Pilot Comparative Study of Unilateral and Bilateral Robot-Assisted Training on Upper-Extremity Performance in Patients With Stroke

Chieh-Ling Yang, Keh-Chung Lin, Hsieh-Ching Chen, Ching-Yi Wu, Chia-Ling Chen

We compared a unilateral robot-assisted training protocol (URTP) and a bilateral robot-assisted training protocol (BRTP) to study their differential effects. We recruited 21 patients with stroke who received 90–105 min of therapy 5 days/wk for 4 wk. Participants in the URTP and BRTP groups practiced forearm pronation and supination and wrist flexion and extension in a simultaneous manner with the Bi-Manu-Track. The control group received standard rehabilitation. Clinical measures included the Fugl-Meyer Assessment, the Medical Research Council instrument, grip strength, and the Modified Ashworth Scale to assess motor impairment, muscle power, muscle strength, and spasticity, respectively. The pilot study indicated that the URTP and BRTP might have differential benefits for movement improvement. URTP might be a more compelling approach to improving upper-limb motor impairment, muscle power, and strength at the distal joints than BRTP, whereas BRTP could be an optimal approach to improving proximal muscle power.


Stroke is the leading cause of long-term disability among adults worldwide (Feigin, Lawes, Bennett, & Anderson, 2003). Severe hemiparesis with limited hand function seriously affects functional recovery in 85% of patients with stroke (Broeks, Lankhorst, Rumping, & Prevo, 1999; Cauraugh, Kim, & Duley, 2005; Hakkennes & Keating, 2005). Optimal rehabilitation protocols of upper-extremity motor function are necessary for patients with stroke to perform activities of daily living (ADLs). Researchers and therapists are searching for effective therapeutic techniques to improve motor recovery. Robot-assisted training is one emerging approach with the advantage of high-intensity, repetitive, and task-specific training, which is essential for motor learning of the impaired upper limb. Numerous studies have shown that robot-assisted arm training may improve motor impairment and strength of the paretic arm (Kwakkel, Kollen, & Krebs, 2008; Mehrholz, Platz, Kugler, & Pohl, 2008).

Current robotic devices can be grouped by technical differences into two general types: end-effector and exoskeleton systems. With end-effector systems, the device provides a resistive or assistive force through the manipulum so that patients can move actively or be guided passively by the device to complete the movements. With exoskeleton systems, the robot joint axis is directly attached to the limb joint axis, and electromagnetic motors are used to actuate limb movements at multiple joints in their degrees of freedom. The end-effector systems are easier to set up and adjust for patients of different body sizes than the exoskeleton systems (Huang & Krakauer, 2009). Accordingly, end-effector systems are more applicable in the clinical setting.
The Bi-Manu-Track (Reha-Stim, Berlin, Germany), a commercially available end-effector robotic device, provides bilateral practice of passive and active forearm and wrist movements. A systematic review by Kwakkel et al. (2008) noted that a study using the Bi-Manu-Track for distal training reported a larger effect size than other studies using robotic devices for proximal training. This larger effect size might have resulted from the training of proximal limb segments causing diminished synapses for the distal limb segment (Krebs et al., 2007) and decreasing the overall effects. Previous studies (Hesse, Schulte-Tigges, Konrad, Bardeleben, & Werner, 2003; Hesse et al., 2005) applied the Bi-Manu-Track with patients with severe hemiparesis because the affected arms can be guided passively in a symmetrical pattern. The Bi-Manu-Track also provides a resistive mode to increase the difficulty level of tasks, a feature that might be appropriate for patients recovering from severe impairments after training and patients with mild to moderate impairments who are focused on regaining upper-extremity performance.

Accordingly, a modified protocol using unilateral limb training with the Bi-Manu-Track could be designed for patients with stroke and mild to moderate impairment. The modified unilateral protocol might lead to distinct benefits compared with the bilateral approach because of the different potential mechanisms underlying the two approaches. The modified unilateral protocol targets facilitation of corticospinal pathways from the damaged cortical hemisphere and results in treatment-related motor gains (Dong, Weinstein, Albitsegui-DuBois, & Dobkin, 2007). The bilateral protocol, in contrast, may increase recruitment of the ipsilateral (i.e., undamaged hemispheric) uncrossed corticospinal pathways projecting to the affected arms to assist in arm movements (Cauraugh & Summers, 2005) and use the template generated by the undamaged hemisphere to control both arm movements.

