Bimanual Training After Stroke: Are Two Hands Better Than One?

Dorian K. Rose and Carolee J. Winston

Functional recovery of the paretic upper extremity continues to be one of the greatest challenges faced by rehabilitation professionals. Although most patients regain walking ability, 30%–66% of stroke survivors fail to regain functional use of their arm and hand.\(^1\) Upper extremity rehabilitation protocols for stroke hemiparesis have traditionally focused primarily on the paretic limb with unilateral strengthening exercises, neuromuscular reeducation, and/or functional training.\(^2–4\) One recent approach, constraint-induced movement therapy, exploits this focus by physically constraining the nonparetic limb with a sling or safety mitt.\(^5,6\) Many daily tasks, however, naturally require the coordinated participation of both hands; this provides a rationale for the incorporation of bimanual movements into upper limb rehabilitation protocols. A small but growing number of investigations have examined the efficacy of bilateral training on the recovery of paretic limb movements post stroke.\(^7–12\) This article outlines the conceptual framework underlying bimanual motor control, reviews both the bimanual motor control and therapeutic intervention literature as applied to persons after stroke, and from this suggests several guidelines concerning patient characteristics and task considerations to maximize the potential benefit from bimanual training protocols for rehabilitation post stroke.

The Nature of Bimanual Motor Control

Remarkably, most of the goal-directed movements in which humans engage emerge from the brilliantly orchestrated and coordinated actions of both hands. Examples from everyday tasks range from the seemingly routine tasks of catching a ball, kneading flour dough, or tying shoelaces to the artistry and skill of playing the piano or communicating with sign language. This coordinated behavior appears effortless in most cases, suggesting that the masterful controller, the central nervous system (CNS), is constrained by a set of rules that naturally reduce this complex coordinated control problem.\(^13\) However, in other cases, the coordination of the two upper limbs for goal achievement presents a challenge for the CNS, which in turn, provides an intriguing experimental paradigm for motor control studies of these actions. Although the majority of systematic investigations of this topic have been conducted during the past 25 years, Woodworth made the first observations over 100 years ago: “It is common knowledge that movements with the left and right hand are easy...”

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to execute simultaneously. We need hardly to try at all for them to be nearly the same.”

Various taxonomies have been used to characterize motor tasks. One useful taxonomy defines tasks with discrete events (e.g., tasks that have a definite beginning and end) or continuous (e.g., tasks without recognizable events such as a beginning or end). Tasks can also be described by both the temporal and spatial features. Experimental paradigms for the study of bimanual coordination have used both types of tasks (continuous and discrete) and have examined interlimb coordination in both temporal and spatial domains. What follows is not an exhaustive review of this literature, but rather, a limited but focused synopsis of research that can provide a reasoned rationale for how, with whom, and why a bimanual training protocol might be included in a comprehensive rehabilitation program for those with stroke hemiparesis.

There is strong evidence from systematic investigations of healthy individuals that performance in unimanual compared to bimanual aiming tasks is not the same. Results for unimanual or symmetrical bimanual aiming movements concur with predictions from Fitts’ Law, that is, movement time increases as movement amplitude or precision requirements increase. However, for bimanual asymmetric goal-directed aiming, Fitts’ Law is not supported. When one limb must move further or aim toward a smaller target compared to the other, the behavior of one hand is affected by the task requirements of the contralateral hand. This phenomenon is commonly known as the assimilation effect. Assimilation effects are usually asymmetric in nature such that the limb performing the more difficult task impacts the limb performing the easier task to a greater extent than the converse. For example, using a bimanual Fitts’ aiming paradigm, movement time of the limb moving to the easy (i.e., large) target is prolonged (compared to its unimanual performance) and therefore is similar to the movement time of the contralateral limb aimed to the difficult (i.e., small) target.

A naturalistic modification to the bimanual Fitts’ paradigm occurs in the case of stroke hemiparesis. After a unilateral stroke, the bimanual constraint is body-centered with the disparate movement ability of the two limbs (i.e., paretic, nonparetic), rather than task-centered with disparate target precision requirements; this offers a unique level of complexity and clinical relevance to the study of bimanual coordination.

Bimanual Motor Control After Stroke

Six investigations of bimanual coordination of participants with adult onset hemiparesis have appeared in the literature within the past 10 years with one exception. A behavioral analysis of two individuals post stroke appeared over 50 years ago. Cohn recorded arm movements from a patient who moved each arm together or independently in a cyclic and continuous pronation–supination motion. When the arms moved together, the movement frequency of the nonparetic limb was slowed dramatically compared to unilateral performance. In addition, although not as striking but certainly more intriguing, the movement trajectory of the paretic limb improved in frequency and regularity in the bilateral compared to the unilateral condition. Cohn did not quantify these results, but the qualitative images provided a provocative impression of the potential of bilateral movements for the facilitation of paretic limb movements after stroke.

