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The effects of musical practice on structural plasticity: The dynamics of grey matter changes

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ABSTRACT

Intensive training and the acquisition of expertise are known to bring about structural changes in the brain. Musical training is a particularly interesting model. Previous studies have reported structural brain modifications in the auditory, motor and visuospatial areas of musicians compared with nonmusicians. The main goal of the present study was to go one step further, by exploring the dynamic of those structural brain changes related to musical experience. To this end, we conducted a regression study on 44 nonmusicians and amateur musicians with 0–26 years of musical practice of a variety instruments. We sought first to highlight brain areas that increased with the duration of practice and secondly distinguish (thanks to an ANOVA analysis) brain areas that undergo grey matter changes after only limited years of musical practice from those that require longer practice before they exhibit changes. Results revealed that musical training results a greater grey matter volumes in different brain areas for musicians. Changes appear gradually in the left hippocampus and right middle and superior frontal regions, but later also include the right insula and supplementary motor area and left superior temporal, and posterior cingulate areas. Given that all participants had the same age and that we controlled for age and education level, these results cannot be ascribed to normal brain maturation. Instead, they support the notion that musical training could induce dynamic structural changes.

1. Introduction

The effects of intensive training and expertise on brain structure have been observed in several areas (for reviews, see Draganski & May, 2008; May, 2010; Zatorre, Fields, & Johansen-Berg, 2012), including the taxi driver's hippocampus (Maguire et al., 2000), the juggler's midtemporal area (hMT/V5) and left posterior intraparietal sulcus (Boyke, Driemeyer, Gaser, Büchel, & May, 2008; Draganski et al., 2004), the basketball player's cerebellum (Park et al., 2009) and the frontal and parietal areas of individuals who engage in physical exercise (Taubert et al., 2010).

It is now well established that musical training requires complex multimodal abilities, including somatosensory and memory processes, motor skills and emotion. Thus, musical expertise can be regarded as a relevant model for studying structural brain plasticity mechanisms (Wan & Schlaug, 2010). Skills acquired by musicians result not only in specific connections and interactions between different brain areas (Altenmüller, 2008; Fauvel et al., 2014), but also in the enlargement of brain regions involved in music-related processes such as auditory, motor and visuospatial abilities (Bermudez, Lerch, Evans, & Zatorre, 2009; Gaser & Schlaug, 2003; James et al., 2014; Luders, Gaser, Jancke, & Schlaug, 2004; Schneider et al., 2002; Seung, Kyong, Woo, Lee, & Lee, 2005). In most studies, structural changes have been observed after only a few months of intensive practice. For example, Hyde et al. (2009) showed that 15 months of instrumental musical training in childhood were enough to increase the volume of the auditory and motor cortices. Moreover, some authors have also shown a relationship between the age of onset of musical training and structural brain modifications particularly in the premotor cortex and corpus callosum (Bailey, Zatorre, & Penhune, 2014; Steele, Bailey, Zatorre, & Penhune, 2013) for early-trained musicians

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(<age 7) suggesting a sensitive period of musical training effect. Nevertheless, these training-induced, regional structural brain changes do not occur solely during brain development, as they can be observed throughout the lifespan (Engvig et al., 2010). Nor are they restricted to specific cognitive demands (for a review, see Draganski & May, 2008), as they can concern many areas sustaining learning, memory, sensory or motor processes (see Fauvel, Groussard, Eustache, Desgranges, & Platel, 2013 for review in musical training). Thus, some investigations have revealed that musical training can have structural and functional effects on regions not directly involved in sensori-motor processes of music practice, such as those that subtend working memory (Oechslin, Van De Ville, Lazeyras, & James, 2012; Schulze, Mueller, & Koelsch, 2011) or long-term memory (Groussard et al., 2010a). In the latter study, a musical memory task revealed both functional and structural greater activation and grey matter in the left hippocampus of adult musicians compared to nonmusicians. Regarding results of our previous study, we would like to go one step further in the assessment of the relationship between the duration of musical expertise and the left hippocampus and generally in whole-brain grey matter changes.

The main goal of the present study is to analyze in what way structural grey matter changes with increasing number of years of musical training. To this end, we conducted a regression study on grey matter volumes of 44 nonmusicians and amateur musicians with 0–26 years of musical practice of a variety instruments. We sought first to highlight brain areas that increased in volume with the duration of practice and secondly distinguish (thanks to an ANOVA analysis) brain areas that underwent grey matter changes after only limited years of musical practice from those that require longer practice before they exhibit changes. Actually, some neuroimaging studies on structural plasticity (for a review, see Jancke, 2009) have suggested that musical training initially induces structural changes in regions that are directly involved in music learning (i.e. auditory and motor cortices). But recently James et al. (2014) studied the expertise effect on grey matter changes comparing three groups: nonmusicians, amateur musicians and professional musicians and observed that grey matter areas related to higher-order cognitive function increase with musical practice.