No study to date has used the same robotic device to investigate the relative effects of unilateral and bilateral modes. One study by Lum et al. (2006), using the Mirror Image Movement Enabler robot, included unilateral and bilateral robot-assisted therapy groups but lacked direct comparison between these two groups.

Comparative effectiveness research on different rehabilitation approaches may provide a clear picture for determining the most appropriate treatment choice for which patients under what circumstances (Freburger & Carey, 2010; French & England, 2010; Gibbons et al., 2009). Comparing unilateral and bilateral robot-assisted training is important for understanding the possible differential effects on motor ability and also for addressing important gaps in the knowledge of robot-assisted training. We designed this study to compare the relative effects of the unilateral (modified) protocol and bilateral protocol of the Bi-Manu-Track. The primary measures included motor impairment as assessed by the upper-extremity portion of the Fugl-Meyer Assessment (FMA–UE; Fugl-Meyer, Jääskö, Leyman, Olsson, & Ståln, 1975; Sanford, Moreland, Swanson, Stratford, & Gowland, 1993), muscle power as assessed by the Medical Research Council (MRC) instrument (Medical Research Council of the United Kingdom, 1978), and muscle strength (grip strength) measured with a dynamometer. The secondary measures included muscle spasticity, evaluated with the Modified Ashworth Scale (MAS; Ashworth, 1964). We hypothesized that both the modified unilateral and the bilateral approaches of the Bi-Manu-Track would elicit better performance than the control treatment. In addition, the unilateral and bilateral modes may have differential effects on different outcome measures.

Method

Study Design

We used a randomized pretest–posttest study design. Eligible participants were randomized to receive the unilateral robot-assisted training protocol (URTP), the bilateral robot-assisted training protocol (BRTP), or the control treatment (Figure 1) by the computerized randomization scheme. The interventions were administered during the occupational therapy sessions. No other occupational therapy interventions were applied to the participants. All other routine interdisciplinary stroke rehabilitation, including physical therapy or speech therapy, proceeded as usual. Five certified occupational therapists were trained to administer the URTP, BRTP, and control treatment protocols at five participating hospitals. Before and after the 4-wk intervention period, clinical outcome measures were administered by a certified, trained occupational therapist blinded to the participants’ group.

Sample

We recruited 21 patients with stroke (14 men, 7 women) with an average age of 51.29 yr (range = 33.75–65.92 yr). Inclusion criteria were (1) clinical diagnosis of a first or recurrent unilateral cerebral stroke within the past 6 mo–5 yr, verified by brain imaging; (2) the ability to reach Brunnstrom Stage III (Brunnstrom, 1966, 1970) or higher in the proximal and distal part of the arm; (3) no excessive spasticity in any joints of the affected arm, including shoulder, elbow, wrist, and fingers (MAS score
≤2 in any joint); (4) no serious cognitive deficits (Mini-Mental State Examination [MMSE] score ≥22; Folstein, Folstein, & McHugh, 1975); (5) FMA–UE sensation score >1 for any item; (6) no other neurologic, neuromuscular, or orthopedic disease; and (7) no participation within the past 3 mo in any experimental rehabilitation or drug studies.

**Apparatus**

The Bi-Manu-Track is a 2 × 1 degree-of-freedom device offering two movement patterns: (1) forearm pronation and supination and (2) wrist flexion and extension. Three computer-controlled modes were offered:

- **Mode 1**: passive–passive, with arms guided passively by the machine;
- **Mode 2**: active–passive, with the nonparetic arm leading the paretic arm (i.e., the nonparetic arm actively moves the handle throughout the whole movement and the paretic arm is guided passively by the device) in a symmetric direction; and
- **Mode 3**: active–active, with both arms performing actively by overcoming resistance.

Mode 3 is an active mode, as is Mode 2, but the paretic arm has to overcome an individually set, initially isometric resistance to allow the bilateral movement. The speed of movement, the amount of resistance, and the range of movement can be adjusted individually.

The participants sat at a height-adjustable table with elbows at 90°, one hand or both hands grasping the 3-cm-diameter handles. Their forearms were placed in the midposition into the arm troughs. The design of the Bi-Manu-Track is described in Hesse et al. (2003).

