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Functional MR Imaging of Cortical Activation of the Cerebral Hemispheres during Motor Tasks

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PURPOSE: **We used functional MR imaging to evaluate cortical activation in the precentral, central, and postcentral regions of the contralateral and ipsilateral cerebral hemispheres during left- and right-handed motor tasks.**

METHODS: **Ten healthy right-handed volunteers were studied with echo-planner MR imaging (1.5 T) while performing alternating finger apposition tasks with both hands. During the hand tasks, the areas of activated pixels were compared between subregions (precentral, central, and postcentral) of the contralateral and ipsilateral sensorimotor cortex.**

RESULTS: **The activated area of the contralateral sensorimotor cortex was significantly larger than that of the ipsilateral cortex during tasks with either hand, whereas the ipsilateral activated area was significantly larger during the left-handed task than during the right-handed task. Ipsilateral activation was greatest in the precentral region, less in the central region, and least prominent in the postcentral region.**

CONCLUSIONS: **Our results confirmed those of previous investigators that ipsilateral activation is more pronounced during left-sided movements than during right-sided movements. The variation in activation of the precentral, central, and postcentral subregions suggests different roles of the ipsilateral and contralateral hemispheres during motor tasks.**

Several reports have been published on the use of functional magnetic resonance (MR) imaging and positron emission tomography (PET) to map activated brain areas during hand movements (1–3). An intriguing finding in those studies is that ipsilateral activation is more pronounced during left-handed than right-handed movements in right-handed subjects. These findings suggest that the left and right cerebral hemispheres may play different roles during sequential hand-movement processes in humans. However, these previous functional MR imaging studies assessed the sensorimotor cortex or motor-related cortex as a whole, and activation was analyzed only on the basis of the area or number of pixels that showed a statistically significant increase in MR signal intensity during stimulation: the change in signal intensity ratio of activated pixels was not investigated.

The aims of our study were to reproduce the previously reported findings of asymmetric activation during hand-movement tasks while examining changes in both the activated area and signal intensity, and to investigate the activated sensorimotor regions of the ipsilateral or contralateral hemisphere by means of detailed anatomic mapping using echo-planar imaging.

Methods

Subjects

Ten healthy right-handed volunteers (six men and four women, 21 to 40 years old; mean age, 30 years) participated in this study. Handedness was assessed by the Edinburgh handedness inventory (mean score, 96.7%), which suggested strong right-handedness in all subjects (4). None of the participants had signs or a history of neurologic disease, and findings on noncontrast brain MR images were normal. All subjects were apprised as to the nature of the experiments and gave informed consent, after which they were instructed to remain awake during the studies and task-related training without thinking of anything in particular.

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Data Acquisition and Task

Studies were performed with a superconducting 1.5-T MR imager and a standard circularly polarized head coil. The head position was adjusted so that the orbitomeatal line was aligned symmetrically using the laser alignment beam, and a partly inflated polystyrene bag was used to limit head movement within the coil. All subjects were instructed to keep their heads steady during the study.

After sagittal localizer images were obtained, 10 T1-weighted axial spin-echo images (500/15/1][repetition time/echo time/excitations]) were acquired parallel to the line between the anterior and posterior commissures covering the whole cerebrum (5-mm section thickness and 5-mm intersection gap). We selected three axial planes of the high convexity that covered the middle to high convolutions of the central sulci, including the region related to hand movements, as represented by the "homunculus" of Penfield.

Functional MR data were obtained using single-shot, spin-echo echo-planar sequences with parameters of 2000/25, a 90° flip angle, a 128 × 192 matrix, and a 30-cm field of view. We chose the spin-echo sequence because of its greater microvascular sensitivity, reflecting more parenchymal activation than gradient-echo sequences (5, 6). Since our MR imager has a minimum field of view of 30 cm when this sequence is used, we chose the matrix size that would afford preferentially better spatial resolution. Before scanning, shimming was performed for each location. A series of 60 images was obtained at each of the three sections at 2-second intervals. The initial 20 images were acquired with the subject at rest, followed by 10 images in four phases of alternate task and rest states (rest-task-rest-task-rest). Total examination time was 45 minutes.

During the rest phases, the subjects performed no voluntary motor activity. During the task phases, the subjects repeatedly apposed the thumb to the tip of each of the other fingers sequentially, as follows: 2, 4, 3, 5; 2, 4, 3, 5; and so on. The task was done in a self-paced manner and either the right or left hand was used according to the verbal command of the examiner.

