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RESEARCH NOTE

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# The role of the left somatosensory cortex in human hand movement

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**Abstract** Hemispheric dominance for motor control in the human brain is still unclear. Here we propose asymmetric sensorimotor integration during human hand movements. We investigated the dexterity of hand movements and related sensory functions in four right-handed patients with cerebrovascular lesions in the postcentral gyrus. To clarify the distributions of cortical damage, semiquantitative analysis of regional cerebral blood flow (rCBF) was performed using single photon emission computed tomography (SPECT), and a three-dimensional surface display was generated from SPECT. Scores on motor and sensory tasks and rCBF values in the patients were compared with those in control subjects. All patients presented with asymmetric clumsiness of complex finger movements, in association with impairments of combined sensations such as stereognosis. These findings were indicative of a disorder of sensory information processing necessary to guide the movements. Two patients with left hemispheric damage showed bilateral clumsy hands, predominating on the right side, while the other two patients with right hemispheric damage showed only a left clumsy hand. In agreement with asymmetric clumsiness, measurement of rCBF along with a three-dimensional surface display revealed cortical hypoperfused areas, mainly in the perirolandic cortices, comprising the primary motor and somatosensory cortices. Perirolandic cortical hypoperfusion was bilateral in the two patients with bilateral clumsy hands, but only on the right side in the other two patients with left clumsy hands. These results suggest a dominant role of the left somatosensory cortex in sensorimotor integration for complex finger movements of humans.

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## Introduction

Hemispheric asymmetry of human brain function has been explored mainly in the field of language and rarely in sensory and motor systems. Initially, Liepmann (1920) proposed that patients with left hemispheric damage were more likely to demonstrate bilateral deficits of hand movements than patients with right hemispheric damage. Although Liepmann attributed the clumsiness of both hands, termed limb-kinetic apraxia, to impairment of stored memory for movements, his hypothesis lacked an anatomical and physiological basis. Later studies supported this hypothesis, but conflicting observations were also made, depending on the tasks used to ascertain the deficit (Howes and Boller 1975; Haaland et al. 1977). After that, less attention has been paid to hemispheric dominance for motor control in the human brain (Kim et al. 1993). With the advent of neuroimaging, recent studies on regional cerebral blood flow (rCBF) have demonstrated that various cortical areas, such as the premotor cortex and superior parietal cortex (SP), and the supplementary motor area, as well as the sensorimotor cortex (SM), increase in rCBF during human hand movements (Seitz et al. 1990; Deiber et al. 1991; Remy et al. 1994). These results indicated the role of these cortical areas in initiating or programming of hand movements. During unilateral hand movements, association cortices are bilaterally activated, but activation of SM is quite asymmetric. Although rCBF changes in SM are mainly related to contralateral hand movements, ipsilateral hand movements can also activate SM. Thus, the SM may contribute not only to contralateral hand movements but also to ipsilateral hand movements (Kim et al. 1993; Remy et al. 1994). However, these rCBF studies have not yet resolved the validity of Liepmann's hypothesis.

The dexterity of hand movements is usually impaired by movement disorders such as paresis or ataxia. Over

recent years, another type of clumpsy hand has been postulated to arise from impairment of higher cortical function (Yamadori 1982). The nature of this clumsiness, manifested by disturbances of complex finger movements, resembles that of Liepmann's limb-kinetic apraxia. Although the interpretation of this clumsy hand still remains controversial, several authors have clearly reported its symptoms, termed limb-kinetic appraxia, afferent apraxia, palpatory apraxia, or astereognosis-clumsy hand, and suggested a disorder of sensorimotor integration involving the SM (Yamadori 1982; Jeannerod et al. 1984; Motomura et al. 1990; Okuda et al. 1992). Our cases with a neurodegenerative disease suggested that sensorimotor integration for complex finger movements might be asymmetric (Okuda et al. 1992). We have encountered this type of clumsy hand in four patients with cerebrovascular lesions in either the left postcentral gyrus or the right one. In the present study, we attempted to clarify hemispheric dominance for sensorimotor integration by comparing the nature of clumsiness and rCBF between patients with left or right hemispheric damage.

