Responses of the Less Affected Arm to Bilateral Upper Limb Task Training in Early Rehabilitation After Stroke: A Randomized Controlled Trial

Jacqui H. Morris, PhD, Frederike Van Wijck, PhD


Objectives: To investigate effects of bilateral training (BT) on ipsilesional arm dexterity and activity limitation; to explore clinical and demographic factors that influence training effects; and to explore relationships between contralesional and ipsilesional recovery.

Design: Single-blind randomized controlled trial with outcome assessment at baseline, postintervention (6wk), and follow-up (18wk).

Setting: Inpatient acute and rehabilitation hospitals.

Participants: Participants were randomized to a BT group in which training involved the ipsilesional and contralesional arms (n=56) or control training involving the contralesional arm only (n=50).

Interventions: Supervised BT or control training for 20 minutes on weekdays over a 6-week period using a standardized program.

Main Outcome Measures: Upper limb activity limitation: Action Research Arm Test; and dexterity: Nine-Hole Peg Test (9HPT).

Results: Lower baseline scores were found for the ipsilesional arm on both measures compared with published normative values. The BT group demonstrated significantly greater change in dexterity (P=.03) during the intervention phase at 0 to 6 weeks (.06±.07 pegs/s) compared with the control group (.02±.02 pegs/s). The effect was lost for overall recovery at 0 to 18 weeks (P=.93). Younger participants (age≥68y) performed faster at baseline than older participants (P=.04) and demonstrated greater overall recovery with BT than older participants (P=.04). There was no significant correlation between ipsilesional and contralesional recovery.

Conclusions: The study suggests that BT may lead to clinically small improvements in ipsilesional performance of fine, rapid dexterity tasks. Younger participants responded better to BT. There was no relationship between contralesional and ipsilesional recovery, suggesting that different causes and recovery mechanisms may exist.

Key Words: Rehabilitation; Stroke; Upper extremity.

STROKE IS THE MAIN CAUSE of complex adult disability in the western world, leading to contralesional hemiparesis that adversely affects independence in daily activities. However, as well as contralesional hemiparesis, deficits in ipsilesional upper limb (UL) motor performance, fine dexterity, finger tapping, and functional performance have been demonstrated. Ipsilesional impairments—although subtle—may adversely affect activities of daily living because people with contralesional hemiplegia often use the ipsilesional UL for functional tasks. Understanding ipsilesional dysfunction and how it can be improved is therefore an important issue in stroke rehabilitation.

Several bilateral neural mechanisms may explain ipsilesional UL dysfunction. Cortical motor area damage may directly affect the 15% to 20% of uncrossed corticospinal fibers that provide some ipsilateral control of unilateral movements. This may cause alterations in ipsilesional UL performance. Secondly, bilaterally organized neural network functioning, which becomes increasingly active as task complexity increases, may be affected after stroke. Loss of network integrity may affect motor control, manifesting itself in ipsilesional performance deficits. Finally, after stroke, the undamaged primary motor cortex receives lowered interhemispheric inhibition from the lesioned hemisphere, which may interfere with normative motor control, causing ipsilesional dysfunction. Therapeutic approaches with potential to normalize bilaterally organized neural mechanisms may thus lead to improved clinical ipsilesional UL performance.

Bilateral training (BT) was developed to address contralesional UL dysfunction after stroke. During BT, identical tasks are practiced with contralesional and ipsilesional arms simultaneously—but independently. Simultaneous task practice with both ULs may modulate hemispheric excitability, restore more normative interhemispheric inhibition, and improve contralesional UL motor functioning. Although evidence for BT in contralesional hemiplegia remains inconclusive, BT has been shown to improve ipsilesional finger tapping coordination. The impact of BT on more functional ipsilesional outcomes is, however, unknown. It also remains unclear whether clinical and demographic factors influence ipsilesional functional outcomes.

