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The Effects of Bilateral Arm Training on Motor Control and Functional Performance in Chronic Stroke: A Randomized Controlled Study

Keh-chung Lin, ScD,[1,2] Yi-an Chen, MS,[3] Chia-ling Chen, MD, PhD,[4] Ching-yi Wu, ScD,[4] and Ya-fen Chang, MS[5]

Abstract

Background. Most studies of bilateral arm training (BAT) did not employ a randomized controlled trial design and involved very limited functional training tasks. *Objective*. Compare the effects of BAT with control intervention (CI) on motor control and motor performance of the upper extremity and also functional gains in patients with chronic stroke. *Methods*. This 2-group randomized controlled trial with pretreatment and posttreatment measures enrolled 33 stroke patients (mean age = 53.85 years) 6 to 67 months after onset of a first stroke. They received either a BAT program concentrating on both upper extremities moving simultaneously in functional tasks by symmetric patterns or CI (control treatment) for 2 hours on weekdays for 3 weeks. Outcome measures included kinematic analyses assessing motor control strategies for unilateral and bimanual reaching and clinical measures involving the Fugl-Meyer Assessment (FMA) of motor-impairment severity and the Functional Independence Measure (FIM) and the Motor Activity Log (MAL) evaluating functional ability. *Results*. After treatment, the BAT group showed better temporal and spatial efficiency during unilateral and bilateral tasks and less online error correction only during the bilateral task than the control group. The BAT group showed a significantly greater improvement in the FMA than the control group but not in the FIM and MAL. *Conclusions*. Relative to CI, BAT improved the spatiotemporal control of the affected arm in both bilateral and unilateral tasks, decreased online corrections to perform bilateral tasks, and reduced motor impairment. These findings support the use of BAT to improve motor control and motor function of the affected upper limb in stroke patients.

Keywords

cerebrovascular accident, motor activity, kinematics, rehabilitation, randomized controlled trial, upper extremity

Introduction

Stroke survivors are often left with hemiplegia or hemiparesis of the upper extremity (UE) that makes functioning in their daily living environment extremely challenging.[1] The disruptions caused to motor control of the UE by stroke are persistent despite usual treatment, and thus, novel intervention techniques are called for.[2] Among the approaches advocated for stroke motor rehabilitation, bilateral arm training (BAT) has received considerable attention.[3-8] Previous studies of BAT, however, employed very small sample sizes and limited functional training tasks without randomized controlled trials to investigate the effects on motor control. This study investigated the effects of BAT on motor control and performance of the affected UE and daily function in patients with chronic stroke.

BAT involves repetitive practice of symmetrical bilateral movements in different forms, including bilateral isokinematic training,[3,9-11] which involves spatiotemporally identical movements with functional activities, and robot-assisted movement training involving assistive exercise on the arm trainer with[5,12-14] or without[6,15-17] auditory cueing. A basic assumption of BAT is that symmetrical bilateral movements activate similar neural networks in both hemispheres when homologous muscle groups are simultaneously activated. Bilateral symmetrical movements, therefore, may allow for the activation of the undamaged hemisphere, thus promoting neural plasticity to increase activation of the damaged hemisphere and facilitate movement control of the impaired limb.[18]

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A number of studies have shown that BAT can reduce motor impairment of the affected arm as measured by the Fugl-Meyer Assessment (FMA)[5,6,12,14,15,17] and enhance motor function as evaluated by the Wolf Motor Function Test.[12,14] Only a few studies[5,12,13] have investigated the impact of BAT on functional performance during daily activities, and the results were inconclusive. To clarify whether and how the BAT involving functional activities may affect motor control during the performance of functional tasks, Mudie and Matyas[9,10] visually observed kinematic aspects of movements (eg, spatiotemporal characteristics of movement), and subsequent studies[7,19] objectively and directly measured the movement kinematics to underscore the spatial and temporal efficiency and control strategy (preplanning control vs online error correction control) of movements. However, Mudie et al employed a single-subject design, and the test tasks were the same as the training tasks. The positive effects of BAT might be owing to practice effects. Another 2 studies[7,19] involved short treatment duration of 1 week and did not show beneficial effects of bilateral training on movement kinematics. One study[14] that used robot-assisted BAT with auditory cues showed beneficial effects of BAT on kinematic measures such as movement efficiency and smoothness.

In addition to the 2 kinematic studies,[7,19] some other research[8,11,13,16] also failed to demonstrate the effects of BAT, though several studies[5,6,9,10,12,15,17] showed the benefits of BAT for improving movement performance after stroke. The small sample size, degree of initial impairment, time since stroke onset, or intensity of treatment might have contributed to the lack of significant effects in these negative studies. For example, Lewis and Byblow[11] recruited only 6 stroke patients across the 3 phases of recovery (acute, subacute, and chronic) and used a low-intensity treatment protocol involving 11 repetitions of each task, 3 tasks at each training session, for a total of about 10 sessions of bilateral training. Lum et al[16] recruited only 5 stroke patients in the bilateral training group, and the study groups were not matched on level of baseline performance. To overcome the limitations in prior research,[5-7,9,10,12,15,17,19] we used a larger sample and implemented a more intense and longer (eg, 3 weeks) treatment protocol in the BAT program.

