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Expertise-related deactivation of the right temporoparietal junction during musical improvisation

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ABSTRACT

Musical training has been associated with structural changes in the brain as well as functional differences in brain activity when musicians are compared to nonmusicians on both perceptual and motor tasks. Previous neuroimaging comparisons of musicians and nonmusicians in the motor domain have used tasks involving prelearned motor sequences or synchronization with an auditorily presented sequence during the experiment. Here we use functional magnetic resonance imaging (fMRI) to examine expertise-related differences in brain activity between musicians and nonmusicians during improvisation – the generation of novel musical–motor sequences – using a paradigm that we previously used in musicians alone. Despite behaviorally matched performance, the two groups showed significant differences in functional brain activity during improvisation. Specifically, musicians deactivated the right temporoparietal junction (rTPJ) during melodic improvisation, while nonmusicians showed no change in activity in this region. The rTPJ is thought to be part of a ventral attentional network for bottom-up stimulus-driven processing, and it has been postulated that deactivation of this region occurs in order to inhibit attentional shifts toward task-irrelevant stimuli during top-down, goal-driven behavior. We propose that the musicians' deactivation of the rTPJ during melodic improvisation may represent a training-induced shift toward inhibition of stimulus-driven attention, allowing for a more goal-directed performance state that aids in creative thought.

Introduction

The musician's brain has come to serve as a model system for the study of expertise-related changes in the brain (for reviews, see Schlaug, 2001; Münte et al., 2002, Pantev et al., 2003). Musicians spend years training their fine motor skills, perception and cognition of auditory patterns, and multimodal processing (e.g., visual–motor and visual–auditory transformations in score reading, auditory–motor processing in performance). The effects of such musical training have been associated with increases in gray matter volume in motor and auditory cortices (Gaser and Schlaug, 2003; Bangert and Schlaug, 2006) as well as in frontal, parietal, and occipital regions (Hyde et al., 2009); increases in white matter tract size (Schlaug et al., 1995) and organization (Bengtsson et al., 2005); and enlargements of both somatosensory (Elbert et al., 1995) and auditory cortical representations (Pantev et al., 1998).

In addition, musical training can lead to changes in patterns of brain activation when musicians are compared to nonmusicians in tasks of auditory perception (Hodges et al., 2005), auditory memory (Gaab et al., 2006), and motor sequencing (Hund-Georgiadis and von Cramon 1999; Krings et al., 2000; Jäncke et al., 2000; Lotze et al., 2003; Chen et al., 2008). These results suggest that musical training can lead to shifts in cognitive strategy on music-related tasks, reflected in changes in the neural networks recruited to perform these tasks.

Most functional brain imaging studies comparing musicians and nonmusicians on perceptual and motor tasks have not used particularly ‘musical’ paradigms, but rather have isolated pitch memory (Gaab et al., 2006) or rhythmic performance (Chen et al., 2008), for example, outside of their musical context. This is, of course, understandable: nonmusicians, by definition, are not trained in specific musical skills, and thus it would be impractical to test them on such skills (e.g., performance of a piece, auditory analysis of a complex example). Although nonmusicians are not typically trained to play pieces of music from memory, they are quite able to improvise melodies and rhythms (Sági and Vityáni, 1988). Thus, in the present study, we compared musicians and nonmusicians during improvisation, the generation of novel auditory–motor sequences. In so doing, we were able to examine the expertise-related differences in

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functional brain activity when subjects performed a musical task involving creative decision making. While previous work has demonstrated the use of improvisation to study the neural correlates of spontaneous novel motor sequence generation in musicians (Brown et al., 2006; Bengtsson et al., 2007; Limb and Braun, 2008; Berkowitz and Ansari, 2008), the degree to which activity in such brain networks represents a specialization due to musical training has thus far not been systematically explored.

In our previous study, we used functional magnetic resonance imaging (fMRI) to examine the neural correlates of musical improvisation by classically trained pianists (Berkowitz and Ansari 2008). We used the same paradigm in the present study with nonmusicians, and compared results between musicians and nonmusicians. Of course it would be nearly impossible to fully replicate the experience of improvisation in the scanner environment: improvisation often takes place in groups, and solo improvisation usually takes place in a meaningful context, both physically (a concert hall, a jazz club, etc.) and musically. Even if it were possible to study the full spectrum of live improvisation in the scanner, the resulting neural activation would represent diverse cognitive processes (decision making, creativity, emotion, memory, attention, etc.), and it would be difficult to tease apart which networks of regions were responsible for which underlying processes. We thus designed a set of tasks that allowed us to focus on the creative decision making involved in generating novel motor sequences in both the rhythmic and melodic domains. Thus, while our tasks may not represent musical improvisation to the fullest extent possible, they are certainly improvisatory, and provide a window into the neural correlates involved in creative decision making in the auditory-motor domain.

