Analysis of Brain Activation during Motor Imagery Based on fMRI

Qin Yang, Wen Huang, Wei Liao, and Hua-Fu Chen

Abstract—Brain activation during motor imagery (MI) has been studied extensively for years. Based on studies of brain activations of MI, in present study, a complex finger tapping imagery and execution experiment is designed to test the brain activation during MI. The experiment results show that during MI, brain activation exists mainly in the supplementary motor area (SMA) and precentral area where the dorsal premotor area (PMd) and the primary motor area (M1) mainly located; and some activation can be also observed in the primary and secondary somatosensory cortex (S1), the inferior parietal lobule (IPL) and the superior parietal lobule (SPL). Additionally, more brain activation can be observed during left-hand MI than during right-hand MI, this difference probably is caused by asymmetry of brain.

Index Terms—Asymmetry, motor imagery, supplementary motor areas.

1. Introduction

Motor imagery (MI), defined as the mental rehearsal of movement without any overt body movements\cite{1,2}, has been demonstrated playing a very important role in training athletes and musicians to improve performance\cite{3} and in recovery of motor abilities for patients with movement disorders\cite{4,5}. In particular, motor imagery is performed in two different strategies: visual imagery (VI)\cite{6} and kinetic imagery. In the former case people produce a visual representation of their movements, and in the later case people simulate the movement with a kinesthetic feeling.

Benefiting from brain imaging techniques such as functional magnetic resonance imaging (fMRI) and positron emission tomography (PET), MI has been studied intensively for years. Among the areas of brain activation during MI, the supplementary motor area (SMA) is frequently studied as a predominant area of MI. Most studies of MI reported the activation of the SMA during MI\cite{7}-\cite{10}. Besides the SMA, several other brain regions, such as the dorsal premotor area (PMD) and the inferior parietal lobule (IPL), also participate in MI as plenty of studies have addressed\cite{3}, \cite{11}.

2. Methods

2.1 Subjects and Behavioral Task

Ten right-handed subjects (four females, age range from 19 years to 25 years) according to the Edinburgh inventory participated in the study after giving informed consent approved by local Institutional Review Board (IRB) approval. The average score on the Edinburgh inventory was 90.72, with a standard deviation of 6.43. None had a history of any neuropsychiatric disorders.

2.2 Experiment

The experiment was performed on a 3.0-T scanner, GE-Signa (Huaxi MR Research Center, Chengdu, China). The gradient-recalled echo planar imaging (EPI) sequence was employed for fMRI scanning. The parameters were as follows: 30 transverse slices, TR (repetition time)=2000 ms, TE (echo time)=30 ms, FOV (field of visual)=24 m, matrix =64×64, voxel size=3.75 mm×3.75 mm×5 mm (without gap), flip angle=90°. The fMRI experiment was designed in two runs: one for left hand performance and the other for right-hand MI, this difference probably is caused by asymmetry of brain.

During each trial, subjects first learned from four sequentially presented pictures, indicating a random order of finger tapping (for example, ring-index-middle, or, index-middle-ring -little), and then started to imagine tapping their fingers in the order that initially informed by the visual stimulus. Importantly, the screen turned black when imagination began. The imagery repeated continuously in the 10 seconds duration. Next, another cue for the next 6 seconds was presented on the screen informing the participants to

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perform the finger tapping exactly as they had imagined. This was the motor execution (ME) condition. The reason that motor imagery was followed by the ME condition is to ensure that subjects concentrated on motor imagery and imagined the finger tapping correctly. Before the fMRI experiment, subjects were trained for about 1 hour.

3. Data Analyses

The experimental data was analyzed using SPM2 software (www.fil.ion.ucl.ac.uk/spm). Spatial transformation including realignment was performed using 3-D rigid body registration to correct head motion. Motion correction parameters were included in the design matrix of six regressive parameters for each run as covariates with no interest. Then, a high-pass filter with a cut-off of 1/128 Hz was used to remove low-frequency noise. After being spatially normalized into standard stereotaxic space at 2 mm×2 mm×2 mm, using the Montreal Neurological Institute (MNI) echo-planar imaging (EPI) template, the voxel coordinates reported in Table 1 and Table 2 were transformed from the MNI template to Talairach space (12). A spatial smoothing filter was employed for each brain’s 3D volume by convolution with an isotropic Gaussian kernel (FWHM = 8 mm) to increase the MR signal-to-noise ratio. Statistical parametric maps (t-statistics) of contrast between MI condition and rest condition was generated with a threshold of \( p < 0.001 \) uncorrected to detect brain areas activated during MI. Subsequently, in order to extend inference based on the individual statistical analysis to the general population from which the subjects were drawn, a random-effect analysis (13) was performed. This estimates the error variance for each condition of interest across subjects, rather than across scans. In this random-effect analysis, one-sample t-test (degree of freedom \( d.f. = 9 \)) group analysis in SPM2 at each voxel was performed across subjects on their individual SPM \( t \) map. Voxels with \( t > 3.5, q = 0.01 \) False discovery rate (FDR)-corrected (14) were considered as significantly activated, and they are superimposed on high-resolution anatomical images as shown in Fig. 1. And the voxel coordinates for left-hand MI and right-hand MI were reported in Table 1.

4. Results

Fig. 1 (a) and Fig. 1 (b) show the maps of activated brain regions during left-hand MI and right-hand MI respectively, mainly including the SMA, precentral area, postcentral area, the IPL, and the superior parietal lobule (SPL). Table 1 summarizes the number of activated voxels and the maximal t-value of each activated area. Notably, either in left-hand MI or right-hand MI, there is a great number of activated voxels in SMA denoting that SMA is the most activated area in MI.

