

Quantitative Assessment of Mirror Movements After Stroke

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Background and Purpose—Mirror movements (MM) are involuntary synchronous movements of one limb during voluntary unilateral movements of the opposite limb. We measured MM in stroke and control subjects and evaluated whether MM after stroke are related to motor function.

Methods—Twenty-three patients and 16 control subjects were studied. A computerized dynamometer was used during two squeezing tasks to measure intended movements from the active hand as well as MM from the opposite hand. Motor deficits were measured with the arm motor component of the Fugl-Meyer scale.

Results—During paretic hand squeezing, MM in the unaffected hand were detected in 70% (repetitive squeeze) to 78% (sustained squeeze) of stroke patients. For both tasks, this was significantly ($P < 0.05$) greater than the incidence of MM in the paretic hand or in either hand of control subjects (17% to 44%), except when compared with the incidence of MM in the dominant hand of control subjects (56%; $P = 0.17$). The incidence of MM in the paretic hand was not significantly different from that seen in either hand of control subjects. Patients with MM in the unaffected hand had significantly greater motor deficit than patients without MM. Patients with MM in the paretic hand had significantly better motor function than patients without MM.

Conclusions—Simultaneously recording motor performances of both hands provides precise information to characterize MM. MM in the unaffected hand and in the paretic hand are associated with different degrees of motor deficit after stroke. Evaluation of MM may be useful for studying mechanisms of stroke recovery. (*Stroke*. 1998;29:1182-1187.)

Key Words: dynamometer, computerized ■ mirror movements ■ motor activity ■ stroke, outcome

Mirror movements are involuntary synchronous movements of one limb during intended movements of contralateral homologous body parts. MM involving distal hand function are normally seen during early childhood and usually disappear during the first decade of life.¹ They may also be seen in healthy adults, particularly in the context of fatigue and extreme effort.²⁻⁴

The persistence of distal upper extremity MM in adults has been associated with a number of pathological conditions, including hereditary disorders,⁵ neuropsychiatric abnormalities,⁶ and perinatal cerebral damage.^{7,8} In some cases, such as Klippel-Feil, MM may be associated with agenesis of the corpus callosum or absence of pyramidal decussation. Few studies have examined MM associated with hemiparesis due to adult-onset stroke. In these studies MM were found in either hand and were observed in 0% to 84% of control subjects and 40% to 100% of stroke patients.^{2,9,10} Measurement of MM has relied on verbal description,³ EMG,⁹⁻¹¹ or ordinal rating scales.¹²⁻¹⁴ To date, the relationship of MM to the degree of neurological deficit has not been carefully examined.

Studies in animals and humans suggest that altered activity of the unaffected hemisphere relates to recovery of function after unilateral brain injury.¹⁵⁻¹⁸ Studies of hemiplegic cerebral palsy^{7,14} and unilateral adult stroke^{15,19} have further suggested that MM may reflect the altered activity in the unaffected hemisphere. A better understanding of the relationship between MM and motor recovery after stroke may therefore provide insights into restorative mechanisms of the motor system. This information could be useful in the development of therapeutic interventions for hemiparetic stroke patients.^{20,21}

In the present study we tested the hypothesis of whether MM are related to the severity of motor deficit after stroke. To measure the incidence and the magnitude of MM, we used a computer-interfaced digital dynamometer. This device records the actual motor performance, has excellent intrarater and interrater reliability, and permits quantitative measurements along a continuous, linear, high-resolution scale. A previous study, evaluating intended motor performances in the same group of stroke subjects as those reported here,

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Selected Abbreviations and Acronyms

EMG = electromyography, electromyographic
FM = Fugl-Meyer arm motor
MM = mirror movements
NIH = National Institutes of Health

found that dynamometer measures of motor performance correlated strongly with measures of standard neurological scales.²² The degree of motor deficit, assessed with the Fugl-Meyer arm motor (FM) score, is compared between those stroke patients with and those without MM of either hand.

Subjects and Methods

Subjects

Stroke subjects were identified from the Stroke Service of Massachusetts General Hospital and Spaulding Rehabilitation Hospital. Stroke subtype was identified by CT or MRI images of the brain. Inclusion criteria for stroke subjects were unilateral motor deficit that included the upper extremity after a unilateral infarct. Exclusion criteria were limiting deficits in language or attention; these were defined by any points on NIH Stroke Scale questions 1a, 1b, or 1c; 2 or more points on question 9; or 3 or more points on question 11.²³ Approximately one in three stroke patients was eligible for this study according to these criteria.

