Temporal Resolution in Individuals with and without Musical Training

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Abstract

Music has recently become a popular topic in neuroscience research. Many studies have focused on long term effect of music training on psychoacoustic and biological processing of auditory stimuli, but few have focused on temporal resolution abilities in individuals with and without musical training. The main aim of this study was to explore the differences between auditory temporal resolution abilities of children with instrumental music training and children and adults who did not have any musical training. A total of 45 participants with normal hearing sensitivity in the age range of 10 to 30 years, participated in the study. They were divided into 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. Three temporal resolution tasks were used, namely were gap detection, duration discrimination, and modulation detection with sinusoidally amplitude-modulated noise at different modulation rates. Results showed that children with musical training performed at par with adults without musical training, and better than children with no musical training, on all tasks except modulation detection at the highest rate of 200 Hz. The results support further exploration into the applications of musical training in enhancing auditory perceptual skills.

Keywords: *Gap detection threshold, Duration discrimination, Speech perception, Modulation detection*

Musical training enhances the ability to code fast varying auditory stimuli (Parbery-Clark, Skoe, Lam, & Kraus 2009). Music contains fine modulations of amplitude, frequency, and temporal aspects. Musicians are trained to identify these fine fluctuations and which in turn codes their neuron system (Parbery-Clark et al., 2009). Generally, a successful musician has decades of training, beginning at an early age with regular practice for several hours every day. Previous studies have shown evidence of structural and functional changes in brain in individuals with musical training (Elbert, Pantev, Wienbruch, Rockstroh, & Taub, 1995; Pantev et al., 1998; Schlaug, 2001). Because of this intense music training for precision in processing auditory signals, the "musician's brain" has been identified as the ideal model for experience-driven neuroplasticity (Gaser & Schlaug, 2003; Schlaug, 2001; Zatorre 2003; Zatorre & McGill, 2005)

According to Schneider and Pichora-Fuller (2001), temporal processing cues are important for speech intelligibility at least on two levels: supra-segmental (prosodic) and segmental (phonemic). At the segmental level, syllable rhythm and speed, influence lexical and syntactic language processing. At the supra-segmental level, cues from duration and gap influence phoneme identification. Most auditory information is influenced by time. Thus temporal processing plays a major role in identifying and discriminating segmental and supra segmental aspects of speech. Long-term musical experience has been shown to result in structural and functional changes for processing auditory stimuli (Gaser & Schlaug, 2003; Pantev, Engelien, Candia, & Elbert, 2001; Peretz & Zatorre, 2005). Early investigations focused on cortical changes induced by musical experience (Lappe, Herholz, Trainor, & Pantev, 2008; Rosenkranz, Williamon, & Rothwell, 2007; Shahin, Bosnyak, Trainor, & Roberts, 2003; Trainor, Shahin, & Roberts, 2003)), but several recent studies have found enhanced stimulus coding even in the subcortical systems of trained musicians (Kraus & Banai 2007; Kraus, Skoe, Parbery-Clark, & Ashley, 2009; Lee, Skoe, Kraus, & Ashley, 2009; Musacchia, Sams, Skoe, & Kraus, 2007; Parbery-Clark et al., 2009; Strait, Kraus, Skoe, & Ashley, 2009; Wong, Skoe, Russo, Dees, & Kraus, 2007)). It has been proposed that this subcortical enhancement may result from corticofugal (top–down) mechanisms, because playing an instrument and listening to music, involve both, high cognitive demands and auditory acuity (Hyde et al., 2009). There are many

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projections in the corticofugal pathway which can alter the function of subcortical neuron circuits (Kral & Eggermont 2007; Strait, Kraus, Skoe, & Ashley, 2009; Winer, 2006).

Musical training requires rigorous and regular practice with complex sounds. Thus, an individual undergoing training spends hours in manipulating and attending to complex sounds. This may provide greater advantages for engendering neural plasticity and learning (Blood & Zattore, 2001). Rigorous training with music may code neurons to identify subtle differences in the acoustical signal. These enhanced perceptual cues help musician to perform better than non-musicians in adverse listening conditions (Allen, Kraus, & Bradlow, 2000; Kraus et al., 2009).