More recently, Rice and Newell used a continuous, temporally symmetric and temporally asymmetric elbow flexion and extension action with 18 poststroke individuals. For the temporally symmetric task, participants were asked to maintain a “comfortable speed” oscillation, initially determined for each limb separately. In the bilateral condition, the nonparetic limb was not able to achieve its unilateral frequency but was constrained to the slower paretic limb frequency. For the temporally asymmetric task, participants were to oscillate one limb at twice the frequency of the other. Those with stroke were unable to perform this task but instead adopted an in-phase movement pattern consisting of bimanual flexion and extension together, at the same rate. Lewis and Byblow examined interlimb temporal and spatial coordination with a continuous circle-drawing task in nine poststroke hemiparetic individuals. Similar to the Rice and Newell study, the paretic limb influenced the behavior of the
nonparetic limb and no improvements in the hemiparetic limb were elicited with the continuous bimanual task.

Dickstein and colleagues and Cunningham and colleagues investigated bimanual coordination with a spatially symmetric discrete motor task. Both of these studies examined movements about the elbow joint. Dickstein and her collaborators reported a prolonged movement time for the nonparetic limb during bilateral elbow flexion compared to the unilateral condition. Although there was an increase in paretic limb movement time as well (11%), in the bilateral condition, movement time for the nonparetic limb was significantly greater (18%). Cunningham and colleagues showed some facilitation of the paretic limb with a smoother elbow extension velocity profile during bimanual movements. Their data also suggested that loading the nonparetic limb in the bimanual condition may facilitate the paretic limb's movements.

A parallel can be drawn between the studies of healthy adults in which the hand aiming to the easy target slows down to a speed similar to that of the hand aiming to the difficult target and the results of patients with unilateral paresis in whom the nonparetic limb slows to a speed similar to that of the paretic limb. In both scenarios, whether the disparate demands on the system were external (unequal-sized targets) or internal (central paresis), the limb with the shorter movement time in the unimanual condition adopts a longer movement time that is similar to that of the slower contralateral limb. This systematic regulation of movement time could result from an implicit constraint for the two hands to achieve simultaneous target impact (i.e., temporal synchrony constraint).

From a clinical perspective, the results from Cohn and Cunningham and colleagues are particularly interesting: Both reported a smoother kinematic profile for the paretic limb when it was moved simultaneously with the nonparetic limb compared to unimanual movement. (Cohn reported forearm supination and pronation, qualitative description only; Cunningham and co-workers reported elbow extension, quantitative description.) When the nonparetic limb is constrained to slow down, there appears to be some facilitation of paretic limb movement.

The investigations discussed above are limited to single joint movements, specifically about the elbow or forearm or use closed-chain, non-goal-directed tasks. In contrast, and outside the laboratory, humans usually display multijoint aiming movements that are purposeful and goal directed. Recently, we developed and have used two different goal-directed aiming paradigms in a series of experiments designed to investigate interlimb coordination after unilateral stroke. The results of this work are described in the next section.

We were particularly interested in capturing the temporal and spatial adjustments of both limbs in spatially symmetric and asymmetric multijoint aiming movements. In three separate experiments, we conducted a systematic examination of the unilateral and bilateral movements of 30 individuals post stroke (18 left cerebral vascular accident, 12 right cerebral vascular accident) who exhibited mild motor impairment (mean Fugl-Meyer motor score 60 ± 5) with intact sensation at the shoulder, elbow, and wrist. We compared their performance to that of 30 age-matched healthy control participants.

Our initial study examined a spatially symmetric, forward aiming movement. In response to an LED signal, participants were to reach forward rapidly and aim with one hand (unimanual) or both hands (bimanual) to hit a switch(es) mounted on the LED target, as soon and as fast as possible. The movement required shoulder flexion and horizontal adduction with elbow extension and forearm supination.

Similar to previous reports, the nonparetic limb exhibited a prolonged movement time in the bimanual compared to the unimanual condition. Kinematic analysis revealed that the primary locus for this prolongation was the deceleration phase of the movement. This adaptive response by the nonparetic limb allowed for a nearly simultaneous (both limbs) target impact in 81% (417/512) of the bimanual trials.