List of Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tr>
<td>ARAT</td>
<td>Action Research Arm Test</td>
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<tr>
<td>BT</td>
<td>bilateral training</td>
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<tr>
<td>9HPT</td>
<td>Nine-Hole Peg Test</td>
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<td>UL</td>
<td>upper limb</td>
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tion, recovery, and training responses. Furthermore, relationships between ipsilesional and contralesional recovery have not been extensively examined.

The aims of this study were to: (1) confirm that ipsilesional UL dysfunction soon after stroke is detectable on standardized clinical measures compared with published norms; (2) test the hypothesis that there would be a significant difference in ipsilesional UL recovery between groups receiving BT versus a control intervention; (3) compare ipsilesional performance of participants with different age, sex, hand dominance, stroke classification, and side of hemispheric lesion and—where baseline differences did exist—to investigate whether training responses also differed; and (4) to explore relationships between ipsilesional and contralesional UL recovery.

**METHODS**

**Design**

This study was part of a randomized controlled trial investigating effects of BT compared with unilateral task training for the hemiparetic arm. Participants assigned to BT simultaneously practiced identical tasks with both ULs. Participants assigned to unilateral training practiced tasks with the hemiparetic arm only. This group formed the control intervention group for the present ipsilesional study. Assessment occurred at baseline, postintervention at 6 weeks, and follow-up at 18 weeks. Preliminary findings on the effects of BT on the hemiparetic arm have been published previously.

**Participants**

Participants were recruited from a patient cohort sequentially admitted to an acute stroke unit with rehabilitation facilities. The local medical research ethics committee provided ethical approval. Participants were identified from medical records and screened for an inclusion 2 to 4 weeks after stroke onset by the lead researcher (J.H.M.). Inclusion criteria were: acute unilateral stroke confirmed on computed tomography scan; contralesional score of less than 6 on 6 UL sections of the Motor Assessment Scale; ability to participate in 30-minute physiotherapy sessions; and the ability to sit unsupported for 1 minute. Exclusion criteria were: severe neglect, aphasia, or cognitive impairment; previous stroke-related disability; pregrip, grasp, pinch, and gross movement. Scores of 0 indicate ability was assessed by each rater independently scoring videotaped ARAT performances. Single-measure intraclass correlation coefficients for raters were greater than .95 (P<.001), which could be classified as high.

**Randomization and Blinding**

Randomization using a concealed, web-based computerized randomization system was conducted 2 to 4 weeks after stroke onset after written informed consent and baseline assessment. An occupational therapist blinded to treatment allocation collected data. The therapist left after recruitment of 50 participants and was replaced by a physiotherapist. Both were trained in use of the measures. Additionally, inter- and intrarater reliability was assessed by each rater independently scoring videotaped ARAT performances. Single-measure intraclass correlation coefficients for raters were greater than .95 (P<.001).

**Intervention**

**Bilateral group (n=56).** The BT group practiced identical tasks simultaneously with both arms. Training lasted 20 minutes per day, 5 weekdays per week over 6 weeks, in addition to usual therapy. Equipment and task protocols were standardized. Participants practiced 4 tasks based on work by Mudie and Matyas: (1) move a doweling peg 2cm diameter × 4cm height from the tabletop to the underside of a shelf placed at eye level; (2) move a 7-cm³ block from the table onto a shelf at shoulder height; (3) grasp an empty glass, take to the mouth, and return to starting position; and (4) point to targets raised 30cm from the table and positioned at midline, 40cm to the right, and left of midline. Tasks were organized into a progressive training program based on contralesional limb performance. Details of task progression, feedback, and practice scheduling are described elsewhere. Participants performed a maximum of 30 trials of each task; a total of 120 trials per session. Outside the training session, participants used their ipsilesional UL as they wished, no instructions were issued and no control was placed on this activity.

**Control group (n=50).** The control group practiced identical tasks to the BT group but with the contralesional, hemiparetic UL only. They received no ipsilesional UL training and no instructions relating to ipsilesional UL activity.

