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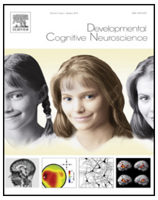

# Neural correlates of accelerated auditory processing in children engaged in music training

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## ABSTRACT

Several studies comparing adult musicians and non-musicians have shown that music training is associated with brain differences. It is unknown, however, whether these differences result from lengthy musical training, from pre-existing biological traits, or from social factors favoring musicality. As part of an ongoing 5-year longitudinal study, we investigated the effects of a music training program on the auditory development of children, over the course of two years, beginning at age 6–7. The training was group-based and inspired by El-Sistema. We compared the children in the music group with two comparison groups of children of the same socio-economic background, one involved in sports training, another not involved in any systematic training. Prior to participating, children who began training in music did not differ from those in the comparison groups in any of the assessed measures. After two years, we now observe that children in the music group, but not in the two comparison groups, show an enhanced ability to detect changes in tonal environment and an accelerated maturity of auditory processing as measured by cortical auditory evoked potentials to musical notes. Our results suggest that music training may result in stimulus specific brain changes in school aged children.

## 1. Introduction

### 1.1. Background

Over the past two decades, numerous studies have reported differences in the brain and behavior of musicians when compared to non-musicians (for comprehensive reviews see: Gaser and Schlaug, 2003; Herholz and Zatorre, 2012; Levitin, 2012; Pantev and Herholz, 2011; Strait and Kraus, 2014). Music training has been found to be positively associated with superior performance on a variety of auditory tasks, including frequency discrimination (Schellenberg and Moreno, 2010), perception of pitch in spoken language (Schön et al., 2004; Wong et al., 2007), detection of minor changes of pitch in familiar (Schellenberg and Moreno, 2010) and unfamiliar melodies (Habibi et al., 2013), identification of a familiar melody when it is played at a fast or slow tempo (Andrews et al., 1998; Dowling et al., 2008) and recognition of whether a sequence of chords ends correctly based on Western classical music rules (Koelsch et al., 2007). Compared to non-musicians, musicians also tend to show enhanced language skills including phonological awareness (Degé and Schwarzer, 2011; Moreno et al., 2009, 2011), vocabulary (Forgeard et al., 2008; Piro and Ortiz, 2009) and verbal memory (Franklin et al., 2008; Jakobson et al., 2008a,b).

Differences between musicians and non-musicians in neural structure and function have also been demonstrated, in particular in auditory (Bangert and Schlaug, 2006; Gaser and Schlaug, 2003; Herholz and Zatorre, 2012; Jäncke, 2009; Schneider et al., 2002; Tillmann et al., 2003; Zatorre, 2005) and sensorimotor areas (Gaser and Schlaug, 2003; Jäncke, 2009; Schlaug, 2001), as measured by magnetic resonance imaging (MRI), and in enhancement of auditory evoked potentials measured by electroencephalography (EEG) (Brattico et al., 2006; Fujioka et al., 2005; Musacchia et al., 2007; Shahin et al., 2004).

In spite of a growing interest in the benefits of music training and in the brain differences of musicians compared to non-musicians within the central auditory system, the interpretation of such findings remains unclear. The differences reported in cross-sectional studies, which mostly employ quasi-experimental designs, might be due to long-term regular and intensive training or might result, either partly or primarily, from pre-existing biological and genetic factors that predispose individuals to develop musical aptitude if exposed to music during a sensitive period of development. An

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appropriate way toward disentangling the effects of predisposing factors from the effects of musical training, involves the longitudinal study of groups of children, of the same age with and without musical training, beginning prior to the onset of their music training. Ideally the comparison group should involve non-musical but comparably socially-interactive training, such as athletics programs.

### *1.2. Electrophysiological response to musical stimuli*

Event related potentials (ERPs) have been extensively used to assess the development of the central auditory system with its developmental related natural anatomical and physiological changes during childhood (Wunderlich and Cone-Wesson, 2006). ERPs are averages of the EEG signal, time-locked to repeated stimuli that allow for the identification of sensory and cognitive processing steps in response to auditory stimuli. Given their excellent temporal resolution, ERPs provide a robust means to measure the maturation of the auditory pathway through changes in latency, amplitude and topography (Luck, 2014).

The cortical P1 component dominates the ERP response to auditory stimuli in early childhood and has a latency of approximately 100 ms; it matures during development and reaches an adult latency of 40–60 ms with a bilateral frontal-positive scalp topography by around age 18–20; it originates from the lateral portion of Heschl's gyrus (Ponton et al., 2000; Sharma et al., 1997; Wunderlich et al., 2006). The cortical P1 is followed by the vertex negative N1, which has a latency of approximately 90–110 ms, in adults, and is generated within primary and secondary auditory cortices (Näätänen and Picton, 1987). Development of the central auditory pathway is accompanied by a decrease in the amplitude and latency of the P1 component and corresponding increase in the amplitude of the N1 component, a process that is completed by young adulthood (Ponton et al., 2000; Shahin et al., 2010; Sharma et al., 1997; Tierney et al., 2015; Wunderlich and Cone-Wesson, 2006).

