Correlations in spontaneous activity and gray matter density between left and right sensoritmotor areas of pianists

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Resting-state functional MRI and structural MRI were used to study correlations of spontaneous activity and gray matter density between the left and right primary sensorimotor areas in pianists and nonmusicians. Functional MRI analysis showed significant correlation of spontaneous activity between the left and right primary sensorimotor area in both groups; however, there was no between-group difference. Structural MRI analysis showed significant correlation in gray matter density between the left and right sensorimotor areas in nonmusicians (r=0.65, P=0.001), but not in pianists (r=0.07, P=0.78), with a significant between-group difference (P=0.035). The lack of correlation of gray matter density between the left and right sensorimotor areas might be the basis of bimanual coordination of the pianists. *NeuroReport* 19:631–634 © 2008 Wolters Kluwer Health | Lippincott Williams & Wilkins.

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Introduction

As musicians undergo long-term training, with complicated bimanual motor activities, they are ideal subjects for investigating adaptations of the brain to unique skill requirements [1–3]. Long-term motor training has been shown to lead to functional and structural adaptations in the sensorimotor areas of musicians [4–7]. Through the use of voxel-based morphometric technique, Gaser and Schlaug [7] demonstrated that increased gray matter density in the primary motor and somatosensory areas of professional musicians, compared with matched groups of amateur musicians and nonmusicians.

Musicians who play keyboard instruments require bimanual coordination, which is accomplished by communication between the brain hemispheres [8]. Although regional changes of brain activation and gray matter density in the sensorimotor area have been shown in previous studies of musicians [4–7], the correlation of brain activity or gray matter density between the left and right sensorimotor areas has not yet been investigated. Resting-state functional magnetic resonance imaging (fMRI) measures spontaneous neuronal activity in the brain [9] and has been widely used to investigate temporally correlated fluctuations (i.e. functional connectivity) between distributed brain areas. For example, there is functional connectivity of spontaneous brain activity between the left and right motor cortex in normal subjects [10–12]; however, patients with multiple sclerosis exhibited decreased functional connectivity between the left and right sensorimotor areas owing to lesions in the corpus callosum [13]. Cortical thickness, or gray matter volume, has been shown to correlate between brain areas [14–17]. Such gray matter density correlation might reflect interregional structural organization [17]. To our knowledge, however, interregional correlations of spontaneous activity or gray matter density have not been studied in musicians.

This study used both resting-state fMRI and structural MRI to investigate correlations of spontaneous activity and gray matter volume between the left and right primary sensorimotor areas of pianists and nonmusicians. The hypothesis was that (i) both groups might exhibit significant correlations of spontaneous activity and gray matter volume between the left and right sensorimotor areas, and (ii) pianists with great bimanual movement coordination might show higher correlations of spontaneous activity or gray matter density between the left and right sensorimotor areas, compared with nonmusicians.

Materials and methods

Participants

Piano players (n=20; 22.3±2.6 years old; 12 females) who were college students studying piano, or had just graduated from a local conservatory school, were chosen for this study. The participants began piano training between the ages of 5.5 and 17 years. Control participants (n=22, 22.4±2.6 years old, 12 females) were enrolled medical students and hospital staff members. Only control participants with no musical training were chosen for the study. According to a simple questionnaire (participants were asked which hand they used to write, use chopsticks, and play table tennis), all participants were right-handed and had no history of neurological, psychiatric, or movement disorders. The Institutional Review Board of Huaxi Hospital approved this study. Written informed consent was obtained from all participants.

MRI

Five scanning sessions, using a 3T GE MRI system (EXCITE, Milwaukee, USA), were needed to acquire the imaging data at Huaxi MR Research Center of West China Hospital. The scanning sessions were as follows: (i) 'two-dimensional-localizer scan'; (ii) 'six axial T1 slices that covered the sensorimotor cortex' [slice thickness/gap=6/1 mm, repetition time (TR)=2153.1 ms, echo time (TE)=27.048 ms, matrix=512×512, field of view=$24 \times 24\,cm^2$]; (iii) 'six resting-state fMRI scanning slices' (slice thickness/gap=6/1 mm, TR=400 ms, TE=30 ms, flip angle FA=90°, matrix=64×64, field of view=$24 \times 24\,cm^2$, total volumes=1000). The slice position was the same as for the T1 images. The participants were instructed to remain as still as possible and not to think about anything in particular; (iv) 'task-state fMRI': before the session, the participants were unaware of this task. The parameters and position were the same as session 3 (resting-state), and the task design was slow event related. The participants were asked to press a key with their left index finger as quickly as possible when a musical note appeared on the screen (every 13–17 s, lasting for 1 s). Response data from two participants were not recorded owing to technical problems. They, however, reported that they had correctly followed the stimuli; therefore, task-state fMRI data from these two participants were also analyzed; and (5) 'three-dimensional (3D)-spoiled gradient-recalled high-resolution anatomical images of the entire brain' were obtained, according to the following parameters: TR=8.528 ms, TE=3.4 ms, matrix size=512×512, 156 axial slices, and thickness/gap=1/0 mm.