Control subjects were recruited through local advertisements. All control subjects were healthy volunteers with a normal neurological examination, no active neurological or psychiatric disease, and no history of stroke. All subjects gave informed consent. Handedness was evaluated with the use of the Edinburgh Inventory.²⁴

Data Acquisition

The components and settings for the dynamometer have been described in detail previously.²² In each hand, subjects held a force transducer that converted the force of squeezing into an electrical signal, which was then amplified, converted to a digital signal, and carried to a laptop computer running strip-chart-emulating software (MacLab, AD Instruments). Two channels simultaneously received, displayed, and stored intended and mirroring motor performances. The system was regularly calibrated with standard test weights (McMaster-Carr) to linearly convert the voltage output of the dynamometer to kilograms. The values measured by the dynamometer are referred to as force but reported in kilograms, reflecting this method of calibration; actual force in newtons is obtained by multiplying reported kilograms values by 9.8 m/s². The dynamometer was approved for experimental use by the Bioengineering Department of Massachusetts General Hospital. The study was approved by the Human Studies Committee of Spaulding Rehabilitation Hospital and Massachusetts General Hospital.

During clinical evaluation, an FM score (motor component for upper extremity) was obtained for each subject (range, 0 to 66; normal score=66).²⁵ The FM scale is a standardized, reliable scale used to assess the neurological status of hemiplegic stroke patients.²⁶

Dynamometer measurements were obtained after clinical evaluation. Data acquisition and analysis methods are as described previously.²² With the subject in standard position, either sitting or lying in bed with head elevated to 45°, a dynamometer handle was placed into each hand. No attention was given to the hand intended to be at rest; a dynamometer handle was casually placed in this hand without comment. Both arms were placed onto a table with elbows flexed to 90° and wrists in neutral position. If either arm moved off the table, data acquisition was repeated after the patient was instructed to keep arms as initially placed. Standard verbal instructions were used to direct the hand intended to be active in two tasks: (1) sustained squeezing with maximum force, and (2) repetitive squeezing with maximum frequency. Subjects were not specifically told that MM

were measured because of concern that such information would alter the MM. Each subject practiced the tasks with verbal feedback from the examiner. Dynamometer data were simultaneously recorded from both hands after a verbal cue to begin. Each task was performed for 7 to 10 seconds. All dynamometer measurements and clinical scale assessments were performed by two of the authors (G.N. and S.C.C.) after being trained by an FM scale video.

Data Analysis

For sustained squeezing, features of the software program were used to determine the maximum force during the first 5 seconds for intended movements. The maximum force from the second channel, representing MM from the hand intended to be at rest, was also determined. The baseline electrical noise of the system ranged from 0.00 to 0.05 kg. To ensure that identification of MM was conservatively determined, only forces exceeding 0.1 kg were considered.

For repetitive squeezing, each squeeze was converted to a series of cycles. Subjects with only one cycle in the hand intended to be at rest were not considered to have MM during this task. Peak cycle values and time between cycles over the first 5 seconds of recording were then exported to a statistics software program (JMP-IN 3.1.5, SAS Institute) to calculate means and SEM of frequency.

Statistical Analysis

The incidence of MM in stroke and control subjects was compared with the use of Fisher's exact test; significance was set at $P < 0.05$. The agreement of the incidence of MM between the two motor tasks was calculated with the use of a kappa statistic. Categorical comparisons were made with the use of Student's *t* test. Comparisons of magnitude of MM used data from sustained squeezing, while comparisons of frequency of MM used data from repetitive squeezing.

Results

Dynamometer recordings were obtained from 23 patients and 16 control subjects. All participants were right-handed except one patient who was ambidextrous but who was treated as right-handed for purposes of data analyses. Fourteen patients had a small-vessel stroke, 8 had a large-vessel infarct, and 1 had a hemorrhage. In 14 patients hemiparesis affected the right side, while 9 patients had involvement of the left side. The median FM score of patients was 47.0 ± 3.7 (\pm SEM). The median time between stroke and dynamometer evaluation was 22.0 ± 18.3 days. Patients were slightly older (median, 69.0 years; range, 36 to 89 years) than control subjects (median, 63.0 years; range, 26 to 76 years; $P < 0.05$) and had more male subjects (78%) versus control subjects (43%; $P < 0.05$). All subjects were able to perform both squeezing tasks. During squeezing, no flexor or extensor synkinesias occurred in the hand intended to be at rest.