Studies on short term training for auditory tasks have shown enhanced auditory evoked potentials (Bosnyak, Eaton, & Roberts, 2004; Reinke, He, Wang, & Alain, 2003; Tremblay, Kraus, McGee, Ponton, & Otis, 2001; Tremblay & Kraus, 2002). Thus, it is of great interest to examine the changes in the brains of children due to musical training. These questions have been addressed in previous studies. Shahin, Roberts, and Trainor (2004) showed that musically trained 4-5 year old children showed larger P1 and P2 responses to piano tones, compared to untrained children. However, the impact of training on developmental trajectory remained unclear because no significant difference was seen between two measurements made one year apart in either group. Recently Fujioka, Ross, Kakigi, Pantev, and Trainor (2006) explored the effect of one year of music training on brain organization, in 4-to 6-year-old children. They recorded magnetic brain potentials using magnetoencephalography before and after Suzuki training (a method of teaching violin music). A clear music training effect was expressed in response to the violin sound via a larger and earlier N250 peak in the left hemisphere. More recently, Moreno et al., (2009) found changes in the pattern of brain waves of 8-year-old children after six months of practice, similar to results previously found in 8-year-old children with three to four years of music training (Magne, Schon, & Besson, 2006). A majority of published studies compare adult musicians and non-musicians. Recent studies evaluating the effects of the initial music learning period in children have also demonstrated functional changes as a result of training.

Research in the past has focused on using evoked potentials and some behavioural measures to examine effects of musical training. Many studies employing behavioural measures have focused on pitch discrimination, backward masking, forward masking and random gap detection threshold test (RGDT) in musicians (Ishii, Midori-Arashiro, & Desgualdo-Pereira 2006; Jeon & Fricke 1997; Nikjeh, Lister, & Frisch 2008; Oxenham, Fligor, & Mason, 2003; Parbery-Clark et al., 2009; Rammsayer & Altenmuller, 2006) and these measures have been found to be enhanced in musicians. Ishii, Midori-Arashiro, and Desgualdo-Pereira (2006) measured temporal resolution in professional and amateur singers and concluded that the random gap detection threshold test is not sensitive enough to distinguish between professional and amateur singers. Temporal processing is involved in most of the auditory processing abilities because auditory information is highly influenced by time (Shinn, 2003). Temporal resolution is the ability to detect time gaps between sounds or the shortest time necessary for an individual to discriminate between two audible sounds (Phillips, Gordon-Salant, Fitzgibbons, & Yeni-Komshian, 2000; Shinn 2003). Accurate temporal resolution is very important for the recognition of speech sounds, changes of duration, pauses, and syllable speed: all of which are important cues for speech perception (Minifie 1973).

As reported in the literature, both short and long term music training enhances auditory evoked potentials in children. But less attention has been paid to the effects of musical training on temporal resolution. So, in this study the authors measured temporal resolution using gap detection threshold, duration discrimination and modulation detection in children who were undergoing instrumental music training, and also in children and adults without musical training.

Method

Participants

A total of 45 participants were included in this study. They were divided into three groups. The first group included 15 children (9 females and 6 male) with musical training (M) in the age range of 10-15 years (Mean age 12.66 years) who were self identified through questionnaire. These children had a minimum of 1 year and maximum of 2 years of instrumental (guitar) music experience and had continued to practice consistently 7 hrs in a week before participating in the study. The other two groups included age-matched children without musical training (NM) [15 participants (7 females and 8 males), mean age 12.89 years] and adults without musical training group (NMA) in the age range of 20-30 years [15 participants (6 females and 9 males), mean age of 24.30 years). All participants had hearing thresholds less than 20 dB HL in the octave frequencies between 250 Hz- 8 kHz and did not report of any otologic or neurological problems. All the participants gave their informed consent before participating in the study. All the participants underwent of the psychophysical tests which included gap detection in noise, duration discrimination in noise, and modulation detection for sinusoidal amplitude modulated noise with modulations of 8 Hz, 20 Hz, 60 Hz and 200 Hz.

Stimuli and Procedure

Psychoacoustic tests were performed using the Maximum Likelihood Procedure (MLP)) tool box (Grassi & Soranzo, 2008) developed in the MATLAB environment. A two-interval force choice method using MLP was being employed to track the 60% correct response criterion (Green 1993, 1990). The MLP procedure employs a large number of candidate psychometric functions and after each trial calculates the probability (or likelihood) of obtaining the listeners response to all of the stimuli that have been presented given each psychometric function. The psychometric function yielding the highest probability is then used to determine the stimulus to be presented on the next trial. Within about 12 trials, the MLP procedure usually converges on a reasonably stable estimate of the most likely psychometric function, which then can be used to estimate the threshold. Because knowing the listeners false-alarm rate is important for the threshold estimate, three catch trials in which the signal is absent are usually added to the number of signal trials. Thus, the MLP procedure can provide an estimate of the listener threshold in about 15 trials, which makes it sufficiently fast to be used in a clinical setting (Green, 1993 as cited in Kumar & Sangamanatha, 2011, p.07). During each trial, stimuli were in two intervals; one interval contained the reference stimulus and the other contained the variable stimulus. This procedure was used in all psychoacoustic tests. For the entire test, stimuli were presented binaurally at an intensity of 80 dB SPL. Stimuli were presented via a laptop (Compaq Presario V6000) connected to headphones. Output of the earphones was calibrated at the beginning of the experiment and regularly thereafter to produce 80 dB SPL for a 1 kHz pure tone in a 2cc coupler. Each participant was given 3-4 practice trials before the commencement of each test.