Data Analysis

Pixels showing significant activation were identified by using the *z* score determined by the built-in program in the MR unit. For every pixel, the mean signal intensity values during the rest and task phases were compared by calculating the *z* value and assessing whether there was a statistically significant difference. Pixels with a *z* value of 1.96 or greater ($P < .05$) were superimposed on correlated T1-weighted images. Since longitudinal magnetization depends on the intervals of repetitive scanning in single-shot echo-planar imaging, the signal intensity of the early images in each series gradually decreased until an equilibrium was attained. In functional MR imaging studies, signal intensity changes have an inherent delay of about 4 to 8 seconds (7). To control for the early signal decrease and the inherent delay, data from 10 images of the first resting phase and data from the initial four images of each of the subsequent four phases were discarded.

For each series, the area (mm^2) of significantly activated pixels in each of three pericentral subregions (defined below) was calculated using a workstation computer (Allegro, ISG, Canada). The central sulcus was identified on T1-weighted images using the criteria of Iwasaki et al (8). The pericentral or sensorimotor region was defined as a region extending from the precentral sulcus to the postcentral sulcus, and was divided into the following three subregions: the precentral area, defined as the area between the anterior lip of the central sulcus and the precentral sulcus; the central area, including the anterior and posterior lips and the interior of the central sulcus; and the postcentral area, defined as an area between the posterior lip of the central sulcus and the postcentral sulcus.

We also evaluated the temporally sequential changes of signal intensity in the activated pixels by assessing regions of interest (ROI). We investigated whether sequential signal changes were correlated with the input of rest-task phases by plotting signal intensity versus time. We calculated the percentage of change in signal intensity between rest and task phases using the following formula:

$$\% \text{ signal change} = (\text{mean signal intensity during task} - \text{mean signal intensity during rest})/\text{mean signal intensity during rest} \times 100.$$

In this calculation, we discarded the same series of data as when evaluating significant activation of pixels.

Results

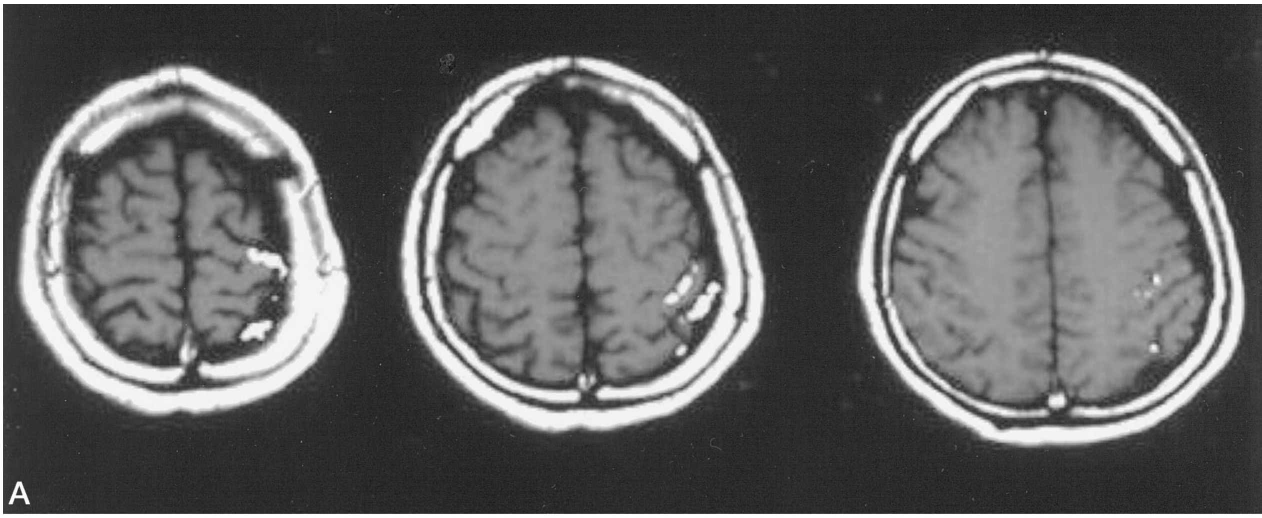
Satisfactory functional MR images showing activated pixels in and around the central sulcus during tasks performed with each hand were obtained in all subjects (Fig 1A and B). The sequential changes of signal intensity for each ROI were well synchronized with the task protocol (Fig 1C).

