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Contralesional arm preference depends on hemisphere of damage and target location in unilateral stroke patients

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Abstract

Background—Previous research has shown that during simulated activities of daily living right handed stroke patients use their contralesional arm more after left than right hemisphere stroke. These findings were attributed to a hand preference effect. However, these decisions about when to use the contralesional arm may be modulated by where in the work space the task is performed, a factor that could be used in physical rehabilitation to influence recovery by decreasing learned non-use.

Objective—To examine how target location and side of stroke influences arm selection choices for simple reaching movements.

Methods—Fourteen right-handed stroke patients (7 with left hemisphere damage, 7 with right hemisphere damage) with similar degree of hemiparesis (Fugl-Meyer motor score), and 16 right-handed control subjects participated in this experiment. Thirty-two targets were presented throughout the reachable horizontal plane workspace in a pseudo-random fashion, and the subjects were asked to select one hand to reach the target on each trial.

Results—The left hemisphere damaged group chose their contralesional arm significantly more often than the right hemisphere damaged group. Patients with right hemisphere damage also chose their left (contralesional) arm significantly less than the control group. However, these patterns of choice were most pronounced in the center of the workspace.

Conclusion—Both the side of hemisphere damage and workspace location played a significant role in the choice of whether to use the contralesional arm for reaching. These findings have implications for structuring rehabilitation for unilateral stroke patients.

Introduction

Stroke is the leading cause of permanent disability in the United States, often producing hemiparesis on the side of the body opposite to the side of the damaged hemisphere (i.e. contralesional). Unilateral stroke can often lead to patients avoiding using their contralesional arm for activities of daily living, and relying more on their ipsilesional arm. For example, Vega-Gonzalez & Granat reported that right-handed stroke patients use the ipsilesional arm more frequently than the affected arm due to contralesional hemiparesis. It is clinically important to address arm preference in chronic stroke patients because it has been shown that movement practice plays a critical role in sustaining and improving gains in performance developed during rehabilitation. In addition, learned non-use can negatively impact recovery, when patients avoid using the contralesional arm. Constraint induced movement therapy was developed to combat this learned non-use of the paretic arm after stroke with the goal of facilitating recovery. However, there could be several factors that influence arm choice in stroke patients. Haaland and colleagues found that arm use was influenced by laterality of stroke in right-handers. When performing simulated instrumental activities of daily living (IADLs) patients with left hemisphere damage (LHD) used their contralesional arm significantly more than patients with right hemisphere damage (RHD), which was attributed to the fact that the LHD group's contralesional arm was their preferred arm. However, as the dominant arm more frequently performs unilateral IADL tasks, these results may be biased due to using an IADL task.

The choice to use the contralesional or ipsilesional arm may also depend on the spatial requirements of the task. For example, in a recent study, we showed that healthy young adults presented with targets throughout the reachable workspace most often chose the ipsilateral arm to reach toward a target on the same side of the workspace. However, the dominant arm was chosen more frequently for targets near midline. Thus, workspace location of the target appears to play a significant role in arm selection. Previous studies examining arm preference in stroke patients have not examined the influence of workspace location, as their focus was mostly on the functional outcome of the task. In addition, our recent studies in stroke patients have also showed that left and right hemisphere damage produces dissociable deficits in both the contralesional and ipsilesional arm during reaching tasks. Thus, it stands to reason that the hemisphere of damage might also play a pivotal role in arm selection. In the current study, we examine whether patients with left or right hemisphere damage show different patterns of arm selection for a reaching task to targets that cover the horizontal plane workspace. The patients were matched for severity of motor impairment and lesion characteristics, and all patients were right hand dominant prior to stroke. Thus, we are able to directly determine whether the hemisphere of damage and the location of the targets influence arm selection patterns in a simple reaching task.

Materials and Methods

The Institutional Review Boards of the New Mexico Veteran Affairs Healthcare System and Hershey Medical Center approved the study protocol. Prior to participation, all subjects gave informed consent according to the Declaration of Helsinki.