### Table 1: Left-hand MI

<table>
<thead>
<tr>
<th>Regions</th>
<th>Hem</th>
<th>Cluster size voxels</th>
<th>t-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMA</td>
<td>L</td>
<td>910</td>
<td>11.9107</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>461</td>
<td>8.1108</td>
</tr>
<tr>
<td>Precentral area</td>
<td>L</td>
<td>870</td>
<td>13.7193</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>244</td>
<td>5.5471</td>
</tr>
<tr>
<td>Postcentral area</td>
<td>L</td>
<td>135</td>
<td>7.4649</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>36</td>
<td>9.1636</td>
</tr>
<tr>
<td>IPL</td>
<td>L</td>
<td>212</td>
<td>4.9801</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>18</td>
<td>4.0979</td>
</tr>
<tr>
<td>Putamen</td>
<td>L</td>
<td>38</td>
<td>4.0886</td>
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</tbody>
</table>

### Table 2: Right-hand MI

<table>
<thead>
<tr>
<th>Regions</th>
<th>Hem</th>
<th>Cluster size voxels</th>
<th>t-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMA</td>
<td>L</td>
<td>504</td>
<td>7.9623</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>97</td>
<td>4.1548</td>
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<tr>
<td>Precentral area</td>
<td>L</td>
<td>313</td>
<td>7.9989</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>67</td>
<td>4.1842</td>
</tr>
<tr>
<td>Postcentral area</td>
<td>L</td>
<td>56</td>
<td>3.5195</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IPL</td>
<td>L</td>
<td>32</td>
<td>3.9958</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPL</td>
<td>L</td>
<td>15</td>
<td>3.7468</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td></td>
<td></td>
</tr>
<tr>
<td>putamen</td>
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<td>500</td>
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</tr>
<tr>
<td></td>
<td>R</td>
<td>183</td>
<td>5.2039</td>
</tr>
</tbody>
</table>

Abbreviations: Hem=hemisphere, IPL=inferior parietal lobule, L=left, R=right, SMA=supplementary motor area, SPL=superior parietal lobule. Voxel coordinates are Talairach coordinates.

Fig. 1. The activated areas of motor imagery obtained by SPM2 group analysis: (a) left-hand and (b) right-hand.

The maximal t-values in the SMA are 11.9107 for left-hand MI and 7.9263 for right-hand MI. Precentral area is also dramatically activated. It is worthy to notice that during both left-hand MI and right-hand MI, left precentral area is more activated than right precentral area. Similarly, only the left IPL and SPL are slightly activated as seen from Table 1 and Table 2. However, the contralateral postcentral area, where the primary and secondary somatosensory cortex (S1) is located, is activated in both left-hand MI and right-hand MI.
Comparing the results of left-hand and right-hand MI, we find that the activated brain regions during left-hand MI are larger than that during right-hand MI, and the maximal t-value of each activated region for left-hand MI is higher than that for right-hand MI. This result probably shows that the brain is more activated when doing left-hand MI.

5. Discussion

5.1 Activations of MI

In present study, several brain regions are found to be activated during MI, such as the SMA, IPL, SPL, precentral area including the PMd and the primary motor area (M1), and postcentral area including the primary and secondary somatosensory cortex (S1). Numerous studies\(^{[9][10][15][16]}\) have demonstrated the activation of these areas during MI. In accordance with previous studies, our results also show that the SMA maintains active throughout the MI period, indicating that the SMA plays a key role in the preparation and readiness for action\(^{[17][18]}\). The PMd is described to play an important role in motor preparation and execution\(^{[3][7][19]}\), and is involved in a system that is responsible for the programming of sequential movements under sensory guidance and for the retrieval of abstract action plans\(^{[20]}\). The results of our study are consistent with those previous ones: extensive activation is found in the bilateral PMd during left-hand and right-hand MI, which is also corroborated by a statement that the involvement of premotor areas increases with increasing complexity of the movements imagined\(^{[10]}\). Besides the PMd, a number of voxels in the M1 are also activated during MI; although the involvement of the M1 in MI remains controversial, some fMRI studies suggest that M1 is activated during MI\(^{[3][8]}\), while others do not\(^{[11][21]}\). It seems that different experimental applications and the complexity of the MI tasks may lead to different results. The widespread activation of the parietal area, including the IPL and SPL, has also been emphasized in plenty of MI-related studies. The IPL and SPL are considered to be active during finger sequence learning\(^{[9][22][23]}\), while the SPL is reported to be more active as the task becomes harder.

5.2 Asymmetry of MI

As shown in this paper, much greater brain activation is detected during left-hand MI than during right-hand MI (in Fig. 1). This result is consistent with the finding that a small region of the cortex is asymmetrical toward the left side in a majority of right-handed people. This asymmetry is probably evoked by right-handedness\(^{[24][25]}\). These results are concordant with several prior positron emission tomography\(^{[26]}\) and fMRI studies\(^{[27][28]}\) which demonstrated that the activity in the motor cortex is less lateralized during left hand movements than during right hand movements for right-handed people.

6. Conclusion

In this study, we analyze the activation of brain during motor imagery. A complex finger tapping imagery experiment is designed to get the MI data for the study. Using group analysis in SPM2, several regions are detected to be activated during MI. In particular, we find that during both left-hand and right-hand MI, there are activations in SMA, precentral area mainly including PMd and M1, postcentral area, IPL, and SPL. Meanwhile, much more activation is involved during left-hand MI than during right-hand MI. This result could probably be explained by the asymmetry of brain caused by right-handedness. These results provide an integrated and interactive view of the brain activation during MI.

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References


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