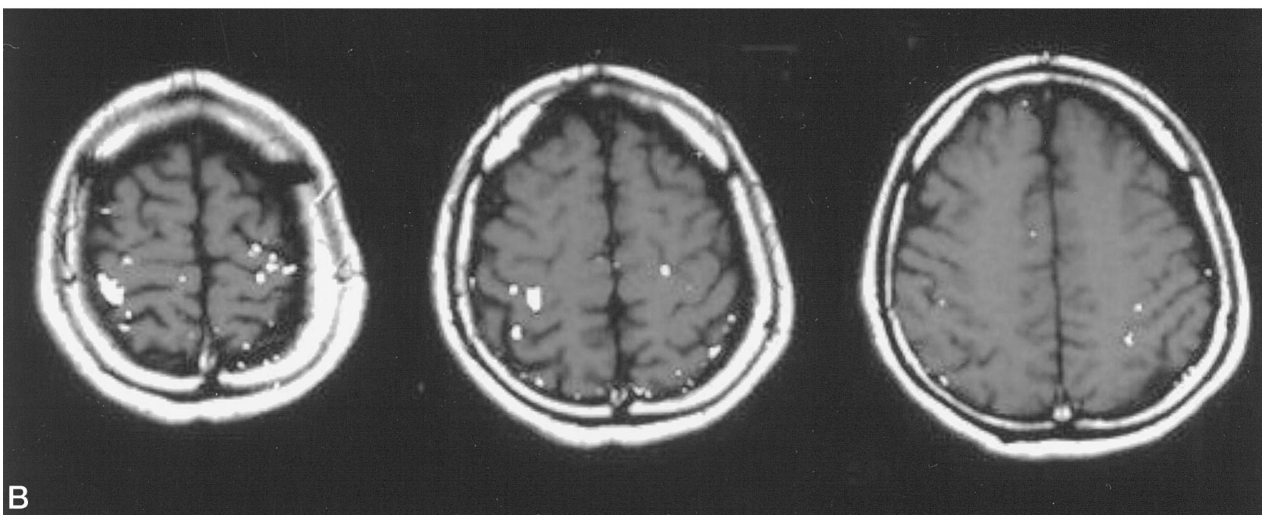
The number of hemispheres with significant activation of pixels in the sensorimotor region is shown in the Table. The contralateral hemisphere showed significant activation in all cases during movement of either hand. In the ipsilateral hemisphere, significant activation was noted in statistically significantly more cases during the left-handed task than during the right-handed task.

Figure 2A shows the mean and standard deviation (SD) of the summed area of the significantly activated pixels in the whole sensorimotor region during the right- and left-handed tasks. The activated area was significantly larger in the contralateral hemisphere than in the ipsilateral hemisphere during either task, whereas no significant difference was noted between movement of the right and left hands (two-way repeated-measures analysis of variance [ANOVA]; $P < .0001$ by hemispheres, $P = .64$ by hands).

In the ipsilateral hemisphere, the activated area was significantly larger during the left-handed task than during the right-handed task (paired *t* test; $P = .05$). Figure 2B shows the mean value and SD of the percentage of increase in the signal intensity of activated pixels during the hand tasks. There was no significant difference between the hemispheres for right- and left-handed tasks (ANOVA; $P > .05$)

Figure 3 shows the mean and SD of the activated areas in the three (precentral, central, and postcentral) subregions. For the ipsilateral hemisphere, the activated area was largest in the precentral area, and no significant difference was noted between the hemispheres (two-way ANOVA; hemispheres by hand, $P > .05$). In the case of the central and postcentral areas, however, the activated area in the contralateral hemisphere was significantly larger than that in the ipsilateral hemisphere for right- and left-handed tasks (two-way ANOVA; hemisphere by hand, $P < .0005$ for the central area, $P < .01$ for the postcentral area). The area of significant activation in the precentral and central areas tended to be larger in both hemispheres for the left-handed task, but no statistical difference was noted.