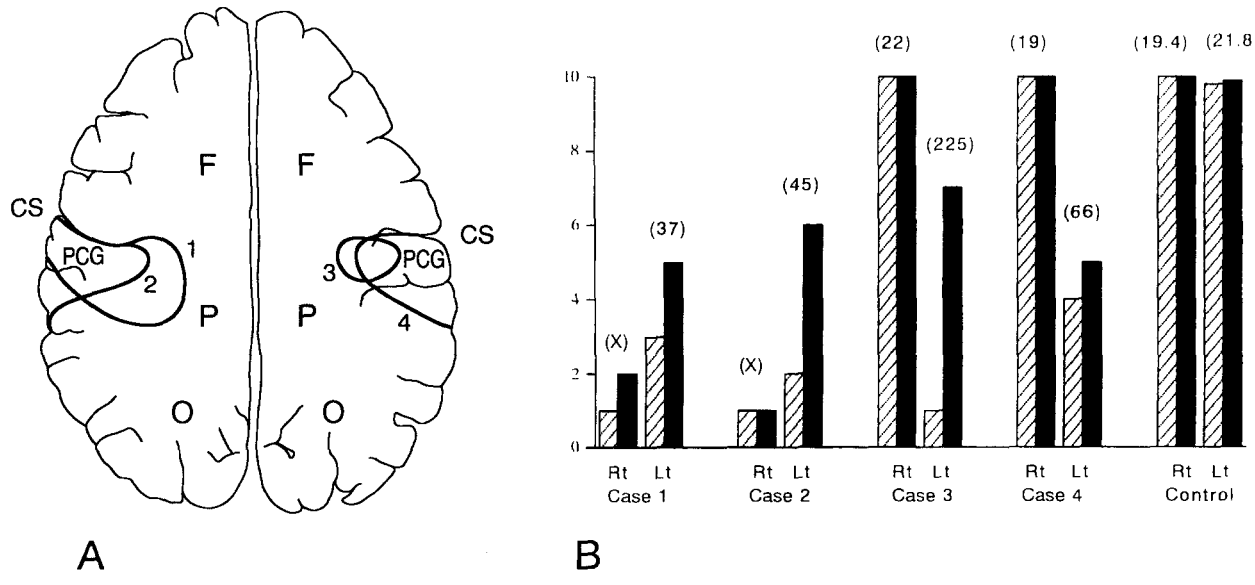
## Materials and methods

We studied four right-handed patients with clumpsy hands following cerebrovascular diseases (cases 1 and 2 with left hemispheric damage, L group; cases 3 and 4 with right hemispheric damage, R group). The investigations were performed 6–12 months after the onset of stroke. The patients, aged 57–66 years, had no impairment of mental functions such as dementia or aphasia and had no movement disorders such as paresis or ataxia during the present study. They suffered from cerebral hemorrhage (case 1) or infarction (cases 2–4). Magnetic resonance imaging using MAGNETOM 05 (Siemens; 0.5 T) with 256×256 matrix (1 mm pixel size, 2 mm spatial resolution) showed their lesions centered upon the postcentral gyrus. Case 1 had the largest lesion that partly involved the supramarginal gyrus and spread to the centrum semiovale without involvement of the frontoparietal operculum. Cases 2 and 4 had comparable distributions of lesions, extending from the postcentral gyrus to the supramarginal gyrus in each hemisphere. Case 3 had the smallest lesion confined to the postcentral gyrus and neighboring white matter. No lesions were found in the frontal lobe or infratentorial region (Fig. 1A). To assess the dexterity of these patients, motor and sensory tasks were used. Ten right-handed subjects without neurological deficits (mean age±SD, 65.8±9.6 years) performed the tasks and served as controls. All patients and control subjects completed the Edinburgh Inventory for handedness (Oldfield 1971). Measurement of rCBF in the patients was performed over the 8 months after onset. The other 11 healthy subjects (mean age±SD, 67.6±10.6 years) underwent rCBF measurement as controls. Informed consent was obtained from the control subjects as well as the patients before participation in this study. This experiment was carried out from August 1992 to June 1994.