Because current approaches to stroke rehabilitation emphasize the importance of task-oriented training,[20] our BAT program used repetitive practice on a variety of functional tasks with spatiotemporally identical movements. Although some previous studies of BAT have adopted functional activities for training, most[7-11,19] included only 1 to 4 types of functional tasks (eg, simulated drinking, picking up a cup). In addition, we used kinematic analysis to investigate the effect of BAT on motor control of reaching and reach-to-grasp movements in experimental tasks that were not practiced during the treatment period. Study of motor control strategy is important for understanding the mechanisms underlying therapeutic gains. Combining kinematic analysis and clinical evaluation might enable comprehensive assessment of the change in control strategies and motor performance after BAT.[14]

We predicted that BAT might confer therapeutic benefits for enhancing motor control strategy during upper limb activity and reduce motor and functional deficits in stroke patients. Specifically, we hypothesized that stroke patients receiving 3 weeks of BAT, compared with patients receiving control intervention (CI), would exhibit better motor control performance in the affected UE during unilateral and bilateral testing tasks (ie, increased movement efficiency and better control strategy) and achieve greater motor (higher FMA scores) and functional gains (greater functional independence).

Methods

Design

This study was a randomized pretest and posttest control group design. Participants were individually randomized to the BAT group or a control group (Figure 1). All patients were blind to the study hypotheses. The outcome measures were administered before and after a 3-week intervention. Training took place during regularly scheduled occupational therapy sessions, and all other routine stroke rehabilitations (eg, physical therapy or speech therapy) that did not involve UE training proceeded as usual.

Participants

We recruited 33 stroke patients (19 men, 14 women; mean age = 53.85 years) after onset of an ischemic or hemorrhagic stroke (onset mean = 13.52 months; range = 6-57 months) from the rehabilitation departments of 3 participating hospitals. All patients signed informed consent forms approved by the institutional review board. The patients were all right-hand dominant before the stroke by self-report.

Inclusion criteria were as follows: (*a*) clinical diagnosis of a first or recurrent unilateral stroke; (*b*) the ability to reach Brunnstrom stage III or above in the proximal and distal part of arm[21]; (*c*) no serious cognitive deficits (Mini-Mental State Examination score ≥24); (*d*) no excessive spasticity in the affected arm, including shoulder, elbow, wrist, and fingers (Modified Ashworth Scale[22] score ≤2 in any joint) that might preclude the functional movements; (*e*) no other neurologic, neuromuscular, or orthopedic disease; and (*f*) lack of participation in any experimental rehabilitation or drug studies. Patients would have been excluded if they had a stroke relapse or seizure attack during the intervention but none did. All potential participants received independent examinations by 4 occupational therapists to determine their eligibility for inclusion.

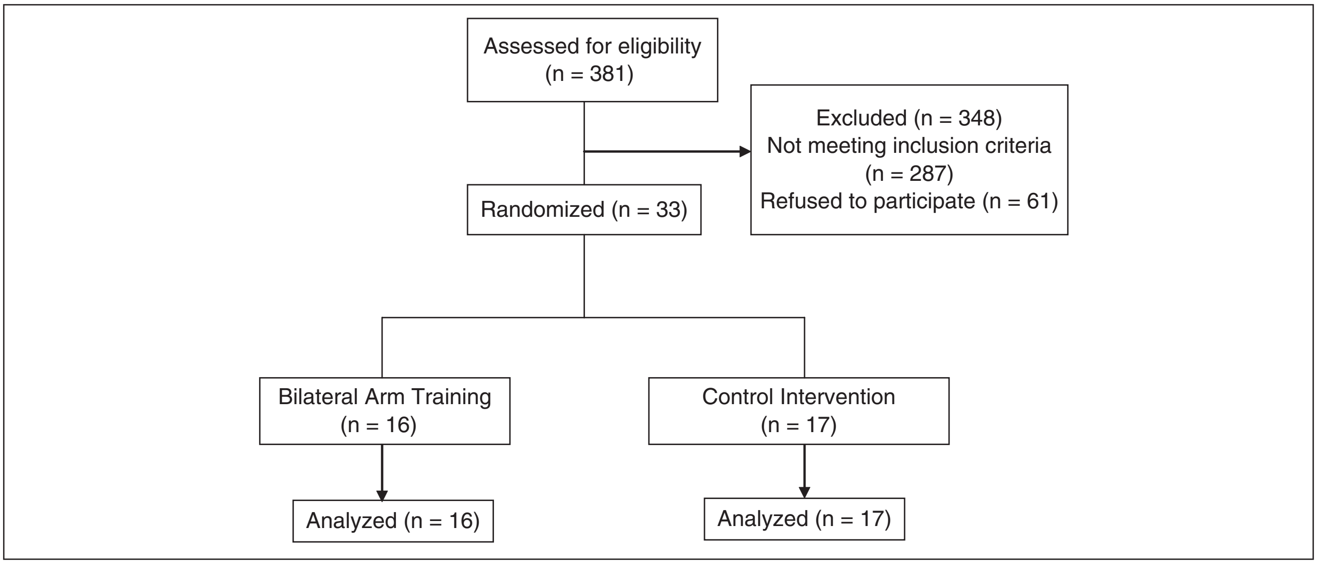

Figure 1. Flow diagram of the randomization procedure.

Intervention

The intervention was provided at 3 participating hospitals under the supervision of 3 occupational therapists. The treating therapists were trained in the administration of the BAT protocol by the investigators and completed a written competency test before subject treatment.

Bilateral arm training group. The BAT group concentrated on both the affected and unaffected UEs moving simultaneously in functional tasks with symmetric patterns for 2 hours per day, 5 days a week, for 3 weeks. The subjects had one-on-one supervision as they practiced on a variety of functional tasks typically found difficult by stroke patients. The participants were instructed to lift 2 cups, stack 2 checkers, pick up 2 small dried beans with a diameter of 0.5 to 1 cm, fold 2 towels, turn 2 large screws, manipulate 2 coins simultaneously by each hand, or use both hands to hold a sprinkler can to water plants.