**Intervention Protocol**

The two robot-assisted groups received 90- to 105-min therapy on weekdays for 4 wk. Participants in the URTP and BRTP groups received 75–80 min of robot-assisted training, followed by 15–20 min of functional task practice. The functional tasks included unilateral tasks (e.g., reaching to move a cup, grasping and releasing blocks, picking up coins) and bilateral tasks (e.g., wiping a table with two hands, picking up two pegs, opening a jar with one hand stabilizing while the other hand manipulated). All patients received 5 min of tone normalization for the arm at the beginning and end of therapy, if necessary.

Each patient in the BRTP group (n = 7) practiced 300–400 repetitions in Modes 1 and 2 of the elbow and wrist cycles and each movement with both arms restrained on the device. In addition, each patient practiced 50–80 repetitions in Mode 3. The training repetitions of each mode fell within the range of the protocols used in previous studies and were below the repetition numbers that might cause adverse events (Hesse et al., 2003, 2005).

In Mode 1, both arms were guided passively by the device; in Mode 2, the paretic arm was guided by the nonparetic arm; in Mode 3, the nonparetic arm had to overcome the continual resistance through the whole movement, and the paretic arm overcame only the initial resistance, which was set by the therapist. The resistance was set according to the one against which the patient performed the voluntary movement with maximal force.

Patients in the URTP group (n = 7) received the modified protocol and practiced only with their paretic arms. The repetitions of the movements for each mode were the same as in the BRTP group. In Mode 1, the paretic arm was guided passively by the device; in Mode 2, the paretic arm moved the handle actively; in Mode 3, the paretic arm moved the handle against a resistance set by the therapist through the whole movement. The magnitude of the resistance was set as in the BRTP.

The control group’s (n = 7) therapy was designed to control for the duration and intensity of the robot-
assisted training (90–105 min/day, 5 days/wk, for 4 wk). The therapeutic activities in the control group involved weight bearing, stretching, strengthening of the paretic arm, coordination tasks, unilateral and bilateral fine motor tasks, and balance.

Outcome Measures

Participants were evaluated at the beginning of the intervention and immediately after its completion. The primary outcomes included motor impairment, muscle power, and strength. Motor impairment was measured by the FMA–UE. Power refers to the ability of neuromuscular system to produce the greatest possible impulses in a given period and was tested with the MRC. Strength is the peak force developed during a maximal voluntary contraction under a certain condition and was measured by grip strength (Sale, 1991). Muscle strength and power are both important for the performance of ADLs (Luo, McNamara, & Moran, 2005). The secondary outcomes included the MAS to indicate muscle spasticity.

Primary Outcomes. The FMA–UE includes items related to movements of the shoulder, elbow, forearm, wrist, and hand and is based on 3-point scale (0 = cannot perform; 1 = can perform partially; 2 = can perform fully). The total scores range between 0 and 66, with a higher FMA–UE score indicating less motor impairment. We also divided the FMA–UE into proximal (shoulder, elbow, forearm, coordination, speed) and distal (wrist and hand) parts to investigate the treatment effects on separate upper-limb elements.

The MRC uses a 6-point scale to measure muscle power for each muscle, ranging from 0 (no muscle contraction) to 5 (normal strength). We used this scale to evaluate the proximal and distal muscle power of paretic arms. The muscles of the proximal part included shoulder flexors, shoulder abductors, elbow flexors, and elbow extensors; the distal part included wrist flexors, wrist extensors, finger flexors, and finger extensors.

The Jamar dynamometer (Lafayette Instrument Co., Lafayette, IN) is a standard, accurate, adjustable-handle tool specifically for measuring grip strength (Mathiowetz, Weber, Volland, & Kashman, 1984). Patients sat with their shoulder adducted and neutrally rotated, elbow flexed at 90°, forearm in neutral position, and wrist between 0° and 30° dorsiflexion and between 0° and 15° ulnar deviation. Patients were asked to perform tasks under the unilateral and bilateral conditions. In the unilateral condition, patients were asked to exert only with their paretic hands; in the bilateral condition, patients were asked to exert with both hands. Three trials were taken at each assessment, and the average of three trials was documented.

Secondary Outcomes. The MAS measures the muscle spasticity of shoulder, elbow, wrist, and finger. Scores range from 0 (no increase in muscle tone) to 4 (affected part rigid in flexion and extension), where lower scores represent normal muscle tone and higher scores represent spasticity or increased resistance to passive movement.

