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Targeted Aiming Movements Are Compromised in Nonaffected Limb of Persons With Stroke

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Background. Research has shown that movement impairments following stroke are typically associated with the limb contralateral to the side of the stroke. Prior studies identified ipsilateral motor declines across a variety of tasks. *Objective.* Two experiments were conducted to better understand the ipsilateral contributions to organization and execution of proximal upper extremity multisegment aiming movements in persons with right-hemispheric stroke. *Methods.* Participants performed reciprocal aiming (Experiment 1) and 2-segment aiming movements (Experiment 2) on a digitizing tablet. In both experiments, target size and/or target orientation were manipulated to examine the influence of accuracy constraints on the planning and organization of movements. *Results.* Kinematic measures, submovement analysis, and harmonicity measures were included in this study. Declines in organization and execution of multisegment movements were found to contribute to performance decrements and slowing in stroke patients. Furthermore, stroke patients were unable to efficiently plan multisegment movements as one functional unit, resulting in discrete movements. *Conclusions.* Results suggest the importance of considering ipsilateral contributions to the control and organization of targeted aiming movements as well as implications for rehabilitation and recovery.

Key Words: *Kinematics—Hemispheric control—Planning—Organization.*

A number of studies examining patients with hemispheric stroke have demonstrated sensory and motor deficits in the ipsilateral limb.[1-3] Motor declines have been reported for aiming movements such as transporting pegs into a pegboard,[4-6] manual dexterity,[4,7] prehension of objects,[8,9] and reciprocal aiming.[10-12] Overall, patients with right-hemisphere damage (RHD) and left-hemisphere damage (LHD) produce longer movement times in the so-called nonaffected upper extremity compared to healthy individuals. However, differences in performance between RHD and LHD patients may depend on the underlying control. The accuracy demands or complexity of the task is also known to be differentially affected based on the side of the lesion.

A number of studies have demonstrated left-hemisphere dominance for complex motor skills. Studies have demonstrated that patients with LHD produce longer movement times and reduced velocities more frequently than patients with RHD, particularly during movements with low-accuracy demands.[10-14] Many of these findings have been attributed to the cognitive-motor requirements of the tasks and the suggested role of the left hemisphere in controlling ballistic, open-loop aiming movements. In contrast, the degree of severity and type of impairment affecting the ipsilateral hand after RHD are less clear. The right hemisphere is thought to play a role during rapid online processing of visual information when precision demands are high. During goal-directed aiming movements requiring high accuracy, RHD patients demonstrated a decrease in performance.[1,12] Similarly, studies on repetitive aiming movements revealed that patients with RHD performed normally when accuracy demands were low[10,11] but exhibited ipsilateral deficits when greater accuracy (narrow targets) was required.[12] Other investigators have reported ipsilateral motor deficits after RHD even in simple tasks (alternating tapping) and specifically in the closed-loop, feedback phase of the movement.[1,12]

Previous research has identified a number of ways to characterize the complexity of a movement. For example, certain task constraints are known to influence the accuracy demands of a task, such as target size,[15-19] number of segments within a movement,[20-24] and the joints involved.[25-28] More recently, however, research has also focused on identifying the underlying control strategies contributing to the control of movements.

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Individuals with unilateral hemispheric damage have demonstrated performance deficits in control mechanisms such as planning and organizing movements,[29,30] preparation and implementation of compensatory adjustment actions,[12,31] and a prolonged adjustment phase[12,32] while using their ipsilesional arm. Control mechanisms also vary based on type of movement.[15,33] Whereas discrete aiming requires cessation of movement at a target endpoint, reciprocal aiming requires timing and a transition between alternating open-loop and closed-loop phases to the target.[34] Rand and colleagues[22] investigated the influence of target size and movement amplitude on the kinematics of 2-segment aiming movements. Results indicated that of these multisegment movements, conditions with larger targets were planned and organized as one functionally continuous movement, whereas conditions with smaller targets of greater complexity led to 2 discrete movements.[22]

Although many of the previously mentioned studies included imaging techniques, few have incorporated kinematic, submovement, or harmonicity analysis. In addition, most relevant experiments have examined either reciprocal aiming tasks or discrete aiming actions. The main objective of the present study was to investigate the underlying control of movements in stroke patients using their ipsilateral arm compared to healthy, age-matched controls. Specifically, we were interested in determining if the organization and execution of both continuous and discrete aiming movements were affected in the dominant ipsilesional arm of stroke patients. Furthermore, our studies were designed to determine whether changes in task complexity (accuracy, joint coordination) lead to greater decrements.