Control intervention group. With equivalent intensity and duration, participants in the control group also received the treatment program for 2 hours per day, 5 days a week, for 3 weeks. This group received standard occupational therapy treatment that also focused on UE training and included neurodevelopmental techniques, trunk–arm control (ie, practice UE tasks during standing), weight bearing by the affected arm, fine motor tasks practice, and practice on compensatory strategies for daily activities.

Outcome Measures

Changes in motor control, motor performance, and functional ability were evaluated using kinematic analysis and clinical evaluation, which were administered within 7 days before and after the 3-week intervention. During evaluation, the participants took rest breaks whenever they requested. Four occupational therapists blind to group allocation were trained to provide the evaluations. The training for the clinical assessment tools included careful examination of written instructions and repeated practice. The training for conducting the kinematic analysis was based on standardized procedures described as follows. Rater competence for performing kinematic and clinical evaluations was assessed by the senior authors. After the 4 raters finished the clinical evaluation of all participants, we calculated the post hoc interrater reliability for FMA and Functional Independence Measure (FIM) and obtained high reliability (intraclass correlation coefficients[23] >.95 for both measures).[24] Patients were advised not to indicate their treatment assignment to the evaluator.

Kinematic analysis. Experimental tasks used in the kinematic analysis included 1 unilateral task and 1 bimanual task. The unilateral task involved pressing a desk bell, and the bilateral task involved opening a box to retrieve a sticky note. During the tasks, each participant sat on a height-adjustable chair with seat height set to 100% of the lower leg length, measured from the lateral knee joint to the floor, with the participant standing. The table height was adjusted to 2 inches. below the elbow. The participant rested his or her hands on the edge of the table. The trunk was harnessed to the chair back to minimize trunk flexion and rotation.

The target object (desk bell or box) was located along the participant's midsagittal plane, and the reaching distance was standardized to the participant's functional arm length. Functional arm length was defined as the distance from the medial border of the axilla to the distal wrist crease.[25] If the maximum distance the patient could reach was less than the functional arm length, the reaching distance to the target was adjusted to the maximum reachable distance.

For the unilateral task, participants reached to press a desk bell 3 cm in length and width and 0.5 cm in height. The participant was instructed to use the index finger of the affected hand to reach and press the task bell as fast as possible. For the bilateral task, participants used the affected hand to open a 10 × 10 × 8 cm (length × width × height) box by holding the lid and used the unaffected hand to retrieve a sticky note (7 × 3 × 6 cm) inside the box at a comfortable speed. Only reaching movements of the affected hand were recorded during this task. After a practice trial, 3 data-producing trials were performed.

During the 2 tasks, an 8-camera motion analysis system (VICON MX; Oxford Metrics Inc, Oxford, UK) was used in conjunction with a personal computer to capture the movement of a marker attached on the ulnar styloid. The system was calibrated to have averaged residual errors not exceeding 0.5 mm for each camera before data acquisition. For the unilateral task, 1 channel of analog signals was collected to signal the end of the movement when the bell was pressed.

The experimenter said "ready' to remind the participant to prepare performing the experimental task and then pressed the desk bell to indicate the start of the task. The time between the warning and start signal was not a fixed length. Movement onset was defined as a rise of tangential wrist velocity above 5% of its peak value for both testing tasks. This practice was based on the proposals of previous reports.[26-28] During the unilateral task, end of movement was defined as the time when the participant pressed the desk bell. During the bilateral task, movement offset was defined as a fall of tangential wrist velocity below 5% of its peak value. Movements were recorded at 120 Hz and digitally low-pass filtered at 5 Hz using a second-order Butterworth filter with forward and backward passes.

Clinical assessment. We used the 66-point, UE section of the FMA to evaluate motor impairment of the affected UE. This instrument assesses several dimensions of motor impairment using a 3-point ordinal scale: 0 = cannot perform; 1 = can perform partially; 2 = can perform fully.[29] A higher FMA score indicates less motor impairment. Test–retest reliability, interrater reliability, and construct validity of the test are well established in stroke patients.[30,31]

We used the FIM instrument to measure the functional ability of participants. It consists of 18 items grouped into 6 subscales measuring self-care, sphincter control, transfer, locomotion, communication, and social ability.[32] Each item is rated with a score from 1 to 7, for a maximum score of 126: 1 = complete assistance to perform basic activities of daily living; 2 = maximal assistance; 3 = moderate assistance; 4 = minimal assistance; 5 = supervision; 6 = modified independence; and 7 = complete independence in performing basic daily living. The FIM has established good interrater reliability, construct validity,[33,34] and discriminate validity.[35] We also used the Motor Activity Log (MAL), a semistructured interview of patients, to assess the amount of use (AOU) and quality of movement (QOM) of the affected UE in 30 important daily activities using a 6-point ordinal scale. Higher scores indicate better performance. This scale shows good reliability and validity in stroke patients.[36-38]

Data Reduction for Kinematic Variables

An analysis program coded by LabVIEW (National Instruments, Inc, Austin, TX) language was used to process kinematic data. Kinematic variables for reaching included normalized movement time (nMT), normalized total distance (nTD), and the percentage of movement time where peak velocity occurs (PPV):