Compared to the unimanual condition, the nonparetic limb exhibited a lower peak resultant velocity (PRV) in the bimanual condition. Conversely,
compared to the unimanual condition, the paretic limb exhibited a higher PRV in the bimanual condition (Figure 1). This disassociation of limb and condition was observed for the stroke group but not the control group. When differences between movement conditions are described with movement duration alone, it appears that nonparetic limb movement time is dictated primarily by the slower paretic limb. However, an examination of the kinematics reveals facilitation of PRV with the paretic limb in the bimanual condition that is not apparent from the movement time data alone. This facilitation effect is similar to that reported by Cunningham and colleagues for their elbow extension paradigm.26

We followed this first investigation with one in which we combined the internal, body-centered asymmetry (unilateral paresis) with an external, target-centered asymmetry (targets located at different distances) in the same experiment.29 As in the symmetric paradigm, in response to an LED signal, participants were to reach and aim forward with one hand (unimanual) or both hands (bimanual) to hit a switch(es) mounted on the LED target, as soon and as fast as possible.

For the bimanual condition, the limbs moved to separate targets. One was a “near” target and the other, a “far” target; the former target was located 50% of the distance in the fore/alt plane from the participant as the latter. The unilateral paresis and asymmetric target location afforded two bimanual asymmetric aiming combinations: (a) nonparetic limb-far target/paretic limb-near target, and (b) paretic limb-far target/nonparetic limb-near target. We defined the first combination that pairs the paretic limb performing an easy task with the nonparetic limb performing a difficult task as congruent in that the two task-limb combinations are more similar in task difficulty level. This is in contrast to the second combination, which pairs the paretic limb performing a difficult task with the nonparetic limb performing an easy task. We define this aiming condition as incongruent in that the two task-limb combinations are more dissimilar in level of difficulty.

Our primary finding was that the temporal constraint on bimanual movements was robust even with the addition of an external task asymmetry to the unilateral stroke-induced paresis. The nonparetic limb prolonged movement execution time when paired with the paretic limb, compared to that in the unimanual condition. Furthermore, the nervous system demonstrated adaptability, with the magnitude of nonparetic limb prolonged movement time being a function of paretic limb aiming distance. The increase in nonparetic limb movement time was greater when it was paired with the paretic limb aiming to the far target than when the paretic limb was aiming to the near target.

Given the increase in paretic limb PRV in the bimanual condition observed in our first experiment,28 we were interested to see if this result was evident in the second experiment that used an asymmetric paradigm. Enhanced paretic limb PRV was evident only in the incongruent condition in Experiment 2. Paretic limb PRV was greater in the bimanual compared to unimanual condition only when the paretic limb aimed a far distance while the nonparetic limb aimed a near distance. No such difference was found with the congruent aiming condition (Figure 2).

To determine if aiming distance alone was the factor that contributed to the enhanced paretic limb PRV, we compared paretic limb PRV in the unimanual aiming conditions for the near and far aiming tasks. Group mean PRV was not different for the two unimanual aiming conditions; thus, it appears that both paretic limb aiming distance and the constraints of bimanual coordination contribute to the enhanced group mean PRV in the incongruent condition.

Results from this experiment provide further insight regarding potential requisite task conditions for the facilitation of the paretic limb in bimanual aiming. Our findings suggest that it may not be the bimanual task alone that affords this facilitation; task requirements for the paretic limb may also be important. Enhanced PRV with bimanual aiming only occurred when the paretic limb aimed a far distance. However, there was no difference in unimanual PRV for near compared to far aiming, which provides evidence that it is not only aiming distance that underlies the larger paretic limb PRV but the bimanual nature of the task is also requisite for the facilitation effect.
Figure 1. Ensemble average time series of instantaneous velocity plotted from movement onset to offset. Figures A–C show data from a single stroke participant. (A) Paretic limb profiles for unimanual (UNI; solid line) and bimanual (BI; dashed line) aiming. Peak resultant velocity (PRV) is greater in bimanual compared to unimanual aiming. (B) Nonparetic limb profiles for unimanual (solid line) and bimanual (dashed line) aiming. PRV is greater in unimanual compared to bimanual aiming. (C) Bimanual aiming profiles of paretic (solid line) and nonparetic (dashed line) limbs plotted together. Paretic limb PRV is greater than nonparetic limb PRV. Error bars are standard deviation. (Adapted from Rose D, Winstein C. The coordination of bimanual rapid aiming movements following stroke. Clin Rehabil. In press.)
on temporal coordination between the two limbs. Data from healthy individuals suggest that the two limbs also exhibit spatial coordination. Therefore, the third experiment in our series examined both the temporal and spatial coordination of bimanual aiming and employed a unilateral barrier paradigm.

