the enhancement in pre-attentive auditory discrimination skills in a musician took place for both speech as well as non-speech stimuli. Marie et al. (2012) investigated pre-attentive skills in musicians and non-musicians using mismatch negativity. The stimuli were presented in the odd ball paradigm, in which deviant tone was different from the standard in terms of frequency. The results revealed that the mismatch negativity peak amplitude was significantly larger in musicians compared to non-musicians for frequency deviants. This showed enhancement in pre-attentive auditory discrimination skills in musicians. Vuust et al. (2012) administered MMN on musicians using fast, novel and musical sounding multi-feature paradigms, in musicians of different styles of music exposure (jazz, classical and pop/rock). The results revealed that jazz musicians had a larger amplitude than rock, classical and non-musicians across the six different sound features.

Boh et al. (2011) recorded MMN on 8 musicians and 13 non-musicians with sine tones. The stimulus induced a larger amplitude of MMN in musicians compared to non-musicians revealing that musicians who underwent long-term musical training had enhanced capacity of auditory short-term memory of sine tones. A similar study was done by Kuhnis et al. (2013) and 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 in musicians and non-musicians to discrepancies of rhythm between pairs of unfamiliar melodies based on western classical rules. They noticed that musicians were 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 a significantly larger amplitude of MMN for all changes in stimuli. Musical training helps enhancing auditory discrimination for musically central sound dimensions in pre-adolescence. Recently, Lappe et al. (2016) assessed pre-attentive processing in musicians by elicited MMN on detection of melodic and rhythmic errors in auditory input. The results revealed that elicitation of MMN for rhythmic errors was shorter in latency compared to MMN elicited by melodic errors. Analysis done by Beamformer source analysis revealed activation of the inferior frontal, superior temporal and superior frontal areas by melodic deviations whereas, inferior and superior parietal areas in addition to the superior temporal area were activated by rhythmic deviations in auditory stimuli. Activation of the broad cortical network was seen in trained musicians on prediction and error detection of musical stimuli. They concluded that melodic and rhythmic errors are processed in partially different cortical streams. Herholz et al. (2009) concluded that probability distribution and auditory grouping of possible patterns within a sequence has an impact on an assumption about the tone which comes next. And it can be said that MMN may also depend on global statistical knowledge instead of a local memory trace.

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

3.5. Neuroplasticity in musicians

Neuroplasticity refers to any change or modification in the central nervous system because of any adaptation or experience to environmental demands. Neuroplasticity denotes changes of structural or functional conditions along with changes at the system or cellular level. Modification of gross anatomy of the brain, structural changes in an individual brain cell and reorganization of the neural network that sub-serve complex cognitive processes are examples of neuroplasticity. Music demands cognitive and neural challenges, which needs precise and accurate timing of many actions. Enhanced auditory perception in musicians is a likely outcome from auditory perceptual learning due to years of practice and training. Previous literature showed plasticity dependent on experience. Kleim and Jones (2008), and Green and Bavelier (2008) explained some of the prerequisites for inducing neuroplasticity, which include involvement, intensity, repetition and frequency of music training. Many of the trained professional and experienced musicians indulge in intensive music training and learning for many years to attain a superior level of expertise. Hence, musicians can be considered as the best group for researches whose results show changes or modification in brain structures and functions across multiple information processing systems. According to Schneider et al. (2002), both the neurophysiology and morphology of Heschl's gyrus have a strong effect on musical aptitude. A similar study by Ragert et al. (2004) on pianists revealed that despite high-level performance in pianists, the effect of Hebbian learning was more in musicians than in controls, hence showing stronger capability for plastic reorganization and points to enhance learning abilities implicating a form of meta-plasticity in professional pianists. Hoenig et al. (2011) reported functional magnetic resonance imaging (fMRI) for conceptual processing of visually presented musical instruments activating auditory association cortex and 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 a variety of musical instruments provide a connection between conceptual brain systems and auditory perceptual skills. White-Schwoch et al. (2013) worked with geriatrics with a whole life of music training and indicated that a moderate amount of music training of 4–14 years early in life has an impact on neural timing (faster) in response to speech later in life, even after the training was stopped. This study also showed that early music training sets the platform for consequent interactions with auditory stimuli and this background may develop over time to maintain enhanced neural processing in central auditory nervous system even in later stages of life. Similarly, Bidelman and Alain (2015) conducted a study on geriatric populations with and without modest musical training. They recorded both cortical neuroelectric and brainstem responses in geriatric individuals with and without modest musical training as they differentiate speech sounds as an acoustic-phonetic continuum. Results showed that in speech evoked responses, superior temporal precision was observed at different levels of central auditory nervous system in experienced musicians who had a good skill to discriminate between phonetic categories. Older musicians also showed a closer correspondence between neural activity and perceptual performance. Kumar et al. (2015) investigated temporal resolution skills in vocal musicians as compared with non-musicians. The results showed enhanced temporal resolution skills in vocal musicians at all measures compared to non-musicians. Pantev et al. (2015) studied the influence of long term and short-term musical training. They showed that musical training of a longer duration leads to a different way of processing multisensory information within the auditory cortex, as compared to short-term training, inferring that multisensory music reading training affects the multimodal processing within the auditory cortex.