### Motor task

All subjects were required to perform complex finger movements in a right-to-left order. These tasks consisted of serial finger tapping (touching the thumb with the tips of the other fingers), picking up a coin, imitating a finger pattern of a fox, putting on gloves, and inserting ten pegs into a pegboard. In each task, the following

**Fig. 1A, B** Lesion sites and scores of tasks. **A** Schematic representation of the patient lesions on a horizontal section (*z*-value of Talairach coordinates, 54 mm). The *number* represents the lesion of each case (cases 1–4). **B** Scores on motor (*hatched bars*) and sensory (*solid bars*) tasks in patients and controls. The *number in parentheses* represents the time to complete peg insertion. Mean scores ±SD of motor and sensory tasks in controls are 10±0 and 10±0, respectively, for the right hand, and 9.8±0.4 and 9.9±0.3, respectively, for the left hand. Mean values ±SD of peg insertion time in controls are 19.4±2.1 s and 21.8±2.2 s for the right and left hands, respectively. The scores on motor and sensory tasks performed with each hand are significantly lower in the L group than in the controls ($P$=0.001 and $P$=0.001, respectively, for the right hand; $P$=0.01 and $P$=0.005, respectively, for the left hand). The scores on motor and sensory tasks performed with the left hand, but not the right hand, are significantly lower in the R group than in the controls ($P$=0.01 and $P$=0.005, respectively). Both the L and R groups demonstrated significantly prolonged peg insertion time with the left hand, compared with the controls ($P$=0.03 and $P$=0.03, respectively). Peg insertion with the right hand was impossible in the L group (*cross*), but was performed skillfully in the R group (*CS* central sulcus; *F* frontal lobe, *Lt* left hand, *P* parietal lobe, *PCG* postcentral gyrus, *O* occipital lobe. *Rt* right hand)



graded accuracy score was used: accurate (2), possible but clumsy (1), and impossible (0). The maximum score on motor tasks was 10. The time required to complete peg insertion was recorded.

### Sensory task

Combined sensations were examined by having subjects perform sensory tasks without sight in a right-to-left order. The subjects were required to identify familiar objects by handling (spoon, comb, scissors, can opener) and numbers written on their hand (1, 3, 9). These abilities for stereognosis and graphesthesia were scored according to the number of correctly identified objects and figures. The subjects next discriminated between the sizes of two balls, the weights of two metals (5 g, 10 g), and the directions of passive finger movements (extension-flexion of the middle finger). Discrimination tasks were scored as correct (1) or incorrect (0). The maximum score on sensory tasks was 10. Motor and sensory tasks were evaluated by a neuropsychologist (H. Tanaka) who did not know about the patients' lesions and data of rCBF.

### Cerebral blood flow measurement

Measurement of rCBF was performed using single photon emission computed tomography (SPECT) with *N*-isopropyl-*p*[$^{123}$I]iodoamphetamine ($^{123}$I-IMP). Subjects were injected with 111 MBq of $^{123}$I-IMP into the antecubital vein while sitting with eyes open in a quiet room. Thirty minutes after the injection, SPECT scanning was started. Subjects lay supine on the Starcam 400 AC/T, a single-head rotating gamma camera SPECT system equipped with a low-energy, general purpose collimator. The data acquisition parameters were 64×64 matrix using ×1.6 zoom (3.75 mm pixel size), 64 views, 30 s per view, i.e., 35 min scan time. Transaxial tomographic slices, 3.75 mm thick, were reconstructed using a Hanning prefilter with 0.8 cycles/cm cut-off frequency and a ramp back-projection filter. Attenuation correction assumed a uniform linear attenuation coefficient (0.064 $cm^{-1}$). Horizontal slices (parallel to the anterior commissure-posterior commissure line), 7.5 mm thick, were obtained by interpolation. The resolution of the system in water was 12 mm in the center of the field of view.

