Cortical Activation in Stroke Patients during Synergistic and Nonsynergistic Motor Tasks

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Introduction

Recovery of hand motor function after hemiparetic stroke in patients typically starts with regaining the ability to perform synergistic movements in which the digits can be flexed and extended in unison. In some patients, hand motor recovery proceeds with regaining the ability to perform dexterous, skillful, nonsynergistic movements in which the digits can be moved independent of one another. The changes in brain activity mediating the restoration of motor skill after stroke are not fully understood. The current study examined the modulation of cortical activity in stroke patients by the level of motor skill challenge.

Subjects

- 10 chronic stroke patients with relatively good recovery of hand motor function after acute hemiparesis
- 10 handedness- and age-matched normal control subjects

Table 1. Patient and Matched Control Subject Characteristics

Patient	Premorbid Hand Dominance	Stroke-Affected Hand	Age (yr)	Gender	Time Post-Stroke (yr)	Acute UL (hand) MRC Score	Lesion		Matched Control Subject		
							Location	Volume (cm^3)	Hand Dominance	Age (yr)	Gender
1	R	L	52	M	0.5	3	R CR, BG, temporal lobe	15.2	R	58	F
2	R	R	47	M	3.9	0 (0)	L CR, BG, IC, inferior frontal lobe	77.3	R	46	M
3	R	R	41	F	5.9	0-3 (0)	L medial temporal lobe, posterior limb IC	0.9	R	43	F
4	R	R	69	M	1.6	4	L CR, BG, temporal lobe	61.2	R	68	M
5	R	L	76	F	2	1 (0)	R CR, temporal lobe	3.4	R	72	M
6	R	R	62	F	1.2	3-4+(3+)	L CR	0.7	R	62	F
7	R	L	48	F	1.7	0 (0)	R frontal and parietal lobe white matter	10.1	R	55	M
8	L	R	60	M	5.8	0-3(0)	L CR, BG	4.2	L	69	M
9	R	R	61	M	2.2	0 (0)	L frontal lobe, parietal lobe	33.8	R	59	M
10	R	L	69	M	1.2	1-3 (1)	R BG	0.7	R	70	M
Summary	9R/1L	6R/4L	59 ± 11	4F/6M	2.6 ± 1.9				9R/1L	60 ± 10	3F/7M

M, male; F, female; R, right; L, left; UL, upper limb; IC, internal capsule; BG, basal ganglia; CR, corona radiata. UL MRC scores are strength measures (scale 0-5; 0 = no power, 5 = normal) for muscles of the affected upper limb acutely after stroke, as reported in the medical record; hand MRC scores are given in parentheses if available; summary values are mean ± SD

Methods

- Hand Motor Function Testing and Analysis
  - Index finger tapping
  - Purdue pegboard
  - Normalized scores (% contralateral hand)
  - Principal component analysis
- Hand Motor Tasks during fMRI[1]
  - Synergistic motor task: relatively unskilled; 5 digits flex and extend in unison
  - Nonsynergistic motor task: skilled; thumb flexes while 4 other digits extend, and visa versa
  - 0.25 Hz
  - Visual cues: schematics of hand movement phases
  - Block design: movement alternating with rest; 5 x 22.5 s
  - Performed by stroke-affected hand of patients, and comparable hand of controls
  - Digit angular velocity monitored on-line[2]; computed movement duration, frequency, amplitude, speed, acceleration, jerk, mirror movements
- MRI Data Acquisition
  - 3 T Siemens Trio, head coil
  - T2*-weighted GE EPI, TR/TE= 1500/30 ms, 165 acquisitions, 23 slices, 3x3x5 mm voxels
  - T1-weighted MPRAGE, TR/TE= 7/3 ms , 1 mm^3 voxels
  - Head restraint using bite bar
- Image Processing and Analysis
  - Flipped data L-R from patients with right-sided lesion, and matched controls
  - Freesurfer cortical surface models,[3,4] converted to SUMA standard mesh
  - Cortical surface-based spatial registration[5]
  - BOLD: motion-corrected, intensity-normalized, mapped to cortical surface, smoothed 6 mm fwhm
  - 1st level GLM: canonical HDR, motion parameters as nuisance regressors
  - 2nd level t-tests: one-sample, unpaired, paired
  - Multiple comparison correction: surface-based cluster threshold method
- Correlations
  - Pearson's correlation coefficient: Hand motor function (1st principal component) versus activation (mean BOLD response) in clusters-of-interest