Participants

A total of 30 subjects participated in this study [16 healthy controls, 7 left hemisphere damaged (LHD) patients, 7 right hemisphere damaged (RHD) patients]. All control subjects self-reported current right-handedness, and all stroke patients self reported right-handedness prior to stroke. All stroke patients were examined at least 6 months after stroke. Subjects were excluded if they had a history of or current (i) substance abuse or other significant psychiatric diagnosis (e.g., psychosis); (ii) non-stroke neurological diagnoses for the stroke patients and all neurological diagnoses for the control subjects; or (iii) peripheral movement restrictions, such as neuropathy or orthopedic disorders. Measures of hemiparesis, and auditory comprehension were used to characterize the degree of impairment in stroke patients across different domains. None of the stroke patients in our study demonstrated unilateral visual neglect, as confirmed by performance on the line cancellation task.

Experimental setup and task

The experimental setup is shown in Figure 1. Subjects sat facing a table with both their left and right arm supported over a horizontal surface by an air-jet system to eliminate the effects of gravity and reduce friction. This support allowed patients to perform the task with both arms, without demonstrating or reporting fatigue. Two start circles, targets, and the subject's fingertips (represented by an on-screen cursor) were displayed on a mirror using an HDTV positioned horizontally above the mirror. The mirror blocked the direct vision of the subject's arm, but reflected the visual display to give the illusion that the display was in the same horizontal plane as the fingertip. Position and orientation of the forearm and upper-arm segments were sampled using a Flock of Birds (Ascension Technology®) system at 130 Hz. The positions of the index finger tip, lateral epicondyle of the humerus and the acromion, directly posterior to the acromio-clavicular joint were digitized using a stylus that was rigidly attached to a 6-DOF Flock of Birds sensor. As sensor data were received, the 3D position of the above-mentioned landmarks was computed using custom software, with the X-Y plane parallel to the tabletop. We used the computed X-Y coordinates of the fingertip to define the projected cursor position.

The experimental task involved reaching to 32 targets, presented one at a time, across the workspace in front of the subject (Figure 1). Prior to the start of each trial, the two start circles and cursors (representing the fingertip of each arm) were displayed on the screen. Each start circle required the arm to be positioned at 30° shoulder flexion and 75° elbow flexion, as depicted in Figure 1. All subjects exhibited full active range of motion in the horizontal plane, when supported against gravity by the air-sled system. To initiate the trial, the subject brought both the cursors into the start circles and after a 500 ms delay, one of the targets appeared on the screen along with an audio-visual “go” signal, which cued the subjects to initiate a single, rapid movement toward the target. The subjects were free to choose whichever arm they wanted to perform the reaching movement. Once the trial was completed, the subjects returned their fingertips to the start positions to begin a new trial. The 32 targets were pseudo-randomly presented over a session of 512 trials, such that no target was presented consecutively.

Measures

To quantitatively determine the preference for using the dominant or premorbidly-dominant right arm, right arm preference was computed as a ratio of the number of reaches performed using the right arm to the number of reaches performed using the left arm for each subject (Figure 3A). We also quantified the percentage of contralesional arm reaches to all targets (Figure 3B) and to the targets on the body's midline, which were equidistant from either arm's starting location (Figure 3C) in the stroke patients. In order to assess the effect of workspace region on arm choice, we computed the average frequency of right and left arm reaches to each target across subjects and used these data to identify the midline of reaching frequency (RF Midline) using a linear approximation to points in space that yielded 50% of right arm reaches at each row of targets (see Figure 4). We also quantified the offset of the RF Midline from the body's midline at each row of targets. This RF Midline offset was computed as a percentage of the distance from the midline of the body and the extreme left or right target at each row.

Statistical Analysis

The arm choice between the three groups (control, LHD, RHD) was analyzed using a one-way ANOVA with group as the factor and right arm preference as the dependent measure. Contralesional arm reaching performances between LHD and RHD groups were analyzed using a one-way ANOVA with laterality of damage (left or right) as a factor and the percentage of contralesional arm use as the dependent measure. RF Midline Offset was analyzed using a 2-way ANOVA with row (1/2/3/4) and group (control, LHD, RHD) as factors. When warranted, post-hoc analyses were performed using Tukey HSD test, which corrects for multiple comparisons. Statistical significance levels were set to 0.05. All statistical analyses were carried out using the software JMP (SAS Institute Inc., USA).