Semiquantitative rCBF value was computed as follows. $^{123}$I-IMP uptake in individual brain area was quantified by visually placing regular 4×4 pixel regions of interest (ROIs), corresponding to 15×15×7.5 $mm^3$ brain volumes on 18 positions standardized by inspection with reference to a stereotactic brain atlas (Talairach and Tournoux 1988). These consisted of the following number of ROIs on each brain region: prefrontal cortex (PF) 3, SM 2, SP 2, and occipital cortex 2, all bilaterally. Uptake in each region was defined as the mean count per pixel in that region. As previously reported (Kawabata et al. 1991), IMP uptake in the occipital cortex is highest among the cortical regions. Thus, the ratio of uptake in each region to the mean uptake of bilateral occipital regions was calculated.

To analyze cortical perfusion defects, a three-dimensional (3D) surface display was constructed from a series of brain SPECT images in two stages using Starcam system computer software (Tachibana et al. 1993; Okuda et al. 1994). First, a distance-shaded surface image was generated from distance information, computed from measurement of the perpendicular distance from the viewing plane to the brain surface. Brain surface boundaries were detected by a simple count threshold of 55% expressed as a percentage of global maximum count in brain SPECT images. We adopted the threshold value, because 11 control subjects showed no perfusion defect in any cortical areas at 55% threshold value. Second, a 3D surface display was made by adding gradient shading to distance-shaded surface images, giving the impression of illumination by a beam of parallel light rays. Gradient shading was dependent on the local angle of the brain surface relative to the position of the light source and viewing plane.

### Statistical analysis

Statistical analysis of the tasks and rCBF was performed using the Kruskal-Wallis test to compare the scores among the three groups (L group, R group, and control group), and using the Mann-Whitney *U*-test to compare scores between the two groups. The criterion of statistical significance was $P<0.05$.

## Results

### Motor and sensory tasks

The results of motor and sensory tasks are shown in Fig. 1B. Among the three groups, a significant main effect of the groups for scores on motor and sensory tasks was found (Kruskal-Wallis test, $H=13.0$ and $H=12.9$, $P=0.002$ and $P=0.002$, respectively, for the right hand; $H=9.84$ and $H=10.9$, $P=0.007$ and $P=0.004$, respectively, for the left hand). As compared to scores of the controls, the patients in the L group showed significantly lower scores on motor and sensory tasks with each hand (Mann-Whitney *U*-test, $Z=-3.32$ and $Z=-3.30$, $P=0.001$ and $P=0.001$, respectively, for the right hand; $Z=-2.56$, and $Z=-2.82$, $P=0.01$ and $P=0.005$, respectively, for the

**Table 1** Semiquantitative rCBF values in patients and controls. Semiquantitative rCBF values are expressed as the ratio to the mean uptake of bilateral occipital regions (*rCBF* cerebral blood flow. *L* left hemisphere. *R* right hemisphere)

| | Prefrontal | | Sensorimotor | | Superior parietal | | Occipital | |
|---|---|---|---|---|---|---|---|---|
| | L | R | L | R | L | R | L | R |
| Case 1 | 0.634 | 0.579 | 0.330* | 0.554* | 0.681* | 0.715* | 1.008 | 0.992 |
| Case 2 | 0.743 | 0.773 | 0.479* | 0.638* | 0.805* | 0.771* | 1.044 | 0.956 |
| Case 3 | 0.852 | 0.750 | 0.770 | 0.656** | 0.794 | 0.719** | 0.989 | 1.011 |
| Case 4 | 0.801 | 0.875 | 0.824 | 0.473** | 0.870 | 0.733** | 1.048 | 0.952 |
| Controls | | | | | | | | |
| Mean | 0.894 | 0.872 | 0.886 | 0.854 | 0.920 | 0.897 | 1.016 | 0.984 |
| SD | 0.073 | 0.061 | 0.075 | 0.063 | 0.054 | 0.051 | 0.041 | 0.041 |