Data Analysis

We performed statistical analyses using SPSS 12.0 software (SPSS Inc, Chicago). Baseline differences between groups were evaluated with χ² or Fisher’s exact test for categoric data and analysis of variance for continuous data. The a priori hypotheses were tested using contrast analyses (focused analysis of variance) in which specific predictions were tested by comparing (or contrasting) them with the obtained data. We obtained the focused F for our contrast analysis as follows: $F_{\text{contrast}} = (r^2) \cdot (F_{\text{omnibus}} \times df_{\text{numerator}})$, where $r^2$ is the square of the correlation between the contrast weights ($\lambda$) and the residualized means (for computational details, see Rosenthal & Rosnow, 1985).

For this study, we assigned contrast weights ($\lambda$) numerically reflecting the hypothesis, and the omnibus $F$ was obtained by the analysis of covariance. For the analysis of covariance, the pretest score was the covariate controlling for pretreatment differences, group was the independent variable, and the posttest score was the dependent variable. A large effect is represented by $r \geq .5$; a moderate effect, by $r \geq .3$; and a small effect, by $r \geq .1$. Level of statistical significance ($\alpha$) was set at .05 (Cohen, 1988).

Results

Baseline demographic and clinical characteristics of the participants in the three groups were comparable and are summarized in Table 1. We found no significant differences among the groups for age, months since stroke, left or right side of brain lesion, or baseline FMA–UE or MMSE scores.

Table 2 reports descriptive statistics from pre- to posttreatment and the results of the contrast analyses. Results of the contrast analysis testing the hypotheses that BRTP and URTP would result in better performance than the control treatment showed moderate effects in the dependent variables of motor impairment as indicated by the FMA–UE overall score, proximal part subscore, and distal part subscore. We found small effects in the dependent variables of muscle power on the MRC score at the proximal joints and grip strength during bilateral conditions.

The mean scores of the dependent variables for the three groups were not fully congruent with the hypotheses, however. The post hoc contrast analyses for the FMA–UE overall score, proximal part subscore, MRC proximal and
distal part subscore, and grip strength during the bilateral condition were used to further explore the data. Results of the post hoc analysis suggest evidence in favor of the new direction and are presented in Table 3.

In general, post hoc contrast analyses showed large and significant effects in the dependent variables of motor impairment as measured by the FMA–UE overall score, proximal part subscore, and the MRC proximal and distal part subscores. The URTP group improved more on the FMA–UE overall score, proximal subscore, and MRC distal part subscore than did the BRTP and control groups. However, the BRTP group had greater gains in the MRC proximal part subscore than the URTP and control groups. We found moderate and marginally significant effects in the dependent variable of grip strength during the bilateral condition. The URTP group tended to improve more in their grip strength during the bilateral condition than did the BRTP and control groups.

Discussion

The URTP and BRTP have distinctive effects on motor impairment, muscle power, and grip strength in patients with stroke. To our knowledge, our study is the first to compare the relative effects of URTP and BRTP among patients with stroke. It extends the research of Lum et al. (2006) and Hesse et al. (2003), which reported effects of only BRTP (or BRTP combined with UTRP) versus control treatment.

In our study, the URTP and BRTP groups improved to a greater extent on some aspects than the control group. The patients receiving the URTP improved significantly more on motor impairment (overall score and proximal FMA–UE scores) and muscle power at the distal joints (MRC distal part subscore) and tended to increase grip strength during the bilateral condition more than the patients in the other groups. Relative to the URTP, the BRTP patients showed greater improvement in muscle power at the proximal joints, as measured by the MRC proximal part subscore. The results partially support our hypothesis that the URTP and BRTP would demonstrate differential effects on specific outcome measures.

