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Asymmetry of parietal lobe activation during piano performance: a high field functional magnetic resonance imaging study

Kosuke Itoh[a,b], Yukihiko Fujii[a], Kiyotaka Suzuki[a], Tsutomu Nakada[a,*]

[a]*Department of Integrated Neuroscience, Brain Research Institute, University of Niigata, 1 Asahimachi, Niigata 951-8585, Japan*
[b]*Department of Behavioral and Brain Sciences, Primate Research Institute, Kyoto University, Kyoto, Japan*

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Abstract

Functional asymmetry of the parietal lobes during piano performance was assessed utilizing independent component-cross correlation-sequential epoch analysis of functional magnetic resonance imaging time series. Eight right handed musically trained subjects played the piano with their right hand, left hand, or both hands as cued by visually presented musical scores. The areas activated included the posterior parietal cortex (PPC) and the primary sensorimotor areas (SM1). While unilateral SM1 activation was correlated to motion of the corresponding contralateral hand, PPC activation was correlated to piano performance irrespective of hand modality. Furthermore, PPC activation exhibited significant asymmetry, with left hemisphere dominance. The results indicate that the left parietal lobe plays a significant role in the cortical processes of piano performance.

Keywords: Piano performance; Posterior parietal cortex, Asymmetry, Sensorimotor, Three-dimensional spatial processing; Independent component-cross correlation-sequential epoch analysis; Functional magnetic resonance imaging

Humans have the enhanced capability for precisely controlling the movement of individual fingers, relative to non-human primates. Sight-reading based piano performance is one such example. The task involves sensorimotor processing in three-dimensional (3D) space for planning the finger movements, which follows visual perception of the particular music score defining the goals of movements and is succeeded by the execution of planned actions. Sensorimotor 3D spatial processing is believed to be symmetrically subserved by the homologous posterior parietal areas bilaterally in monkeys [1,13]. In contrast to the non-human primate data, the distinguishing feature of the human parietal lobes is its functional asymmetry. It is generally believed that the perceptual component of sensorimotor 3D processing is dominantly subserved by the right parietal cortex [2,17] whereas the executive component by the left parietal cortex [7,8,18].

In this study we accordingly investigated the functional asymmetry of the parietal lobes during sight-reading based piano performance.

Validated multivariate analysis in functional magnetic resonance imaging (fMRI) studies is extremely challenging if not impossible, since human behavior is a process where a large number of functions and variables interact with considerable attendant confounding effects. Independent component-cross correlation-sequential epoch (ICS) analysis [11,16] was utilized in this study to enable such analysis. Implementation of independent component analysis (ICA) [9] in ICS ensures to negate significant confounding effects as long as activated areas are spatially independent. Functional localization is a salient characteristic of the brain and activation studies are generally based on the concept that a brain function of interest can be assigned to discrete areas of the brain, implying the basic assumption of spatial independence of the activation areas. Another advantageous feature of ICS is that the validity of the experiment may be tested internally. It is established by incorporating into the paradigm some 'control' functional components with their well identified corresponding physiological areas, verified by equivalent analysis on the same data set as that used for obtaining the results of interest.

Eight right-handed [12] normal volunteers (seven females and one male, ages 19–23 years), with at least 10 years of training in piano, participated in the study. All subjects gave their informed consent and the study was carried out in

* Corresponding author. Tel.: +81-25-227-0677; fax: +81-25-227-0821.
E-mail address: tnakada@bri.niigata-u.ac.jp (T. Nakada).

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accordance with the human research guidelines of the Internal Review Board of the University of Niigata.

A Signa 3.0 T (GE Medical System, Waukesha, WI) research imaging system equipped with a superconductive magnet operated at 3.0 tesla (Magnex, Abingdon, Oxon, UK) and Advanced NMR echo-planar imaging (EPI) module was used to perform all the imaging studies. Gradient echo echo-planar images were obtained utilizing the following parameter settings: FOV, 40×20 cm; matrix, 128×64; slice thickness, 5 mm; inter-slice gap, 2.5 mm; TR, 1 s. To obtain high field homogeneity each slab was restricted to 30 mm, or four slices. Spatial resolution was approximately $3 \times 3 \times 5$ mm. The chosen imaging slab covered the primary sensorimotor cortex (SM1) and the posterior parietal cortex (PPC).