1. *Normalized movement time (nMT):* Movement time (MT) refers to the time for execution of the reaching movement. It is the interval between movement onset and movement offset, representing temporal efficiency.[25,39,40] Because the task distance varied across subjects, MT was normalized to correct for variations in reaching distance.
2. *Normalized total distance (nTD):* Spatial efficiency was characterized by nTD, which refers to the path of hand in 3-dimensional space and normalized by the direct distance between hand at start position and target in each participant. The smaller the nTD was the more direct the movement path would be.[40]
3. *The percentage of movement time at which peak velocity occurs (PPV):* This variable was used to characterize the control strategy of reaching. It reflects the percentage of movement time used for the acceleration phase. The acceleration phase represents the major preplanned aspect of the movement.[41] A higher PPV value indicates a longer acceleration phase, suggesting less online error correction and more preplanned control of the reaching movement.[42-44]

Data Analysis

Analysis of covariance (ANCOVA), controlling for pretreatment differences, was used to compare the 2 groups' improvement for each outcome variable (kinematic values and FMA, FIM, and MAL scores). Pretest performance was the covariate, group was the independent variable, and posttest performance was the dependent variable. Statistical significance was determined based on 1-tailed tests with an α of .05. To index the magnitude of group differences in performance, $\eta^2 = SS_b/SS_{total}$ was calculated for each outcome variable. The value of η^2 represents the variability in the dependent variable (posttest performance) that can be explained or accounted for by the independent variable (group).[20] A large effect is represented by an η^2 of at least .138, a moderate effect by an η^2 of .059, and a small effect by an η^2 of .01.[45]

Results

Characteristics of Participants

After being randomly assigned, 16 participants received BAT intervention, and 17 were in the control group. Table 1 summarizes the demographic and clinical characteristics of the participants in the 2 groups. Baseline characteristics were comparable across these 2 groups. There were no significant differences between the groups for age, months since stroke, side of stroke lesion (left/right), or Brunnstrom stage of proximal/distal part.

Kinematic Analysis

Table 2 summarizes the descriptive statistics and the results of the ANCOVA that tested the effects of BAT relative to CI on kinematic variables during the unilateral and bilateral tasks.

For kinematic variables in the unilateral functional task, the ANCOVA results showed that nMT and nTD were significantly less in the BAT group than in the control group ($F_{1,30}$ = 3.601, P = .034, η^2 = .107; $F_{1,30}$ = 3.352, P = .039, η^2 = .101, respectively). A nonsignificant and small effect was found for the kinematic variable of PPV ($F_{1,30}$ = .071, P = .396, η^2 = .002). The results of the kinematic analysis indicated that the BAT group showed higher efficiency in the temporal and spatial aspects after treatment than the control group during the unilateral task, but there was no difference in relative time for online error correction.

The effects of BAT on reaching kinematics of the affected UE were significant and moderate for the bilateral functional task. The results of ANCOVA showed significantly lower nMT ($F_{1,30}$ = 5.268, P = .015, η^2 = .149), lower nTD ($F_{1,30}$ = 5.046, P = .016, η^2 = .144), and higher PPV ($F_{1,30}$ = 11.811, P = .001, η^2 = .282) after BAT relative to CI. The BAT group showed higher efficiency in the temporal and spatial aspects and less online error correction control after treatment than the control group during the bilateral task.

Motor Performance

Table 3 summarizes the descriptive statistics and the results of the ANCOVA that tested the effects of BAT relative to CI on the FMA (ie, degree of motor impairment). The BAT group demonstrated a significantly greater improvement on the FMA than the control group ($F_{1,30}$ = 3.257, P = .041, η^2 = .098).

Functional Ability

Table 3 also presents the descriptive statistics and the results of the ANCOVA in functional ability as measured by the FIM and the MAL. No significant differences were noted in FIM total scores ($F_{1,30}$ = 0.839, P = .18, η^2 = .027) or in any domains of the FIM between the 2 groups. No significant differences were found in the AOU or QOM (AOU: $F_{1,30}$ = 1.436, P = .12, η^2 = .046; QOM: $F_{1,30}$ = 1.495, P = .17, η^2 = .047) between the 2 groups.

Discussion

Only a few randomized controlled trials[3,19] have studied the effects of BAT without robot assistance on motor control, motor impairment, and functional abilities. However, these previous studies involved very low intensity of training (eg, 30 minutes per session). The present study used a more intensive BAT program (ie, 2 hours per day) for comparison with a dose-matched control intervention. The results are consistent in part with the a priori hypotheses that patients with BAT would have better motor control, show less motor impairment, and obtain a greater gain in functional abilities than the control group. The BAT group showed a greater efficiency of reaching in the temporal and spatial aspects (less nMT and less nTD) during both the unilateral and bilateral tasks. The BAT group also showed better (more preplanned) control strategy (ie, higher PPV) than the control group in the bilateral task. In addition, the BAT group achieved greater gains in FMA scores than did the control group but not in the FIM and MAL.

Kinematic Analysis

Consistent with previous studies,[4,7,17] the BAT group participants performed the reaching task more efficiently (less nMT) and more directly (less nTD) with the affected arm in both unilateral and bilateral tasks. This study extended previous research[9,10] by using test tasks different from the training tasks. The possibility that the therapeutic effects could be specific to the task being trained is ruled out in the present study. The beneficial effects might be attributed to bilateral simultaneous movements promoting interhemispheric disinhibition and allowing for cortical reorganization by sharing normal movement commands from the undamaged hemisphere.[9,46] When the intact arm performed the same spatiotemporal pattern as the affected arm, the "template" from the undamaged hemisphere would be generated, which could be applied to both limbs in bilateral actions[9,10,47] and thus lead to more efficient performance of the affected

Table 1. Demographic and Clinical Characteristics of the Participants[a]

	BAT (n = 16)	Control (n = 17)	Statistic	P^b
Gender (male/female)	10/6	9/8	.041	.839
Age (years)	52.08 ± 9.60	55.50 ± 13.17	–.842	.406
Months since stroke	13.94 ± 12.73	13.12 ± 8.13	.222	.826
Side of stroke lesion (right/left)	7/9	9/8	.279	.732
Brunnstrom stage of proximal part of UE (median [range])	5 (3-5)	5 (4-5)	111.50	.297
Brunnstrom stage of distal part of UE (median [range])	4 (3-6)	5 (4-6)	90.00	.080

Abbreviations: BAT, bilateral arm training; UE, upper extremity.
[a]Values are mean ± standard deviation or as otherwise indicated.
[b]*P* associated with the χ^2 test for categorical variables, with the independent *t* test for continuous variables, and with the Mann–Whitney *U* test for ordinal variables.