Incidence of MM

The dynamometer reliably captured intended movements and MM (Figure 1). The highest incidence of MM (78.3%) was found in the unaffected hand of patients during sustained squeezing of the paretic hand (Figure 2). This value was significantly greater than the incidence of MM in the paretic hand and in the nondominant hand of control subjects; it was also greater than the incidence of MM in the dominant hand of control subjects during sustained squeezing of the nondominant hand (56.3%), but this difference did not reach significance ($P = 0.17$). The trend toward a higher incidence of MM in the unaffected hand persisted when performances of patients with paretic hand on the right (71.4% of whom

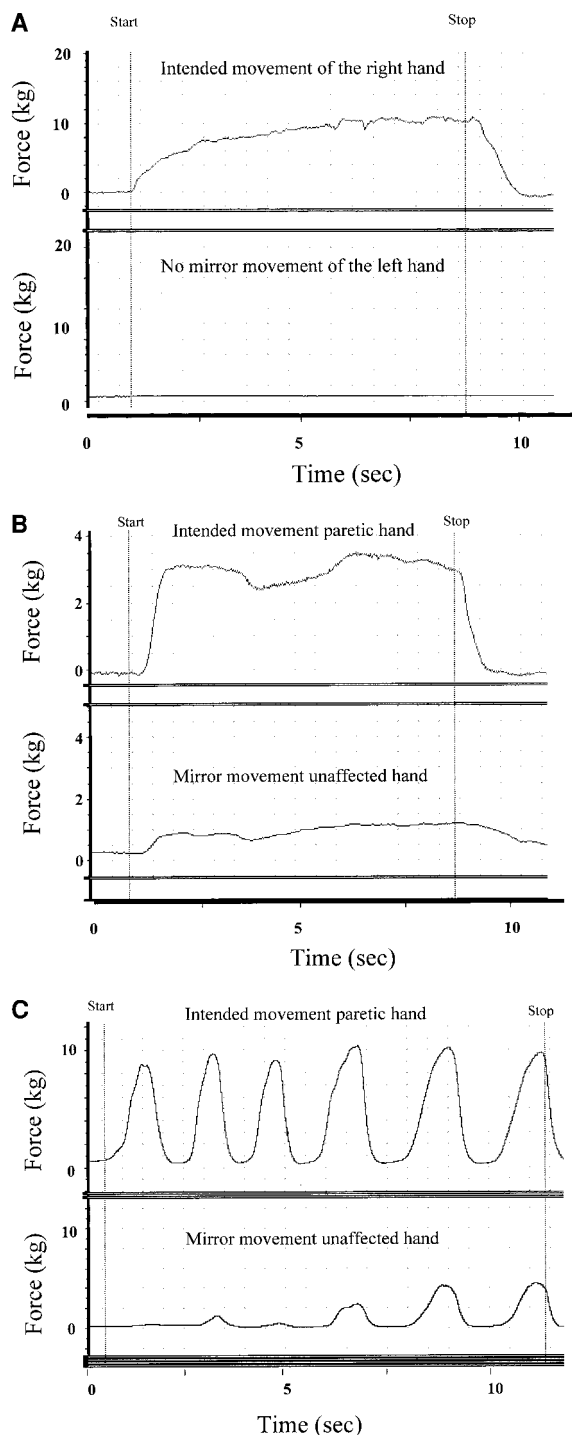


Figure 1. Intended movements and MM were recorded simultaneously during a unilateral motor task with the use of a computerized dynamometer. A, Results from a 62-year-old control subject during sustained squeezing of the right hand. The maximum force was 11.3 kg in the right hand (top) with no MM in the left hand (bottom). B, Results from a 64-year-old patient studied 4 days after a left small-vessel stroke during sustained squeezing of the paretic right hand. The maximum force in the paretic hand (top) was 3.6 kg, while the force of MM simultaneously appearing in the unaffected left hand (bottom) was 0.97 kg (27% of intended movement force). C, Results from a 74-year-old patient studied 90 days after a left small-vessel stroke during repetitive squeezing of the paretic right hand. The frequencies of the intended movement in the paretic hand (top) and MM in the unaffected hand (lower) were identical at 0.5 Hz.

showed MM in the unaffected hand) were compared with right-hand performances of control subjects (43.8% with MM), and when performances of patients with paretic hand on the left (88.9% with MM) were compared with left-hand performances of control subjects (56.3% with MM), but these did not achieve significance.

