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Research report

How the degree of instrumental practice in music increases perceptual sensitivity

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ABSTRACT

Literature has shown that playing a musical instrument is associated with the formation of multimodal audio visuomotor representations that are strongly instrument-specific. Here, we investigated the effect of increased motor practice on perceptual sensitivity in 32 professional musicians of comparable expertise but with different amounts of instrumental practice with piano (10,000 vs. 3000 estimated hours). Stimuli consisted of images of pianists' hands and piano arpeggio sounds. In half of the cases, the piano fingering and piano sounds were congruent, while they were incongruent in the other cases. ERPs were recorded from 128 sites while musicians performed a congruent vs. incongruent discrimination task. A fronto-central *error-related negativity* (ERN), mainly generated within the anterior cingulate cortex, was observed in response to incongruent videos only in pianists. Non-pianist musicians were able to carry out the task (with a worse performance) but exhibited a smaller response-related N400 to incongruent stimuli. Source reconstruction applied to ERP responses to incongruent stimuli indicated a less automatic mechanism for detecting sensory-motor deviance and a greater emphasis on visual rather than on acoustic features in non-pianists. Overall the data suggest a profound difference between the two populations of musicians and advise against considering "expert" populations to include those that undertook only a few weeks/months of training in a new discipline.

1. Introduction

A few weeks/months of musical, motor or linguistic training in a novel discipline has been shown to be sufficient to induce visible changes in cortical plasticity. For example, four weeks of unimanual motor training can produce changes in cortical thickness in the right precentral gyrus, right post central gyrus, and right dorsolateral prefrontal cortex, as shown by structural MRI (Sale et al., 2017). Again, with regard to visual perception, practicing a motion direction discrimination task for only 2 weeks has been shown to sharpen the cortical tuning in MT and enhance the connectivity strength from MT to the intraparietal sulcus (Chen et al., 2017) in a pre- vs. post-training contrast. In another study concerning language learning, a 12-week intensive French language training produced greater fMRI activation in the left supramarginal gyrus (Barbeau et al., 2017), just to make a few examples. These effects are certainly intriguing and encouraging in view of the possibility of a training-dependent rehabilitation of neurological patients. However, these results refer to a very short-term learning; therefore, this form of plasticity may be temporally reversed or annulled over the course of years.

In contrast, evidence of dramatic changes in cortical structure (Schlaug et al., 1995a; Perani and Abutalebi, 2005; Hernandez and Li, 2007; Zatorre et al., 2012), connectivity (Bengtsson et al., 2005; Hämäläinen et al., 2017) and functional hemispheric lateralization (Schlaug et al., 1995b; Proverbio et al., 2002; Proverbio et al., 2013a,b) due to an early and prolonged linguistic or musical training (see Altenmüller and Furuya, 2016, for a review) have been provided. Studies of bilingualism have shown that late learners with comparable proficiency to native speakers, for example professional interpreters (Proverbio et al., 2004), have a different functional organization of the semantic neural system due to the later age of acquisition of the second language than the first. The difference between early and late learners increases when proficiency is not comparable (Hesling et al., 2012). In studying musical ability, for example, Groussard et al. (2014) performed a regression analysis on 44 non-musicians and amateur musicians with 0–26 years of musical training (with a variety musical instruments) to identify which brain areas underwent cortical changes as a function of expertise. The authors of this cross-sectional (correlational) study discovered that some brain areas underwent volume changes even in the less expert individuals, whereas others

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(namely, the auditory and motor areas, such as the supplementary motor area or the superior temporal area) required a longer practice before they exhibited changes, thus suggesting a long-lasting learning process.

Again, Pantev et al. (1998) measured the cortical representations of highly skilled musicians using functional magnetic source imaging. The age-of-onset of musical training ranged from 3 to 12 years. Magnetic dipole activations for piano tones but not for pure tones were enlarged by approximately 25% in the skilled group relative to the non-musician controls. The enhancement was inversely correlated with the age at which musicians started piano studies, i.e., the younger the musicians were when they started to practice, the larger the cortical reorganization in response to piano sounds. Overall, many differences in behavior, brain functional organization, and white and gray matter anatomy were described as a function of the age of acquisition onset and the sensitive period for learning (see the review of White et al., 2013, at this specific regard).

Again, Proverbio et al. (2015) showed (in a group of violin and clarinet students) that by increasing the number of years of constant practice (musical expertise), the ability to detect an audiovisual incongruence in musical performance improved monotonically, thus suggesting a relation between musical expertise and the development of audio visuomotor representations in the superior temporal gyrus and other multimodal areas (including the frontoparietal mirror system).

Although numerous studies have ascertained the presence of audiomotor representations in skilled musicians (e.g., Baumann et al., 2007; Candidi et al., 2014; Hasegawa et al., 2004; Pantev et al., 2008, 2003), which encode specific links between musical gestures (visuomotor component) and auditory information, little information is available on the development of such representations across years, in groups with a different amount of expertise. This study examines the effect of prolonged practice on cortical plasticity as investigated in professional musicians with a minimum of 2–3 years vs. 12 years of piano academic study by means of electrophysiological recordings.