The sight-reading piano performance task consisted of four different epochs lasting 30 s each. Subjects played the piano with different hand assignments in three of the epochs: right hand only (R), left hand only (L), and both hands together (B). The fourth epoch was a rest period (r). The musical pieces were based on a technical finger exercise book for pianists [6] edited into unpredictable patterns. The upper and lower staves of the piano score corresponded to the music to be performed by the right and left hand, respectively. Rest marks in either part indicated the corresponding hand to be at rest, i.e. no movement condition. In the both hands together (B) condition, the notes were identical for both hands, except that they were an octave apart. Music scores were presented to the subjects in sequential orders (r-r-L-R-B-r-L-R-B-r, r-r-R-L-B-r-R-L-B-r). Data from the first rest epoch were discarded to ensure steady state of the magnetizations. A non-magnetic silent piano keyboard was placed on the subject's lap. Subjects were instructed not to look at the keyboard except for initial hand positioning. Subjects used sounds generated by the switching magnetic gradients for EPI readout occurring at a rate of once per 250 ms as metronome, and the tempo was assigned at two scanner sounds per note. Performance was monitored by a video camera, and all subjects were monitored for smooth execution of the motor task. A non-performance hand motion task, self-paced hand grasping in the identical sequence, was utilized as the control condition.

Data were analyzed using ICS analysis [9,10,16]. In brief, following spatial smoothing with 5 mm full-width-at-half-maximum isotropic Gaussian kernel, each set of fMRI time series was blindly separated into 270 spatially independent components by ICA. The spatial components were normalized to a norm of one, with complementary scaling in the matrix representing time series. Subsequently, the unmixed time series were subjected to correlation analysis using given model functions. In this study, three patterns of delayed (6 s) boxcar functions, referred to here as the left hand performance pattern function f(L), right hand performance pattern function f(R), and 'either hand' performance pattern function f(E), were utilized as model functions (Fig. 1, dotted lines). The region of interest (ROI) for f(L) and f(R) was the precentral and postcentral gyri (SM1), and that for f(E) was the superior and inferior parietal lobules (PPC). f(E) represented the function of interest whereas f(L) and f(R) served as the internal controls for the validity check. Activations in other areas were not targeted for the present analysis. For the construction of activation maps, independent components located in each ROI which showed significant correlation ($cc > 0.6$, $P < 0.001$) with the corresponding model functions were extracted and displayed in the original two dimensional image matrix.

The results were as follows. Representative time series correlated with f(L), f(R), and f(E) activation patterns are shown in Fig. 1. Functional maps are displayed in Fig. 2. Activation which correlated with f(L) and f(R) mapped onto the corresponding contralateral primary sensorimotor area, SM1, while those which correlated with f(E) mapped onto the PPC. During the non-specific hand grasping task, activation was observed in SM1 but not in PPC. Further quantitative analysis of PPC activation revealed that the number of components in the left PPC was greater than that in the