In Experiment 1, patients performed reciprocal aiming movements. In Experiment 2, they produced 2-segment aiming movements. The use of 2 movement types allowed us to examine performance differences due to differing control requirements. Duration and kinematic measures were used, as well as submovement analysis[35] and harmonicity.[34] Harmonicity analysis describes the fluidity of movements, in addition to their efficiency of organization and execution.[36-38] In Experiment 1, target size and orientation were manipulated to examine the influence of accuracy constraints on the kinematics of movements. This experiment considered the effect of multijoint versus single-joint movements on movement performance. It was hypothesized that stroke patients would be affected by high-accuracy demands (small target size) and increased joint involvement (vertical movements) to a greater extent than controls. Experiment 2 examined whether the patients were compromised in their ability to plan 2-segment movements into an organized sequence prior to onset of movement. We hypothesized that those with stroke would be able to effectively plan their movements as a single unit when accuracy requirements of the first segment were low but would be unable to maintain that plan when accuracy constraints increased. Furthermore, we expected deficits to be observed in the execution of movements regardless of accuracy constraints.

METHODS

Subjects

Six stroke patients (69.7 ± 10.9 years) and 6 healthy, age-matched controls (68.8 ± 16.9 years) without a history of stroke or neurological trauma were included in this study. All participants signed a consent form approved by the local institutional review board. A Mini-Mental State Examination,[39] medical history questionnaire, and Webster Exam[40] were administered to all participants. Persons who scored less than 27 (out of 30) on the Mini-Mental State Examination were excluded. The medical history questionnaire asked patients about the side affected by the stroke, time poststroke, motor impairments, and cognitive impairments prior to and following their stroke. All reported prestroke right-handed dominance. This information was further supported by results from the Webster Exam, an assessment of motor impairments (Table 1). All stroke patients reported pronounced deficits on the left side. Experimenters did not have access to medical records to document exact lesion location. Results from the Webster Exam confirmed that the right upper extremity did not differ from age-matched controls and that the left side was affected on assessment of bradykinesia, movement amplitude, coordination, and rigidity. For both experiments, stroke patients were required to use their "unaffected" right hand. All 6 age-matched controls also used their right hand, which in each case was their self-reported dominant hand. The purpose for comparing the ipsilateral limb of stroke patients to the same limb of controls was to control for hand asymmetries that can result from hemiparesis and hemisensory loss.[10] Each participant in this study completed a series of 2 experiments, each lasting approximately 30 minutes with a break between experiments.

Equipment and Recording

Experimental setup was the same for both experiments. Each experiment was performed on a Wacom Graphire 3 digitizing tablet (6 × 8 in; sampling rate, 120 Hz) with stylus. Experiments were designed and conducted with MovAlyzeR (Version 3.0) software by Neuroscript L.L.C. MovAlyzeR is a movement analysis program designed to measure and analyze fine motor

Table 1. Stroke Patients and Healthy Controls Descriptive Information

Stroke Patients	Age (yrs)	Sex	Months Poststroke	Webster Right Side	Webster Left Side	Self-Reported Findings
S01	78	F	16		B,R,D	Limited left shoulder movement
S02	61	F	18		B,R,	Loss of strength
S03	80	M	12	B	B,R	
S04	54	M	36		B,R,D	Loss of balance
S05	71	F	22		B, D	
S06	75	F	39	B	B,R,D	Loss of strength
Controls	**Age (yrs)**	**Sex**				
C01	81	F				
C02	53	F				
C03	80	F				
C04	77	M				
C05	63	M				
C06	55	M				

Age at the time of testing (years), time poststroke (months), and right and left side motor declines such as bradykinesia (B), rigidity (R), and incoordination (D) are reported.

movements including handwriting, drawing, and goal-directed movements (Neuroscript Copyright 2001-2006). A wrist brace was worn to restrict wrist movement and thus confine movements to the shoulder and elbow. This also aided in constraining movements to abduction and adduction for particular conditions. Participants sat in a chair located directly in front of a tabletop. Holding the stylus, participants performed reciprocal (Experiment 1) and 2-segment (Experiment 2) aiming movements onto the digitizing tablet located on the tabletop. The tablet was aligned in front of each patient's right shoulder. Square targets for each condition were shown at all times on the digitizing tablet. Prior to testing, participants were given 5 practice trials to become familiar with the setup. In each experiment, movements were required to be performed as fast and as accurately as possible. For both experiments, the distance between targets remained constant while target size and/or target orientation was manipulated.

EXPERIMENT 1: RECIPROCAL AIMING

Participants moved a stylus atop a digitizing tablet reciprocally for 10 seconds between 2 square targets of equal size (small = 0.5 cm or large = 1 cm) at a distance of 5 cm apart in 1 of 2 directions (horizontal or vertical) (Figure 1). Thus, 4 conditions were included. Two same-sized targets were oriented either horizontally, requiring reciprocal aiming between a left target and a right target, or vertically, requiring reciprocal aiming between a bottom target and a top target. For movements in the horizontal direction participants were required to isolate motion only to that of abduction-adduction at the shoulder, whereas vertical movements were performed using both shoulder and elbow flexion-extension. Thus, the vertical movement was determined a priori to be a more difficult coordination pattern. Conditions were as follows: SV = small targets (0.5 cm) oriented vertically; LV = large targets (1 cm) oriented vertically; SH = small targets (0.5 cm) oriented horizontally; and LH = large targets (1 cm) oriented horizontally. There were 15 trials in each condition. A total of 60 10-second trials were completed. Between conditions, participants were given short breaks to reduce the possibility of fatigue.