In this study, professional pianists, with at least 10,000 estimated hours of practice (roughly corresponding to 10 years of academic study) were compared with professional musicians (non-pianists) with at least the same amount of estimated practice (e.g., 10,000 h) on their instrument, namely, violin, viola, cello, viola da gamba, double bass, flute, horn, harp or flute, but that had studied piano for (approximately) 3 years to acquire the compulsory "complementary piano" certificate in the conservatory program. This contrast allowed to compare two groups of equally skilled musicians that specifically differed in piano ability.

On the basis of the previous literature, we expected to find a modulation of the *Error-related Negativity* (ERN) response to audiomotor incongruence (see Proverbio et al., 2014, for violinists and clarinetists, and Proverbio et al. (2017) for pianists) and were interested in investigating possible differences in morphology and neural generators of surface electrical activity dependent on the effect of prolonged and extensive practice. In an interesting MRI study (Vaquero et al., 2016), voxel-based morphometry analysis was used to compare neuroplastic changes induced by long-term vs. short-term musical training. Expert pianists were compared to less proficient pianists (considering the age of onset (AoO) of piano playing) and with non-musician controls. Pianists showed a greater increase in gray matter volume of the putamen, hippocampus, lingual gyri and left superior temporal gyrus and a reduced volume of the right supramarginal, right superior temporal and right postcentral gyri than non-musician controls. First, these findings indicate a complex pattern of plastic effects due to sustained musical training that correlated behaviorally with a better performance. Furthermore, early-onset pianists showed higher temporal precision in their piano performance than late-onset pianists, especially in the left hand, and this was paralleled by a smaller volume in their right putamen.

Here, we investigated the effect of extensive motor practice on perceptual audiomotor sensitivity in musicians of comparable professional expertise but with different amounts of instrumental practice on the same instrument (piano). Indeed, several instrument-specific effects have been show to affect brain structure and function (Elbert et al., 1995; Halwani et al., 2011; Pantev and Herholz, 2011; Pantev et al., 2001; Tervaniemi, 2009; Proverbio and Orlandi, 2016). For example Bangert and Schlaug (2006) found a motor-related specialization in hand dominance, with keyboard players showing a left and string players showing a right hemispheric advantage, thus suggesting a differential brain adaptation depending on the instrument played.

In order to observe plastic changes in performance and brain responses dependent on the degree of musical practice and not the specificity of the musical instrument played, in this study, audiomotor sensitivity was investigated on the same musical instrument (i.e., piano) in pianists of different proficiency levels (deriving from a different length of academic studies, therefore from more or less experience). Proficiency was ascertained by the possession of an academic degree in piano (for pianists) vs. a triennial complementary piano certificate (for non-pianist musicians).

Besides *Error-related Negativity* (ERN) to audiomotor incongruence, we assumed that musical expertise might also modulate perceptual ERP responses to musical stimuli such as the anterior N2 component (Proverbio et al., 2016, Vuust et al., 2012). On the basis of previous literature (e.g. Proverbio et al., 2014) we also expected to find enhanced N400 responses to incongruent responses in pianists than non-pianist musicians, reflecting a finer coding of audiovisual incongruence in musicians who underwent a more extensive musical practice on the same instrument (namely: piano).

2. Results

2.1. Behavioral data

The ANOVA performed on the mean percentage of correct responses (hits) revealed a significance of the group factor [F (1, 26) = 4.914, p < 0.03; $\eta_p^2 = 0.16$], with more correct responses in pianists (arc sin hits = 64.72%, SE = 1.55) than non-pianists (arc sin hits = 59.88%, SE = 1.55), as shown in Fig. 3 (left). Also significant was the main factor condition [F (1, 26) = 7.176, p < 0.01; $\eta_p^2 = 0.22$], indicating a better performance with congruent (65.4%, SE = 1.47) than incongruent stimuli (59.19%, SE = 1.70), especially in non-pianists. No group or condition effect was found significant for response times (RTs). The mean RT was 753 ms (SE = 53.2) for pianists and 652 ms (SE = 53 ms) for non-pianists.

2.2. Electrophysiological data

2.2.1. Stimulus-related N280 (250–300 ms)

The ANOVA performed on the amplitude of N280 response recorded at AFz, Fz, and FCz sites indicated a significance of the group factor [F (1, 26) = 10.95114, p < 0.03; $\eta_p^2 = 0.42$], showing that N280 was larger in pianists than in non-pianists (pianists = 0.96 uV, SE = 0.9; non-pianists = 2.4 uV, SE = 0.9), as demonstrated in Fig. 3 (right).

2.2.2. Stimulus-related ERN (750–950)

The ANOVA carried out on the amplitude values of the ERN deflection recorded at the AFz–Fz sites demonstrated a significant group × condition interaction [F (1, 26) = 5.48, p < 0.03; $\eta_p^2 = 0.17$]. Relative post hoc comparisons among means (Fisher F, p < 0.03)