Table 2. Descriptive and Inferential Statistics for Analysis of Reaching Kinematics[a]

	Pretreatment		Posttreatment		Adjusted Means[b]		ANCOVA		
	BAT (n = 16)	Control (n = 17)	BAT (n = 16)	Control (n = 17)	BAT (n = 16)	Control (n = 17)	$F_{1,30}$	P	η^2
Unilateral task									
nMT (s/cm)	0.04 ± 0.03	0.01 ± 0.02	0.03 ± 0.03	0.01 ± 0.02	0.02	0.03	3.60	.034[c]	.107
nTD (unit)	1.38 ± 0.46	1.26 ± 0.26	1.34 ± 0.35	1.19 ± 0.16	1.23	1.30	3.35	.039[c]	.101
PPV (%)	36.74 ± 12.72	36.45 ± 10.84	40.75 ± 15.00	41.33 ± 10.40	40.63	41.44	0.071	.40	.002
Bilateral task									
nMT (s/cm)	0.17 ± 0.12	0.13 ± 0.13	0.09 ± 0.03	0.10 ± 0.06	0.09	0.11	5.27	.015[c]	.149
nTD (unit)	1.57 ± 0.07	1.41 ± 0.34	1.31 ± 0.26	1.36 ± 0.20	1.29	1.39	5.05	.016[c]	.144
PPV (%)	22.97 ± 10.36	21.64 ± 10.24	29.02 ± 11.90	20.54 ± 9.35	28.44	21.09	11.81	.001[c]	.282

Abbreviations: ANCOVA, analysis of covariance; BAT, bilateral arm training; nMT, normalized movement time; nTD, normalized total displacement; PPV, percentage of movement time to peak velocity.
[a]Values are mean ± standard deviation or as otherwise indicated.
[b]Adjusted means (ie, adjusted posttreatment means) are usually part of ANCOVA output and obtained from altering the original means to control for the covariates (ie, pretreatment values).[23,24]
[c]$P < .05$.

arm. The postulated mechanism for the effects of BAT requires further study using functional brain imaging techniques. A second possible explanation for the beneficial effects lies in the limb-coupling mechanism for symmetric tasks. During the bilateral symmetric tasks of daily living, the temporal and spatial parameters of the 2 arms are substantially similar, and the coupling mechanism is maximally operative.[18] Accordingly, the performance of the affected arm improved in the spatial and temporal aspects (movement straightness and efficiency) for both bilateral and unilateral tasks.

However, differences in the control strategy between the BAT and control group were found in the bilateral task but not in the unilateral task, consistent with a previous study.[3] The BAT group used less online correction control strategies to implement the bilateral task than the control group. Both groups used less online control in the unilateral task posttreatment with no significant between-group differences.[44] The possible explanation for the differential performance of the unilateral versus bilateral task pertains to the concept of interhemispheric disinhibition triggered by bilateral movements. When the intact arm was resting during the unilateral task, the undamaged hemisphere was not activated to generate the "template" of firing organization to guide the affected arm during skilled actions.[9,10,47] Another possible account is that the unilateral and bilateral experimental tasks involved different task objects (ie, target size and shape) that may affect the control strategy.[48] The bilateral task involved movement sequencing and might be easier to induce different strategies between the 2 groups than the unilateral task.

Motor Performance

The results showed that BAT demonstrated greater reduction of motor impairment as measured by the FMA than the control treatment. Simultaneous activation of both hands may have rebalanced interhemispheric activation and inhibition, causing an additional facilitation in the affected hemisphere and positive after effects for reducing the motor impairment of the affected UE.[18,46,47] In addition, a variety of functional symmetric tasks were incorporated into the

Table 3. Descriptive and Inferential Statistics for Analysis of Motor Impairments (FMA) and Functional Ability (FIM and MAL)[a]

	Pretreatment		Posttreatment		Adjusted Means[b]		ANCOVA		
	BAT (n = 16)	Control (n = 17)	BAT (n = 16)	Control (n = 17)	BAT (n = 16)	Control (n =17)	$F_{1,30}$	P	η^2
FMA	48.00 ± 12.35	53.53 ± 7.58	57.63 ± 1.03	54.99 ± 1.00	57.63	54.99	3.26	.041[c]	.098
FIM									
Self-care	37.38 ± 5.49	36.94 ± 7.30	38.38 ± 5.48	37.41 ± 6.69	38.36	37.39	0.97	.17	.031
Sphincter	13.37 ± 2.03	14.00 ± 0.00	13.50 ± 2.00	14.00 ± 0.00	13.49	13.99	0.61	.22	.020
Transfer	20.06 ± 2.38	20.47 ± 1.07	19.94 ± 2.35	20.35 ± 1.06	19.93	20.34	0.03	.43	.001
Locomotion	13.13 ± 1.78	13.24 ± 0.90	13.19 ± 1.83	13.00 ± 1.32	13.19	13.01	1.21	.14	.039
Communication	13.63 ± 0.72	13.00 ± 1.84	13.69 ± 0.60	13.06 ± 1.78	13.70	13.07	0.17	.34	.006
Social cognition	19.81 ± 1.52	19.00 ± 3.50	20.19 ± 1.38	19.35 ± 2.40	20.18	19.35	0.79	.19	.026
Total	117.38 ± 12.09	116.65 ± 10.82	118.88 ± 11.75	117.18 ± 9.63	118.84	117.14	0.84	.18	.027
MAL									
AOU	1.06 ± 0.83	1.27 ± 0.91	1.25 ± 0.92	1.70 ± 1.04	1.34	1.61	1.44	.12	.046
QOM	1.18 ± 0.80	1.54 ± 1.18	1.42 ±0.97	1.99 ± 1.10	1.56	1.86	1.50	.17	.047