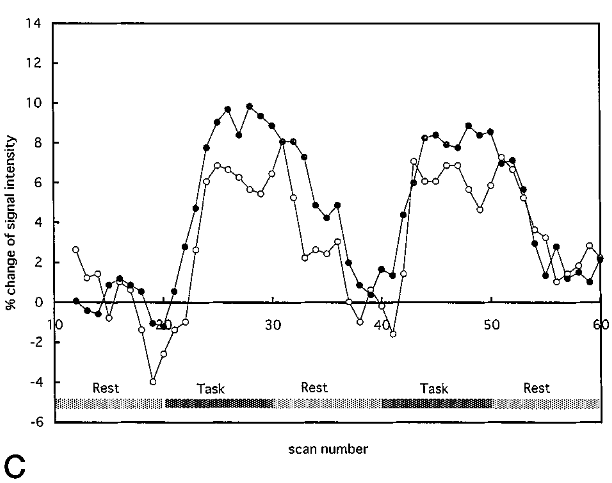


FIG 1. Activated pixels superimposed on the corresponding T1-weighted images (500/15/2) show the three consecutive sections of high convexity of the brain.

A, During the right-handed task, activated pixels are noted in and around the contralateral central sulcus.

B, During the left-handed task, bilateral activation is noted; ipsilateral activation was prominent in the precentral area.

C, During the left-handed task, chronological changes of signal intensity in activated pixels are noted in the contralateral (*white circles*) and ipsilateral (*black circles*) central area. Plotted values were normalized by the mean signal intensity during the initial resting phase. The data from the first 10 images of the initial resting phase were discarded.

Number of hemispheres with significantly activated pixels in sensorimotor region during motor tasks with either hand

	Contralateral Hemisphere	Ipsilateral Hemisphere	Fisher's Exact Test (Contralateral versus Ipsilateral)
Left-handed task	10	9	not significant
Right-handed task	10	4	$P = .01$
Fisher's Exact Test (R versus L)	not significant	$P = .03$	

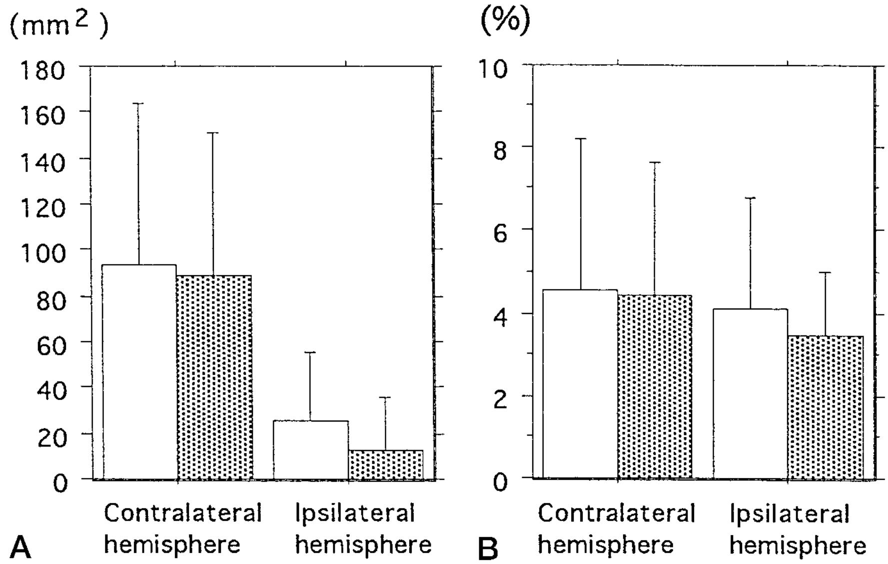


FIG 2. The summed area of activation (*A*) and the percentage of change in signal intensity (*B*) in the contralateral and ipsilateral sensorimotor regions (mean and SD). *White bars* represent the left-handed task and *shaded bars* show the right-handed task.

Discussion

Several investigators have reported that ipsilateral hemispheric activation is greater during left-handed movements than during right-handed tasks in right-handers. Kim et al (2) performed a functional MR imaging study using a 4.0-T unit and found that the ipsilateral motor cortex was substantially activated during left-handed finger tapping, while it was only minimally activated during right-handed movements. Li et al (1) obtained similar findings with a 1.5-T clinical MR system; that is, substantial activation of the ipsilateral posterior frontal and anterior parietal lobes during left-handed finger movements. Furthermore, Kawashima et al (3), using PET, showed that regional cerebral blood flow (rCBF) in the ipsilateral motor area increased significantly during left-handed movements but not during right-handed movements in right-handers. Our results replicated those of the functional MR imaging studies, and were compatible with the rCBF study. Although the methods for identifying activated pixels and for evaluating the anatomic sites of activation in our study were slightly different from those of Kim et al and Li et al, a significantly larger number and larger area of the ipsilateral hemispheres still showed substantial activation in the sensorimotor region during the left-handed task.