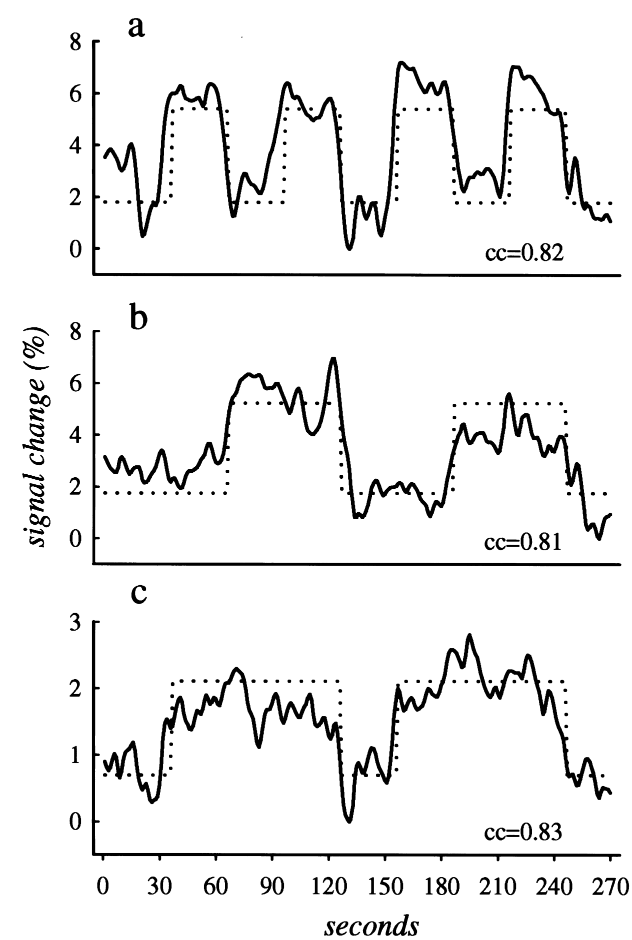

Fig. 1. Modeled (dotted lines) and observed (solid lines) activation patterns of fMRI time series for the task sequence 'r-r-L-R-B-r-L-R-B-r': (a) f(L) pattern in the right SM1, (b) f(R) pattern in the left SM1, and (c) f(E) pattern in the PPC.

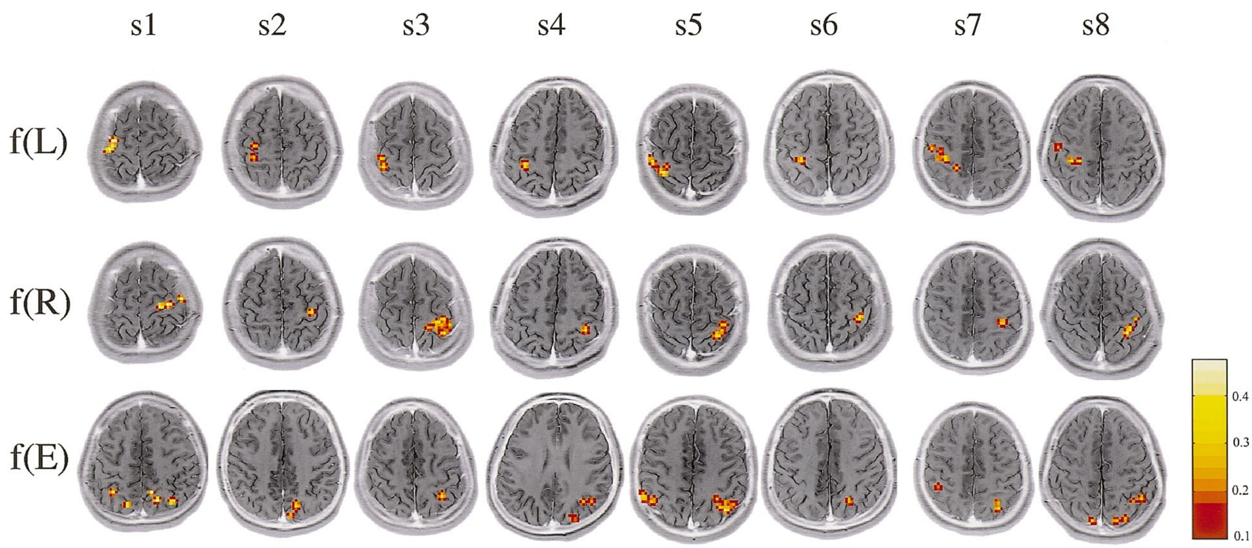

Fig. 2. Components with correlation coefficients larger than 0.6 for functions f(L), F(R), and f(E) are displayed in representative slices for each subject (s1-s8). The component maps were normalized to a norm of one and thresholded at 0.1 for display. The left hemisphere is represented on the right.

right in all eight subjects. This trend was statistically significant ($P < 0.05$, Wilcoxon's test, Fig. 3).