Results

Table 1 shows that all three groups (control, LHD, RHD) were not significantly different in age ($F_{2,27} = 1.52$; $P = 0.23$) and education ($F_{2,27} = 0.96$; $P = 0.39$). The stroke groups (LHD, RHD) were not significantly different for upper extremity motor impairment (Fugl-Meyer motor score (FM): $F_{1,12} = 0.72$; $P = 0.41$), or time post-stroke ($F_{1,12} = 0.28$; $P = 0.61$). The FM scores of the patients in this study ranged from 46 to 64, indicating moderate to mild motor impairment.

High-resolution T1-weighted MRI scans were obtained from stroke patients and then normalized to a standard template in Montreal Neurological Institute space using unified segmentation and normalization routines in SPM8, and custom MATLAB scripts. Adobe Photoshop was used to reconstruct the lesions, and custom-written MATLAB code was used to convert the traced lesions into volume-of-interest files. The lesion volume-of-interests from multiple patients within a group (left or right hemisphere damage) were then overlaid in MRIcron to create overlap images showing areas of damage common to different number of patients within a group. Figures 2A and B show the superimposed lesion locations for all subjects within each stroke group. All lesions were confined to either the left or the right hemisphere. Importantly, all patients with left and right hemisphere damage had damage in

at least one region of the sensorimotor motor system (Brodmann areas 4, 6, 3, 1, 2 and/or internal capsule), and the intrahemispheric lesion locations were similar, though slightly more posterior in the LHD group. Colors of the shaded region denote the number of subjects in each group with damage in the corresponding area. Lesion volumes were not significantly different between the two groups ($F_{1,12} = 0.02$; $P = 0.92$). We quantified the duration of movements to the targets near the body's midline (midline column, and the column to either side of it) as they received substantial reaches from both arms of the stroke patients. Figure 2C and D shows that the duration of movements did not differ between the LHD and RHD groups irrespective of whether they used their contralesional or ipsilesional arm. Our ANOVA revealed no significant differences for the interaction between group and arm for either the contralesional arm performance ($F_{1,42} = 0.06$, $P = 0.79$) or ipsilesional arm performance ($F_{1,42} = 0.27$, $P = 0.60$). These results suggest that the duration of movements was similar between the two stroke groups, and thus, any differences in arm choices cannot be explained by performance differences.

Figure 3 shows the patterns of arm choices for all 3 groups across all targets (3A), and comparing only the stroke groups' contralesional reaches (all targets, 3B or only the 4 midline targets, 3C). Figure 3A shows that the RHD group chose their right arm substantially more than did the control and LHD groups across all targets as confirmed by a significant main effect of group ($F_{2,27} = 3.43$, $P = 0.04$). Post hoc analyses indicated that the right arm preference of the RHD group was significantly greater than the control group ($P = 0.04$), and because of the nature of the ratio measure (right hand/left hand) this finding also shows that the RHD group used their left arm significantly less than the control group. In addition, there was no significant difference between the control and LHD groups ($P = 0.97$). These findings indicate that the LHD group chose to use their contralesional, right arm as often as the control group used their right arm, despite mild to moderate paresis. In contrast, the RHD group chose to use their contralesional, non-dominant arm less than control subjects chose to use their left, non-dominant arm across the entire workspace.

Figure 3B directly compares the choice to reach with the contralesional arm between LHD and RHD groups to all targets. The percentage of contralesional arm reaches for the RHD group was lower than that of the LHD group. Because the midline targets were equidistant from both the right and left hand start positions, these targets had no geometrical or biomechanical bias. We, thus separately compared contralesional reaches to these symmetrically positioned targets (Figure 3C). This comparison revealed that the RHD group used their contralesional arm less than the LHD group, which was confirmed by ANOVA, which showed statistically significant main effect of group for all targets ($F_{1,40} = 4.93$; $P = 0.03$) and midline targets ($F_{1,12} = 27.9$; $P = 0.0002$). This result suggests that the preference of using the dominant arm is preserved in LHD patients, while RHD patients reach more with the dominant arm than do control subjects. We also examined whether the arm preference during the first and the second half of the session were different, indicating changes in choices with experience. Our 3-way ANOVA with group, arm and session as factors showed no significant main effect of session ($F_{1,108} = 0.02$; $P = 0.89$). There was also no significant effect of the interactions between session and group ($F_{2,108} = 0.0075$; $P = 0.99$), nor between session, group and arm ($F_{2,108} = 0.04$; $P = 0.95$). This indicated that the