In the previous functional MR imaging studies, the degree of activation was evaluated by counting the number of activated pixels, which was similar to our method of measuring the area of activated pixels. On the other hand, in the PET study, activation was evaluated by assessing the increase in rCBF. Changes in signal intensity on functional MR imaging with echo-planar sequences may be caused by the blood oxygenation level–dependent (BOLD) phenomenon (9, 10). According to the results of the PET study performed by Fox et al (10), a consistently minimal increase (less than 5% on average) in the cerebral oxygen metabolic rate ($CMRO_2$) was induced by somatosensory stimulation, producing an average increase in rCBF of 30%. Because the BOLD effect is based on the discrepancy between the increases in $CMRO_2$ and rCBF, an increase in the signal intensity ratio should be almost linearly correlated with that of rCBF. However, we found that the signal intensity changes were almost identical in both hemispheres and during both right- and left-handed tasks. The signal intensity changes in our functional MR imaging studies were calculated by using data from ROIs set on significantly activated pixels, while the PET study used ROIs of a similar volume that were symmetrically set in the corresponding motor areas of both hemispheres (3). The pattern of motor cortex activation in the functional MR imaging study by Kim et al (2) was consistent with that of the increase of rCBF in the motor area shown in the PET study by Kawashima et al (3). Both the identical signal intensity changes of activated pixels shown by functional MR imaging and the consistency between functional MR imaging and PET findings suggest that the rCBF changes seen in the PET study were caused by the partial volume effect of relatively large ROIs, which were identical in size and symmetrically set in both hemispheres. Therefore, we assume that an increase of rCBF to individual activated neurons might have been almost identical in every region of the sensorimotor cortex.

One of the most interesting findings of our study was that the ipsilateral activation was most prominent in the precentral area, moderate in the central area, and least prominent in the postcentral area. We also noted greater ipsilateral activation with the left-handed task than with the right-handed task. Anatomically, the precentral area consists of Brodmann's area 6 and therefore mainly represents the premotor cortex; the central area includes the primary motor cortex with a small portion of the primary sensory area; and the postcentral area mainly includes the primary sensory cortex. The activation pattern of the central area in this study was consistent with previous