We therefore hypothesized that musical practice would have differential effects on the brain according to its duration, affecting first regions involved in motor and perceptual processes, to subsequently include regions involved in higher cognitive processes (i.e. executive functions, memory, and emotion).

2. Methods

2.1. Participants

Forty-four young volunteers (26 men, mean age ± *SD*: 23.75 ± 3.43 years, mean education level ± *SD*: 15.45 ± 2.02 years) with no history of neurological or psychiatric disease took part in this study. All participants were right-handed according to the Edinburgh Inventory (Oldfield, 1971), none of them reported having hearing deficits and none had perfect pitch. This study was approved by the regional ethics committee, and written informed consent was obtained from all the participants.

In order to study the progression of musical expertise from the very beginning, eleven nonmusician participants were included. They were classified as strictly nonmusicians, and met the following criteria: (1) none had ever taken part in musical performances or received music lessons (except for basic musical education at French high school, corresponding to 1 hour/week), (2) they were *common listeners* (i.e., not music lovers, who tend to listen to one specific type of music), and (3) they scored normally on a test of pitch perception. The remaining 33 participants were amateur musicians that had been playing music several times a week (5 minimum to 10 hours maximum per week was our range of inclusion), for a time duration ranging from one to 26 years at the time of the study. We chose to select young adult participants in order to exclude possible effects of age on grey matter and to focus mainly on the effect of the duration of musical practice. Thus, in order to reveal the dynamic of grey matter changes, the musicians were divided into three groups according to the musical education phases and levels of trainings such as they are cut out in the musical academies in France (Table 1). Thus, the 11 musicians with 1–8 years' musical practice constituted the novice group. These novice musicians were in the process of acquiring basic musical skills (rhythm and music reading), which takes 8 years to be completed. The 11 musicians with 9–14 years' musical practice constituted the intermediate group. In this group, musicians were working on their musical training in preparation for the French final musical diploma. Finally, the 11 musicians with 15 or more years' musical practice constituted the expert musician group who had obtained their French final musical diploma *('Certificat de fin d'études musicales*'). Thus, within each group, musical proficiencies of our participants are pretty homogeneous. Moreover, we intentionally set up our groups of musicians by choosing various types of instrumental practice (violin, cello, guitar, flute, recorder, trumpet, clarinet and piano) in order to avoid the possible bias induced by a particular type of instrumental practice (in reference to the work of Sluming et al., 2002). Most of our musicians played more than one instrument. The distribution of the primary instrument played by the musicians of our three groups is the following one: 9 strings and 2 winds in novice musician group; 5 strings, 5 winds and 1 pianist in intermediate musician group; 1 string, 5 winds and 5 pianists in expert musician group.

2.2. MRI data acquisition

Each participant underwent an MRI examination at the CYCERON center (Caen, France) using the Philips (Eindhoven, The Netherlands) Achieva 3.0T scanner. T1-weighted structural images were acquired using a 3D fast field-echo sequence (3D-T1-FFE sagittal; TR = 20 ms; TE = 4.6 ms; flip angle = 20°; 170 slices; slice thickness = 1 mm; no gap; FOV = 256×256 mm^2; matrix = 256×256; in-plane resolution = 1×1 mm^2; acquisition time = 9.7 min).

2.3. Data preprocessing and statistical analysis

2.3.1. Demographic statistical analyses

One-way ANOVA were run on the demographic data: age and level of education. Mean level of education differed significantly between the nonmusician (16.9 ± 2.17 years) and novice musician groups (14.64 ± 2.80 years), $p < .05$; see Table 1). Mean age differed significantly between the nonmusician (25 ± 3.41 years) and intermediate musician groups (21.09 ± .94 years), and between the novice (24.90 ± 3.80 years) and intermediate musician groups (21.09 ± .94 years, $p < .05$; see Table 1). Consequently, in all the statistical analyses, age and educational level were included as confounding variables.

We performed a Kruskal-Wallis one-way ANOVA in order to test gender distribution and no difference was observed between the four groups.

2.3.2. Anatomical data preprocessing

Imaging data preprocessing and analysis were performed using SPM12 software (Wellcome Trust Center for Neuroimaging, London, UK) implemented in Matlab 7.4. Briefly, individual MRI data were spatially normalized to the Montreal Neurological Institute (MNI) template and segmented to isolate the grey matter partitions