

Cortical involvement for action imitation of hand/arm postures versus finger configurations: an fMRI study

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We used fMRI to study the human imitation of hand/arm postures and finger configuration, subjects imitated hand/arm postures in the hand condition, and they imitated finger configurations in the finger condition. Compared with the control condition, only the finger condition showed significant activation in Broca's area and symmetrical activation in the bilateral inferior parietal lobes, while the hand condition showed left lateralised superior parietal

activation pattern. Our findings suggest that Broca's area might be involved more in the imitation of finger configuration than that of hand/arm postures. The result of parietal activation patterns was fully consistent with formerly reported clinical findings, and the relationship between the lesion laterality and the patients' performance of hand/finger action imitation. *NeuroReport* 13:1599-1602
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Key words: Action imitation; Body-centered coordinates; Broca's area; Finger configuration; Object-centered coordinates; Parietal lobes

INTRODUCTION

Since the discovery of the mirror neuron in the monkey brain, neural networks for action imitation have been studied intensively in neurophysiology [1-3]. There have also been many neuroimaging studies concerning human action imitation [4-10]. Iacoboni *et al.* reported Broca's area involvement during finger action imitation tasks using fMRI [4]. Because there had been few imaging studies of human action imitation that focused on the perceiving process including detailed observation and understanding of the presented action and the manipulation of the motor representation, we targeted those points in our former fMRI study [9]. We used a rather complicated and meaningless finger configurations as visual stimuli and found specific parietal involvement for action imitation.

Goldenberg stressed the importance of using meaningless postures as visual stimuli in the neuropsychological study of human action imitation. Using symbolic or commonly-used gestures, we cannot avoid the contamination of semantic elements, whereas meaningless and novel actions are without semantic content [11]. Goldenberg also reported interesting clinical findings that patients with the right brain damage performed poorly in finger configuration imitation than in hand/arm action imitation, and vice versa for patients with left brain damage. A related imaging study showed different parietal involvement in the recognition tasks of hand/arm action and finger configuration [12].

In order to determine the difference in the neural networks for action imitation of hand/arm and those of finger configurations, we studied cerebral activation of healthy subjects during action imitation using fMRI. To the best of our knowledge, this is the first imaging study that directly compares the action imitation of hand and finger gestures with actual execution of subjects' action.

MATERIALS AND METHODS

Subjects: A total of 12 healthy volunteers (six male; mean (\pm s.d.) age 24.8 ± 3.7 ; range 21-34 years) were studied. All subjects were not under any medication, and were free from any history of neurological or psychiatric illness. All gave written informed consent. They were all strongly right-handed on the Edinburgh Handedness Inventory [14]. This study was approved by our local ethical committee.

Tasks: An imitation task with three conditions was used. In all conditions, subjects were instructed to imitate presented postures using their right hand or fingers. The first condition was a control condition (rest) in which the picture shown in Fig. 1a was presented for 2 s followed by a fixation point for 1 s, which was repeated 10 times in one block. Subjects were instructed just to watch it without any motion. In the second (hand) condition, one of six pictures of meaningless hand/arm postures was presented to the

subjects (Fig. 2, top row). There were two patterns of the elbow joint angle, straight or bent, and three patterns of hand shape. Subjects were required to imitate the presented posture using their right arm and hand; stimulus movement were performed with the left hand of the demonstrator, so that subjects imitated as if they were seeing themselves in a mirror. At each trial, as the stimulus disappeared, they were required to go back to the rest position. Stimuli were presented for 2 s each (SOA = 3 s, ISI = 1 s, 10 pictures in random order per block, block duration = 30 s). In the third (finger) condition, one of six pictures of meaningless finger configurations (Fig. 2, bottom row) was presented in the same fashion as in the hand condition. The hand and the finger conditions were repeated four times in a counter-balanced order with the rest condition, as r-H-r-F-r-F-r-H-r-F-r-H-r-F (r: rest, H: hand, F: finger).