Gap detection in noise

In this task, participant's ability to detect a temporal gap in the center of 750 msec duration band-pass noise was measured. Gap durations were varied according to listener performance using maximum likelihood procedure. The noise had 0.5 msec cosine ramps at the beginning and end of the gap. In the two-interval alternate forced choice task, the reference stimulus was always a 750 msec broadband noise with no gap whereas the variable stimulus contained a gap.

Duration discrimination test

In this task, the minimum difference in duration required to perceive the two otherwise identical stimuli was measured. The duration of the standard stimulus was 250 msec. The duration of the variable stimulus was changed based on the response of the participant. Using the two-interval alternate forced choice procedure, the participant was asked to indicate which interval contained the longer duration signal.

Modulation detection for sinusoidally amplitude-modulated noise

Temporal modulation refers to a re-occurring change (e.g. frequency or amplitude) in a signal over time. A 500 msec Gaussian noise was sinusoidally amplitude modulated at 8 Hz, 20 Hz, 60 Hz, and at 200 Hz. The participant had to detect the presence of modulation and indicate which interval contained the modulated noise. Modulated and un-modulated stimuli were equated for total root mean square (RMS) power. The depth of the modulated signal was varied according to participant's response to track the 60% criterion level. The noises had 10-msec raised cosine ramps at onset and offset. The modulation detection thresholds were expressed in dB.

Results

The results are reported separately for each psychoacoustic test.

Gap detection thresholds

Figure 1 shows the mean and 1 SD values for the gap detection thresholds in three groups. As it can be seen in the figure, mean gap detection threshold were lower for children with musical training (M) [3.13 msec] and adult group (NMA) [3.10 msec] compared to children without musical training (NM) [4.09 msec]. One way ANOVA showed a significant main effect on gap detection threshold [F (2, 42) = 4.156, p=.03]. Bonferroni's post-hoc test showed that group M performed better than NM (p<.005) and there was no significant difference (p=1.00.) between the M and NMA groups.

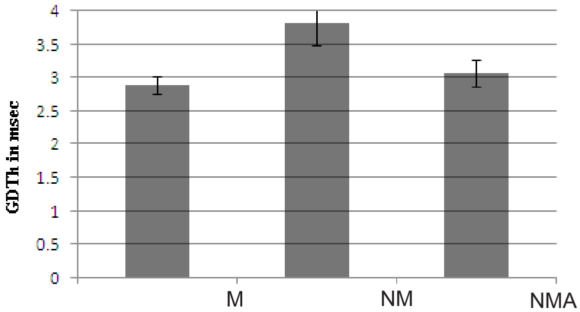

Figure 1: Mean gap detection thresholds (GDTh) for children with musical training (M), children without musical training (NM), and adults without musical training (NMA). The error bar depicts 1 SD.

Duration discrimination test

Figure 2 shows mean duration discrimination threshold along with 1 SD of variation for different groups. Mean duration discrimination thresholds were lower for both M (319.65 msec) and NMA (303.77 msec) compared to NM (357.03 msec) group. One way ANOVA showed a significant main effect of subject group on duration discrimination threshold [F (2, 42) = 6.594, p=0.01]. Bonferroni's posthoc test showed that group M performed better than NM (p=.02) and there was no significant difference (p=1.00) between group M and group NMA.

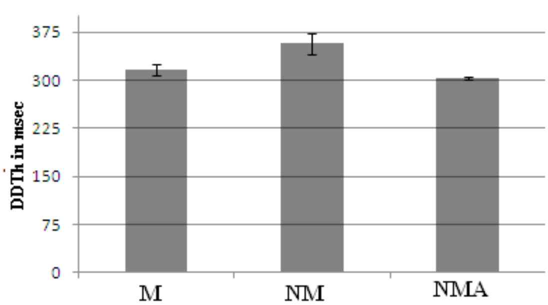

Figure 2 : Mean duration discrimination threshold ld (DDTh) for children with musical training (M), children without musical training (NMA), and adults without musical training (MA). The error bar depicts 1 SD.