* Mean rank of rCBF value in cases 1 and 2 is significantly decreased, compared with controls, by nonparametric analysis (Mann-Whitney *U*-test, $P<0.05$)

** Mean rank of rCBF value in cases 3 and 4 is significantly decreased, compared with controls, by nonparametric analysis (Mann-Whitney *U*-test, $P<0.05$)

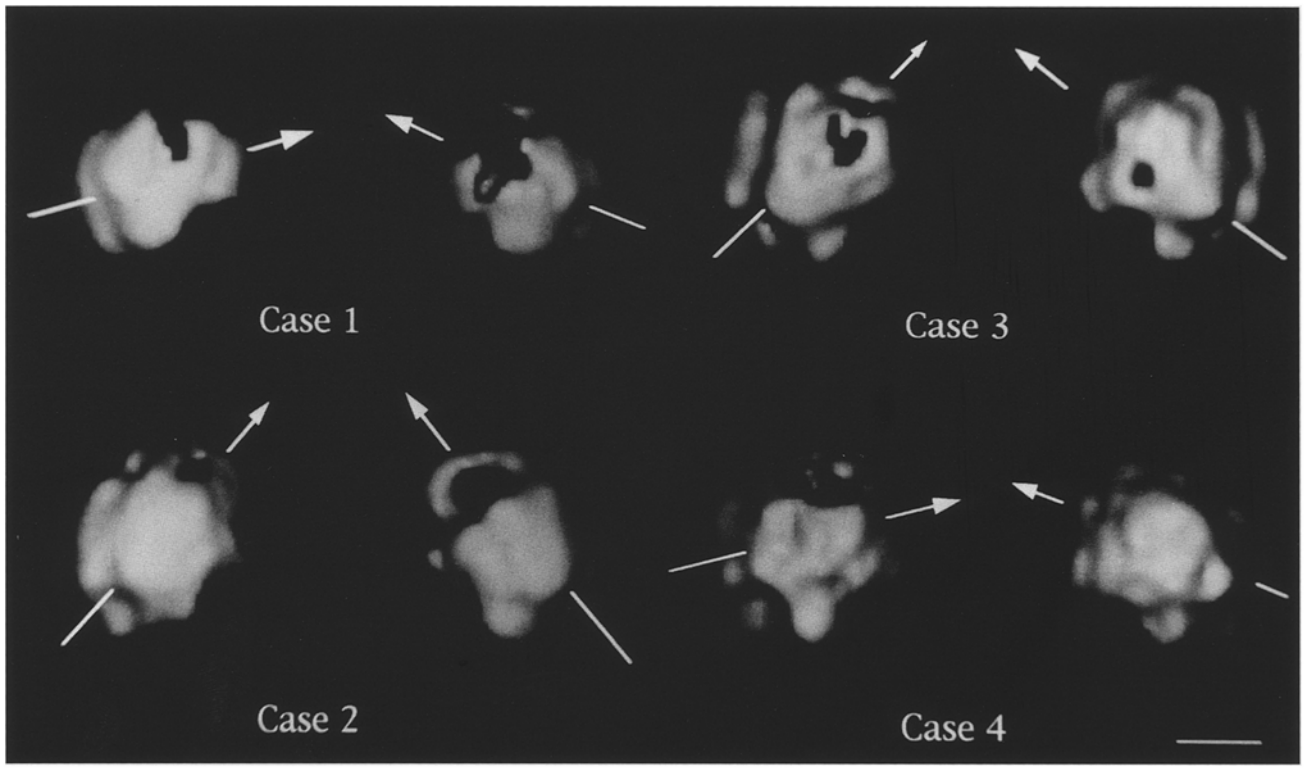



**Fig. 2** Three-dimensional surface displays demonstrating cerebral blood flow of four patients. These images were generated from single photon emission computed tomography (SPECT) early images with *N*-isopropyl-*p* [$^{123}$I] iodoamphetamine ($^{123}$I-IMP) as a tracer, and the threshold value to define the surface boundary was 55% of the global maximum counts in SPECT images. For each case, images on the left represent the right posterior oblique view, and images on the *right* represent the left posterior oblique view. *Arrows* indicate caudorostral directions of midlines in the anterior commissure-posterior commissure (AC-PC) plane. In cases 1 and 2, cerebral blood flow was decreased in the bilateral perirolandic cortices, predominating on the left side. In addition, left cortical hypoperfusion in case 1 extended to the frontal cortex. In case 3, cerebral blood flow was decreased in the right perirolandic and posterior parietal cortices and the left posterior temporal cortex. In case 4, cortical hypoperfusion was confined to the right perirolandic cortex. *Scale bar* 100 mm

left hand), while the patients in the R group showed significantly lower scores on motor and sensory tasks with the left hand only ($Z$=–2.56 and $Z$=–2.82, $P$=0.01 and $P$=0.005, respectively). The peg insertion time with the left hand was significantly longer in both the L and R groups ($Z$=–2.17 and $Z$=–2.17, $P$=0.03 and $P$=0.03, respectively), but that with the right hand in the R group was not prolonged ($Z$=–0.77, $P$=0.44), compared with that of the controls. Two patients in the L group could not complete peg insertion with the right hand. On the sensory tasks, identification of objects (stereognosis) was consistently impaired in all patients.