Measures

Duration and kinematic variables were used to determine performance and underlying movement characteristic differences between groups. The variables measured included total duration of each movement between targets, peak velocity, and distance traveled in the primary submovement. Submovement analysis partitioned out primary and secondary submovements, based on acceleration profiles. The primary submovement is the portion of the movement that occurred prior to the first zero crossings in acceleration, whereas the secondary submovement is defined as the portion following.[35] The theoretical implications of this analysis suggest that performance in the primary submovement (or ballistic phase) is the preplanned portion of the movement and the secondary submovement includes feedback control.

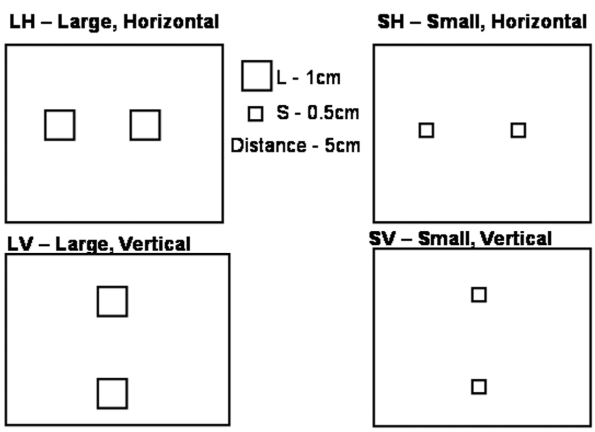

Figure 1. Experiment 1 conditions. Overhead view of templates for each condition as they appeared on a Wacom Graphire 3 digitizing tablet (6 × 8 in.; sampling rate, 120 Hz). Participants moved a stylus atop a digitizing tablet reciprocally for 10 seconds between 2 square targets of equal size (small, 0.5 cm; large, 1 cm) at a distance of 5 cm apart in 1 of 2 directions (horizontal or vertical). Conditions are shown as follows: *top*, SH = small targets (0.5 cm) oriented horizontally, LH = large targets (1 cm) oriented horizontally; *bottom*, SV = small targets (0.5 cm) oriented vertically, LV = large targets (1 cm) oriented vertically.

As an additional analysis and a way to further communicate the planning and organization of the movements, harmonicity was calculated and used to determine the fluidity of movement. Also, because the submovement analysis did not address reversal times in the reciprocal aiming, harmonicity allowed us to examine planning during the reversal phase. Mean harmonicity was based on acceleration profiles and was computed for every half cycle of motion. Harmonicity is the ratio of the highest and lowest absolute values of local extrema found in acceleration profiles. A harmonicity value of 0 indicates that acceleration crosses zero, or stops, at reversal points. A harmonicity value of 1 indicates that acceleration was maximal at the reversals. Movement continuity was the ratio of acceleration at each reversal point in reciprocal aiming over peak acceleration. A continuity value of 0 indicates full stops at the reversal points, whereas a value of 1 indicates harmonic motion where peak acceleration occurs at reversal points. Following manual inspection of all trials, analyses were performed on the individual strokes of a 10-second trial. Trials where the participant did not initiate movement (very few for less than 3% of all trials) due to failing to hear the auditory cue were not included in the analysis. A 2 (group: stroke, control) × 2 (direction: horizontal, vertical) × 2 (target size: large, small) repeated-measures ANOVA was used to analyze the data.

EXPERIMENT 2: 2-SEGMENT AIMING

Each participant performed 4 conditions of 2-segmented goal-directed aiming movement in the horizontal plane (Figure 5). At the start of each trial, participants positioned the stylus in the starting position, a square 1 cm in diameter. An auditory cue was administered to cue movement initiation. The task was to move the stylus across the digitizing tablet, pausing in the first square target (T1) and continuing to the second square target (T2) to complete 1 trial. Participants were instructed to move as fast and as accurately as possible. The size of T1 and T2 changed based on the condition (large: 1 cm in diameter, small: 0.5 cm in diameter); however, distance between targets (5 cm) remained constant across conditions. A different auditory signal at the end of each trial cued participants to return the stylus to the starting position. Four conditions with 20 trials in each condition were recorded for each participant. A total of 80 trials were collected. Between conditions, breaks were given to reduce the possibility of fatigue.

Measures

Total duration, peak velocity, and submovement analysis were assessed for each segment of the 2-segment movement. Between segments 1 and 2, dwell time at T1 was determined for each trial. Dwell time was the time spent dwelling on T1, when velocity and acceleration were temporarily sustained at zero. Dwell time is interpreted to represent the amount of time needed to plan subsequent movements. Dwell times > 200 ms suggest movements were planned individually, whereas < 200 ms suggest movements were planned as a whole prior to onset.