During repetitive squeezing, the incidence of MM in the unaffected hand (69.6%) was approximately the same as during sustained squeezing. This was significantly greater than the incidence of MM seen in the paretic hand, dominant hand of control subjects, or nondominant hand of control subjects. There was very good agreement for the detection of unaffected hand MM between sustained squeezing and repetitive squeezing among patients ($\kappa=0.78$, $P<0.0001$). Two patients with MM in the unaffected hand during sustained squeezing did not show MM during repetitive squeezing; otherwise, the two different tasks showed perfect agreement. The incidences of MM in the paretic hand, the dominant hand of control subjects, or nondominant hand of control subjects were not significantly different during either motor task.

MM Force and Frequency

The magnitudes of MM in the unaffected hand during paretic hand squeezing (1.0 ± 0.3 kg, mean \pm SEM) and in the paretic hand during unaffected hand squeezing (1.7 ± 0.6 kg) were greater than the MM magnitudes during dominant hand (0.6 ± 0.2 kg) or nondominant hand (0.4 ± 0.2 kg) squeezing by control subjects, but these trends did not achieve significance. When the MM magnitude was considered as a percentage of the concomitant force of the intended movement, to account for the increase in MM force that can occur with greater intended movement force,²⁻⁴ the magnitude of MM in the unaffected hand (23.0 ± 5.9) was significantly greater than that of control subjects (1.3 ± 0.4 to 3.0 ± 1.3 ; $P<0.05$). During repetitive squeezing, intended movements in the paretic hand were significantly slower (1.0 ± 0.1 Hz) than in either hand of control subjects (1.8 ± 0.5 to 2.7 ± 0.3 Hz; $P<0.01$). In each hand, the frequency of MM was identical to the frequency of intended movements.

Relationship Between Motor Deficit and MM

There was a consistent relationship between the motor deficit of the paretic arm and the incidence of MM. For both tasks, patients with MM in the unaffected hand had significantly greater motor deficit (lower FM scores) than patients without these MM (sustained squeezing, 40.5 ± 4.1 versus 57.8 ± 5.3 [$P<0.05$]; repetitive squeezing, 38.4 ± 4.3 versus 57.6 ± 3.8 [$P<0.01$]) (Figure 3A).

In contrast, patients with MM in the paretic hand had significantly better motor function than patients without MM in the paretic hand (sustained squeezing, 53.8 ± 3.4 versus 36.9 ± 5.2 [$P<0.05$]; repetitive squeezing, 62.8 ± 1.4 versus 40.4 ± 3.9 [$P<0.0001$]) (Figure 3B). There were 9 patients who had MM in both hands during either task; the mean FM score for these subjects was 53.2 ± 3.7 . Two patients had no MM during either task; the mean FM score for these subjects was 50.5 ± 13.5 .

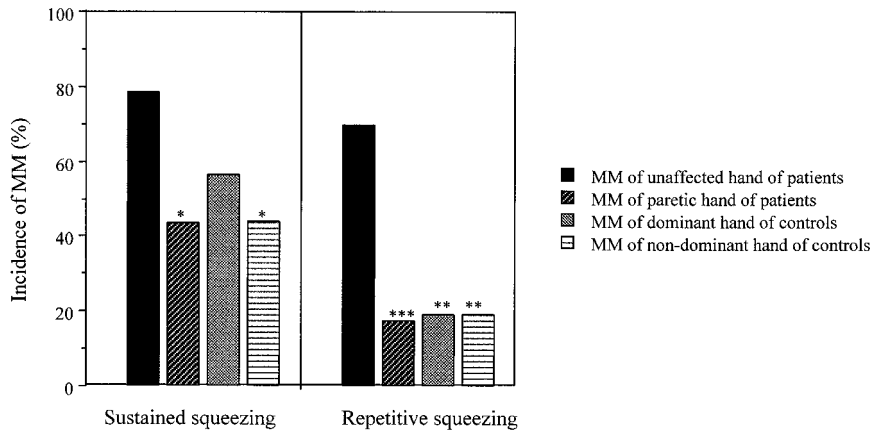


Figure 2. For both hand motor tasks, the highest incidence of MM was in the unaffected hand during squeezing of the paretic hand. This was significantly greater than the incidence of MM in the paretic hand, dominant hand, or non-dominant hand, with one exception: for sustained squeezing, the incidence of MM was 78.3% in the unaffected hand compared with 56.3% in the dominant hand ($P=0.17$). No significant difference was found between the incidence of MM in the paretic hand and either hand of control subjects. * $P<0.05$, ** $P<0.01$, *** $P<0.001$ vs incidence of MM in the unaffected hand.