From a seated position and in response to an LED signal, participants moved both hands away from midline, laterally and in the frontal plane, to hit switches mounted on targets, as soon and as fast as possible. The movement required shoulder abduction with elbow extension. A vertical barrier (10-, 15-, and 20-cm high) was placed midway between the home and target position and only on one side. The task was adapted from previous work of Kelso and colleagues and Goodman and co-workers. We captured both movement time and movement displacement of both limbs and quantified the temporal and spatial coupling, respectively, between the limbs and groups (stroke and matched control).

Regression analysis was used to quantify the interlimb coupling strength. For each participant, nonbarrier limb movement time (60 trials) or maximum vertical displacement (60 trials) was regressed on the corresponding barrier limb dependent measure to determine the strength of temporal and spatial interlimb coupling. Nonbarrier limb temporal and spatial behaviors were predicted significantly by performance of the contralateral barrier limb. Both temporal (control, \( R^2 = .61 \pm .04 \); stroke, \( R^2 = .44 \pm .03 \)) and spatial (control, \( R^2 = .62 \pm .04 \); stroke, \( R^2 = .31 \pm .04 \)) coupling were weaker for the stroke group compared to the control group. However, of potential clinical interest was the result that between-limb temporal coupling (\( R^2 = .44 \pm .03 \)) was more robust than spatial coupling (\( R^2 = .31 \pm .04 \)) to the central motor paresis.

An analysis of the velocity profile (Figure 3) corroborates the theory that for bimanual movements the CNS specifies a single temporal structure for both limbs. It is of interest and clinical relevance to note that the paretic limb, in the role of nonbarrier limb, mirrors the temporal structure of the contralateral barrier limb. The normal system's temporal constraint on the two limbs during

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**Figure 2.** Line graphs of group means by aiming condition and limb for peak resultant velocity (PRV). Dashed line indicates paretic; solid line indicates nonparetic. Error bars are standard error. (A) Congruent aiming: no difference in paretic limb PRV between unimanual and bimanual aiming. (B) Incongruent aiming: paretic limb PRV greater in bimanual compared to unimanual aiming (\( p < .05 \)).
bimanual movements persists in those with mild motor hemiparesis. Could this persistent temporal constraint be harnessed as a rehabilitation strategy?

The studies reviewed above are instructive about what features of a bimanual task may be used to facilitate paretic limb movements. Cunningham and colleagues suggest that loading of the nonparetic limb may be beneficial. Our data provide evidence that peak velocity of the paretic limb can be facilitated through interlimb effects from the nonparetic limb for rapid aiming tasks. It is of interest and, to some extent, counterintuitive that in these cases a paretic limb facilitation occurs despite a pronounced slowing of the nonparetic limb’s movements in the bimanual condition. Future research should attempt to exploit this temporal constraint by entraining the nonparetic limb to its unimanual movement time or even a proportion of that duration during bimanual tasks.

**Bimanual Intervention Paradigms for Upper Extremity Rehabilitation After Stroke**

Within the last 4 years, six published reports have appeared that employed bimanual intervention protocols for upper extremity rehabilitation post stroke. Two of these involved an intervention that used a custom-designed arm-training machine and required repetitive rhythmical shoulder flexion with elbow extension and shoulder extension with elbow flexion timed to an auditory cue. A third also used a custom-designed apparatus to enable bilateral passive and active motion of forearm pronation and supination and wrist flexion and extension. Two other studies involved functional reaching, grasping, and placing of various objects. The sixth study was an EMG-triggered neuromuscular stimulation program. These studies are briefly reviewed in the next section.

Chronic stroke participants (mean Fugl-Meyer Upper Extremity Motor Score = 15 ± 2 out of 66) in Whitall and colleagues’ study performed rhythmic bilateral shoulder flexion with elbow extension on a custom-designed arm-training machine for four 5-minute bouts, three times a week for 6 weeks. Pre- versus posttest comparisons revealed decreased arm impairment (Fugl-Meyer Upper Extremity Motor Performance Test), increased arm function (Wolf Motor Function Test), increased daily use (University of Maryland Arm Questionnaire for Stroke), and increased isometric strength of the paretic arm elbow and wrist flexors. These improvements were sustained 8 weeks after cessation of the training.