**Procedures**

Potential participants were screened and provided with study information. After obtaining informed consent and baseline assessment, participants were randomized to BT or control groups. The lead investigator (J.H.M.) entered participant identification numbers into the randomization program with the following stratification factors: side of hemiplegia, stroke classification according to the Oxfordshire Stroke Classification, and baseline contralesional UL activity measured by the ARAT. Therapists were then informed of group allocation.

Measures were conducted at baseline (2–4 weeks after stroke onset), immediately after training (at 6 weeks after baseline), and at 18 weeks (at 12 weeks after intervention completion). To maintain blinding, participants were instructed not to indicate group allocation to assessors.

One senior stroke rehabilitation physiotherapist delivered the intervention in the acute hospital and a second delivered it in rehabilitation facilities to which participants were transferred across Tayside, both following the same intervention manual. Intervention occurred away from normal therapy areas. Participants discharged home during the intervention period received the intervention there 2 days per week, to reflect usual service delivery pattern.

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Data Analysis

Data were examined for quality and missing data. Baseline scores were inspected and compared with published normative values to determine if detectable deficits existed. Baseline differences between bilateral and control groups were then examined using independent sample t tests and nonparametric equivalents, as appropriate. Differences in ipsilesional performance at baseline for age (median split), sex, and side of hemispheric lesion, hand dominance, and stroke classification were examined using independent sample t tests, and 1-way analysis of variance as appropriate. Change in ipsilesional scores between baseline and 6 weeks (0–6wk) and baseline and 18 weeks (0–18wk) for each training group were compared as the main variables of interest. Change between 0 to 6 weeks and 0 to 18 weeks were analyzed as dependent variables using factorial analysis of variance with the intervention group and any clinical or demographic factors shown as important at baseline as independent variables. Finally, correlations between change in ipsilesional and contralesional UL scores 0 to 6 weeks and 0 to 18 weeks in each training group were conducted on the 9HPT and the ARAT using Kendall τ. Analysis was by intention-to-treat with estimates of missing data imputed using estimated maximization. Analysis was conducted using SPSS version 16.

RESULTS

Participants

Between October 2002 and June 2005, 1239 patients were screened for inclusion. A total of 106 patients (61 men, 45 women; mean age ± SD, 67.9 ± 11.7y) met criteria and agreed to participate. Ninety-seven (91.5%) participants completed the intervention. Eighty-five (80%) participants completed follow-up at 18 weeks. Participant flow through the trial is described in figure 1.

Clinical, demographic characteristics, and baseline UL scores for the sample and each training group are presented in table 1. More control group participants (n = 27, 54%) than bilateral group participants (n = 19, 34%) went home during the intervention period (see table 1); however, no significant differences between groups were found in characteristics or baseline scores.

Baseline Performance

At baseline, 7 participants (6.6%) had ipsilesional scores less than 57 on the ARAT, with scores ranging from 42 to 56. Of these, 6 participants scored submaximally for pinch, 2 additionally scored submaximally on grip. Another participant scored submaximally on gross movement. The mean 9HPT score ± SD was 48 ± 15 pegs/s (see table 1).

Differences in Baseline Ipsilesional ARAT and 9HPT Scores for Clinical and Demographic Factors

Participants aged ≥69 years performed the 9HPT significantly more slowly than participants aged ≤68 years (t = 2.29; P = .04; 95% confidence interval, .00–.12) (table 2). There were no significant baseline differences according to sex, Oxford Community Stroke Project classification, side of lesion, or hand dominance (see table 2).

Differential Effects of BT: Between-Group Differences in Activity Limitation

ARAT change scores were positively skewed and did not respond to transformation; therefore, between-group differences for the BT and control groups were compared using Kruskal-Wallis tests (table 3). There was no significant difference in change between groups 0 to 6 weeks or 0 to 18 weeks (P > .05) (see table 3).