subjects did not alter their behavior along the course of the session. Given the large array of targets, and high repetition to each target (16 times per target), this was not surprising.

To examine the effect of workspace location on hand choice, we evaluated the reach percentage of each arm to each target across all 3 groups, as shown in Figure 4A-C. We then calculated the midpoint of reach frequency for each target row, and the reach frequency midline indicates the interpolated location in space, in which 50% of the reaches would be made with left arm and 50% with the right arm. One can think of this as the point in space in which a subject switched their reaching preference to the other hand. Our ANOVA revealed a significant effect of group ($F_{2,108} = 9.81$; $P < 0.0001$) for RF midline offset. Post-hoc analysis revealed that the RF midline offset was significantly leftward for the RHD group, when compared to the control and LHD groups ($P < 0.0058$, in both cases). However, the RF midline offset of the LHD group was not significantly different from the control group ($P = 0.79$). This indicates that the RHD patients reached significantly further across the midline than did the control group. In contrast, the LHD patients reached with their contralesional right arm across midline to the same extent as the control group. We conclude that in right-handers, the side of hemisphere damage interacts with premorbid hand preference following stroke. If the nondominant arm is contralesional (RHD patients), the preference to use that arm drops significantly, whereas if the dominant arm is contralesional (LHD patients), the patients' preference to use that arm is retained.

Discussion

Previous studies that have examined arm use during IADL tasks have suggested that right and left hemisphere damaged patients tend to use their contralesional arm to different extents. However, ADL tasks do not allow one to examine the influence of workspace location on arm preferences. In addition, premorbid patterns of ADL performance could strongly bias arm use patterns in such tasks. In the current study, we presented an arm choice paradigm, in which subjects had the option to reach with either arm to each of 32 targets that were distributed throughout the reachable horizontal plane workspace. Our results indicated that the laterality of hemispheric damage has a substantial impact on the choice to use the contralesional arm, such that LHD patients are more likely to choose their contralesional arm, than are RHD patients. Thus, the hemisphere that is damaged has a substantial impact on the patient's choice to use the contralesional arm, and this choice is also modulated by the location of the target in the workspace. The RHD group used their right (ipsilesional) arm substantially more than the controls to reach across the midline to the left hemispace, but the LHD group's decision to use their right (contralesional) arm was similar to that of control participants.

The influence of side of lesion on limb choices

Our mildly hemiparetic stroke groups (RHD and LHD) and our control participants reached to an array of 32 targets, that covered the reachable horizontal plane workspace. Our findings revealed a consistent bias of RHD patients against reaching with the non-dominant contralesional arm. Because our groups were matched for degree of motor impairment and lesion size and their lesion locations were fairly similar, our findings are not likely to have

resulted from the degree of hemiparesis or intrahemispheric lesion characteristics. The tendency to avoid use of the contralesional arm in RHD patients was modified substantially by workspace region. While almost all targets in the far right or far left of the workspace were reached using the right arm for right space and left arm for left space, the dominant arm bias of RHD patients was strongest in the midline regions. In contrast, for LHD patients, their arm choices were similar to that of our healthy age matched control group despite right hemiparesis. The tendency of RHD patients to avoid using the contralesional non-dominant arm is consistent with previous findings during simulated activities of daily living. The current results extend these findings to show that this tendency is not due to the nature of daily living activities, but persists for simple reaching movements. In addition, we show that workspace location modulates these choices, especially in RHD patients. Specifically, the RHD patients are likely to use their contralesional arm only in the left side of the workspace. Thus, the location of objects in the workspace can counteract the tendency of these patients to avoid the use of the contralesional non-dominant arm. We expect that this information can be important in structuring rehabilitation experiences to encourage spontaneous contralesional arm choices in patients with right hemisphere damage.