Similar to Lum et al.’s (2006) results that the bilateral mode alone may not show plausible effects on the motor impairment, our findings showed that the URTP group demonstrated better therapeutic effects on motor impairment (FMA–UE overall score and proximal part subscore but not distal part subscore) and muscle power at the distal joints and tended to obtain greater grip

Table 2. Descriptive and Inferential Statistics for the Outcome Measures

<table>
<thead>
<tr>
<th>Outcome Measure</th>
<th>Pretreatment, M (SD)</th>
<th>Posttreatment, M (SD)</th>
<th>Contrast Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BRTP (n = 7)</td>
<td>URTP (n = 7)</td>
<td>CT (n = 7)</td>
</tr>
<tr>
<td>FMA–UE score</td>
<td>Overall</td>
<td>41.9 (9.4)</td>
<td>40.9 (6.4)</td>
</tr>
<tr>
<td></td>
<td>Proximal</td>
<td>31.9 (5.0)</td>
<td>29.6 (4.6)</td>
</tr>
<tr>
<td></td>
<td>Distal</td>
<td>10.0 (6.5)</td>
<td>11.3 (7.3)</td>
</tr>
<tr>
<td>MRC score</td>
<td>Overall</td>
<td>3.5 (0.7)</td>
<td>3.4 (0.4)</td>
</tr>
<tr>
<td></td>
<td>Proximal</td>
<td>4.5 (0.7)</td>
<td>4.0 (0.8)</td>
</tr>
<tr>
<td></td>
<td>Distal</td>
<td>2.5 (1.1)</td>
<td>2.9 (1.0)</td>
</tr>
<tr>
<td>Grip strength (kg)</td>
<td>Unilateral condition</td>
<td>9.9 (4.2)</td>
<td>10.2 (6.2)</td>
</tr>
<tr>
<td></td>
<td>Bilateral condition</td>
<td>10.4 (4.0)</td>
<td>10.0 (5.8)</td>
</tr>
<tr>
<td></td>
<td>MAS score</td>
<td>0.5 (0.1)</td>
<td>0.6 (0.3)</td>
</tr>
</tbody>
</table>

Note. BRTP = bilateral robot-assisted training protocol; CT = control treatment; FMA–UE = upper-extremity portion of the Fugl-Meyer Assessment; M = mean; MRC = Medical Research Council; SD = standard deviation; UTRP = unilateral robot-assisted therapy training protocol.

Table 1. Demographic and Clinical Characteristics of the Participants

<table>
<thead>
<tr>
<th>Variable</th>
<th>BRTP (n = 7)</th>
<th>URTP (n = 7)</th>
<th>CT (n = 7)</th>
<th>p a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex, n (male/female)</td>
<td>4/3</td>
<td>5/2</td>
<td>5/2</td>
<td>.81</td>
</tr>
<tr>
<td>Age, yr, M (SD)</td>
<td>51.4 (10.9)</td>
<td>50.8 (6.1)</td>
<td>51.6 (7.6)</td>
<td>.98</td>
</tr>
<tr>
<td>Side of brain lesion, n (right/left)</td>
<td>4/3</td>
<td>4/3</td>
<td>3/4</td>
<td>.83</td>
</tr>
<tr>
<td>Months after stroke, M (SD)</td>
<td>14.7 (5.7)</td>
<td>12.3 (4.4)</td>
<td>14.3 (6.8)</td>
<td>.70</td>
</tr>
<tr>
<td>MMSE score, M (SD)</td>
<td>26.5 (3.0)</td>
<td>27.4 (2.4)</td>
<td>28.3 (1.4)</td>
<td>.43</td>
</tr>
<tr>
<td>FMA–UE score, M (SD)</td>
<td>41.9 (9.4)</td>
<td>40.9 (6.4)</td>
<td>43.3 (12.6)</td>
<td>.90</td>
</tr>
</tbody>
</table>

Note. BRTP = bilateral robot-assisted training protocol; CT = control treatment; FMA–UE = upper-extremity portion of the Fugl-Meyer Assessment; M = mean; MMSE = Mini-Mental State Examination; SD = standard deviation; UTRP = unilateral robot-assisted therapy training protocol.

aFisher’s exact test for categoric variables (two-tailed); analysis of variance for continuous variables (two-tailed).
strength during the bilateral condition than the BRTP and control groups. A possible explanation for the larger improvement in FMA–UE overall score and proximal part subscore is that the URTP patients might have been more attentive to their paretic arms than the BRTP and control treatment patients. Simultaneous movement of both arms requires visualizing and processing information from the paretic and nonparetic arms (Morris et al., 2008). Therefore, BRTP may be a dual-task challenge and more difficult for patients with stroke than URTP.