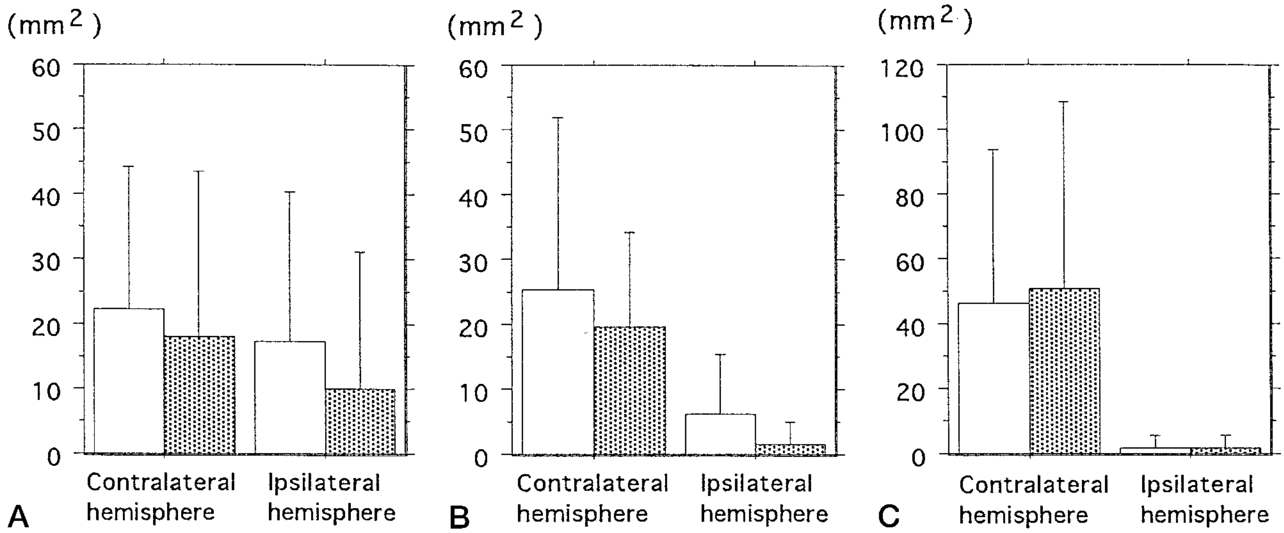


FIG 3. The activated area in the precentral (*A*), central (*B*), and postcentral (*C*) areas (mean and SD). *White bars* represent the right-handed task and *shaded bars* show the left-handed task.

functional MR imaging and PET data; that is, the central area was activated more prominently in the contralateral than in the ipsilateral hemisphere during either right- or left-handed tasks, and activation in both hemispheres was larger during the left-handed task (2, 3). Using functional MR imaging, Boeker et al (11) reported activation in the contralateral premotor area during unilateral middle-finger tapping in right-handers. However, these investigators did not refer to the activation of the ipsilateral premotor area. In their PET study, Kawashima et al (3) found a tendency for rCBF to increase in both premotor areas in relation to left- and right-handed movements, although a significant ipsilateral increase of rCBF was found only during the left-handed task. Since the pattern of rCBF change should correlate with the pattern of activated pixels on functional MR images, as discussed above, our results may be regarded as having shown a similar trend.

Some activation of the ipsilateral motor-related cortex during movements with either hand may be explained on the basis of the anatomic evidence that about 10% to 15% of fibers remain uncrossed in the human pyramidal tracts (12). Neurophysiological studies in monkeys have also shown that the majority of neurons in the primary motor area are related to contralateral movements, but 7% to 8% of neurons control ipsilateral hand movements (13, 14). These studies have suggested that an ipsilateral cortical connection might play a subsidiary role in the control of ipsilateral movements (14).

However, these facts do not fully explain why ipsilateral activation is more prominent in the premotor than the primary motor areas and with movements of the left rather than the right hand. Some physiological experiments and human PET studies have revealed bilateral activation of the premotor area during unilateral hand movements (3, 14). This activation was more prominent during complex hand movements than during simple tasks; and in PET studies as well as in the present study, ipsilateral activation was more prominent with the left-handed task. One possible explanation for this asymmetry is that left-handed movements may be more complex for right-handed subjects, so that the ipsilateral motor-related region (including the premotor area) is involved in the control of such movements. Thus, prominent activation of the ipsilateral precentral area in the present study may reflect a role of the premotor area in complex hand movements. Also, several investigators have reported that some patients with a left (but not right) hemispheric lesion showed not only contralateral but also ipsilateral deficits of motor performance, especially in complex tasks (15, 16).

The task adopted in this study augmented postcentral area activation mainly in the contralateral hemisphere. This finding may be explained by the inevitable activation of proprioceptive sensation associated with digital opposition during our designed task. There have been only a few comparable studies on activation of the postcentral area during stimulation of either hand. Li et al (1) reported that activation of the ipsilateral hemisphere was significantly less pronounced during a sensory task than during a motor task. The exact reason for this remains unclear. If the sensory task had been more complex, we speculate that the secondary sensory area might have been activated bilaterally, analogous to the motor changes.

The limitations of our study were as follows. We evaluated significant activation of pixels by comparing the mean signal intensity between rest and task using the *z* score for only several data sets of 10 images each. To distinguish actual activation from motion artifacts, we tested whether the chronological signal intensity changes of such selected pixels were correlated with the input pattern of the task, but this analysis might not have excluded all the artifacts. Another limitation is that we observed activation in only three axial sections with a 5-mm intersection gap. Although we carefully selected these sections to include the sensorimotor area presumed to be involved in hand and finger function, the coverage might not have been completely satisfactory.

Conclusion

Despite these limitations, our results confirmed previous reports that ipsilateral activation is more pronounced during left-sided finger movements than during right-sided movements in right-handers. We also found that ipsilateral activation is more prominent in the premotor area than in the central and postcentral regions. These facts suggest that subregions around the central sulcus as well as both hemispheres may have different roles during motor tasks.

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