DATA ANALYSIS

The recorded x-y position data were low-pass filtered with a dual-pass Butterworth filter and used to calculate velocity and acceleration profiles. A 2 (group: stroke patients, controls) × 4 (conditions: LL, LS, SL, SS) repeated-measures ANOVA was used to analyze the data. The probability level of statistical significance was $P < .05$. Movement onset, dwell time, movement termination, and overall duration were computed by MovAlyzeR computer software. Criteria for trials to be included required that movements begin within 3 seconds, not exceed 2 strokes, and successfully land in both targets. Trails that did not meet the criteria were not included in analysis.

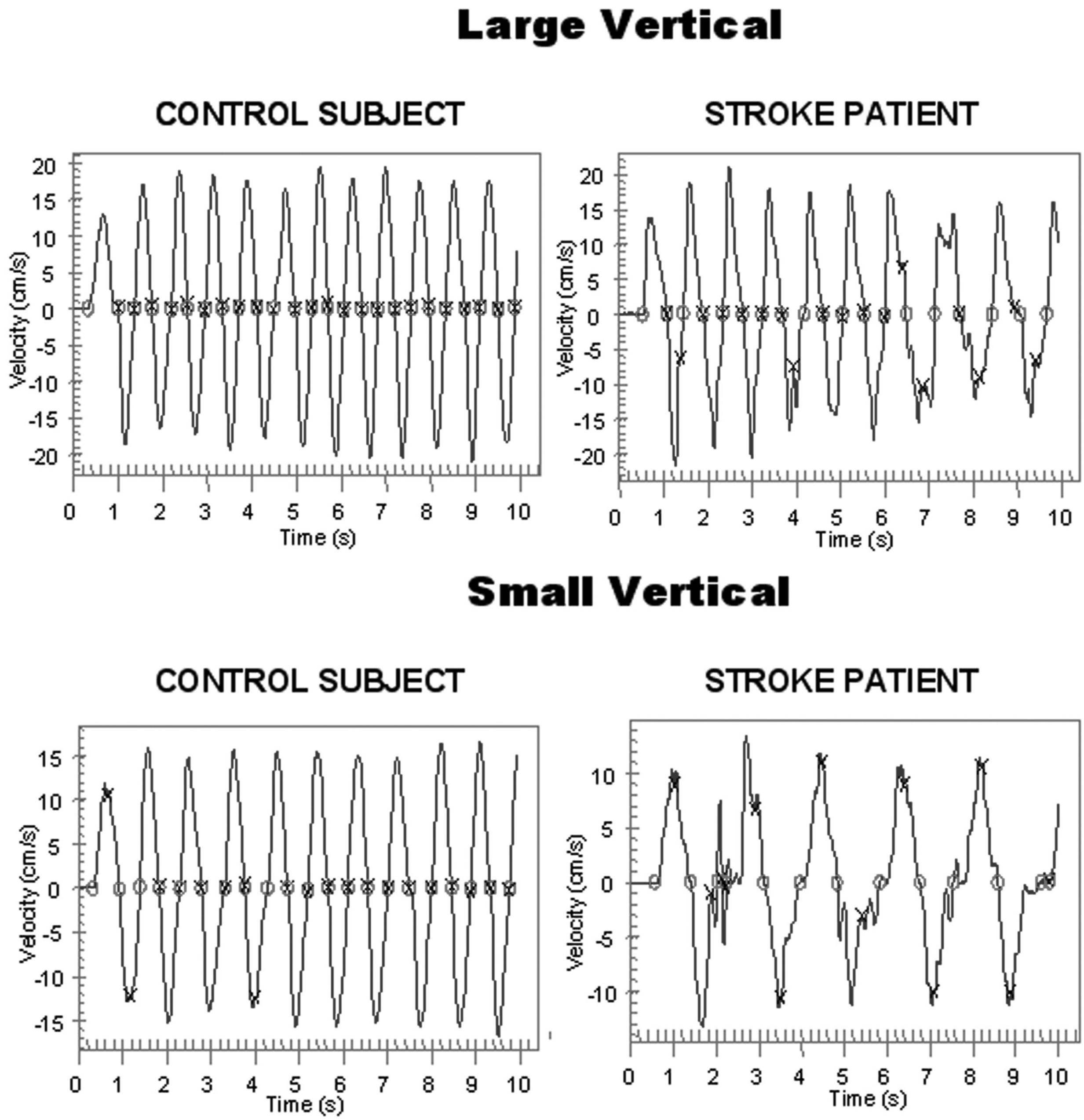

Figure 2. Example velocity profiles for a stroke patient (left) and an age-matched control for vertical conditions (large targets on top; small targets on bottom). Velocity zero crossings are demarked by O, and inflections in acceleration crossing are marked by an X. On average, across all conditions, controls produced symmetric profiles whereas stroke patients tended to produce less symmetric profiles.

RESULTS

Experiment 1

Representative individual velocity profiles of the reciprocal aiming conditions as performed by a stroke patient and control are shown in Figure 2. Controls typically produced symmetrical profiles regardless of the accuracy demands in both vertical and horizontal movements. Conversely, stroke patients produced more asymmetric profiles with inflections in all conditions.