Data analysis

Preprocessing of functional MRI data (task and resting states)

Preprocessing was performed with the AFNI package [18]. The first 25 volumes (i.e. 10 s) were discarded to allow for signal equilibration and to allow the participants to get used to scanning noise. Slice timing and head motion correction were performed; no participant exceeded 1 mm of head motion displacement or 1° of rotation. The fMRI data were resampled ($3 \times 3 \times 3\,mm^3$) and spatially smoothed (full width at half maximum=8 mm).

Generation of right voxel of interest

The right voxel of interest (VOI) was defined on the activation map of task-state fMRI. A '3dDeconvolution' program in the AFNI software [18] was used to generate the left finger button-press activation map. As the purpose of using the finger movement task in this study was to generate the right VOI of the anterior wall of central sulcus (AW-CS), we were only interested in the activation of primary motor cortex. Significantly ($F > 1.5$, $P < 0.05$) activated voxels were displayed (Fig. 1a). The most significantly activated voxel in the right AW-CS was taken as the VOI for individual connectivity analysis. Three participants did not pass the significance level, so the greatest activated voxel from the right AW-CS was selected as the right VOI.

Generation of left VOI

Following bandpass filtering (0.01–0.08 Hz) [10,19] and linear-trend removal, the individual time course from resting-state fMRI data of the right VOI served as the reference function for individual voxel-wise correlation analysis. All subjects displayed significant ($P < 1.0 \times 10^{-47}$) correlation in the left primary sensorimotor cortex (Fig. 1b). The majority of subjects (36/42) had a peak voxel (largest correlation coefficient) located precisely in the left AW-CS, which was chosen as the left VOI. For the other 6 subjects, the peak voxel was located in the left precentral gyrus; therefore, a voxel that was situated in the left AW-CS, but adjacent to the peak voxel (within 10 mm), was chosen as the left VOI.

Definition of regions of interest (ROI)

The preprocessed resting-state fMRI data, and the left and right VOIs were coregistered to individual 3D images via T1 images and subsequently spatially normalized to the Montreal Neurology Institute (MNI) template using statistical parametric mapping (SPM2, *http://www.fil.ion.ucl.ac.uk/spm*). Two spherical ROIs (radius=10 mm), covering the anterior and posterior CS wall, were centered at the left and right VOIs (Fig. 1c), respectively.

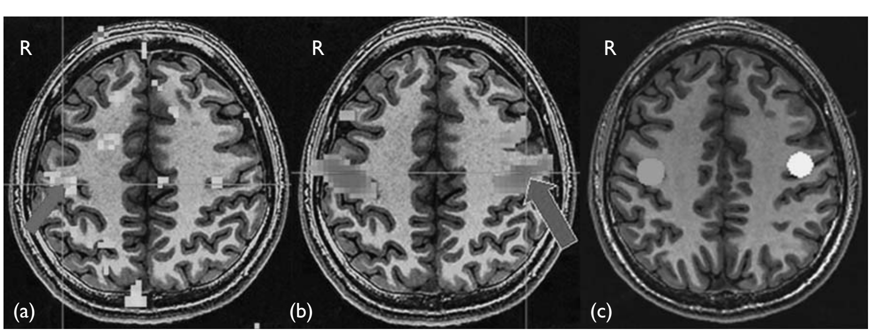

Fig. 1 (a) Individual activation map and right voxel of interest (VOI) of the primary sensorimotor area (arrow). (b) Functional connectivity map and left VOI of the primary sensorimotor area (arrow). (c) The spherical regions of interest (radius=10 mm) are centered at the right (left grey circle) and left (right white circle) VOIs. For details, see Materials and Methods.

Functional connectivity analysis

The correlation analysis was performed on the averaged time courses of the left and right ROIs. The individual correlation coefficient was transformed to a z value using Fisher's transformation [20]. A two-sample t-test was performed on the z value to determine differences between the groups.

Correlations of gray matter density

The normalized 3D images were segmented into gray matter, white matter, and cerebrospinal fluid using SPM2 (*http://www.fil.ion.ucl.ac.uk/spm*). The resultant gray matter maps were further smoothed with an 8-mm full width at half maximum isotropic Gaussian Kernel. The averaged gray matter density within each spherical ROI was calculated, and a correlation analysis was performed between the left and right ROIs of the pianists and nonmusicians.

Results

Functional connectivity

For all participants, the time courses of the left and right VOIs exhibited a correlation ($P<1.0\times10^{-47}$) (Fig. 1b). A two-sample t-test indicated no difference of the z score between the two groups, that is, the functional connectivity between the left and right sensorimotor ROIs showed no difference between the two groups (P=0.202).

Gray matter density correlations

No local gray matter density differences in the left ROI (musicians: 0.42 ± 0.10, nonmusicians: 0.42 ± 0.12, P=0.90) or the right ROI (musicians: 0.44 ± 0.08, nonmusicians: 0.47 ± 0.07, P=0.22) between the groups were observed. Gray matter density of the two ROIs in the left and right hemispheres was not correlated to each other in pianists (r=0.07, P=0.78), whereas correlated in nonmusicians (r=0.65, P=0.001). The two r values were significantly different (permutation test, P=0.035) (Fig. 2).

