Neuropsychologia 51 (2013) 538–549

Contents lists available at SciVerse ScienceDirect

Neuropsychologia

journal homepage: www.elsevier.com/locate/neuropsychologia

Musical expertise affects neural bases of letter recognition

Alice Mado Proverbio [a,*], Mirella Manfredi [a], Alberto Zani [b], Roberta Adorni [a]

[a] Dept of Psychology, University of Milano-Bicocca Ateneo Nuovo 1, 20126 Milan, Italy
[b] Institute of Molecular Bioimaging & Physiology (IBFM), CNR, Milan, Italy

ARTICLE INFO

Article history:
Received 30 May 2012
Received in revised form
16 November 2012
Accepted 2 December 2012
Available online 11 December 2012

Keywords:
Hemispheric asymmetry
VWFA
Fusiform gyrus
Reading
Learning
Expertise
Brain plasticity
Musicians
Music

ABSTRACT

It is known that early music learning (playing of an instrument) modifies functional brain structure (both white and gray matter) and connectivity, especially callosal transfer, motor control/coordination and auditory processing. We compared visual processing of notes and words in 15 professional musicians and 15 controls by recording their synchronized bioelectrical activity (ERPs) in response to words and notes. We found that musical training in childhood (from age ~8 years) modifies neural mechanisms of word reading, whatever the genetic predisposition, which was unknown. While letter processing was strongly left-lateralized in controls, the fusiform (BA37) and inferior occipital gyri (BA18) were activated in both hemispheres in musicians for both word and music processing. The evidence that the neural mechanism of letter processing differed in musicians and controls (being absolutely bilateral in musicians) suggests that musical expertise modifies the neural mechanisms of letter reading.

1. Introduction

Does listening to Mozart make you more intelligent? Musicians are becoming the objects of great interest in the neuroscientific community, as accumulating evidence indicates that their brains may differ from those with no musical background. It is well known, for example, that musical training in childhood modifies brain connectivity, volume and functioning (Münte, Altenmüller, & Jäncke, 2002; Münte, Nager, Beiss, Schroeder, & Altenmüller, 2003; Schlaug, 2001), especially as motor performance (in the basal ganglia, cerebellum, and motor and premotor cortices), visuo-motor transformation (in the superior parietal cortex: (Gaser & Schlaug, 2003; Sergent, Zuck, & Terriah, 1992), inter-hemispheric interchanges (via the corpus callosum) (Lee & Chen, 2003; Oztürk, Tasçioglu, Aktekin, Kurtoglu, & Erden, 2002), and auditory analysis (in the superior temporal cortex and in brain-stem) (Chobert, Marie, François, Schön, & Besson, 2011; Gaab et al., 2005; Parbery-Clark, Tierney, Strait, & Kraus, 2012; Strait & Kraus, 2011) are concerned (see Kraus & Chandrasekaran, 2010for an excellent review). These neuroplastic changes involve not only the gray but also the white matter architecture (Schmithorst & Wilke, 2002) and white matter myelination (Bengtsson et al., 2005).

More specifically, Amunts et al. (1997) demonstrated altered motor representation by showing that the primary hand motor area is more extended and less asymmetrical in musicians than in naïve controls; this suggests an enhanced development of the motor cortex controlling the left hand, which is required by the high level of bimanual coordination required to play musical instruments. Additionally, Schlaug, Jancke, Huang, Staiger, and Steinmetz (1995) measured the size of the midsagittal area of the corpus callosum in musicians and non-musicians using *in vivo* magnetic resonance morphometry and found that the anterior region (which transfers motor information) was larger in musicians than in non-musicians. Besides these plastic changes due to intense motor training, many studies have shown an increased ability to process both non linguistic and linguistic aspects of auditory information both in children and adult musicians (sound pitch, timing, timbre, spatio-temporal spectrum, harmonic and musical sounds, phonemic processing, vowel frequency, vowel duration, voice onset time (VOT), etc. (see Kraus & Chandrasekaran, 2010; Besson, Chobert, & Marie, 2011). For example, Marie, Magne, and Besson (2011) have recently shown that musical expertise facilitates the processing of the temporal structure of syllables and of the metric structure of words. Quite interestingly, cross-sectional studies (Bidelman, Gandour, & Krishnan, 2011; Marie et al., 2011; Marie, Kujala, & Besson; 2012a,b; Slevc & Miyake, 2006) have demonstrated

Abbreviations: BA, Brodmann area; EEG, Electroencephalogram; ERP, Event-related potential; swLORETA, Standardized weighted low-resolution electromagnetic tomography

* Corresponding author. Tel.: +3902 64483755x3777.
E-mail address: mado.proverbio@unimib.it (A.M. Proverbio).

0028-3932/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.neuropsychologia.2012.12.001

differences between musicians and non-musicians in perceptive and cognitive activities other than music. In addition, a few longitudinal studies have examined near and far transfer effects (Helmbold, Rammsayer, & Altenmüller, 2005; Chobert et al. (2013) Schellenberg & Mankarious, 2012). This suggests that musical training might have effects on brain functional organization and processing of stimuli not necessarily auditory or motor in nature (but possibly revealing differences in attention, motivation, memory, intelligence, emotion, etc.). People with music training often outperform their non-musical peers on cognitive tasks (Schellenberg, 2004). For instance, a study of 4 to 6-year olds found that musically-trained kids performed better on a test of working memory (Fujioka, Ross, Kakigi, Pantev & Trainor, 2006). Other research indicates that musicians perform significantly better on tests of spatial-temporal skills, math ability, vocabulary, verbal memory (for a review, see Patel & Iverson, 2007).