Discussion

MM have been recognized in stroke patients for over a century²¹ but have previously been characterized to a limited extent. We used a newly developed computerized dynamometer to evaluate the incidence of MM in stroke patients with varying degrees of motor deficits. The dynamometer creates a permanent, quantitative record of the motor event; a previous report found that dynamometer measurements of motor task force and frequency correlate well with scores from the FM scale and the NIH Stroke Scale.²² Another advantage of this method for studying MM is the use of a continuous scale as opposed to an ordinal rating scale used in prior studies to compare MM between subjects.¹²⁻¹⁴ These

features may be important for the assessment of MM in studies of stroke recovery.

The highest incidence of MM was observed in the unaffected hand of stroke patients during intended squeezing of the paretic hand. These MM were larger and slower than MM in control subjects. Limited data for comparison exist on MM after adult-onset stroke. Cernacek,⁹ using surface EMG during a finger flexion task, found that the incidence of MM in control subjects was significantly lower than the incidence in stroke patients in the paretic or unaffected hand only when intended movements were performed with the nondominant hand. In that study MM were present during 64% of left- and 84% of right-hand movements of control subjects, consider-

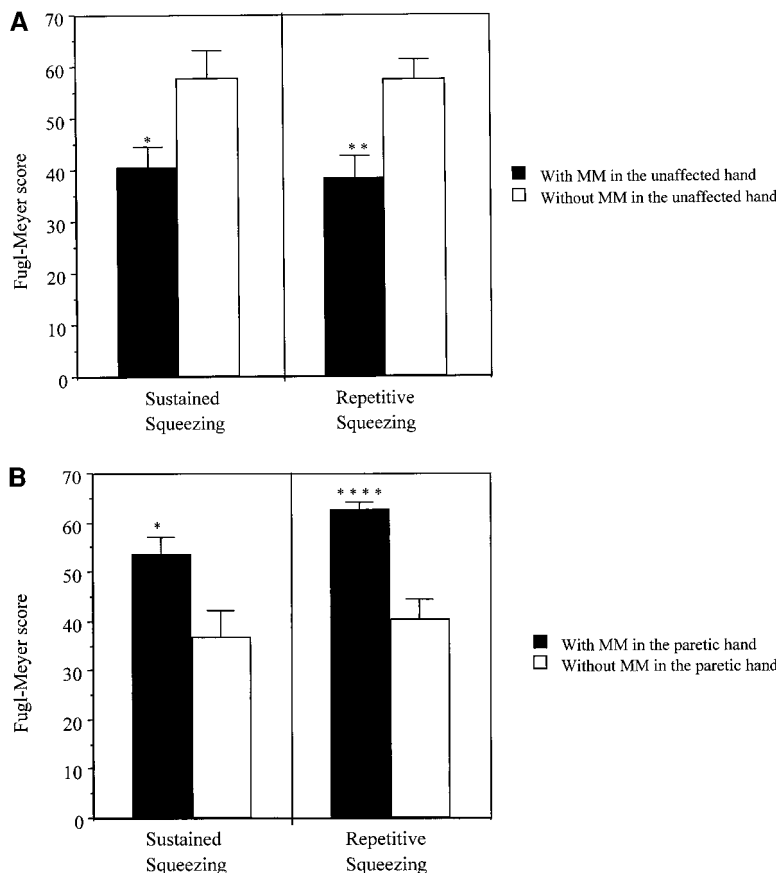


Figure 3. FM scores of patients with and without MM. Data are mean ± SEM. A, The mean FM score was lower among patients with MM in the unaffected hand for both tasks (sustained squeezing, 40.5 ± 4.1 vs 57.8 ± 5.3; repetitive squeezing, 38.4 ± 4.3 vs 57.6 ± 3.8). B, The mean FM score was higher among patients with MM in the paretic hand for both tasks (sustained squeezing, 53.8 ± 3.4 vs 36.9 ± 5.2; repetitive squeezing, 62.8 ± 1.4 vs 40.4 ± 3.9). * $P<0.05$, ** $P<0.01$, **** $P<0.0001$.

ably higher than in the present study. These results may reflect differences in the sensitivity of MM detection methods. Chaco and Blank,¹⁰ using needle EMG during sustained movements by fingers of the unaffected hand, found MM in the paretic hand in 40% of patients and no MM in 25 control subjects. The result for stroke patients is similar to the value of 43.5% obtained in the present study during sustained squeezing, but the absence of MM in control subjects is lower than results from the present study. In the study by Chaco and Blank,¹⁰ unaffected hand MM were not examined. Differences between the incidence of MM in our study and prior studies may be due to the different methods used for the detection of MM. An advantage of the method used here is that the digital dynamometer permits the assessment of the actual motor performance and allows simultaneous recording of movement patterns from both hands.