The influence of workspace location

Previous studies that have examined arm preference across the workspace have shown that healthy adults generally prefer to make ipsilateral reaches, avoiding crossing the midline. The rationale for this is that reaches that cross midline require more energy, although some have also attributed the tendency to the greater demands of intrahemispheric visual-motor processing. However, even in healthy adults this reaching pattern appears to be asymmetric, with the dominant arm making slightly more reaches into the contralateral hemisphere. In the current study, our findings for healthy aged matched control subjects are generally in agreement with these previous studies. However, the percentage of reaches into the contralateral hemisphere with the dominant right arm were not as high as that observed for young adults in several previous studies, even those with the same array of targets as we presented in our current study. This difference in reaching pattern between young and older adults (current study) could be attributed to the reported reduction in motor performance and motor transfer asymmetries with aging. Consistent with this idea, neuroimaging studies have shown that, as people age, there is a considerable reduction of hemispheric asymmetry. However, it has also been suggested that the manual asymmetries observed in young adults also persist with aging. For example, in a study by Chua et al, it was observed that the elderly participants continued to exhibit asymmetries in movement duration that were consistent with the asymmetries shown by younger adults. On the other hand, more recent studies examining detailed kinematics during more complex and varied tasks have provided evidence for reduction of motor performance asymmetries with aging. Further research is required to conclusively determine whether aging reduces the performance asymmetries observed in young adults.

The current study shows that the hemisphere of damage modulated the pattern of arm choices across the horizontal plane workspace (Figure 4A-C). RHD patients used their right, dominant arm to reach across the midline to the contralateral hemisphere significantly more than did the age matched control subjects. This difference seems to persist irrespective of the

distance from the body required for the reach. In contrast, the pattern of reaches for the LHD patients was similar to that of the age matched control group. These findings suggest that when the non-dominant arm was contralesional (as for the RHD group), the patients' preference to use that arm to reach to targets was substantially reduced, compared to when the contralesional arm was dominant. While all subjects had mild impairment, as indicated by the Fugl-Meyer, and demonstrated full active range of motion in the horizontal plane with their arms supported against gravity, we do not know whether the restricted choice to use the contralesional arm for contralateral reaches near midline in RHD patients was affected by the quality of movement. It is notable that the movement durations of RHD patients were similar to that of the LHD patients. This suggests that the choice to avoid contralesional arm use was not dictated by movement quality differences. Nevertheless, it remains possible that arm selection differences between patient groups were influenced by potential differences in movement quality toward the different targets.

These findings bring up the question of whether this pattern of choices would occur during more natural activities of daily living. More recently, Haaland and coworkers' investigated arm use during simulated activities of daily living in stroke patients. In these studies, patients performed instrumental activities of daily living (IADL), including tasks such as writing checks, using a telephone, and meal preparation. The performance in these IADL tasks was assessed using either the Arm Motor Ability Test or the Functional Impact Assessment and duration of contralesional and ipsilesional arm movements was quantified separately using accelerometers. Both studies reported that the RHD patients used their ipsilesional arm significantly more often than the LHD patients, while one reported that RHD patients used their contralesional arm less than LHD patients. It should be stressed that many of these tasks are normally performed unilaterally by the dominant arm, and therefore might show a bias based on premorbid task practice. However, taken together with our current study, we can conclude that RHD reduces the tendency to spontaneously choose the contralesional left arm for reaching or while performing activities of daily living. In contrast, left hemisphere damage has little effect on arm choices, when the severity of motor impairment is mild to moderate. The study by Haaland et al. suggest that the asymmetry in this pattern may persist with more severe impairments. Based on these findings, we suggest that the side of hemisphere damage may play a significant role in the degree to which the effects of physical rehabilitation are transferred from the clinic to the home setting, where patients make spontaneous choices about arm use. We speculate from previous literature that the trend to avoid contralesional arm use in RHD patients may limit the efficiency of performance on functional tasks, such as ADL. However, this speculation is limited by the fact that we did not assess functional performance on scales such as the Wolf Motor Function, nor Arm Motor Ability Test in this study.