### Cerebral blood flow

Table 1 illustrates the ratio of $^{123}$-I-IMP uptake in each region. In all subjects, $^{123}$I-IMP uptake was greatest in the occipital region. Among the three groups, a significant main effect was found in bilateral SM and SP (Kruskal-Wallis test, $H$=6.77 and $H$=7.02, $P$=0.034 and $P$=0.030, respectively, for the left hemisphere, $H$=8.25 and $H$=8.25, $P$=0.016 and $P$=0.016, respectively, for the right hemisphere). A main effect for rCBF in PF in each hemisphere was not significant among the groups. As compared with rCBF of the controls, the L group showed the significantly lower ratio in bilateral SM and SP (Mann-Whitney $U$-test, $Z$=–2.17, $P$=0.030, for each region). The R group showed a significantly lower ratio in right SM and SP ($Z$=–2.17, $P$=0.030, for each region), with normal ratio in left SM and SP ($Z$=–1.58 and $Z$=–1.78, $P$=0.114 and $P$=0.076, respectively). In all patients, a 3D surface display revealed cortical hypoperfusion mainly in the perirolandic area, comprising the primary motor and somatosensory cortices (Fig. 2). In the L group, perirolandic cortical hypoperfusion was bilateral, predominating on the left side. In the R group, perirolandic cortical hypoperfusion was only on the right side.

## Discussion

The nature of the affected hand movements in our patients, comprising clumsiness of complex finger movements and astereognosis, suggests a disorder of sensory information processing necessary to guide the movements (Yamadori 1982; Jeannerod et al. 1984; Motomura et al. 1990). Based on results of the present study, the role of the human somatosensory cortex in conveying highly organized sensory information to the motor cortex does not seem symmetric. Damage to the left somatosen-