The motor learning literature has suggested that the extent of performance improvement is related to the amount of practice devoted to learning a particular skill (French et al., 2007; Schaechter, 2004). Compared with the control treatment, URTP provides the highly intensive, repetitive, and task-specific interventions that are necessary for motor learning of the paretic arms. It is not surprising that participants in the URTP group demonstrated larger improvement in motor impairment than the control group, as measured by the FMA–UE overall and proximal part subscores.

However, we found no significant difference in the FMA distal part subscore among the three groups. Half of the FMA–UE distal part test items measure various types of grasp (e.g., spherical, cylindrical, and pinch grasp; Fugl-Meyer et al., 1975; Sanford et al., 1993). Patients in both the URTP and BRTP groups focused on the practice of forearm and wrist movement. Different types of grasping were sometimes practiced in the functional task practice only after robot-assisted training. Also, training of these movements made up only a small proportion of the therapy in the control group. Accordingly, the motor impairment at the distal joints measured by the FMA–UE distal part subscore may not reveal any significant differences among the three groups. Incorporating practice movements for distal fine motor tasks, which were not provided by the robotic device, may be necessary to extend the therapeutic effects of robot-assisted training.

An interpretation of the URTP group’s better performance on distal muscle power and URTP’s possible benefits on grip strength during the bilateral condition compared with the BRTP and control groups is that patients in the URTP group practiced more actively with their paretic arm than did the patients in the other groups. Active training may lead to more prominent activation in the brain (Lotze, Braun, Birbaumer, Anders, & Cohen, 2003). The URTP group exerted cocontraction and muscle activation of the distal part when attempting to move the handle in Modes 2 (move actively throughout the whole movement) and 3 (move against resistance throughout the whole movement). This exertion may lead to greater motor unit recruitment and contribute to increased frequency and synchronization of motor unit discharge throughout the hemiparetic arm (Carr & Shepherd, 1998). However, the patients in the BRTP and control groups did not experience as much active exertion of the distal part as those in the URTP group. The affected limbs of the patients in the BRTP group were guided passively by the unaffected limbs in Mode 2 and moved against only initial resistance in Mode 3. Therapy in the control group did not emphasize continuous muscle exertion during the training.

We noted a marginally significant difference in grip strength during the bilateral training, but not during the unilateral training, among the three groups. When attempting to perform bilateral movements simultaneously, the interlimb coupling (i.e., the movement pattern of one arm influences that of the other) might translate into benefit for the affected arm (Waller, Harris-Love, Liu, & Whitall, 2006). Accordingly, the improvement in grip strength might be more prominent during the bilateral mode than during the unilateral mode.

In summary, the URTP appears to be superior to the BRTP in improving motor impairment, muscle power at the distal joints, and grip strength because of the larger proportion of active training in the unilateral approach among the three groups. Future research may increase the amount of active training in the bilateral mode to maximize the treatment’s effects. Future research may also compare different types of robotic devices (end-effector vs. exoskeleton) on movement outcomes.

Although we did not find a significant difference in the MRC overall score, we noted moderate to large and significant effects in the MRC proximal part subscore. The BRTP group improved more on muscle power at the proximal joints (MRC proximal part subscore) than the

### Table 3. Results of Post Hoc Contrast Analysis

<table>
<thead>
<tr>
<th>Outcome Measure</th>
<th>Post Hoc Hypotheses</th>
<th>Focused</th>
<th>$t(2,17)$</th>
<th>$p$</th>
<th>$r$</th>
</tr>
</thead>
<tbody>
<tr>
<td>FMA–UE score</td>
<td>Overall: URTP &gt; BRTP = CT</td>
<td>10.68</td>
<td>&lt;.01**</td>
<td>.61</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Proximal: URTP &gt; BRTP = CT</td>
<td>17.56</td>
<td>&lt;.01**</td>
<td>.70</td>
<td></td>
</tr>
<tr>
<td>MRC score</td>
<td>Proximal: BRTP &gt; CT &gt; URTP</td>
<td>4.43</td>
<td>.03*</td>
<td>.44</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Distal: URTP &gt; CT &gt; BRTP</td>
<td>5.32</td>
<td>.02*</td>
<td>.48</td>
<td></td>
</tr>
<tr>
<td>Grip strength (kg)</td>
<td>Bilateral condition: URTP &gt; BRTP = CT</td>
<td>2.21</td>
<td>.08</td>
<td>.33</td>
<td></td>
</tr>
</tbody>
</table>

Note: BRTP = bilateral robot-assisted training protocol; CT = control treatment; FMA–UE = upper-extremity portion of Fugl-Meyer Assessment; MRC = Medical Research Council; URTP = unilateral robot-assisted therapy training protocol.