Modulation detection thresholds for sinusoidally amplitude-modulated noise

Figure 3 shows the mean modulation detection threshold for 8, 20, 60, and 200 Hz modulation frequency along with 1 SD variation for different groups. It is clear from the figure that, M and NMA groups had better thresholds at 8, 20, 60, and 200 Hz modulation frequency than the NM groups. Repeated measures ANOVA revealed an overall main effect of musical training on modulation detection threshold, [F (2.021, 84.86)=23.884]. The degrees of freedom was adjusted as per the green house correction factor, which was added as the sphericity principle was violated [x2(5) = 28.17, p=0.000. Repeated measures

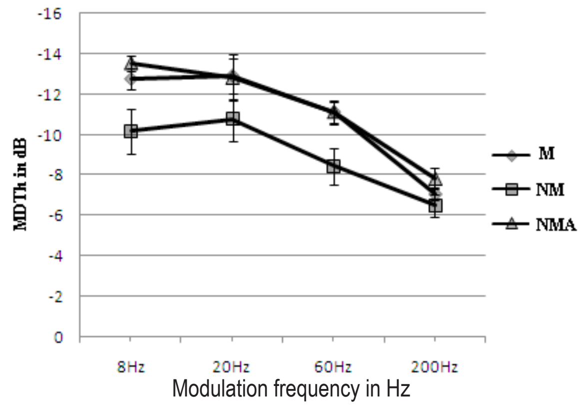

Figure 3: Mean modulation detection thresholds (MDTh) for children with musical training (M), children without musical training (NM), and adults without musical training (NMA). The error bar depicts 1 SD.

ANOVA also revealed no significant (p=1.00) interaction between modulation detection threshold and group. Pair-wise comparison of data revealed that the M and NMA groups performed significantly better than the NM group (p=0.02) on modulation detection threshold. There was no significant difference between M and NMA groups (p=1.00).

Discussion

The main purpose of the study was to document the differences in temporal coding abilities in individual with and without musical training. In line with our hypothesis, children who practiced music were able to perform better on temporal resolution tasks than those without any musical training. The performance of children with was at par with adults on tasks requiring temporal resolution. Our findings are in accordance with the growing body of literature in support of short term music training inducing neuroplastic changes in auditory processing (Bosnyak et al., 2004; Fujioka et al., 2006; Magne et al., 2006; Moreno et al., 2008; Reinke et al., 2003; Tremblay et al., 2001; Tremblay & Kraus, 2002). To the best of our knowledge, the effect of music training on temporal resolution has not been studied using a combination of tasks including gap detection, duration discrimination and modulation detection. The findings of the present study indicate that these tests can be sensitive enough to examine the effects of short-term musical training in children. Ishii et al., (2006) reported in his study that the random gap detection threshold (RGDT) is not sensitive enough to differentiate the temporal resolution abilities of professional versus amateur adult singers. However it is important to consider the difference in stimulus bandwidth and procedures used in both the studies.

Music and speech are perceptually distinct, but they do share some commonalities at acoustic and cognitive level. At acoustic level humans take advantage of dynamic modulation of acoustic parameters in both speech and music. Analysis of the acoustic properties of speech demonstrates that the ability to track brief, rapidly successive (dynamic) acoustic changes within a complex acoustic waveform is essential for speech processing. Music relies on fine distinctions in pitch, timbre, and duration (Kraus et al., 2009). At cognitive level, music and speech share the same memory and attention skills which are important to track down the acoustic event which helps in auditory scene analysis (Patel, 2003). In our study children with instrumental music training had better thresholds in temporal resolution tasks than children without any music training. These results may be due to the effect of musical training, which perhaps enhanced the ability to make use of basic acoustic cues. Children without any musical training had poorer thresholds compared to those with musical training and also, adults. Children with musical training were able to perform like adults on all the temporal resolution tasks measured, except modulation detection at 200 Hz. Mean performance on modulation detection at 200 Hz was comparatively poorer in children with music training than the adult group. One to two years of musical training were efficient enough to enhance the modulation detection at lower rates (8, 20 & 60 Hz) but not at high rates (200Hz). Music, by its nature, contains fine frequency and amplitude fluctuations, therefore, individuals with musical training would be expected to have better performance on such tasks, but their performance was same as children without musical training. This indicates that one to two years of music training may be inadequate to train the neurons to detect amplitude changes at higher modulation rates. These children might need more training to detect these small fluctuations.