Results

I. Hand Motor Function

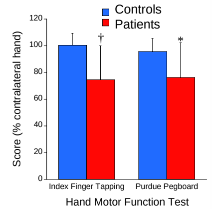

Fig. 1. Motor function of the affected hand of stroke patients and normal control subjects. Test scores are normalized relative to the contralateral hand, and are reported as the mean ± SD. * $P < 0.05$, † $P < 0.01$ vs controls, unpaired t-test.

II. Motor Performance during fMRI

A. Digit motion time-series

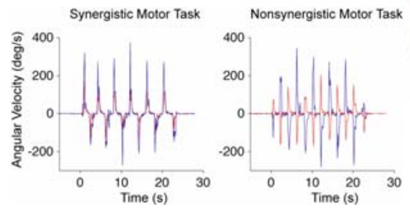

Fig. 2. Angular velocity time-series of digit motion acquired during fMRI from a representative control subject. Measurements of the thumb (red) and middle finger (blue) during a movement epoch are shown. **Left:** Time-series of the synergistic hand motor task showing the digits moving in unison. **Right:** Time-series of the nonsynergistic hand motor task showing the thumb and middle finger moving in opposite directions.

B. Quantitative assessment of digit motion during fMRI

Table 2. Motor performance during fMRI

Movement parameter	Synergistic Motor Task		Nonsynergistic Motor Task	
	Patients	Controls	Patients	Controls
Duration (s)	22.5 ± 0.7	22.2 ± 0.2	22.8 ± 0.4	22.3 ± 0.2
Frequency (Hz)	0.25 ± 0.00	0.25 ± 0.00	0.25 ± 0.00	0.25 ± 0.00
Amplitude (% max range-of-motion) *	78.2 ± 9.1	85.2 ± 5.0	81.1 ± 4.8	84.5 ± 4.6
Speed (deg/s)	75.5 ±16.2	74.8 ± 14.0	73.5 ± 19.8	83.3 ± 11.2
Acceleration x 10^2 (deg/s^2)	15.2 ± 5.4	13.2 ± 2.5	13.7 ± 5.7	13.0 ± 4.0
Jerk x 10^3 (counts > 5 × 10^4 deg/s^3)	18.8 ± 11.5	17.3 ± 5.4	19.8 ± 7.9	18.8 ± 5.7
Mirror movements (% amplitude of moving digits)	0.12 ± 0.80	-0.04 ± 0.41	-0.02 ± 0.62	0.08 ± 0.45

*$P < 0.05$ main effect of group, mixed model ANOVA; values are mean ± SD

III. Functional MRI

A. Control Subjects

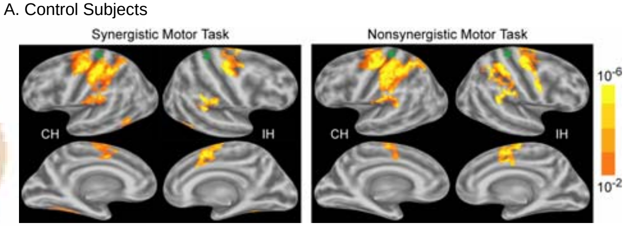

Fig. 3. Group-average statistical maps of activation in normal control subjects during performance of the synergistic and nonsynergistic motor tasks ($P < 0.01$, corrected, one sample t-test). The maps are overlaid on a model of the group-average, inflated cortical surface. Dark gray regions are the fundus of a sulcus; light gray regions are the crowns of a gyrus. Green arrowheads point to central sulcus. First row are lateral surfaces of the hemispheres, second row are medial surfaces of the hemispheres. CH = contralateral hemisphere; IH = ipsilateral hemisphere.