*p < .05. **p < .01.
URTP group. The bilateral training was exclusively beneficial for the proximal joints, possibly because of the presence of descending motor pathways that are bilateral and primarily support proximal limb function and trunk stability (Bawa, Hamm, Dhillon, & Gross, 2004; Colebatch, Rothwell, Day, Thompson, & Marsden, 1990).

Given the larger contribution of bilateral descending pathways to the proximal (postural) musculature (Bawa et al., 2004; Colebatch et al., 1990), practicing movements in a symmetrical pattern may reinforce these motor pathways (McCombe Waller & Whitall, 2008) and therefore increase activation of the proximal muscles. A study by Lewis and Byblow (2004) also suggested that movements requiring proximal muscle activation might benefit from bilateral training protocols. Therefore, the proximal muscle power as measured by the MRC proximal part subscore may profit more from the BRTP than the URTP.

Measurements of spasticity using the MAS did not reveal any difference among these three groups. This study’s finding contrasts with that of Lum et al.’s (2006) previous study, showing that incorporating the bilateral mode may be more beneficial for normalizing spasticity than the unilateral mode. Participant characteristics might account for this discrepancy. Our study recruited patients without excessive spasticity, whereas the participants in Lum et al.’s study had abnormally higher spasticity. Given the very low mean MAS score before intervention, the small changes for this variable and nonsignificant difference among the three groups may be the result of a ceiling effect. However, spasticity might alternatively be viewed as an index of adverse events and not as an expected outcome of improvement (Hammer & Lindmark, 2009), because the patients in this study had no excessive spasticity at baseline. This finding supports that robot-assisted training, even including resistive training, did not exacerbate spasticity in patients with hemiparetic stroke (Fasoli et al., 2004; Hogan, Krebs, Sharon, & Charnnarong, 1995; Stein et al., 2004).

A few limitations to this study should be considered. First, the small sample size limited the power to detect statistically significant differences among the treatment groups. However, moderate to large effects were found for some dependent variables. The study’s results should be used as a foundation for future larger-scale research. Second, we did not study changes in motor control strategy after the intervention. Future research may use kinematic analysis to examine the changes in movement quality and control strategy (Lin, Chen, Chen, Wu, & Chang, 2010; Subramanian, Yamanaka, Chilingaryan, & Levin, 2010) after robot-assisted interventions. Third, this study did not include occupation-based outcome measures. Further research may use occupation-based outcome measures such as Canadian Occupational Performance Measure (Law et al., 1988) to study functional changes relevant to improvements in motor impairment, muscle power, and grip strength. Fourth, the study did not have a follow-up phase. Future research should include a follow-up evaluation to study potential long-term benefits and retention of therapeutic gains after robot-assisted training. Fifth, most participants in this study received physical therapy that focused mainly on lower-extremity training, but one cannot rule out the possibility that physical therapy interventions that involved upper-extremity training may have contributed to the improvements in upper-limb motor function.

Implications for Occupational Therapy Practice

The results of this study have the following implications for occupational therapy practice:

- The URTP and BRTP might have differential benefits for movement improvement.
- The URTP might be a better option than the bilateral approach if the treatment goal is to improve motor impairment of the upper extremity or muscle power at the distal joint.
- In contrast, the BRTP could be an optimal approach to improving muscle power at the proximal joint.

Conclusion

Robot-assisted training with bilateral and unilateral protocols appears applicable to patients with various levels of motor impairment and stages of recovery. This comparative trial shows that robot-assisted training is a promising rehabilitation approach and extends previous research on robot-assisted training in patients with stroke by studying the relative effects of URTP, BRTP, and control treatment. This study may provide preliminary evidence for planning individualized rehabilitation therapies and address the gaps in knowledge of robot-assisted training. Our findings suggest that URTP appears to be a favorable approach to improving motor impairment, distal muscle power, and grip strength during the bilateral condition of the paretic arms, whereas BRTP might be more effective in enhancing proximal muscle power than URTP. This study’s findings provide directions for further research on the clinical use of rehabilitation robots with a large sample of patients with stroke.
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