Subjects performed four tasks on a 5-key piano keyboard (Fig. 1; see also Methods), and heard what they played in real time through scanner safe headphones. When asked to improvise melodies, subjects continuously invented 5-note melodies. This was compared to subjects' performance of simple, prelearned 5-note patterns to assess brain activity in melodic improvisation. Each of these two conditions had two subconditions: subjects either synchronized their improvised melodies or patterns with a metronome or improvised their own rhythms to those invented sequences or patterns. Comparison of rhythmic improvisation conditions with metronome conditions allowed for the examination of rhythmic freedom. The four conditions were thus Patterns/Metronome, Melodic Improvisation/Metronome, Patterns/Rhythmic Improvisation, Melodic Improvisation/Rhythmic Improvisation.

Using this paradigm with trained musicians (Berkowitz and Ansari 2008), we found that brain areas demonstrating changes in activity included the inferior frontal gyrus (IFG), rostral cingulate zone (RCZ) of the anterior cingulate cortex (ACC), and dorsal premotor cortex (dPMC) for both melodic and rhythmic freedom; ipsilateral sensorimotor cortex, superior parietal lobule, and inferior parietal lobule for rhythmic freedom alone; and deactivations for melodic freedom alone including the right middle and superior frontal gyrus, bilateral posterior cingulate, left supramarginal gyrus, and right angular gyrus. We interpreted the activations in IFG, RCZ, and dPMC in the previous study as being involved in the generation, selection, and execution of novel auditory–motor sequences; the parietal activation to be involved in spatiomotor integration for movement selection and skilled action; and the deactivations to be task-induced, associated with the goal-directed and attention-requiring nature of improvisation. Using the same tasks, in the present study, we sought to examine which, if any, of the brain regions active in musicians in our previous study or other regions differed in activation between musicians versus nonmusicians.

We hypothesized that given that both groups would be involved in a task of motor creativity requiring goal-directed attention, they would likely differ in degree of activation in one or more of the regions listed above rather than having involvement of a different network entirely, presuming matched motor performance. Specifically, we suspected that the regions involved in generation and selection (i.e., the IFG, RCZ, and dPMC) would be activated to a greater degree in musicians rather than nonmusicians, since musicians would ostensibly be generating more possible musical sequences among which to select and execute.

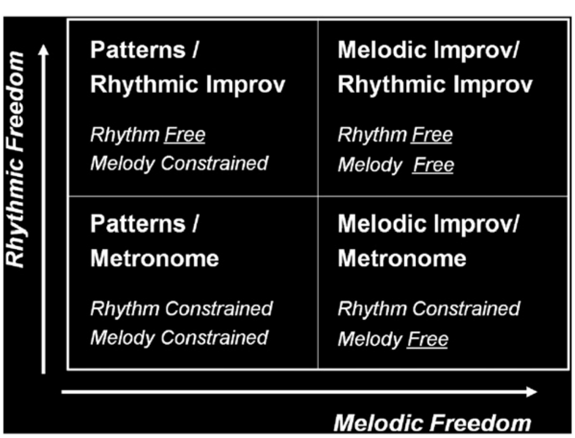

Fig. 1. Task design. Four conditions with varying degrees of rhythmic and melodic freedom.

Methods

Our methods with respect to the behavioral paradigm, analysis of behavioral results, imaging parameters, and imaging analysis were identical to that in our previous study (Berkowitz and Ansari, 2008), with the addition of the between-groups comparisons on all measures. We have reiterated our methods here for the reader's convenience.

Subjects

We recruited 13 classically trained undergraduate pianists from the Dartmouth College Music Department (8 female, mean age = 21.9 years, mean musical training = 13 years of piano experience) and 15 subjects from the Dartmouth community at large who do not currently and have not recently played a musical instrument, and whose past experience playing and/or learning a musical instrument was for 3 years or less (7 female, mean age = 22.9 years, mean musical training = 0.67 years [8 subjects had no musical training at all, and of those with training during childhood, one had 1 year, two had 2 years, and one had 3 years of music lessons]). The musician subjects were the same as the subjects whose data were analyzed in Berkowitz and Ansari (2008). One musician subject and three nonmusician subjects were excluded from analysis because of excessive head motion, leaving 12 subjects in each group in the final analyses.

Task

Prior to functional scanning, each subject was familiarized with the 5-key piano keyboard and the four tasks were explained. Subjects were told that they would see two types of task instructions, either "Make up melodies" or "Play patterns." For "Make up melodies," subjects were told to make up as many unique 5-note melodies as they could in each block. For "Play patterns," seven simple pattern sequences were demonstrated to each subject: five sequential presses of any key (CCCCC, DDDDD, etc.), a 5-note ascending scale (CDEFG), and a 5-note descending scale (GFEDC). Subjects were told that they could play the patterns in any random order of their choosing during "Play patterns" conditions. All subjects were able to immediately recall and demonstrate these patterns before scanning, suggesting