Despite the several studies investigating musicians' motor and auditory abilities, not much is known about the effect of note reading ability on brain neuroplasticity, espacially related to the orthographic ability.

In the fMRI study by Nakada, Fuji, Suzuki, and Kwee (1998) the cortical areas subserving music literacy were investigated. In this study, music score reading was compared with reading texts in the subjects' primary (L1) or secondary (L2) languages. They found an area within the occipital cortex that was activated exclusively by music score reading, the right transverse occipital sulcus.

Another fMRI study (Schön, Anton, Roth, & Besson, 2002) compared the brain areas involved in reading music notation vs. verbal and number notations while piano player subjects reproduced notes by playing them on a keyboard. They found that reading music notation specifically activated the right occipito–temporal junction, the superior parietal lobule and the intraparietal sulcus. Together, these results suggest that reading musical notation might engage the right occipital cortex to a greater extent than language processing. However, in these studies, linguistic and musical processing were not directly compared in skilled and naïve people. Thus, one may still hypothesize that musicians might activate the same brain areas and functional mechanism as non-musicians for both language and note processing. However, some very recent investigations have shown important effects of musical training on brain processing of linguistic and auditory (both speech and non speech) stimuli. For example, an interesting study (Deg & Schwarzer, 2011) demonstrated that phonological awareness, which is crucial for reading and writing skills, is closely related to pitch awareness and musical expertise. Other investigations examined the interactions between musical expertise and language functions and found that musical training is beneficial for phonetic perception. In fact, Ott, Langer, Oechslin, Meyer, and Jancke (2011) demonstrated that professional musicians process unvoiced stimuli (irrespective of whether these stimuli are speech or non-speech stimuli) differently than controls, this suggesting that early phonetic processing is differently organized depending on musical expertise. In one of the first longitudinal studies aimed at testing for the causality of musical training, Moreno et al. (2009) have shown that musical training enhanced the reading of phonologically complex words in Portuguese children.

Again, Besson et al. (2011) discovered interesting transfer effects from music to speech as a result of musical expertise in musicians. More in detail, Besson and co-authors have demonstrated that musical training enhances pitch perception in both adults (Schön, Magne, & Besson, 2004) and children (Magne, Schön, & Besson, 2006), as well as the metric structure of words (Marie et al, 2010) and tone perception (Marie et al, 2011) in adults, and the pre-attentive processing of vowel duration and voice onset time in children (Chobert et al., 2011). Furthermore, it has been demonstrated (Francois & Schoen, 2011) that musical expertise facilitates the learning of both linguistic and musical structures. All in all, these studies provide evidence that musicians are better than non-musicians at processing linguistic and non-linguistic phonetic and auditory information (Jancke, 2012) (e.g., phonemes). However, not much is known about the effect of early musical training on visual processing of linguistic information, i.e.,: reading. Interestingly, Moreno et al. (2009) showed that the reading of phonologically complex words was improved in children with musical training. However, the present paper is probably the first at investigating (and demonstrating) differences between musicians and non-musicians in the neural mechanism of visual orthographic analysis in silent reading. Therefore these finding may have possible applications in the prevention and treatment of developmental dyslexia, especially if related to an insufficient or atypical activation of left-hemispheric brain areas processing orthographic and phonologic audio/visual information. As for phonologic linguistic processing, it can be speculated that early musical training can be a valid aid for preventing/curing dyslexia in genetically at risk infants/children, especially as for general auditory processing, phonological awareness, pitch processing in speech, rapid spectrotemporal processing, are concerned (Kraus & Chandrasekaran, 2010; Chobert et al., 2011). This has brought to the development of remediation programs for language learning impairment (e.g., Tallal & Gaab, 2006).

In the present study, we investigated the possible plastic developmental changes in musicians' brains due to their continuous and intensive music training by comparing brain processing of words and music scores in professional musicians and naïve controls during a selective attention task. High density EEG was recorded from 128 scalp sites in order to compute ERP (Event-related potentials) measures of letters and notes in the two groups. We hypothesized that the processing of notes in musicians and non-musicians is radically different and expected to find indices of extra neural processing related to the semantic/conceptual meaning of notes, auditory representation and visuomotor transformation that allows first-sight reading in musicians. We did not specifically expect to find a difference in the way the left occipito/temporal cortex processes alphabetic stimuli between the two groups. Because musicians and non-musicians were matched for age and socio/cultural status, we assumed that the ERP responses found (namely N170 and N2) over visual, auditory or motor areas, for both note and letter processing, might be in part or entirely related to the musicians' ability to read musical scores, activate the note/sound acoustic representation and transfer the visual information to a motor program as required by first sight reading.

2. Methods

2.1. Participants

Thirty healthy right-handed participants (18 males and 12 females) were recruited for this experiment. They were matched for cultural status and education level (except for musical expertise) across groups. Schooling was 15.4 and 15.3 years for musicians and controls, respectively (see more details on subjects' educational level and profession in Table 1 and Table 2). All had normal or corrected-to-normal vision and reported no history of neurological illness or drug abuse. Half of them were professional musicians with a Conservatory degree in violin, cello, trumpet, clarinet, piano, composition, orchestra conduction, flute, or organ (see Table 1). Musicians usually read their music scores in Violin and/or Bass clefs. The mean age of acquisition (AoA) of musical abilities (playing an instrument) for musicians was 8.57years ($SD=3$). The mean age of musicians was 31.7 years ($SD=12$), while of control was 26 years ($SD=9$). Non musicians (control