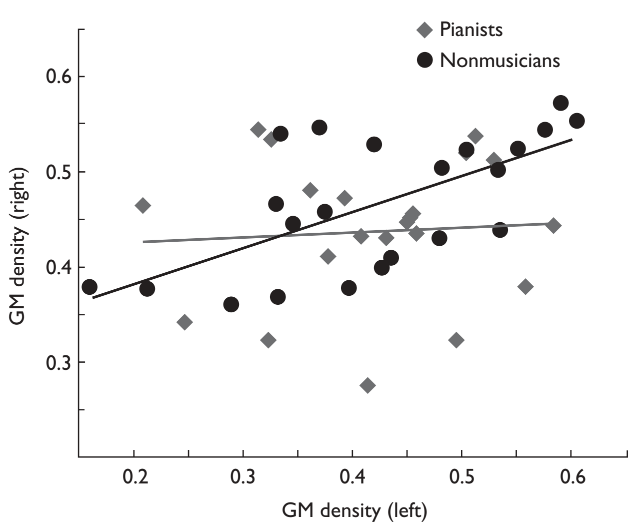

Fig. 2 Averaged gray matter (GM) density of left and right primary sensorimotor areas regions of interest. No correlation in pianists was observed (r=0.07, P=0.78), whereas nonmusicians exhibited a correlation (r=0.65, P=0.001). Significant difference between the two r values (permutation test, P=0.035) was seen.

Discussion

Previous studies have shown that musicians, who undergo long-term training, have an extended central sulcus [6] or increased gray matter density [7] in the left and right sensorimotor areas. Functional or structural imaging studies have, however, not focused on the correlation of spontaneous brain activity or gray matter density between the left and right sensorimotor areas in musicians.

This study determined that pianists and nonmusicians exhibited functional connectivity between the left and right primary sensorimotor areas, which is consistent with previous resting-state fMRI studies [10–12]. In the nonmusician group, gray matter density of the two ROIs in the left and right primary sensorimotor areas was found to correlate to each other (r=0.65, P=0.001), which was also consistent with previous studies [15,17]. The pianists, however, did not exhibit gray matter correlation (r=0.07, P=0.78).

Bimanual coordination in pianists could be associated with increased functional or structural correlations between the left and right sensorimotor areas; however, there was not functional connectivity difference between the two groups (P=0.202). Contrary to expectations, gray matter density correlation between the left and right sensorimotor cortex was less in the pianists than in the nonmusicians (permutation test, P=0.035 for the r values). Pianists can simultaneously tap left and right fingers to different rhythms and with different strengths when playing the piano. The current result suggests that the low correlation between left and right gray matter density might be the basis of the independence of the left and right hand movement. In other words, lower gray matter correlation between the left and right sensorimotor areas in pianists might be associated with behavioral coordination or independence.

Recent studies have suggested that the structural and functional organization of musician's brains correlates to the age at which musical training begins [6,21–23]. Jäncke *et al.* [21] described diminished asymmetry when musicians performed a finger-tapping task, which is related to early musical training. Amunts *et al.* [6] demonstrated that intrasulcal length of the precentral gyrus correlated negatively to age onset of musical training. This study also analyzed the correlation between age onset of musical training and neuroimaging measurements (regional gray matter density and the z value of functional connectivity). No correlations in gray matter density (r=−0.30 and P=0.22 for the left ROI, r=−0.35 and P=0.16 for the right ROI) or the z value of functional connectivity (r=0.35, P=0.15), however, were observed. The inconsistent results from these various studies might be because of the range of ages at musical training commencement.

Some issues should be addressed. First, in this study, there were no group differences in functional connectivity between the two ROIs of the left and right sensorimotor areas. The two selected ROIs, however, did not represent the entire primary sensorimotor areas. In future studies, accurate anatomical registration should be used to reduce variability across participants, and therefore, a voxel-by-voxel analysis of functional or anatomical data could be performed. Second, this study investigated structural and functional correlations between the left and right primary sensorimotor areas using a multimodal imaging approach. Previous studies in monkeys have demonstrated that interregional correlated fluctuations of spontaneous neuronal activity might be related to the underlying structural connectivity [24,25]. Structural MRI studies have suggested that functionally or anatomically connected systems exhibit correlated variations in brain morphology (e.g. volume, density, and thickness of gray matter) [15–17]. The present finding of structural (gray matter density) correlations and functional connectivity between the left and right primary sensorimotor areas in control participants provides further evidence for a strong relationship between brain structure and function. Results from the musician group, however, did not reflect an association, which suggests that the two correlation measurements might represent two different aspects of brain organization (function and morphology). Future studies are required to clarify the association between structure and function of the human brain.

Conclusion

Pianists exhibit no gray matter density correlation between the left and right sensorimotor areas, whereas a correlation was present in the nonmusicians. Reduced gray matter correlation may underlie behavioral coordination or independence.

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