Thus, activation in the PPC was found to correlate to piano performance irrespective of hand movement modality. Furthermore, the finding that a greater number of spatially independent components lateralized to the left PPC as compared to the right suggests that there was a greater number of functional components employed for the task in the left hemisphere than in the right, in other words, left hemisphere dominance. In contrast, activation in SM1 was consistently contralateral to the moving hand, as can be appreciated from the right hand or left hand only movements. These SM1 results, obtained using similar analytical processes on the identical data set as that of PPC results, were consistent with the well-known function of SM1 and provided validation to the present study.

The observed asymmetric parietal activation is consistent with, and also adds, to the findings from a positron emission tomography (PET) study on piano performance [15]. In this study, Sergent et al. reported on posterior parietal activation related to piano performance, but evaluation for asymmetry was not possible due to the use of a test paradigm which called for subjects to play the piano with the right hand only. The results from the present study on right handed subjects uniquely showed that the left PPC had greater activation than the contralateral homologous cortex during piano performance tasks utilizing left hand only, right hand only, or both hands together.

The left hemisphere dominant PPC activation is consistent with the widely accepted view about parietal functional asymmetry. It has long been suggested by clinical studies that the perceptual component of 3D spatial processing is principally subserved by the right PPC [2,8,17], while the executive component of 3D spatial processing is subserved predominantly by the left PPC [7,18]. Given that piano performance involves 2D visual perception of music score followed by sensorimotor 3D spatial processing for organizing finger movements, the left hemisphere dominant activation in the PPC is compatible with known PPC lateralization of function.

Imaging studies of other spatial motor tasks [3–5,14,19] (e.g. mouse movement, finger tapping, and typing) have

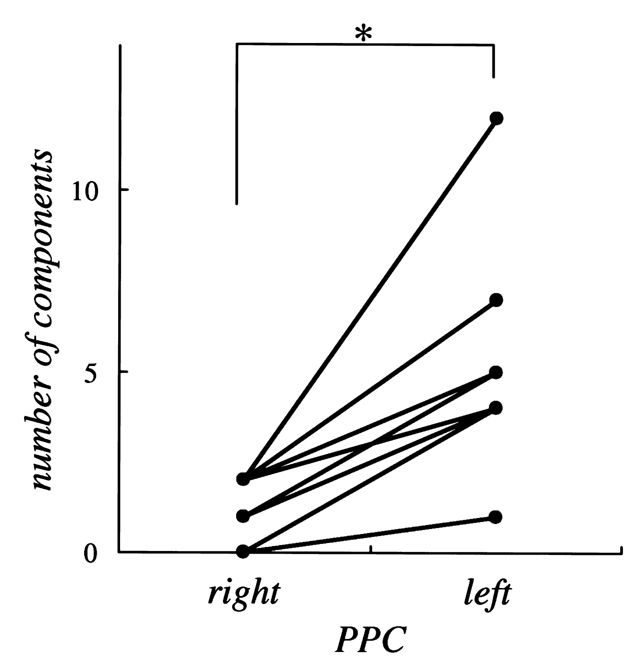

Fig. 3. Asymmetry in the number of components of activation found in PPC associated with the f(E) pattern. Each line represents data from a single subject. The difference in the numbers is significant at the 5% significance level, Wilcoxon's test.

reported to show bilateral or right dominant PPC activation. The distinctive result of left hemisphere dominance in the present study may be interpreted as underscoring the unique nature of piano performance as a spatial motor task. Sight-reading piano performance requires the fingers to be independently guided to target keys in extra-personal space, in contrast to, for example, mouse movement and finger tapping. In addition, finger-to-key correspondence in piano performance is variably dependent on the context of the music comprehended on-line. In the simple act of selecting a finger to hit a key, the player must determine the unengaged fingers and subsequently select from these alternatives the best finger in terms of providing the smoothest movement to the designated key. The selection is furthermore required to be preparative for the notes yet to follow, providing for easy fingering. In skilled typewriting, on the other hand, the finger-to-key correspondence is invariably fixed and is independent of the context. Thus it may be deduced that piano performance is qualitatively more complex and demanding where sensorimotor 3D spatial processing is concerned than the aforementioned motor tasks, leading to the distinctive result in the present study.

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