This same group of investigators report interesting evidence that bilateral proximal exercise may positively influence distal fine motor control. Improvements in paretic finger function in two of four participants occurred after the same type
of training protocol described above. The lack of a control group in both of these studies and the small number of participants in the latter, however, limit the interpretation of the results.

Hesse and colleagues enrolled 12 severely involved chronic stroke participants with moderate flexor spasticity to perform passive or active assistive forearm pronation and supination or wrist flexion and extension with a computer-assisted arm trainer for fifteen, 15-minute sessions over 3 weeks, in addition to participation in an ongoing comprehensive rehabilitation program. Wrist and finger spasticity decreased in 8 participants and volitional motor ability improved for 5 of the 12 participants after the intervention. Although the intervention did not lead to functional motor changes in this severely involved cohort, participants reported that the intervention eased hand hygiene and relieved spasticity-related pain. As with the previous two studies discussed, these investigators did not use a control group.

Mudie and Matyas report observational kinematic improvements in paretic limb performance of three functional tasks requiring proximal and distal arm musculature—placing a block on a shelf at arm’s length and shoulder height, drinking from a glass, and transporting a peg from the table to place the peg on the undersurface of a shelf set at eye height—after bilateral isokinematic training (spatiotemporally identical movements performed bilaterally but with each limb independently). This type of training was superior to unilateral training of the paretic limb, bilateral training where the stronger limb guided the paretic limb through the movement, and bilateral training where the two limbs performed different movements.

In contrast, Byblow and Lewis did not find superiority for a bimanual compared to a unimanual training intervention in a small crossover design study of six individuals post stroke. Although some participants did improve on some tasks with bimanual training, these results were not consistent across tasks and participants, leading to no overall differences between the two interventions.

Finally, Cauraugh and Kim examined the efficacy of a unilateral versus bilateral EMG-triggered neuromuscular stimulation program that targeted the wrist and finger extensors. EMG-triggered stimulation was applied to the impaired limb to assist with wrist and finger extension while either the unimpaired limb remained at rest (unilateral training) or while the unimpaired wrist and fingers actively extended simultaneously with the paretic limb (bilateral training). Participants completed three sets of 30 trials on four separate days over 2 weeks. Outcome measures at the post test of paretic limb reaction time, sustained muscle contraction capability, and number of blocks moved in a functional task all favored the bilateral movement training group. There was no follow-up testing, so the long-term effects of this intervention are not known.

Overall, there appears to be at least a short-term beneficial effect for bilateral training protocols, although the results are not overwhelming. As with any intervention, a bimanual approach may not be the most appropriate for all individuals post stroke, nor may it be appropriate throughout the course of rehabilitation. As one can tell by a review of this small number of published studies, bimanual intervention is a relatively generic term and can encompass a wide range of therapeutic protocols. One may simply not be able to conclude that a bimanual intervention is or is not beneficial. It will be important to qualify such a statement by describing the specific nature of that intervention, what is meant by an improvement, and the population to whom it is directed.

Implications for Rehabilitation

Although these studies report paretic limb improvement with a bimanual intervention approach, in each instance the critical feature(s) of the intervention underlying these improvements is not clear. The two literature sets reviewed—one focused on the nature of bimanual motor control, the other focused on investigations of efficacy for bimanual training protocols to enhance recovery after stroke—exist somewhat in isolation of one another. There has yet to be a hypothesis-driven test of the critical features inherent to bimanual coordination that are thought to enhance paretic limb movements in the application of bimanual training protocols.
As with any therapeutic intervention, it would help rehabilitation professionals to know if individuals of a certain level of stroke severity, age, time post stroke, side of hemispheric lesion, or lesion location would most benefit from bimanual training protocols. This list represents only a sample of the myriad patient characteristics that could influence rehabilitation outcomes. Again, because the numbers of studies conducted are few, it is not possible to generalize the results. However, we can begin to draw some speculative conclusions from the evidence that does exist.

Although neither the motor control nor intervention studies reviewed point to the role of sensation in successful coordination of bimanual actions, it should be highlighted. Proprioceptive information is vital for controlling naturalistic movements involving multiple joints and is considered to play an even larger role in bimanual coordination. Jackson and colleagues have argued that a sensorimotor mechanism, based upon proprioceptive coding of limb position and motion, exists to maintain interlimb coordination during movement execution. Although untested to date, this would suggest that intact proprioception is a critical prerequisite for beneficial effects with bimanual training protocols.