The visual stimuli were controlled by a personal computer (PowerBookG3, Apple) using PsyScope PPC software (<http://psyscope.psy.cmu.edu>). They were projected onto a screen by a liquid crystal display projector seen through a mirror set above their eyes as the subjects lay in the MRI machine. The visual angle was $5.3 \times 5.3^\circ$. Subjects responses through all sessions were recorded by a digital video camera for estimating their performance.

fMRI: A conventional 1.5 T MRI scanner was used (Magnex, Shimazu). A total of 100 scans were acquired

with a gradient echo EPI sequence (TR/TE 5000/55 ms, FA 90, FOV 240 mm, matrix 64×64 , 38 axial slices, 5 mm slice thickness without gap). The first four scans were removed to avoid initial instability. Data analysis was performed using SPM 99 (<http://www.fil.ion.ucl.ac.uk>) [15]. All EPI images were acquisition-corrected for sampling bias effects caused by different times relative to the haemodynamic response for each subject. The images were realigned to correct for interscan movement and spatially normalized with MNI template for group analysis. The images were smoothed with an isotropic Gaussian kernel of 8 mm FWHM. Significance was assessed using the delayed box-car reference convolved with a haemodynamic response function. Linear contrasts between different conditions gave the results as activated areas by creating a spatially distributed map of the *t*-statistic (SPM(*t*)). Activation was thresholded at $p < 0.001$, corrected for multiple comparisons for each subject. The acquired four contrast maps, hand *vs* rest, finger *vs* rest, hand *vs* finger and finger *vs* hand, of each subject were jointly used for group analysis based on the random effects analysis [16]. Calculated coordinates of activation peaks were converted from the MNI brain-based system into the Talairach brain system using a non-linear transformation method (<http://www.mrc-cbu.cam.ac.uk/Imaging/mnispace.html>) [17].

RESULTS

All subjects' responses recorded by the digital video camera were evaluated by a naive observer who judged each response in a multiple choice fashion; the observer selected one picture out of all stimuli pictures on each subjects' response. All subjects responded correctly on all trials.

Activation peaks that belong to Broca's area or the parietal lobes are shown in Table 1; they were significant at $p < 0.001$ for voxel level (uncorrected) and $p < 0.05$ for cluster level (corrected). Compared with the control condition, in the hand condition a significant activation was detected in the bilateral precentral and postcentral gyri, inferior parietal gyri, and the cerebellum, and in the right occipital lobe, the thalamus and the putamen. In the finger condition, significant activation was detected in various areas including the bilateral pre/postcentral gyri and the inferior frontal gyrus (BA 44).

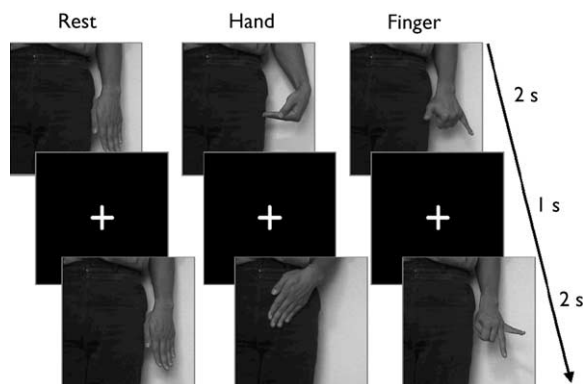


Fig. 1. The experimental design for the three conditions.

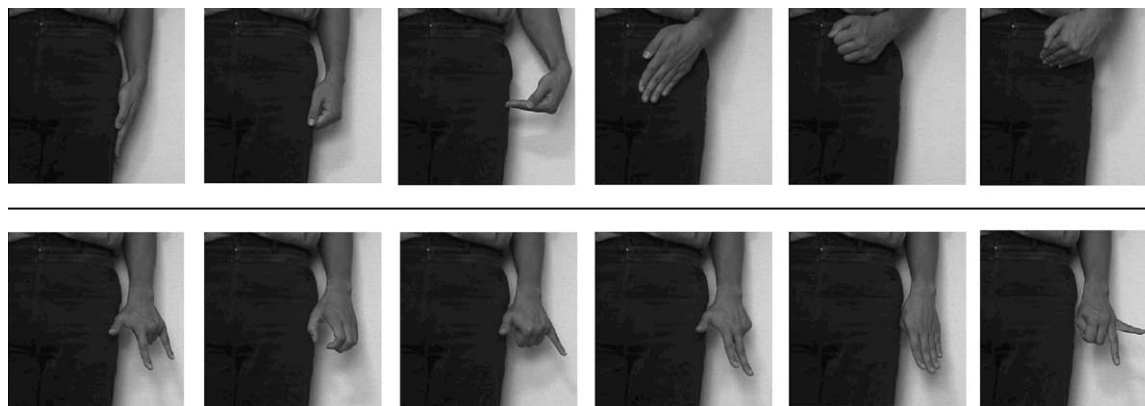


Fig. 2. Visual stimuli. Hand/arm postures (top row) and Finger configuration (bottom row).