The small number of participants demonstrating deficits on the ARAT meant it was not appropriate to undertake statistical analysis for effect of age on training responses. Change scores for older and younger participants are therefore described (table 4). Median change 0 to 6 weeks and 0 to 18 weeks for each age group in each training group was 0. ARAT change scores 0 to 6 weeks for older participants in the control group, however, ranged between –2 and 5 whereas older participants in the bilateral group all demonstrated 0 change scores over this period.

Differential Effects of BT: Between-Group Differences in Dexterity

Mean change in the 9HPT from 0 to 6 weeks was .06 ± .07 pegs/s for the BT group and .02 ± .02 pegs/s for the control group (table 5). Change scores for age subgroups are also presented in table 5. There was a significant main effect of group for change in the 9HPT from 0 to 6 weeks (see table 5), in which the BT group improved significantly more than the control group (P = .03). However, for overall change between 0 to 18 weeks, change was .04 ± .04 pegs/s for the BT group and .05 ± .04 pegs/s for the control group, and there was no significant effect of group (P = .93) (see table 5). There was a significant interaction effect between age and group for change at 0 to 18 weeks (P = .04) (see table 5), in which younger participants in the BT group and older participants in the control group demonstrated the greatest improvement.

The other clinical and demographic factors examined—sex, hand dominance, side of lesion, and stroke classification—did not influence baseline scores and were therefore not evaluated further.

Relationship Between Contralesional and Ipsilesional Recovery

There were no significant correlations between change in ipsilesional and contralesional arm performance between 0 to 6 weeks and 0 to 18 weeks for the bilateral and control groups. Correlations were weak with r < .08 for all measures (table 6).

DISCUSSION

This study confirmed that ipsilesional UL dysfunction soon after stroke is detectable on standardized clinical measures. Seven percent of participants at baseline, 3.5% at 6 weeks, and 3% at 18 weeks demonstrated submaximal ARAT scores. Submaximal scores occurred mainly in the pinch subsection, which involves picking up ball bearings. Additionally, fine dexterity, at .48 ± .15 pegs/s on the 9HPT, was slower than .68 ± .14, described as normative for elderly individuals. Taken together, these findings confirm that ipsilesional UL dysfunction after stroke is observable in fine dexterity tasks whether these are fast or self-paced.

We also investigated effects of bilateral UL task training on the ipsilesional arm. As far as we are aware, this is the first study to document the effects of bilateral functional training on performance of the ipsilesional arm after stroke. Greater improvement in timed dexterity—but not gross UL function—was found during the intervention (0–6wk) with BT compared with the no-intervention control group. However, BT did not affect overall change (0–18wk) for either measure. Younger participants demonstrated a larger response to BT than older participants.
Randomized 2-4 weeks after stroke onset Met inclusion criteria and agreed to participate (n=106)

Baseline Measures conducted

Randomized

Bilateral Group (n=56) Control Group (n=50)

Withdraw
- Died (n=3)
- Moved away (n=1)
- Requested withdrawal (n=1)

Completed intervention (n=51)

Completed intervention (n=46)

Outcome measures conducted at six weeks

Follow up at 18 weeks

Lost to follow-up
- Too unwell (n=2)
- Unable to contact (n=2)
- Refused (n=1)

Lost to follow-up
- Too unwell (n=2)
- Unable to contact (n=3)
- Refused (n=2)

Completed Trial (n=46)
Completed Trial (n=39)

Patients screened for inclusion (n=1239)

Excluded (n=1133):
- No upper limb deficit (n=499)
- Previous upper limb disability (n=54)
- Died (n=99)
- Medically unwell (n=157)
- Impaired cognition or communication (n=82)
- Unable to sit unsupported (n=27)
- Severe neglect (n=9)
- Refused consent (n=9)
- Lived or transferred to hospital outside the area (n=134)
- Miscellaneous other comorbidities (n=63)

Completed Trial (n=46)
Completed Trial (n=39)

Fig 1. Progress of participants through the trial.
Effects of BT

**Dexterity of the ipsilesional UL.** The bilateral intervention improved recovery of ipsilesional arm dexterity (0–6 wk) compared with the control group. The effect was statistically significant but small at .04 peg/s, a percentage difference between groups of 6% representing 1 additional peg placed per 25 seconds. Donaldson et al. suggested .02 pegs/s as an arbitrary threshold for a minimal clinically important difference on the 9HPT. However, representing change of just over 1 extra peg per minute, clinical importance of this difference is questionable. Instead, if the minimal clinically important difference suggested for the ARAT (ie, 10% of the normative score) was applied to Heller et al’s published norm, our finding would not meet the criterion of .07 peg/s. The small difference implies cautious interpretation.