Abbreviations: FMA, Fugl-Meyer Assessment; FIM, Functional Independence Measure; BAT, bilateral arm training; ANCOVA, analysis of covariance; MAL, Motor Activity Log; AOU, Amount of Use; QOM, Quality of Movement.
[a]Values are mean ± standard deviation.
[b]Adjusted means (ie, adjusted posttreatment means) are usually part of ANCOVA output and obtained from altering the original means to control for the covariates (ie, pretreatment scores).[23,24]
[c]$P < .05$.

BAT program in the study that allowed repetitive practice on skilled movements. Our findings are consistent with previous studies[5,6,12,15,17] that found improvements after BAT. In contrast, some studies[8,11,16] did not corroborate the benefits of BAT, possibly because these studies were based on a small trial with heterogeneous characteristics of study subjects (eg, time after onset of stroke).

Functional Ability

Consistent with some previous research,[5,8,13,16] this study found no significant differences between the treatment groups in daily function as measured by the FIM and the MAL. This result might be due to the measurement tool that we used for assessing ADL. Although the FIM is a commonly used evaluation tool in the efficacy research of stroke rehabilitation, it is a measure of level of assistance and is not specific to use and function of the paretic limb. The FIM might not be sensitive to detect changes for high functioning patients of stroke as studied in this present research. Furthermore, patients in the BAT group did not perceive increased paretic UE use or better quality of UE movements as measured by the MAL than those in the CI group. It is possible that we did not specifically recruit patients with the learned nonuse phenomenon who demonstrated to habitually use the unaffected UE although the affected UE has the potential to perform the task. Furthermore, the BAT program did not emphasize mass practice of the affected UE as constraint-induced therapy does, but involved bilateral symmetrical activities. In daily life, many bimanual tasks are bilateral complementary tasks that require a differentiated role for each hand, for example, opening a jam jar.[18] Practice on symmetric bilateral tasks might not be sufficient for improving functional performance. The findings suggest that other activities of daily living (ADL) instruments that measure specific daily functional abilities that depend on the improved UE function (eg, the Klein-Bell ADL scale[49]) should be employed in future research to study the effects of BAT on daily functions. In addition, stroke patients may need to relearn various types of bimanual skills, including bilateral symmetric and complementary tasks, to achieve improvement in the wide variety of daily activities. Whitall et al[12] reported greater gains in functional ability after bilateral training. Of note, their study involved no control group for comparison and thus failed to provide compelling evidence to support the benefits of BAT for improving daily function.

The overall findings of this study suggest that BAT might be a better approach than conventional rehabilitation to improve motor impairment and enhance motor control, especially during bilateral arm movements. However, the benefits of BAT for improving functional ability need further examination using appropriate measurements that may specifically detect changes in functional performance of the UE as a result of the treatment.

A few limitations of the present study warrant considerations when generalizing the results beyond the study. First, there is a lack of follow-up data to address whether the benefits of BAT persist. The advantages of BAT for motor control and motor performance over CI might be reversed over time, and follow-up study is required to examine this possibility. Second, this study only used a bilateral complementary task to evaluate the changes in motor control after intervention. Whether the effects of BAT on such a bilateral task can be generalized to bilateral symmetrical tasks remains to be scrutinized. Third, PPV used in this study may not fully represent the control strategy of movement. Future research may measure the number of acceleration and deceleration phases to study the control strategy.[39]

Finally, although we used a sample larger than previous trials,[7,8,11,13,16,19] our study subjects were higher functioning patients and represented only a small percentage of all eligible patients. Further research should recruit a larger sample and study patients differing in severity of motor impairment. Future research also needs to identify factors that may affect study findings, including premorbid hand dominance and cognitive function relevant for stroke rehabilitation such as divided attention[50] and sequencing.

Future work should also address optimal dose and training characteristics for BAT and use outcome measures relevant for daily life situations (eg, the accelerometry system[51,52] that monitors activity of the bilateral UEs[53] in the community). In addition, brain imaging research is needed to verify the suppositions regarding brain plastic change after BAT.

Conclusion

Extending previous research on BAT after stroke, this study incorporated a variety of bilateral symmetrical and functional tasks into a BAT program in chronic stroke patients who are not expected to show spontaneous recovery. The study showed the effects of the BAT program for improving some aspects of motor control strategies of the affected arm in both bilateral and unilateral tasks and reducing motor impairments. The findings suggest that the BAT should be a favorable approach if improving motor control and motor performance of the affected UE in stroke patients is the primary treatment goal. Future research might consider coupling bilateral with unilateral approaches to further improve the control strategy of the affected arm in unilateral functional tasks.

Authors' Note

No commercial party having a direct financial interest in the results of research supporting this article has or will confer a benefit on the authors or on any organization with which the authors are associated.

Declaration of Conflicting Interests

The authors declared no conflicts of interest with respect to the authorship and/or publication of this article.