The choice of motor task influences the incidence of MM,^{13,27} although there was very good agreement between the two tasks for the detection of unaffected hand MM during paretic hand squeezing ($\kappa=0.78$). Sustained squeezing induced MM in a larger fraction of stroke patients, but the difference between stroke patients and control subjects was more pronounced with repetitive squeezing. Squeezing tasks were selected in this study because the ability to perform the tasks returns early during recovery, whereas individual finger movements return late and only in a subset of patients.²⁸ Squeezing may be expected to induce more synkinesias,¹³ complicating comparison of the present results with studies examining MM during single finger movements. However, the design of the data acquisition methods aimed to eliminate this effect. Compared with motor tasks restricted to distal musculature, squeezing would be expected to induce MM more easily and with a greater magnitude because the muscles involved receive an approximately fivefold greater degree of ipsilateral supraspinal innervation.^{21,29} The equal incidence of MM in the dominant and nondominant hands of control subjects may in part be a consequence of the selected tasks; in prior investigations, MM during dominant hand motor tasks have been increased, decreased, and equal compared with during nondominant hand tasks.^{9,13,27}

The incidence of MM has not previously been related to degree of stroke deficit. In this study MM in the unaffected hand were observed more often in patients with greater motor deficits, while the incidence and magnitude of MM in the paretic hand more closely resembled results of control subjects. These contrasting characteristics suggest that the MM observed in each hand relate to different mechanisms.

Functional imaging has provided insights into the mechanisms underlying unaffected hand MM after adult-onset stroke. Two positron emission tomography studies of patients with adult-onset stroke and MM in the unaffected hand during active movements of the paretic hand suggest that such MM are related to increased activation in the unaffected sensorimotor cortex with preservation of activation in the stroke hemisphere.^{15,19} In stroke patients with lesions confined to the posterior internal capsule causing degeneration of the pyramidal tract, suprathreshold electrical stimulation of the damaged hemisphere elicited bilateral motor responses.³⁰ All of these patients showed unaffected hand MM during in-

tended movements of the paretic hand. Bilateral hemispheric responses to unilateral intended movements are also a part of normal motor control. Most normal adult subjects show premovement potentials in the hemisphere ipsilateral to a unilateral movement.³¹ Studies of normal adults conducted with magnetoencephalography³² or functional MRI^{18,33} have found bilateral sensorimotor cortex activation during a unilateral hand motor task in most normal subjects. Divergent results have been found to explain the genesis of MM in other conditions, possibly related to the increased capacity for axonal sprouting when brain injury occurs at a very early age.¹⁴ In patients with cerebral palsy and MM, transcranial magnetic stimulation studies suggest that a representation for both hands may be present in the unaffected hemisphere; however, unlike adult stroke patients, decreased hand representation may be present in the damaged hemisphere.^{7,14} In some patients with primary MM syndromes, transcranial magnetic stimulation has disclosed an increased ipsilateral hand representation in the motor cortex of each hemisphere.³⁴ During a hand motor task by such subjects, PET studies have found contralateral³⁴ or bilateral³⁵ motor cortex activation. Together, these data suggest that MM after adult stroke may represent an exaggeration of the degree of bilateral motor representation normally seen in adults; some patients with cerebral palsy and primary MM may also have a different mechanism underlying MM.

MM in the paretic hand during unaffected hand movements have received less attention. In the present study such MM were associated with better motor function. Furthermore, the incidence of these MM was not significantly different between patients and control subjects, suggesting that MM in the paretic hand are associated with less extensive changes in motor control for unilateral hand movements compared with MM in the unaffected hand. The magnitude of paretic hand MM was significantly greater than that of control subjects during intended use of the left hand. These observations might be explained by reduced transcallosal inhibition of ipsilaterally projecting corticospinal tract fibers.¹²

In conclusion, MM in the unaffected hand and MM in the paretic hand are associated with different degrees of motor deficit. Some of these MM may reflect restorative processes related to recovery from stroke. The observation of unaffected hand MM in subjects with greater motor deficit may suggest that these MM represent a clinical sign of restorative processes after a unilateral stroke. In the present study each subject was studied only once. Further studies using serial assessments of MM are necessary to better understand the role and the temporal evolution of MM during recovery after stroke.

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