The 9HPT scoring was conducted using a stopwatch. The between-group difference may thus reflect measurement error caused by variations in start and stop times. Missing data represented 8% of baseline data at 6 weeks, and 19% at 18 weeks. We imputed missing data using estimated maximization iterations, which may have caused spurious findings. Thus, we cannot exclude the possibility of measurement or statistical artifact.

Intervention tasks in the present study involved reaching, grasping, and targeting specific locations. Task practice with both arms may, therefore, have transferred to tasks included in the outcome measures, which involved similar actions that are likely to be controlled by the same generalized motor program. Previous ipsilesional stroke studies have also demonstrated small but significant improvements in accuracy and speed after unilateral training targeted at those parameters. However, in our study we observed that tasks undertaken by the BT group were often constrained in speed by the contralesional limb, leading to suboptimal training conditions for the ipsilesional arm in terms of speed. The magnitude of between-group differences in our study may have been greater if, like the other ipsilesional studies, training had specifically targeted ipsilesional speed and accuracy at a pace that participants could manage. However, this is difficult to achieve when the

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**Table 1: Clinical and Demographic Characteristics and Baseline UL Scores and Group Equivalence at Baseline**

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Whole Sample (N=106)</th>
<th>Bilateral Group (n=56)</th>
<th>Control Group (n=50)</th>
<th>Test Statistic</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>67.9±11.6</td>
<td>67.9±13.1</td>
<td>67.8±9.9</td>
<td>t_{104}=−0.07</td>
<td>.94</td>
</tr>
<tr>
<td>Sex (M/F)</td>
<td>61/41</td>
<td>34/22</td>
<td>27/23</td>
<td>χ^2=0.49</td>
<td>.48</td>
</tr>
<tr>
<td>Type of stroke (ischemic/hemorrhagic)</td>
<td>92/14</td>
<td>49/7</td>
<td>43/7</td>
<td>χ^2=0.06</td>
<td>.82</td>
</tr>
<tr>
<td>Side of lesion (right/left)</td>
<td>54/52</td>
<td>27/29</td>
<td>27/23</td>
<td>χ^2=0.35</td>
<td>.55</td>
</tr>
<tr>
<td>Handedness (left/right)</td>
<td>97/9</td>
<td>54/35</td>
<td>44/44</td>
<td>χ^2=1.50</td>
<td>.30</td>
</tr>
<tr>
<td>Modified Barthel Index</td>
<td>61.9±24.6</td>
<td>58.6±25.3</td>
<td>65.5±23.5</td>
<td>t_{104}=1.52</td>
<td>.13</td>
</tr>
<tr>
<td>ARAT score baseline</td>
<td>57 (42–57)</td>
<td>57 (53–57)</td>
<td>57 (42–57)</td>
<td>χ^2=0.23</td>
<td>.63</td>
</tr>
<tr>
<td>9HPT score baseline</td>
<td>0.48±0.15</td>
<td>0.48±0.14</td>
<td>0.49±0.14</td>
<td>t_{104}=0.15</td>
<td>.88</td>
</tr>
<tr>
<td>No. of participants discharged home</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>during intervention period</td>
<td>46</td>
<td>19</td>
<td>27</td>
<td></td>
<td></td>
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<tr>
<td>Abbreviations: F, female; M, male.</td>
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</tbody>
</table>