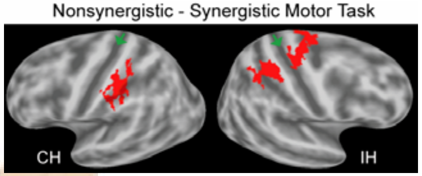

Fig. 4. Clusters of significantly increased activation in the normal control subjects during performance of the nonsynergistic motor task relative to the synergistic motor task. These clusters are located in the contralateral postcentral gyrus/sulcus region ($P < 0.05$, corrected, paired t-test), as well as regions about the ipsilateral postcentral gyrus/sulcus ($P < 0.05$) and precentral gyrus/sulcus ($P < 0.01$).

B. Stroke Patients versus Control Subjects

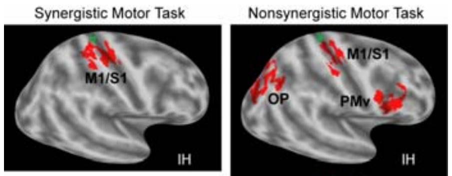

Fig. 5. Differences in activation in the chronic stroke patients relative to normal control subjects during performance of the hand motor tasks. **Left**: During performance of the synergistic motor task, the patients showed a significant ($P < 0.01$, corrected, unpaired t-test) increase in activation in the ipsilateral primary sensorimotor cortex (M1/S1). **Right**: During performance of the nonsynergistic motor task, the patients showed significant increases in activation in the ipsilateral M1/S1 ($P < 0.05$, corrected, unpaired t-test), ventral premotor cortex (PMv; $P < 0.01$), occipito-parietal cortex (OP; $P < 0.01$), and SMA/cingulate ($P < 0.05$).

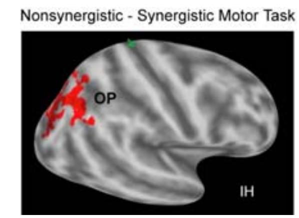

Fig. 6. Between-group differences in cortical activation changes associated with performance of the nonsynergistic motor task versus the synergistic motor task. The patients showed a significant task-dependent increase in activation in the ipsilateral occipito-parietal cortex ($P < 0.01$, corrected, unpaired t-test) relative to that in controls.

IV. Correlation Analysis

No significant ($P > 0.05$) correlation between hand motor function (1st pc) and activation (mean BOLD response) in:
- ipsilateral M1/S1 during synergistic movement
- ipsilateral M1/S1, PMv, SMA/cingulate, or OP during nonsynergistic mov't

Summary & Discussion

- The chronic stroke patients, who had relatively good recovery of hand motor function, showed increased cortical activation in the ipsilateral hemisphere during motor tasks performed by the affected hand, relative to that of controls, dependent on the level of motor skill challenge. These changes in ipsilateral cortical activation were not related to residual motor impairment or mirror movements.
  Suggests functional relevance of increased activation in ipsilateral motor task-related cortices in patients.
- During performance of a relatively unskilled motor task, the patients showed increased activation, relative to that in controls, in ipsilateral M1/S1. During performance of a skilled motor task, the patients showed increased activation in the ipsilateral M1/S1 as well as in ipsilateral ventral premotor cortex, SMA/cingulate, and occipito-parietal cortex.
  Increased activation in ipsilateral M1/S1 may be a fundamental compensatory mechanism utilized by stroke patients to perform hand movements in the presence of damage to motor-related brain structures. Performance of skillful hand movements by stroke patients may involve enhanced processing of additional ipsilateral motor task-related cortices.
- Activation in the ipsilateral occipito-parietal cortex was differentially elevated in the patients relative to controls with the increase in motor skill challenge.
  The ipsilateral occipito-parietal cortex may be particularly important to the restoration of dexterous, skillful movement after hemiparetic stroke. Activation in this cortical region may reflect its role in the visual guidance of hand movement, coordination of digit movements, and attention.

References

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