There was a significant group main effect of duration between groups, $F(1, 10) = 8.687$, $P < .05$, indicating that stroke patients moved significantly slower than controls across conditions (837 ms vs 432 ms). There was also a significant target size main effect, $F(1, 10) = 14.957$,

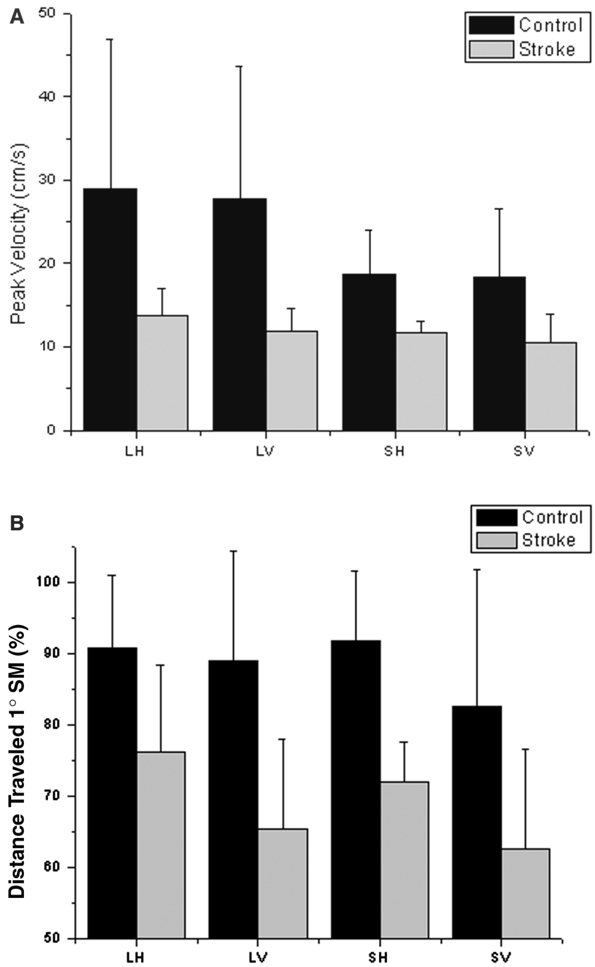

Figure 3. A. Means and standard deviations of peak velocity for controls (black) and stroke patients (gray) across all conditions (LH, LV, SH, SV). B. Relative distance traveled in the primary submovement (SM). Black bars indicate mean performance of controls. Means for relative distance traveled in the primary submovement are shown in gray for stroke patients. LH = large targets (1 cm) oriented horizontally; LV = large targets (1 cm) oriented vertically; SH = small targets (0.5 cm) oriented horizontally; SV = small targets (0.5 cm) oriented vertically.

$P < .005$, where both groups had shorter duration scores when moving to large targets compared to small (569 ms vs 725 ms). Overall, stroke patients moved more slowly than controls. Both groups were affected by target size accuracy demands. No Group × Target Size interaction, direction main effect, or Group × Direction interaction was found ($P > .05$).

Mean peak velocities and standard deviations for both groups across all conditions are shown in Figure 3A. A significant group main effect occurred for peak velocities, $F(1, 10) = 5.718$, $P < .05$, suggesting that stroke patients produced lower peak velocities than controls (1.21 cm/sec vs 2.35 cm/sec). Results also indicated a significant target size main effect, $F(1, 10) = 6.669$, $P < .05$, which indicated that participants produced lower peak velocities when moving to small targets compared to large (1.48 cm/sec vs 2.05 cm/sec). Neither a Group × Target Size interaction nor a Group × Direction interaction reached significance ($P > .05$).

To examine the microstructure of movements, the distance traveled in the primary submovement was analyzed (Figure 3B) as a measure of the efficiency of the planned portion of the movement. Longer distances traveled in the primary submovement signified more efficient planning or execution of planned movements with less reliance on feedback control. Conversely, shorter distances traveled signified more of the movement was performed utilizing feedback. Analysis found a significant group main effect, $F(1, 10) = 12.36$, $P < .005$, in which stroke patients advanced a shorter distance in the primary submovement (60%-70%) compared to controls (80%-90%). A direction trend, $F(1, 10) = 3.845$, $P = .07$, indicated that less distance was traveled in the primary submovement for movements in the vertical direction (2-joint movement) compared to those in the horizontal direction. No significant target size main effect, Group × Target Size interaction or Group × Direction interaction, was found ($P > .05$).

Harmonicity was calculated to further examine the microstructure of movements, particularly the continuity of the movement at the reversal phase. Mean harmonicity results are shown in Figure 4. A significant difference was observed between groups, $F(1, 10) = 6.255$, $P < .05$. More harmonic movements occurred to large targets compared to small, $F(1, 10) = 6.421$, $P < .05$. A significant Group × Target Size interaction, $F(1, 10) = 6.038$, $P < .05$, was also found. Whereas controls performed differently based on target size, the stroke patients were less fluid regardless of size. A significant direction main effect or Group × Direction interaction did not occur ($P > .05$). Overall, these results demonstrate that stroke patients produced less harmonic and more discrete movements compared to controls.