**Table 2: Differences in Baseline Ipsilesional ARAT and 9HPT Scores for Clinical and Demographic Factors**

<table>
<thead>
<tr>
<th>Factors</th>
<th>Median ARAT Baseline (range)</th>
<th>Kruskal-Wallis Test</th>
<th>9HPT Baseline (pegs/s) (mean ± SD)</th>
<th>Test Statistic</th>
<th>P (95% CI)</th>
</tr>
</thead>
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<tr>
<td>Age (median split)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≤68y</td>
<td>57 (42–57)</td>
<td>χ^2=0.44; P=.51</td>
<td>0.51±0.13</td>
<td>t_{104}=2.29</td>
<td>.04*</td>
</tr>
<tr>
<td>≥69y</td>
<td>57 (50–57)</td>
<td>0.45±0.15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>57 (42–57)</td>
<td>χ^2=1.73; P=.19</td>
<td>0.50±0.16</td>
<td>t_{104}=1.53</td>
<td>.13 (−0.0 to 0.09)</td>
</tr>
<tr>
<td>Female</td>
<td>57 (53–57)</td>
<td>0.46±0.11</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Side of hemispheric lesion</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LHL</td>
<td>57 (51–57)</td>
<td>χ^2=0.00; P=.98</td>
<td>0.49±0.15</td>
<td>t_{104}=0.19</td>
<td>.85 (0.05 to 0.06)</td>
</tr>
<tr>
<td>RHL</td>
<td>57 (42–57)</td>
<td>0.48±0.13</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dominant hand affected</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>57 (51–57)</td>
<td>0.48±0.13</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>57 (42–57)</td>
<td>χ^2=0.00; P=.98</td>
<td>0.48±0.15</td>
<td>t_{104}=0.26</td>
<td>.79 (0.00 to 0.12)</td>
</tr>
<tr>
<td>Oxfordshire Stroke Classification</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TACS</td>
<td>57 (57–57)</td>
<td>0.54±0.14</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PACS</td>
<td>57 (42–57)</td>
<td>0.48±0.14</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LACS</td>
<td>57 (50–57)</td>
<td>χ^2=0.81; P=.85</td>
<td>0.49±0.15</td>
<td>F_{3,101}=0.51</td>
<td>.67</td>
</tr>
<tr>
<td>POCS</td>
<td>57 (57–57)</td>
<td>0.42±0.19</td>
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</tr>
</tbody>
</table>

**Table 2: Differences in Baseline Ipsilesional ARAT and 9HPT Scores for Clinical and Demographic Factors**

**NOTE.** Test statistic refers to t [t(df)] or one-way analysis of variance [F(df)].

**Abbreviations:** ANOVA, analysis of variance; LACS, lacunar stroke; LHL, left hemisphere lesion; 95% CI, 95% confidence interval for difference in means; PACS, partial anterior circulation stroke; POCS, posterior circulation stroke; RHL, right hemisphere lesion; TACS, total anterior circulation stroke.

*Significant difference P<.05.
ipsilesional limb is constrained during bilateral movement by speed and accuracy of the hemiparetic limb.

BT may nonetheless have temporarily normalized interhemispheric inhibition, leading to the apparent improvement in dexterity; however, only for the duration of the intervention period because effects were not apparent for change at 0 to 18 weeks. Other ipsilesional intervention studies provided no follow-up, making it difficult to determine whether our findings are unique. Our study suggests that BT may influence ipsilesional arm dexterity; however, further studies are clearly required. The studies should employ robust and sensitive outcome measures, examining training conditions targeted specifically at ipsilesional arm recovery. Furthermore, the relative effect of unilateral versus BT requires investigation.

**BT and Activity Limitation**

In line with other work, ipsilesional dysfunction was observed in ARAT performance; however, average ARAT scores were high, creating a ceiling effect. It was, therefore, unlikely that we would detect a significant between-group difference with training. Timed performance of the ARAT tasks would have provided us with a more sensitive measure of ipsilesional performance and effect of BT. Accurate timing should be undertaken in future studies, alongside kinematic analysis, which would provide detailed analysis of how BT influences ipsilesional movement performance.

