Right Hemisphere Contributions to Bilateral Force Control in Chronic Stroke: A Preliminary Report

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Background: Bilateral motor control deficits poststroke may be lateralized by hemisphere damage. This preliminary study investigated bilateral force control between left and right hemisphere-damaged groups at baseline and after coupled bilateral movement training with neuromuscular stimulation. *Methods:* Stroke participants (8 left hemisphere and 6 right hemisphere cerebrovascular accidents) performed a bilateral isometric force control task at 3 submaximal force levels (5%, 25%, and 50% of maximum voluntary contraction [MVC]) before and after training. Force accuracy, force variability, and interlimb force coordination were analyzed in 3-way mixed design ANOVAs (2 × 2 × 3; Group × Test Session × Force Level) with repeated measures on test session and force level. *Results:* The findings indicated that force accuracy and variability at 50% of MVC in the right hemisphere-damaged group were more impaired than lower targeted force levels at baseline, and the impairment at the highest target level was improved after coupled bilateral movement training. However, these patterns were not observed in the left hemisphere-damaged group. *Conclusions:* Current findings support a proposition that the right hemisphere presumably contributes to controlling bilateral force production.
Key Words: Stroke—bilateral force control—hemisphere lateralization—coupled bilateral movement training—wrist and fingers extension.

Introduction

Contralesional deficits in the upper extremities are common dysfunctions after unilateral stroke.[1] A predominant goal of stroke rehabilitation is relearning motor functions on the impaired extremities. Rehabilitation protocols are typically based on observed motor deficits and control problems. Given that common motor deficits reflect stroke location and hemisphere involvement, lateralization appears to be a critical component that should be included in the recovery process.[2,3] Lateralization evidence from motor control studies revealed contrasting motor dysfunctions: left hemisphere strokes caused directional errors during movement control, whereas right hemisphere strokes caused end-position errors.[3-5]

An unanswered question concerns a change in bilateral motor control deficits lateralized by hemisphere damage. Previous stroke studies that used an isometric force control paradigm reported impaired bilateral force control capabilities, as indicated by higher task error, greater variability, and less coordination of total force produced by 2 hands.[6,7] These impairments in bilateral force control may be attributed to asymmetrical brain activation and motor unit firing between more-affected and less-affected sides of the body. Moreover, a possibility is that impaired bilateral force control poststroke is presumably differentiated by the hemisphere damaged. Previous studies on right hemisphere-damaged groups revealed impairments in cognition and perception (e.g., visual neglect or optic ataxia), and these deficits were associated with a higher error rate in movement tasks than left hemisphere-damaged groups.[2,8-10] Further, even though stroke participants did not have any visual deficits poststroke, motor lateralization evidence in the contralesional arms persisted during movement control.[2] For example, a left hemisphere stroke causes deficits in predicting dynamic

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limb movements and right hemisphere damage compromises the capability to stabilize limb movements using an impedance control, a reactive motor control strategy to maintain movement stability.[2,3,11,12]

While using impedance control, the central nervous system may deal with unpredictable external perturbations contributing to stability disturbances. The central nervous system typically generates reactive forces to stabilize unstable motions or force outputs. For example, while holding an umbrella, arm stiffness increases in response to an unpredictable wind.[13] This impedance control mechanism is crucial for both arm movements and force control.[11,13,14] In general, these findings support the argument that the right hemisphere may have a specific role of arm stability during force control.[2-4,12] Thus, right hemisphere damage may facilitate less stable force control in comparison to left hemisphere damage because of a missing impedance control or inability to activate an impedance control.

In this preliminary study, we investigated whether bilateral motor control poststroke is influenced by hemisphere lateralization. We tested 2 hypotheses using an isometric force control paradigm: (1) bilateral force control in individuals with right hemisphere stroke is more impaired than a left hemisphere-damaged group at baseline; and (2) improvements of bilateral force control after motor training are greater in individuals with right hemisphere stroke than with left hemisphere stroke. This rationale served as the basis for the current study administering coupled bilateral movement training (i.e., bilateral movements and active neuromuscular stimulation on the paretic arm).[15-19] Most importantly, if a differential magnitude of motor improvements after bilateral movement training is shown between left hemisphere and right hemisphere-damaged participants, then a specific rehabilitation protocol should be prescribed for the side of hemisphere damaged.[2,20,21]

Materials and Methods

Participants

Fourteen right-handed stroke patients (8 left hemisphere damage and 6 right hemisphere damage) volunteered for this study. Stroke participants met 4 inclusion criteria: (a) unilateral stroke at least 6 months before baseline testing, (b) voluntary range of motion for 3 major movements of the upper extremities (e.g., wrist and fingers extension: 10° of extension to 80° of flexion; elbow extension: 145°-0°; and shoulder abduction: 0°-90°), (c) ability to voluntarily trigger a NeuroMove microprocessor unit (Zyntex NeuroDiagnostics, Englewood, Colorado, USA) for neuromuscular stimulation, and (d) normal cognitive function (Mini-Mental State Examination score > 23).[22] Three exclusion criteria were as follows: (a) additional musculoskeletal deficits, (b) visual deficits, and (c) orthopedic injury pain in the upper extremities. Table 1 shows demographic and clinical details for stroke participants. Before baseline testing started, all participants read and signed an informed consent form approved by an Institutional Review Board at the University of Florida.

Bilateral Isometric Force Control

The bilateral isometric force control task required participants to produce force while executing wrist and fingers extension movements. Functions of the wrist and fingers extension were meaningful in quantifying progress toward motor recovery.[6,7,23] Participants performed maximum voluntary contraction (MVC) and isometric force control tasks at 3 submaximal target levels (i.e., 5%, 25%, and 50% of MVC) before and after the rehabilitation protocol.[6,7,24]

To begin testing, participants sat in an adjustable chair and placed their left and right forearms on the table with 15°-20° of shoulder flexion and 20°-40° of elbow flexion. Participants placed both hands under custom padded platforms and the height of platforms was adjusted to accommodate each hand's thickness. A 43.2-cm LCD computer monitor (1024 × 768 pixels; 100 Hz refresh rate) was located in front of each participant. A 78-cm horizontal distance between individuals' eye level and LCD computer monitor was maintained for all participants (Fig 1, A). Each volunteer bilaterally performed wrist and fingers extension against the padded platforms. Two trials of the

Table 1. *Clinical information of stroke participants*

Group	Left hemisphere damage	Right hemisphere damage	*P* value
Sample size	N = 8	N = 6	
Age (years; mean and range)	60.9 (52.3-79.8)	76.1 (73.0-76.8)	0.13
Time since stroke (month; mean and range)	31.1 (7-87)	45.0 (8-105)	0.48
Gender	Female = 4, male = 4	Female = 6	
Stroke type	Ischemic = 8	Ischemic = 6	
Box and block manual dexterity test			
Paretic arm (N; mean and range)	42.4 (13-76)	59.5 (51-71)	0.09
Nonparetic arm (N; mean and range)	59.3 (35-74)	67.8 (55-82)	0.24

Note that the box and block manual dexterity test was used for determining an ability to repetitively grasp and move a block from one side of the box to the other side for 60 seconds. *P* value indicates significant difference level between 2 groups using independent *t* test.