Experiment 2

Statistical analysis of total duration of movement indicated a significant group effect, $F(1, 10) = 10.29$, $P < .01$. Stroke patients were significantly slower than controls across all conditions (2.28 seconds vs 1.47 seconds). A significant condition main effect also occurred, $F(3, 30) = 16.86$, $P < .01$. Post hoc pairwise comparison found the LL condition to differ from the other 3, whereby participants produced shorter duration scores when both targets were large. A Group × Condition interaction did not reach significance ($P > .05$).

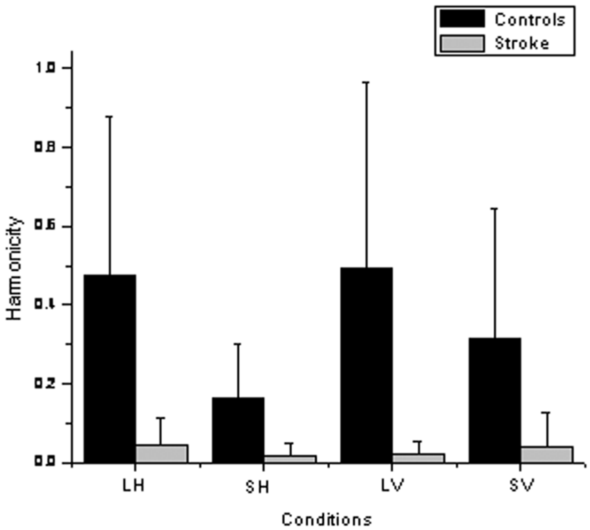

Figure 4. Mean harmonicity and standard deviation for stroke patients (gray) and controls (black) for all conditions (LH, LV, SH, SV). A value of 1 indicates fluid/continuous movement, and a value of 0 represents discrete/segmented movement. LH = large targets (1 cm) oriented horizontally; LV = large targets (1 cm) oriented vertically; SH = small targets (0.5 cm) oriented horizontally; SV = small targets (0.5 cm) oriented vertically.

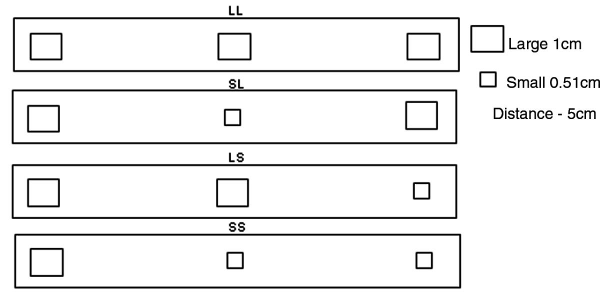

Figure 5. Experiment 2 conditions. Overhead view of all 4 conditions, as would be presented individually as a template on a digitizing tablet. Participants began trials holding a stylus in the starting position target (on left) and moved to target 1 (T1, center) and then on to target 2 (T2, right side). Targets could be 1 of 2 sizes: large, 1 cm, or small, 0.5 cm. The distance between targets remained constant, 5 cm. The 4 conditions shown, starting from the top, are LL (T1-Large, T2-Large), SL (T1-Small, T2-Large), LS (T1-Large, T2-Small), and SS (T1-Small, T2-Small).

Figure 6A illustrates mean peak velocity results of all conditions as performed by both groups. Results of peak velocity in the first and second segment revealed a significant group main effect, $F(1, 10) = 5.4$, $P < .05$, with stroke patients producing lower peak velocities than controls (9.23 cm/sec vs 16.95 cm/sec). There was also a significant condition main effect, $F(3, 30) = 9.3$, $P < .001$, which found that controls, unlike stroke patients, modulated peak velocity based on accuracy demands. Conversely, stroke patients produced consistent peak velocities regardless of accuracy demands, suggesting an inability to modulate peak velocities as a result of varying accuracy constraints. There was not a Group × Condition interaction ($P > .05$).

Additional investigation of kinematics examined the microstructure of the movements. Figure 6B represents mean percentage scores and standard deviation for distance traveled in the primary submovement. A significant group main effect in relative distance traveled in the primary submovement occurred, $F(1, 10) = 7.79$, $P < .01$, indicating stroke patients traveled less distance in the primary submovement compared to controls across all conditions (67% vs 84%). Results also revealed a significant condition main effect, $F(3, 30) = 3.69$, $P < .05$. Additional post hoc pairwise analysis found that differences in relative size of primary submovements occurred between the LL and SS conditions. For both groups, distance traveled in the primary submovement was longer during conditions where accuracy constraints were low compared to high (79% vs 70%). A Group × Condition interaction did not reach significance ($P > .05$).

The group with stroke had longer dwell times (Figure 7) across all conditions (220-250 ms vs 120-150 ms; $F(1, 10) = 7.35$, $P < .05$). There was not a significant condition main effect or Group × Condition interaction ($P > .05$).