**Clinical and Demographic Factors and Ipsilesional Recovery**

Congruent with other clinical studies, we found no effect of lesion side on baseline scores. The selected measures were probably insensitive to the impact of hemispheric differences on kinematics. In contrast, in several studies of motor control, differences in speed and spatial accuracy during complex movement have been demonstrated using sensitive kinematic and timed measures.

Congruent with studies demonstrating decline in dexterity with age, younger participants performed the 9HPT faster at baseline than older participants. Younger compared with older participants in the bilateral group also demonstrated significantly greater overall improvement in dexterity (0–18wk). Younger participants possibly responded better to the physical and attentional demands of BT than older participants, thereby achieving greater improvements in dexterity. It is not clear why, in the control group, older participants demonstrated greater overall change than younger participants, but again the finding may be because of measurement artifact.

### Table 3: ARAT Scores and Change Scores for the Ipsilesional Arm

<table>
<thead>
<tr>
<th>Measure</th>
<th>Baseline ARAT (N=106)</th>
<th>6-week ARAT (n=97)</th>
<th>18-week ARAT (n=85)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grasp (max subscore=18)</td>
<td>18 (18–18)</td>
<td>18 (18–18)</td>
<td>12 (12–12)</td>
</tr>
<tr>
<td>Grip (max subscore=12)</td>
<td>12 (12–12)</td>
<td>12 (15–18)</td>
<td>12 (11–12)</td>
</tr>
<tr>
<td>Pinch (max subscore=18)</td>
<td>18 (15–18)</td>
<td>18 (14–18)</td>
<td>18 (17–18)</td>
</tr>
<tr>
<td>Gross (max subscore=9)</td>
<td>9 (9–9)</td>
<td>9 (9–9)</td>
<td>9 (9–9)</td>
</tr>
<tr>
<td>Total ARAT score</td>
<td>57 (53–57)</td>
<td>57 (42–57)</td>
<td>57 (56–57)</td>
</tr>
</tbody>
</table>

**Table 4: Change in Total ARAT Score for Age Group (median split)**

<table>
<thead>
<tr>
<th>Age Group</th>
<th>Change 0–6wk</th>
<th>Change 0–18wk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bilateral Group (n=56)</td>
<td>Control Group (n=50)</td>
<td>Bilateral Group (n=56)</td>
</tr>
<tr>
<td>≤68y</td>
<td>0 (0 to 4)</td>
<td>0 (0 to 0)</td>
</tr>
<tr>
<td>≥69y</td>
<td>0 (0 to 0)</td>
<td>0 (−2 to 5)</td>
</tr>
</tbody>
</table>

NOTE. Values refer to median (range). Between group differences were examined using Kruskal-Wallis tests.

Abbreviations: max, maximum; min, minimum.
Table 5: Comparison Between BT and Control Groups for Change in Dexterity Measured on the 9HPT

<table>
<thead>
<tr>
<th>Assessment</th>
<th>Bilateral Group (n=56)</th>
<th>Control Group (n=50)</th>
<th>Change</th>
<th>Bilateral Group (n=56)</th>
<th>Control Group (n=50)</th>
<th>Analysis of Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>0.48 ± 0.14</td>
<td>0.48 ± 0.14</td>
<td>0–6wk</td>
<td>0.06 ± 0.07</td>
<td>0.02 ± 0.02</td>
<td></td>
</tr>
<tr>
<td>6wk</td>
<td>0.55 ± 0.15</td>
<td>0.51 ± 0.14</td>
<td>0–18wk</td>
<td>0.04 ± 0.04</td>
<td>0.05 ± 0.04</td>
<td></td>
</tr>
<tr>
<td>18wk</td>
<td>0.53 ± 0.16</td>
<td>0.54 ± 0.14</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NOTE. Values are mean ± SD or as otherwise indicated. Main and interaction effects for change 0 to 6 weeks and 0 to 18 weeks were examined using 2 × 2 factorial analysis of variance with change scores as the dependent variables and age and training group as independent variables. *Significant difference P<0.05.