Musical training improves auditory temporal resolution which in turn enhances the auditory perceptual skills. Temporal resolution is defined as the perception of the temporal characteristics of a sound or the alteration of durational characteristics within a restricted or defined time interval. It can also be viewed as the processing of the temporal features of sounds that unfold over time (Shinn, 2003). Therefore, auditory perception requires an accurate processing of the sound time structure of the signal. Fine auditory acuity, including the ability to detect brief silent gaps, is critical for accurate decoding of the speech stream. The ability to discriminate duration differences may also be important for speech perception because phonemic contrasts can be cued by differences in vowel duration (Peterson & Lehiste, 1960), or consonant transitions (e.g. weed versus bead) (Miller & Liberman, 1979). Since music has larger fluctuation in frequency and amplitude compared to speech (Chasin, 2003), training with this kind of stimuli over a period of time will enhance the basic perceptual skills. Listeners with better perceptual skills may detect more subtle acoustic cues and thereby improve their ability to separate and group the target signal from the background noise. A clearer representation of the acoustic stream would in turn reduce the attentional demands, leaving more resources available for the rehearsal and recall of the target words (Parbery-Clark et al., 2009). These enhancements in temporal resolution are not surprising given that music learning and performance invokes high level cognitive engagement, required for sound mapping patterns to meaning and online manipulation of musical output. The results of the current study showed that children who received instrumental music training for short duration outperformed their control counterparts. Ability of children with musical training to code finer variation in the psychoacoustic stimuli was better than children without any musical training although it was not significant compared to adult group. Thus, instrumental music training induced changes in the coding of auditory temporal features with coding efficiency similar to the adult group.

Musicians' perceptual acuity may relate to experience-dependent neural plasticity; in fact, the very neural measures of auditory encoding that are deficient in children with language-based learning problems (Banai et al., 2009; Hornickel, Skoe, Nicol, Zecker, & Kraus, 2009) are enhanced in musicians (Kraus et al., 2009; Parbery-Clark et al., 2009; Tzounopoulos & Kraus, 2009). Such neural enhancements relate with musical experience histories (e.g., years of musical practice) (Musacchia et al., 2007, 2008; Kraus et al., 2009; Strait et al., 2009; Wong et al., 2007). Likewise, results from the present study revealed enhanced temporal resolution which was measured using gap detection threshold, duration discrimination and modulation detection at 8, 20 & 60 Hz. These one to two years of music training did not however enhance detection of amplitude modulation at high rates (200 Hz) indicating that advantages shown by children trained in music are driven,, at least in part, by experience rather than innate abilities. A recent study indicated this same dependent relationship between musical training and musician abilities by assessing neural, cognitive and musical abilities in a group of untrained children, half of whom were about to initiate musical training. Initially, the two groups showed no measurable differences but, after just 18 months of lessons, children with music training demonstrated neural, cognitive, and musical ability enhancements (Norton et al., 2005).

Timing measures provide clear information regarding coding of auditory stimuli in the auditory system. Temporal features of sound are important for accurate representation of speech stimuli. Disruption in coding of this timed information, even at the order of milliseconds, can have significant effect on auditory processing (Banai, Nicol, Zecker, & Kraus, 2005). In this study, compared to children without musical training, children with musical training had accurate coding of temporal resolution. These results suggest that experience with music contributes to the changes seen in musicians over and above genetic factors. Benefit of musical training on temporal processing may provide remedial benefit for individuals with temporal processing-related deficits (Overy, 2003), such as Specific Language Impairment (Tallal & Gaab, 2006; Wright, 1998), Dyslexia (Conlon, Sanders, & Zapart, 2004; Hari & Kiesila, 1996; Walker, Hall, Klein, & Phillips, 2006), Auditory Processing Disorder (Chermak, 2002; Chermak & Musiek, 1997; Moore, 2007) and other conditions in which auditory processing is impaired (e.g., hearing loss, older adults) (Fitzgibbons & Gordon-Salant, 1994; Phillips et al., 1994; Strouse, Ashmead, Ohde, & Grantham, 1998).

The results of the present study provide some evidence of the potential benefit of musical training on the processing of specific psychoacoustic cues. However, we cannot determine the extent to which this enhancement is mediated through musical training, and innate differences including genetic differences. Results from this study are encouraging enough to consider longitudinal studies to explore the effects of musical training on the perception of auditory cues.

Conclusion

Data from the present study indicate a possibility that instrumental music training may enhance temporal resolution abilities in children. Such enhancements could be the result of more efficient neural mechanisms for performing auditory tasks, such as gap detection in noise, duration discrimination, and modulation detection. Results from the present study support further exploration into the effectiveness of musical training as a potential remediation strategy for children with language-based learning and auditory processing disorders.

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