DISCUSSION

In Experiment 1, the stroke patients performed reciprocal aiming movements more slowly than healthy age-matched controls when accuracy was constrained. For stroke patients, lower peak velocities accompanied slower movements. Submovement analysis revealed that longer movement times were a result of less distance traveled in the ballistic phase of the movement when accuracy demands were high. This was further substantiated by harmonicity data, which demonstrated that stroke patients performed discrete movements regardless of target size, whereas controls produced more continuous movement to large targets and discrete movement to small targets. This suggests that controls planned movements to large targets as one chunk, whereas stroke patients primarily planned discrete movements. Finally, there was a minor effect of target orientation (joint coordination) on performance in

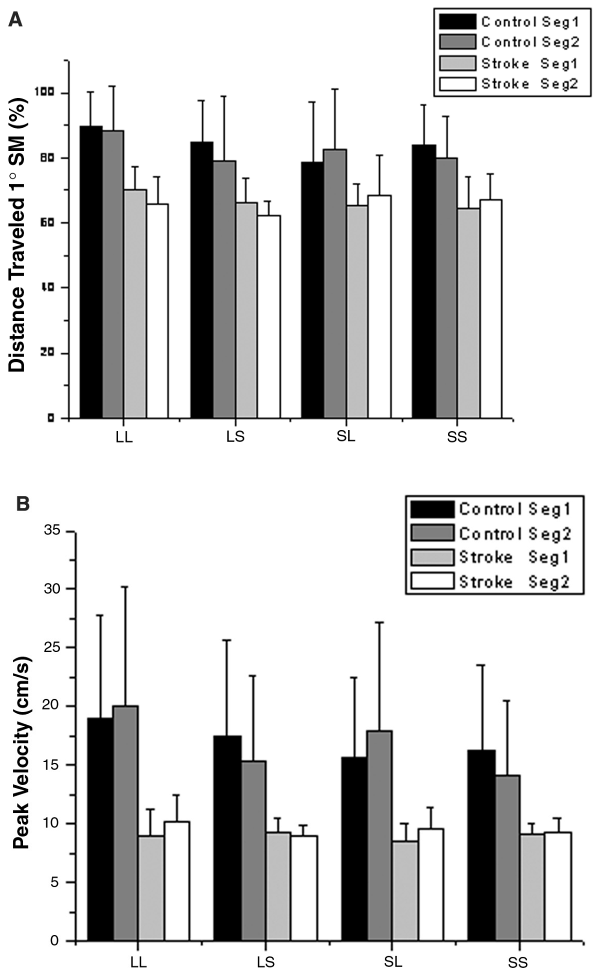

Figure 6. A. Mean peak velocity scores and standard deviation bars for controls and stroke patients when aiming to 4 different target size combinations (LL, LS, SL, SS) for both segments. Black and dark gray bars (controls) represent the mean peak velocity scores and standard deviation for the first and second segments, respectively. The light gray and white bars (stroke patients) demonstrate mean peak velocity scores and standard deviations for both the first and second segments. Across both segments and target size combinations, stroke patients did not modulate their peak velocity based on accuracy constraints (ie, target size) and performed fairly consistently across all conditions. B. Mean and standard deviation results for relative distance traveled in the primary submovement (SM) as performed by both groups across the 2 segments and all target size combinations (LL, LS, SL, SS). Black and dark gray bars (control) represent the relative percent of distance traveled in the ballistic or preplanned phase of the first segment (black) and second segment (dark gray). Light gray and white bars (stroke patients) demonstrate the results for movements in the first and second segments, respectively. Stroke patients traveled less distance in the primary submovement compared to controls for each target size combination. LL = T1-Large, T2-Large; SL = T1-Small, T2-Large; LS = T1-Large, T2-Small; SS = T1-Small, T2-Small; T1 = target 1; T2 = target 2.

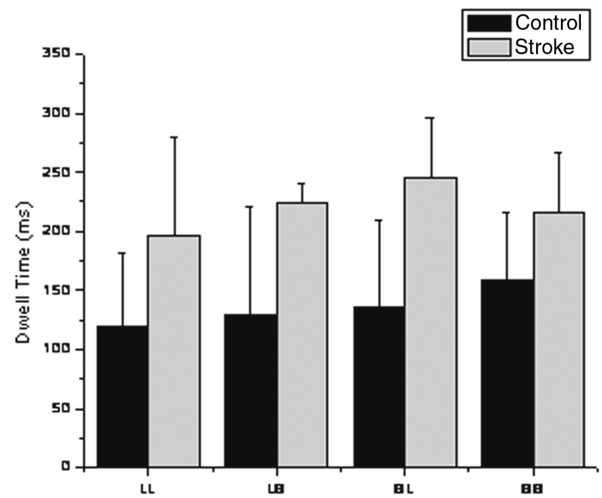

Figure 7. Mean dwell time scores and standard deviation bars for stroke patients (gray) and controls (black) across all 4 target size conditions (LL, LS, SL, SS). Dwell time was the amount of time spent dwelling on the first target and is thought to represent the amount of time needed to plan the next segment of movement. Across all conditions, stroke patients spent more time dwelling on this first target compared to controls. LL = T1-Large, T2-Large; SL = T1-Small, T2-Large; LS = T1-Large, T2-Small; SS = T1-Small, T2-Small; T1 = target 1; T2 = target 2.

stroke patients. Shorter distance traveled in the primary submovement suggests that the 2 joint vertical movements were less efficiently planned and executed compared to the single joint horizontal movements.