In relation to the impact of musical training, adult musicians have been shown to have enhanced auditory N1 amplitude (Shahin et al., 2003). The magnetic counterpart N1m has also been reported to be larger in musicians compared to non-musicians, as evoked by musical stimuli (Pantev et al., 1998). In addition, relative to non-musicians, musicians display larger mismatch negativity (MMN) in response to changes of chords, melody and rhythm (Brattico et al., 2006; Koelsch et al., 1999; Vuust et al., 2005). Recent studies have shown accelerated maturation of the cortical auditory response (P1 and N1) in high school students who underwent three years of school-based music training (Tierney et al., 2015), and enhancement of MMN in school-age children involved in music training (Chobert et al., 2014; Putkinen et al., 2014; Virtala et al., 2012).

The P2 peak has an adult latency of approximately 200 ms (it varies between about 150 and 275 ms) after the onset of an auditory stimulus. It is generated in associative auditory temporal regions with additional contributions from frontal areas (Bishop et al., 2011; Tremblay et al., 2001). Traditionally, the P2 was considered to be an automatic response, modulated only by the stimulus; but it has been shown that its latency and amplitude are sensitive to learning and attentional processes (Lappe et al., 2011). Specifically, P2 amplitude accompanying the processing of music has been reported to be larger in adult musicians compared to non-musicians (Pantev et al., 2001; Shahin et al., 2003).

The P3 is a positive potential that appears in response to target stimuli or rare, unexpected stimuli presented among standard stimuli. It reflects context updating and the orienting of attention. It has a peak latency between 250 and 700 ms and is maximally distributed at fronto-central or parietal areas of the scalp depending on the type of eliciting stimulus (Donchin and Coles, 1988; Picton, 1992). The P3 is comprised of two contributing subcomponents—the P3a and the P3b. The auditory P3a typically has a peak latency within ∼300 ms, is generated primarily by the anterior cingulate cortex and displays a fronto-central distribution on the scalp. The P3a is related to the automatic orienting of attention as occurs in paradigms in which distracting stimuli engage attention without any required behavioral response. The P3b usually peaks later than 300 ms, often at 300–500 ms or later, and is generated primarily by medial temporal areas and the temporo-parietal junction, thus displaying a parietal distribution on the scalp. The P3b is elicited by stimuli that require a behavioral response or clearly match with a target stimulus template held in working memory (Polich, 2007). Larger amplitude N2b-P3 potentials in response to deviations in melody and rhythm have been reported in individuals with music training (Habibi et al., 2013; Nikjeh et al., 2008; Seppänenet al., 2012; Tervaniemi et al., 2005; Trainor, 2012).

### *1.3. Design, aims and hypotheses*

Given the above knowledge on the effects of music training in the brain of adults, we used auditory evoked potentials and behavioral tasks to investigate whether the development of the auditory system was sensitive to musical training in 6–7 year old children and, if so, determine which components were affected. To address the issues related to pre-existing differences between musicians and non-musicians, we employed a longitudinal design comparing children involved with music training with two age-matched comparison groups without music involvement but with the same socio-economic and cultural background (Habibi et al., 2014).

We assessed all participants at baseline and then again two years later. We compared auditory evoked potentials elicited by violin, piano and pure tones at the two time points. Also, at year 2, using a same-different judgement design, we assessed the participants' ability to detect changes in tonal or rhythmic content of unfamiliar melodies and the associated brain processing. We hypothesized that:

1. Music trained children would show accelerated development of the P1-N1 complex. The rational for this hypothesis is as follows: the cortical N1 component emerges between 8 and 10 years of age, while the P1 amplitude decreases; furthermore, enhanced N1 amplitude has been associated with music training in adults and adolescents, therefore, we predicted the development of the N1 would be associated with music training in children as well.
2. Music trained children would show a heightened ability to detect changes in pitch and rhythm, and would show enhanced amplitude of correlated P3 auditory cortical potentials.

## 2. Materials and methods

### *2.1. Subjects*

Fifty children were recruited from public elementary schools and community music and sports programs in the greater Los Angeles area. Between induction and baselines assessment, 5 enrolled participants discontinued their participation, in their respective program or relocated. Between baseline assessment and evaluation two years later, 8 participants (2 music, 4 sports-comparison & 2 non-sports comparisons) discontinued their participation, in their respective program or the research study, or relocated and thus were not included in the final analysis (Fig. 1). Thirty-seven remaining participants formed the following three groups: Thirteen children (6 girls and 8 boys, mean age at baseline assessment = 6.68 yrs., SD = 0.6) who were beginning their participation