sory cortex induced bilateral clumsy hands, while damage to the right somatosensory cortex affected the left hand only. Semiquantitative analysis of rCBF revealed that a decrease in rCBF in SM and SP was bilateral in the L group but unilateral in the R group. Cortical hypoperfusion in the perirolandic area (SM) contralateral to the lesion, presumably due to a remote effect or diaschisis (Mori et al. 1994; Okuda et al. 1994), could account for the ipsilateral clumsiness. In contrast, perirolandic cortical hypoperfusion was found on only the right side following damage to the right somatosensory cortex. A decrease in rCBF in SP may suggest a role for SP in movement selection (Deiber et al. 1991) or a contribution of intraparietal connections to sensory information transfer (Iwamura et al. 1994). The sizes of lesions and associated cortical hypoperfusion were larger in cases 1 and 2 than in case 3. This raises the possibility that the laterality of clumsy hands after brain damage depends on the size and not on the side of lesions. However, cases 2 and 4 had comparable lesion sizes, whereas cortical hypoperfusion was bilateral in case 2 but unilateral in case 4. Furthermore, 3D images showed that cortical hypoperfusion contralateral to the lesion was confined to the perirolandic areas in cases 1 and 2, suggesting a functional significance of the interhemispheric transfer from the left to the right perirolandic cortex. Thus we suppose that the left somatosensory cortex plays a dominant role in sensorimotor integration for executing human hand movements.

Clinical reports of the clumsy hand due to impaired sensorimotor integration are very rare. Why does the clumsy hand occur in only a small proportion of patients with brain damage? The most plausible explanation is that associated movement disorders such as paresis may mask the deficit. Furthermore, clinical features of the disturbances have been poorly understood. The clumsy hand has been analyzed mainly in Japan (Yamadori 1982; Hikosaka et al. 1985; Motomura et al. 1990; Okuda et al. 1992). In these studies, damage to each hemisphere consistently produced the contralateral clumsy hand, but the effect of left hemispheric damage on the left hand has been rarely described. Sensorimotor deficits ipsilateral to the lesion vary from case to case (Jones et al. 1989). Individual variations of compensatory brain functions may, at least in part, account for such inconsistency (Okuda et al. 1990; Weiller et al. 1993).

In conjunction with the motor cortex, the primary somatosensory cortex contributes to purposive hand movements (Gemba and Sasaki 1984; Sasaki and Gemba 1984). To execute complex finger movements or manipulate objects, highly organized sensations, including a kinesthetic sense and stereognosis, are needed (Hikosaka et al. 1985). There are intrinsic corticocortical connections within the postcentral gyrus, extending from area 3b to areas 1 and 2, which work as hierarchical processing from the primary sensory receiving stage to the more associative, integrative stages (Iwamura et al. 1993). Such hierarchical processing of sensory information occurs not only within one hemisphere but also between both hemispheres via interhemispheric connections. A substantial number of neurons with receptive fields on the bilateral hands are present in the monkey postcentral somatosensory cortex, depending on callosal connections (Iwamura et al. 1994). This indicates that interhemispheric transfer occurs at higher levels of hierarchical processing, where integration of signals from two hands can take place. Undoubtedly, the interhemispheric interaction is symmetric in monkeys, but it does not seem to be the case in humans (Kim et al. 1993).

During human finger movements, movement-related potentials arise from bilateral SM finger areas (Ikeda et al. 1992), and a larger increase in rCBF occurs in the hand area of ipsilateral SM during complex finger movements than during simple finger movements (Shibasaki et al. 1993). These correlative results suggest a contribution of bilateral SM to complex finger movements of humans. Regarding handedness in humans, an increase in rCBF in the ipsilateral motor area during right or left hand movements is not symmetric in right-handed subjects (Kawashima et al. 1993). However, these experimental studies have not yet determined whether or not hemispheric dominance for sensorimotor integration exists. Here we would like to propose the laterality of highly organized sensory information processing in humans. The point of view of asymmetric sensorimotor integration is necessary for the design of clinical and experimental studies that explore the mechanisms of human hand movements.

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