In Experiment 2, the stroke group had longer movement times and lower peak velocities. Additionally, kinematic analysis revealed that stroke patients traveled less distance in the primary submovement regardless of accuracy demands. This suggests that they were unable to efficiently and effectively plan their movement and, thus, used more online sensory feedback control. Dwell time analysis indicated that stroke patients were unable to plan movements as a single chunk (dwell times > 200 ms), whereas controls planned movements as a single unit with the SS condition requiring additional planning on the first target.

The differences in control strategies based on movement type have many possible explanations. Differences between movements could be explained by the biomechanical properties each movement requires. For example, reciprocal aiming requires the coordination of contracting alternating muscles, whereas 2-segment aiming necessitates a starting and stopping of the same muscle group. Similarities in control strategies of stroke patients were found between experiments. The decrements in performance of stroke patients for both movement types occurred at the final stages of the movement as they approached a target, which resulted in less distance traveled in the primary submovement. These findings suggest stroke patients had trouble with the accurate execution of a planned movement, not specifically in the initial planning. Specifically, our results suggest these changes were due to decrements in the ability to modulate accurate forces and efficiently utilize online sensory feedback control. The findings support the notion that upper extremity movements after a right cerebral stroke are greatly affected during the closed-loop phase. A study by Winstein and Pohl[12] examined ipsilateral limb control of rapid reciprocal aiming movements in patients with unilateral brain damage and controls using the same limb. Detailed kinematic analysis was reported on alternating tapping movements under 3 conditions of task complexity. Whereas participants with LHD demonstrated deficits with open-loop components of the movement in all 3 task complexities, RHD participants revealed deficits in the closed-loop phase of the movement prior to target impact, particularly when task complexity was greatest.

In the current study, the additional measure of harmonicity supports the conclusions drawn from the submovement analysis regarding how the movements were planned. Taken together, our findings suggest that stroke patients planned and executed their movements in a discrete manner, especially when constrained by more precise accuracy demands. In contrast, controls demonstrate cyclical or continuous movements characterized by few to no stoppages as they aim between targets. These findings are in agreement with previous studies demonstrating that individuals with RHD have difficulty producing movements with high-accuracy demands.[12] At the same time, these findings add to the literature by showing deficits resulting in discrete or less continuous movements in patients with RHD. Previous research has suggested that continuous movements were impaired in the ipsilesional upper extremity for individuals with LHD, but not for those with RHD. Specifically, left lesion patients were shown to fail to link temporal phases of a continuous movement into a single temporal unit.[3] This performance difference might be due to differences in tasks. Most previous research on reciprocal aiming in stroke patients had participants tap between targets; in this study, participants moved a stylus reciprocally on a tablet. Neuroimaging results from healthy participants also provide evidence in support of our findings. Winstein, Grafton, and Pohl[41] found significant increases in regional cerebral blood flow in ipsilateral dorsal premotor, contralateral inferior parietal, and bilateral occipital areas during continuous reciprocal aiming movements when task complexity was increased, pointing to a contribution from each hemisphere.[41]

Some limitations of this study should be acknowledged. First, the experimenters had no structural imaging data to define the location of the lesions. Consequently, our convenience sample may be heterogeneous, with cortical and subcortical lesions affecting a range of pathways on the right and possibly subclinical lesions of the left hemisphere. However, all participants did show decrements of the left arm and few or no differences of the right arm compared to controls on their motor examination. A second limitation was in not including a left hemisphere stroke group with right arm paresis. Our resources for recruitment were limited. Also, the tests of the dominant, nonaffected arm on a digitizing tablet are very sensitive, so dominant/nondominant control issues may have been difficult to assess. Prior studies suggest that the dominant hand in patients with chronic stroke is less impaired compared to when the nondominant hand is affected, regardless of side of the lesion, but this may not lessen disability.[42] Furthermore, our task required the ability to meet accuracy demands and utilize feedback control, both of which have previously been shown to be impaired in RHD[3] but have not been tested in the same participants with a discrete and continuous task. Reaching further out into peri-personal space could alter the findings.[43]

The results may affect daily activities and recovery poststroke. A number of everyday tasks require multiple steps such as grabbing a glass out of a cupboard and filling it with a liquid. Furthermore, accuracy demands are increased when the glass is filled, for example, with a hot liquid. Rehabilitation interventions must take into account that the efficiency of fine motor movements is compromised not only in the affected limb but also in the nonaffected limb. In addition, patient awareness that deficits of their “good side” can be expected will encourage patients to take measures to improve and maintain motor control of both upper extremities.

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