Relationship Between Contralesional and Ipsilesional Recovery

No significant correlations were found between ipsilesional and contralesional recovery on the ARAT, probably because few participants demonstrated ipsilesional deficit. Magnitude of and scope for recovery was therefore small compared with the contralesional limb. However, contralesional and ipsilesional recovery on the timed 9HPT was also extremely weakly correlated, suggesting impairment and recovery of each arm may occur via different mechanisms. The absence of similar patterns of limb recovery suggests that direct damage to cortical or white matter, responsible for contralesional dysfunction, may not be the main factor responsible for ipsilesional dysfunction. Noskin et al.53 demonstrated similar findings, suggesting that a more plausible causative mechanism for ipsilesional dysfunction was disruption to bilaterally distributed neural networks relating to the ipsilesional arm, which are activated during complex movements such as those required by the 9HPT. Evaluation using functional neuroimaging is required to confirm these hypothetical assertions about mechanisms underlying ipsilesional dysfunction, but our findings suggest that mechanisms underpinning contralesional and ipsilesional dysfunction may be different.

Clinical Impact of Ipsilesional Arm Dysfunction

We found that ipsilesional dysfunction resulted in slowed performance of complex tasks involving fine dexterity. Clinically, slowness in tasks such as tying shoe laces,13 dressing, stacking checkers, and simulated feeding4,11 have also been demonstrated. We did not ask participants if they experienced difficulty using the ipsilesional arm; however, personal experiences of ipsilesional deficits, such as changes in handwriting, have been reported.34 Clearly, the impact of ipsilesional dysfunction perceived by people with stroke should be explored using qualitative methods to determine how ipsilesional arm dysfunction is experienced. Our findings suggest that recovery of ipsilesional dexterity may be accelerated using bilateral task training while that intervention is applied; however, effects are lost after the end of the intervention. We found that although recovery of ipsilesional arm dexterity continued until at least 22 weeks after stroke onset, speed of dexterity at that time was still slower than that of healthy age-matched controls.35 This finding has implications for therapists treating these patients and suggests that there may be a role of ipsilesional training for improving performance of dexterity. This may be particularly relevant for performance of rapid dexterity tasks, such as keyboard use and texting. Future studies should, therefore,
investigate effects of ipsilesional arm dysfunction and training on a wider range of functional tasks and over a longer period of time.

Study Limitations

We examined baseline scores compared with published norms. Comparison with healthy age-matched controls would have been more robust but was beyond the scope of the study. In this clinical rehabilitation study we had no access to detailed radiologic analysis and could not accurately assess lesion location other than by clinical examination using the Oxfordshire Stroke Classification scale. Conclusions that could be made about anatomical correlates of ipsilesional dysfunction were therefore limited. Additionally, outcome measures that are commonly used in clinical practice were employed, which have limited sensitivity. Future studies should use detailed kinematic measures, in conjunction with neuroimaging techniques, in order to correlate changes in brain activity with changes in motor function. We also did not ascertain what ipsilesional activity was performed outside therapy sessions. The observed improvement in dexterity in the BT group may have occurred simply through self-directed activities. Future studies should use arm activity monitors to account for usual arm activity as a factor that might influence ipsilesional outcomes. Finally, apraxia has been cited as a cause of some ipsilesional motor deficits. We did not assess apraxia in this trial. Future studies should include apraxia measures as possible explanatory variables for deficits and treatment responses.

CONCLUSIONS

This study confirms that ipsilesional arm dysfunction, although subtle, is detectable using common clinical tests. It suggests that bilateral task training may lead to clinically small improvements in ipsilesional performance of fine, rapid dexterity tasks, and that responses may vary depending on age. Future research should investigate mechanisms underpinning ipsilesional dysfunction and determine optimal training characteristics. Therapists should also evaluate ipsilesional arm dexterity after stroke in early rehabilitation to consider whether treatment is warranted.

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References