3.6. Clinical implication of present review

The present review shows that musical training enhances electrophysiological responses in musicians. From the support of the literature, it can be inferred that music therapy or musical training can be used to enhance brainstem, cortical and subcortical encoding of speech. Musical training also enhances pre-attentive and attentive auditory discrimination skills in clinical populations with central auditory processing disorders (Näätänen et al., 2012), dyslexia (Kujala and Näätänen, 2001), Parkinson's disease (Pekkonen, 2000), Alzheimer's disease (Pekkonen, 2000), schizophrenia (Perez et al., 2014), developmental language disorders (Bishop, 2007) and cochlear implant (Kuo et al., 2014). Similarly, various studies on cortical and sub-cortical processing of auditory stimuli in different clinical populations also show enhanced auditory evoked potentials after musical or auditory training (Tarasenko et al., 2013; Anderson and Jenkins, 2015; Flaugnacco et al., 2015; Alonso and Schochat., 2009). Bregman (1990) reported auditory scene analysis as the internal process of segregating and subsequent grouping within the auditory system for better speech perception. It is based on the assumption that pre-attentive process uses the Gesalt laws of organization which says that temporal proximity, physical similarity and good continuity are required to group the sound, which improves speech perception in quiet as well as in noise (Koffka, 1935). Enhanced pre-attentive auditory discrimination skills in musicians have been reported by many researchers (Marie et al., 2012; Kuhnis et al., 2013; Habibi et al., 2014; Putkinen et al., 2014). So it can be hypothesized that musical training can be used for enhancement of pre-attentive auditory discrimination skills in clinical populations and it may result in improvement in speech perception.

Musical training helps in fostering plasticity of the brain and it improves cognitive skills and linguistic abilities. Music requires a broad range of processing mechanism which includes encoding of sound to higher cognitive functions, i.e. attention, memory, learning and sequencing. These higher cognitive functions can be enhanced by musical training which indirectly improves speech and language processing (François et al., 2013). Previous literature has also indicated that musical training acts as a boon to linguistic skills, i.e. phonological awareness, dynamic acoustic analysis, reading, pitch and lexical stress processing and speech-language proficiency (Tallal and Gaab, 2006; Kraus and Chandrasekaran, 2010). Kraus and Chandrasekaran (2010) reported better detection of pitch changes in speech by musically trained children who also had increased verbal and reading abilities, providing evidence for a music to language transfer effect. François et al. (2013) conducted a longitudinal study over two years using electrophysiological and behavioral tests. They administered a test–training–retest procedure to assess the impact of musical training on speech segmentation in children (8 years). The outcome of their study showed that music training benefited in speech segmentation and they pointed to the strong implication of musical training in the improvement of speech perception and language development in children. These results are strong evidence for promoting the development of music-based rehabilitation techniques for children with language based impairment. Musical training may enhance auditory coding competence at brainstem and auditory regions that leads to improvement in speech perception and speech segmentation abilities among musicians (Tallal and Gaab 2006; Kraus and Chandrasekaran 2010). In another way, it can be said that musical training may help in the development of a more stable memory trace via a more competent working memory and sequencing process which unify pitch and syllabic structures, through functional and anatomical modification. Musical training may slow down the effect of interference of neighboring syllables. This may be due to more potent temporal processing (Tallal and Gaab, 2006), enhanced attention (Baumann et al., 2008) or executive functions (Moreno et al., 2011). A study was done by Sluming et al. (2002) which reported increased gray matter density and volume in the left frontal gyrus of musicians. So musical training certainly has an effect on the functional plasticity of the subcortical and cortical network. The influence of musical training on brain plasticity goes beyond the auditory system and influences the ventral and dorsal pathways which play an important role in higher order processing which is essential for speech and language acquisition (Scott and Wise, 2004; Hickok and Poeppel, 2007; Rodríguez-Fornells et al., 2009). Enhancement of brainstem, cortical and subcortical encoding of speech with pre-attentive and attentive auditory discrimination skills due to musical training in clinical populations may result in improvement in speech perception.

4. Conclusion

The above literature shows enhanced auditory evoked potentials in musicians compared to non-musicians from brainstem to cortical levels. Present review also shows enhanced attentive and pre-attentive skills in musicians compared to non-musicians. It can be concluded that an increment in neuroplasticity assessed by auditory evoked potentials in musicians at sub-cortical and cortical levels of the auditory pathway can act as an evidence of music-induced neuroplasticity. Musical training or music therapy in various clinical populations can be an effective tool to remediate various processing difficulties at different levels of the auditory pathway. The current review also opens the gate for future research on musical training with auditory evoked potentials in different populations. There should be further research on the intensity of musical training for modification of neural organization on different clinical populations, the effectiveness of different styles of musical training, the efficacy of different auditory evoked potentials in the assessment of changes in neuroplasticity in different clinical populations at various levels of the auditory pathway. Our present review mostly discusses studies with cross-sectional designs that compare musicians with non-musicians presenting the inherent problem of confounding factors. Indeed, genetic predispositions and other general factors like the level of education and socioeconomic status can explain the differences observed. Therefore, longitudinal studies should be done in this area to reduce the inherent problem of confounding factors.

Conflict of interest

None.

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