Table 1. Regions of statistically significant activation ($p < 0.001$ at voxel level, corrected for multiple comparison) in the inferior frontal lobe, the inferior parietal and the superior parietal lobules.

	Hand	Finger	Hand vs finger	Finger vs hand
Inferior frontal lobe (BA 44)		L, 5.14; -51 5 29 L, 4.70; -53 10 12		L, 4.15; -44 9 25 L, 3.80; -55 14 16
Inferior parietal lobe (BA 40)		L, 4.91; -36 -46 48		L, 3.95; -50 29 47 L, 4.74; -48 33 37
Superior parietal lobe (BA 7)	L, 4.70; -14 -48 59 R, 4.36; 20 -66 44	L, 4.56; -20 -66 44	L, 4.68; -10 -43 65 R, 4.28; 6 -47 61	R, 4.79; 22 -58 47

L (left) or R (right), Z score and XYZ coordinates are shown.

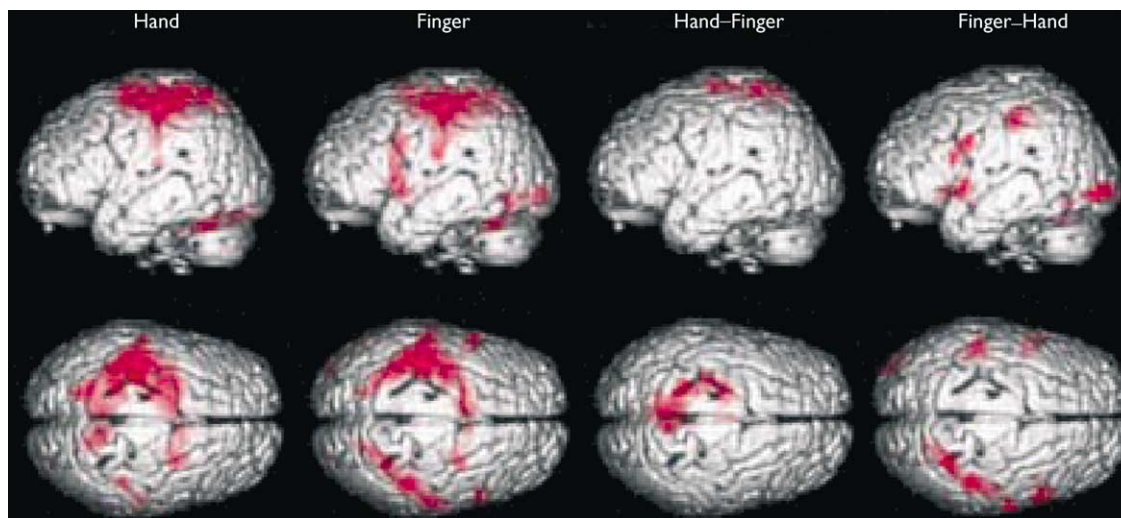


Fig. 3. The results of the random effects analysis on 12 subjects shown on the T1-weighted anatomical template. Hand vs rest, finger vs rest, hand vs finger, and finger vs hand respectively from left to right. The statistical threshold is voxel level $p < 0.001$ uncorrected without multiple comparison for display reasons.

When the hand condition is compared with the finger condition, significant activation was detected in the bilateral superior parietal lobule and the bilateral pre/post central gyri. The finger condition compared with the hand condition revealed significant activation in the left inferior frontal area (BA 44, 47), the bilateral inferior parietal lobules and the right superior parietal lobule (Fig. 3).