In the first two experiments from our laboratory, we describe a group average increase in paretic limb PRV in the bimanual condition. A closer look revealed that 63% of participants demonstrated this increase in the symmetrical aiming experiment and 59% in the asymmetrical aiming experiment. A subgroup analysis revealed a trend (although not statistically significant) for those who demonstrated this enhanced paretic limb PRV to have slightly lower Fugl-Meyer motor scores (59 ± 5), indicative of a more impaired upper limb, relative to those who did not exhibit this enhancement (62 ± 5). This result will require corroboration before a definitive conclusion can be made, but it is suggestive that impairment level may be an important factor to consider in establishing inclusion criteria for appropriate application.

Related to our findings, Lewis and Byblow concluded from their intervention study of 6 individuals post stroke that in most of the tasks performed by the more well-recovered patients there was no real additional beneficial effect of bilateral practice. When a positive influence of the bilateral intervention was suggested, it tended to be in tasks with lower performance scores for participants with moderate motor deficits. They also note that the task that had the largest involvement of proximal musculature also had the more reliable facilitatory effects. Given the contribution of bilateral descending pathways to proximal musculature, movements requiring activation of these proximal muscles may profit most from bilateral training protocols.

Cunningham and colleagues describe a facilitation of the paretic limb during bilateral elbow extension, but this group effect was only observed when the oldest participant was removed from the data set. Five of the six study participants demonstrated paretic limb facilitation in the bilateral condition, only the eldest participant did not. There may be age-related deficits in the ability to engage in dual-task performance, but again this merits further investigation.

McCombe-Waller and Whitall report that two of four participants with preservation of distal hand function demonstrated improved paretic finger function after bilateral arm-based training. These two had lesions affecting their motor dominant hemispheres, and the two who had more equivocal results had lesions to their non-dominant hemispheres. Although no definitive conclusions can be made given this small sample size, there is the suggestion that a lesion to the dominant hemisphere may provide an advantage in recovery from stroke with bilateral training.

Exchange of information from one to the other side of the brain and spinal cord is possible via several commissural fiber systems. Of particular interest, the brain structure most implicated in the coordination of bimanual tasks is the rich callosal interconnection between the supplementary motor hand areas that is significantly larger than the sparse callosal interconnection between the hand areas of the primary motor cortices. Although earlier studies implicated the supplementary motor area in bimanual coordination, it is now widely accepted that the locus of bimanual control is more distributed than relegated to a single brain structure or even brain region.
The control of bimanual movements is not allocated to one neuroanatomical structure, but rather appears to be the result of a distributed network involving both cortical and subcortical areas. Wiesendanger and Serrien have concluded, "It begs credulity to imagine that one particular brain structure could control the diversity of bimanual activities." Lesion location alone, therefore, may not be very useful in predicting who will or will not benefit from bimanual training protocols. Given the distributed nature of bimanual coordination, we can also conclude that the majority of our patients will manifest deficits in bimanual coordination, and, therefore, bimanual training activities should be at least a part of any comprehensive rehabilitation program.

These studies provide insight as to who may benefit from bilateral training protocols, but these observations were made post hoc. None of the studies were designed to specifically answer this question. We can conclude with confidence that inclusion of a bimanual training protocol did not result in any decline in the participants’ movement abilities or any reported adverse events. Numerous previous investigations of bimanual coordination for neurologically intact adults have reported extreme variability in the degree to which individuals coordinate their two limbs; in some cases, the two limbs are influenced by one another quite readily, and for other individuals, the two limbs operate quite independently of one another. For example, in our asymmetric barrier experiment, strength of bimanual coupling for our control participants, as quantified by regression analysis, ranged from 0.0, indicative that none of the variance in nonbarrier limb behavior was explained by the barrier limb, to 0.96, indicative that 96% of the variance in the nonbarrier limb was explained by the barrier limb (group mean = 0.61 ± .03). This relatively high between-subject variability for neurologically normal individuals should not be forgotten when the effectiveness of bilateral training protocols are evaluated for individuals after unilateral stroke.

Bimanual coordination for functional tasks is ubiquitous in everyday life, yet has not received a great deal of attention as a modality for poststroke rehabilitation. The focus has been either on teaching the individual how to use their nonparetic arm to compensate for the weakened arm or on strengthening and functional tasks for the paretic arm alone. We have provided evidence that, even after a hemispheric stroke, bimanual movements retain a similar underlying structure to that seen in the healthy participant. There is an entire class of actions that has been virtually ignored by rehabilitation specialists, a class of actions that, if practiced properly, may indeed have beneficial effects on upper limb functional recovery after a hemispheric stroke.

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