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References

1. Schaechter JD. Motor rehabilitation and brain plasticity after hemiparetic stroke. *Prog Neurobiol*. 2004;73:61-72.
2. Pomeroy V, Tallis R. Neurological rehabilitation: a science struggling to come of age. *Physiother Res Int*. 2002;7:76-89.
3. Mudie MH, Matyas TA. Responses of the densely hemiplegic upper extremity to bilateral training. *Neurorehabil Neural Repair*. 2001;15:129-140.
4. Platz T, Winter T, Muller N, Pinkowski C, Eickhof C, Maurita KH. Arm ability training for stroke and traumatic brain injury patients with mild arm paresis: a single-blind, randomized, controlled trial. *Arch Phys Med Rehabil*. 2001;82:961-968.
5. Luft A, McCombe Waller S, et al. Repetitive bilateral arm training and motor cortex activation in chronic stroke. A randomized controlled trial. *JAMA*. 2004;292:1853-1861.
6. Hesse S, Werner C, Pohl M, Rueckriem S, Mehrholz J, Lingnau ML. Computerized arm training improves the motor control of the severely affected arm after stroke. A single-blinded randomized trial in two centers. *Stroke*. 2005;36:1960-1966.
7. Summers JJ, Kagerer FA, Garry MI, Hiraga CY, Loftus A, Cauraugh JH. Bilateral and unilateral movement training on upper limb function in chronic stroke patients: a TMS study. *J Neurol Sci*. 2007;252:76-82.
8. Morris JH, van Wijck F, Joice S, Ogston SA, Cole I, MacWalter RS. A comparison of bilateral and unilateral upper-limb task training in early poststroke rehabilitation: a randomized controlled trial. *Arch Phys Med Rehabil*. 2008;89:1237-1245.
9. Mudie MH, Matyas TA. Upper extremity retraining following stroke: effects of bilateral practice. *J Neurol Rehabil*. 1996;10:167-184.
10. Mudie MH, Matyas TA. Can simultaneous bilateral movement involve the undamaged hemisphere in reconstruction of neural networks damaged by stroke? *Disabil Rehabil*. 2000;22:23-37.
11. Lewis GN, Byblow WD. Neurophysiological and behavioral adaptations to a bilateral training intervention in individuals following stroke. *Clin Rehabil*. 2004;18:48-59.
12. Whitall J, McCombe Waller S, Silver KHC, Macko RF. Repetitive bilateral arm training with rhythmic auditory cueing improves motor function in chronic hemiparetic stroke. *Stroke*. 2000;31:2390-2395.
13. Richards LG, Senesac CR, Davis SB, Woodbury ML, Nadeau SE. Bilateral arm training with rhythmic auditory cueing in chronic stroke: not always efficacious. *Neurorehabil Neural Repair*. 2008;22:180-184.
14. McCombe Waller S, Liu W, Whitall J. Temporal and spatial control following bilateral versus unilateral training. *Hum Mov Sci*. 2008;27:749-758.