DISCUSSION

Broca's area: The present study clearly showed differential activation in the left inferior frontal lobe; significant activation was observed in Broca's area in the finger condition compared with the rest condition as well as the hand condition. Broca's area might be more important in imitating finger actions than that of hand/arm actions. Since the first report of mirror neurons by Rizzolatti and colleagues, many studies indicated involvement of Broca's area in human action imitation or observation [4–6,18]. Broca's area activation was not reported in some imaging studies in which task conditions include recognition of hand/finger postures or simple observation of other's grasping action [10,18]. In Buccino's fMRI study on the observation of other's action, Broca's area activation was detected when subjects observed hand actions that actually manipulated objects but not when

subjects observed pantomimes of object manipulation [19]. In the PET study by Hermsdorfer *et al.* neither task conditions of the recognition for hand/arm action *vs* that for finger configuration showed any Broca's area activation. In our study subjects actually performed imitating action and the finger condition showed Broca's area activation. We suppose that Broca's area might be involved more in the process of execution than in the process of recognition in human action imitation.

Parietal lobe: Previous neuropsychological studies suggested that there might be differences in the neural networks involved in hand gesture imitation and that for finger configurations [11–13]. Goldenberg reported that patients with right brain damage performed more poorly in the imitating task of finger configurations than in the task for hand gesture imitation, and *vice versa* for patients with left brain damage [12]. He proposed that the imitations of hand and finger gestures are subserved by at least partially different mechanisms that are differently distributed across the two hemispheres: the right hemisphere being more involved in the process of visuospatial cognition of presented gestures, while the left hemisphere is more involved in the process of referring to knowledge of one's

own body as well as in the process of preparing and executing one's own action [11,12]. In the results of their PET study for the recognition of other's action, they reported that the recognition of finger configurations showed more symmetrical activation in the parietal area, while that of hand postures showed left lateralised parietal activation, which is consistent with their clinical observations [10]. In the present study, the activated area in the parietal lobe was located mainly in the left hemisphere in the hand condition and bilaterally in the finger condition, a result that is consistent with Hermsdorfer's PET study. It is also consistent with the neuropsychological findings of Goldenberg *et al.* [11], who reported that the patients with left brain damage performed more poorly in hand than finger action imitation, whereas the patients with right brain damage performed more poorly in the task of finger action imitation. He proposed that hand action imitation requiring knowledge of the structure of the human body as one transforms the perceived other's action into one's own action might involve more the left hemisphere. By contrast, finger configuration imitation requiring more detailed observation of presented stimuli in order to understand the spatial relations among the fingers is lateralised more to the right hemisphere. Choi *et al.* reported not inferior but superior parietal activation in their fMRI study in which subjects performed pantomimes for tool use [20]. Their result is similar to the Hand condition of our study, due possibly to the fact that most of the actions using tools consist of not finger but hand/arm actions.

In light of these results, we propose that different cortical networks are involved in hand/arm posture *vs* finger configuration imitation; specifically, a modality difference of feedback (visual *vs* somatosensory) during development. That is, one can see one's own fingers during imitation of another's finger configuration, but one cannot see one's own body movement during imitating hand/arm postures without using a mirror. Thus visual feedback is more important for finger action imitation, while somatosensory feedback plays a main role for imitating hand/arm posture. It may therefore be that through the developmental process, different cortical networks come to be involved in those two types of action imitation. With regard to the coordinates of the mental representation, hand/arm posture is related more to self-centered coordinates; the arms and hands might be represented using spatial relations referred to the body. Contrarily, object-centered coordinates might be more important for the representation of finger configurations, the mutual spatial relations among the fingers being more important than their relation to the body. Interestingly, patients with visual constructional disturbance, known as a defect in copying geometric figures caused by right hemisphere damage, are known to show defect in imitating finger configurations [21,22].

CONCLUSION

The difference in the cortical involvement during imitation of finger and hand/arm actions was studied using fMRI. Broca's area activation was detected in finger action imitation but not in hand/arm action imitation. Broca's area is believed to play an important role in action imitation, and our findings suggest that it is more involved in finger action imitation than that of hand/arm action. We conclude that the difference in the type of sensory feedback during imitation of finger and hand/arm movements, visual for the former and somatosensory for the latter, might be the reason for the different cortical involvement in those two tasks. There was also an interesting findings in the parietal activation pattern; the finger condition showed bilateral parietal activation, while the hand condition showed a more left lateralised one. This pattern is consistent with neuropsychological findings on patients with unilateral brain damage, as well as our former fMRI study on finger action imitation.

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