15. Stinear JW, Byblow WD. Rhythmic bilateral movement training modulates corticomotor excitability and enhances upper limb motricity poststroke: a pilot study. *J Clin Neurophysiol*. 2004;21:124-131.
16. Lum PS, Burgar CG, van der Loos M, Shor PC, Majmundar M, Yap R. MIME robotic device for upper-limb neurorehabilitation in subacute stroke subjects: a follow-up study. *J Rehabil Res Dev*. 2006;43:631-642.
17. Chang JJ, Tung WL, Wu WL, Huang MH, Su FC. Effects of robot-aided bilateral force-induced isokinematic arm training combined with conventional rehabilitation on arm motor function in patients with chronic stroke. *Arch Phys Med Rehabil*. 2007;88:1332-1338.
18. McCombe Waller S, Whitall J. Bilateral arm training: why and who benefits? *NeuroRehabilitation*. 2008;23:29-41.
19. Platz T, Bock S, Prass K. Reduced skillfulness of arm motor behaviour among motor stroke patients with good clinical recovery: does it indicate reduced automaticity? Can it be improved by unilateral or bilateral training? A kinematic motion analysis study. *Neuropsychologia*. 2001;39:687-698.
20. Carr JH, Shepherd RB. Reaching and manipulation. In: Carr JH, Shepherd RB, eds. *Stroke Rehabilitation: Guidelines for Exercise and Training to Optimize Motor Skill*. Edinburgh, UK: Butterworth Heinemann; 2003:159-191.
21. Brunnstrom S. *Movement Therapy in Hemiplegia*. New York, NY: Harper & Row; 1970.
22. Bohannon RW, Smith MB. Interrater reliability of a Modified Ashworth Scale of muscle spasticity. *Phys Ther*. 1987;67:206-207.
23. Rosenthal R, Rosnow RL. *Essentials of Behavioral Research: Methods and Data Analysis*. 2nd ed. New York, NY: McGraw-Hill; 1991.
24. Portney LG, Watkins MP. *Foundations of Clinical Research: Application to Practice*. 3rd ed. Upper Saddle River, NJ: Prentice Hall Health; 2009.
25. Wu CY, Chen CL, Tang SF, Lin KC, Huang YY. Kinematic and clinical analyses of upper-extremity movements after constraint-induced movement therapy in patients with stroke: a randomized controlled trial. *Arch Phys Med Rehabil*. 2007;88:964-670.
26. Michaelsen SM, Levin MF. Short-term effects of practice with trunk restraint on reaching movements in patients with chronic stroke. *Stroke*. 2004;35:1914-1919.
27. Michaelsen SM, Dannenbaum R, Levin MF. Task-specific training with trunk restraint on arm recovery in stroke: randomized control trial. *Stroke*. 2006;37:186-192.
28. Tunik E, Poizner H, Levin MF, et al. Arm-trunk coordination in the absence of proprioception. *Exp Brain Res*. 2003;153:343-355.
29. Fugl-Meyer AR, Jaasko L, Leyman I, Olsson S, Steglind S. The post-strike hemiplegia patient. I. A method for evaluation of physical performance. *Scand J Rehabil Med*. 1975;7:13-31.
30. Duncan PW, Propst M, Nelson SG. Reliability of the Fugl-Meyer assessment of sensorimotor recovery following cerebrovascular accident. *Phys Ther*. 1983;63:1601-1610.
31. DiFabio RP, Badke RB. Relationship of sensory organization to balance function in patients with hemiplegia. *Phys Ther*. 1990;70:542-548.
32. Hamilton BB, Granger CV, Sherwin FS, Zielezny M, Tashman JS. A uniform national data system for medical rehabilitation. In: Fuhrer MJ, ed. *Rehabilitation Outcomes: Analysis and Measurements*. Baltimore, MD: Brookes; 1987:137-147.
33. Chau N, Daler S, Andre JM, Patris A. Inter-rater agreement of two functional independence scales: the Functional Independence Measure (FIM) and a subjective uniform continuous scale. *Disabil Rehabil*. 1994;16:63-71.
34. Hamilton BB, Laughlin JA, Fiedler RC, Granger CV. Interrater reliability of the 7-level Functional Independence Measure (FIM). *Scand J Rehabil Med*. 1994;26:115-119.
35. Gosman-Hedstrom G, Svensson E. Parallel reliability of the Functional Independence Measure and the Barthel ADL index. *Disabil Rehabil*. 2000;22:702-715.
36. Sterr A, Elbert T, Berthold I, Kolbel S, Rockstroh B, Taub E. Longer versus shorter daily constraint-induced movement therapy of chronic hemiparesis: an exploratory study. *Arch Phys Med Rehabil*. 2002;83:1374-1377.
37. Uswatte G, Taub E, Morris D, Light K, Thompson PA. The Motor Activity Log-28: assessing daily use of the hemiparetic arm after stroke. *Neurology*. 2006;67:1189-1194.
38. van der Lee JH, Beckerman H, Knol DL, de Vet HCW, Bouter LM. Clinimetric properties of the Motor Activity Log for the assessment of arm use in hemiparetic patients. *Stroke*. 2004;35:1410-1414.
39. Lin KC, Wu CY, Wei TH, Lee CY, Liu JS. Effects of modified constraint-induced movement therapy on reach-to-grasp movements and functional performance after chronic stroke: a randomized controlled study. *Clin Rehabil*. 2007;21:1075-1086.
40. Wu CY, Lin KC, Chen HC, Chen IH, Hong WH. Effects of modified constraint-induced movement therapy on movement kinematics and daily function in patients with stroke: a kinematic study of motor control mechanisms. *Neurorehabil Neural Repair*. 2007;21:460-466.
41. Georgopoulos AP. On reaching. *Annu Rev Neurosci*. 1986;9:147-170.
42. Kamper DG, McKenna AN, Kahn LE, Reinkensmeyer DJ. Alterations in reaching after stroke and their relationship to movement direction and impairment severity. *Arch Phys Med Rehabil*. 2002;83:702-707.
43. Haaland KY, Prestopnik J, Lee RR, Adair J. Hemispheric asymmetries for kinematic and positional aspects of reaching. *Brain*. 2004;127:1145-1158.
44. Elliott D, Helsen, WF, Chua R. A century later: Woodworth's (1899) two-component model of goal-directed aiming. *Psychol Bull*. 2001;127:342-357.

45. Cohen J. *Statistical Power Analysis for the Behavioral Sciences*. 2nd ed. Hillsdale, NJ: Erlbaum; 1988.
46. Cauraugh JH, Summers JJ. Neural plasticity and bilateral movements: a rehabilitation approach for chronic stroke. *Prog Neurobiol*. 2005;75:309-320.
47. Stewart KC, Cauraugh JH, Summers JJ. Bilateral movement training and stroke rehabilitation: a systematic review and meta-analysis. *J Neurol Sci*. 2006;244:89-95.
48. Adam JJ. The effects of objectives and constraints on motor control strategy in reciprocal aiming movements. *J Mot Behav*. 1992;24:173-185.
49. Smith RO, Morrow ME, Heitman JK, Rardin WJ, Powelson JL, Von T. The effects of introducing the Klein-Bell ADL Scale in a rehabilitation service. *Am J Occup Ther*. 1986;40:420-424.
50. McDowd JM, Filion DL, Pohl PS, Richards LG, Stiers W. Attentional abilities and functional outcomes following stroke. *J Gerontol B Psychol Sci Soc Sci*. 2003;58:P45-P53.
51. Uswatte G, Giuliani G, Winstein C, Zeringue A, Hobbs L, Wolf SL. Validity of accelerometry for monitoring real-world arm activity in patients with subacute stroke: evidence from the extremity constraint-induced therapy evaluation trial. *Arch Phys Med Rehabil*. 2006;87:1340-1345.
52. Choquette S, Hamel M, Boissy P. Accelerometer-based wireless body area network to estimate intensity of therapy in post-acute rehabilitation. *J Neuroeng Rehabil*. 2008;5:20.
53. Mehrholz J, Wagner K, Rutte K, Meissner D, Pohl M. Predictive validity and responsiveness of the functional ambulation category in hemiparetic patients after stroke. *Arch Phys Med Rehabil*. 2007;88:1314-1319.