Implications for Rehabilitation

The current findings might be important in structuring rehabilitation for patients with unilateral stroke. Our findings, taken together with the literature reviewed above, indicate that right-handed patients with right hemisphere stroke show a strong tendency to avoid using their contralesional, nondominant arm. It is important to note that neither our study nor previous studies have systematically examined left-handed stroke patients; therefore we

cannot directly generalize our findings to this group. Nevertheless, we consider our findings important because of the impact that this trend may have on contralesional impairment during and following rehabilitation after stroke. It has been well established that when patients do not use their paretic arm, learned nonuse develops, which is associated with further motor deterioration. Our current findings may be a result of the greater tendency of the RHD group to avoid spontaneously using the nondominant arm, especially as our stroke patients were in the chronic stage of recovery (at least 6 months post stroke). Our results suggest that the previous findings in hemiparetic stroke patients showing greater motor deficits in the contralesional nondominant as compared to the contralesional dominant arm may be related to this tendency to avoid spontaneously using the nondominant paretic arm and learned non-use.

To sustain and improve gains in performance developed during rehabilitation, it is critical for patients to continue to use the contralesional arm in non-supervised settings. In fact, regardless of intervention technique, it appears that movement practice may be the single most critical determinant in the efficacy of movement training interventions. Good et al recently conducted a meta-analysis, which indicated that physical rehabilitation programs of greater intensity and longer duration tended to produce better outcomes. Unfortunately, due to current reimbursement limitations, patients rarely spend more than a few weeks in intensive rehabilitation centers following stroke. This emphasizes the importance of the spontaneous choices that individuals make to use the contralesional arm in unsupervised settings. We now suggest that occupational and physical therapists pay particular attention to encouraging right hemisphere damaged patients to choose the contralesional arm in the therapeutic environment. It is plausible that shaping these choices through successive approximations of workspace location might develop patterns that can be carried out in more natural settings. For example, placing objects in the far left of the workspace would tend to produce spontaneous left-hand reaches. It is possible that gradually moving the objects toward the midline during successive reaches might encourage habitual patterns of choice that may be carried out in more natural settings. Techniques such as constraint-induced therapy could be combined with these manipulations to further offset the RHD patients' tendency to avoid using the contralesional arm.

Limitations in our current study and future directions

We designed this study to determine whether the hemisphere of damage influences one's choice to use the contralesional or ipsilesional arm, following stroke. We hypothesized that left and right hemisphere damage might produce asymmetrical influences on limb choices, based on previous reports, indicating differential effects of left and right hemisphere lesions on motor control and use of each arm. We limited our subjects' selection to those patients with moderate to low hemiparesis (Fugl-Meyer score > 45), so that all patients could successfully reach to all targets in the workspace. We also restricted movements to a two-dimensional surface, in order to reduce potential mechanical asymmetries associated with different limb elevation postures and to reduce the potential for fatigue. Finally, we restricted our patient population to premorbid right-handed patients. This was done for two reasons: First, we matched patients for lesion size and location, as well as impairment level, between our groups. This type of matching precluded our ability to include left-handers, because

there were simply not enough left-handed patients in our database to differentiate by lesion characteristics and by impairment level. Second, our previous research upon which we based our hypotheses was similarly restricted to right-handers. While our results are consistent with previous reports of arm use in a larger and more varied patient cohort, generalization of our current results must be done with caution due to the above-mentioned restrictions. Overall, our current study has certain limitations, which raise important questions for future research. These include questions regarding the generality of our results to unconstrained movement conditions, and to left-handed patient groups. However, we believe that our findings provide strong evidence that the side of brain damage has a substantial impact on spontaneous choices to use the contralesional arm following sensorimotor stroke.

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Figure 1.

Schematic of the experimental setup. Subjects sat facing a mirror onto which the start position and targets were projected using a HDTV, and rested their arms in an air-sled system placed on a glass tabletop. The top-view of the experimental interface depicting targets and start circles is also shown. HDTV - High Definition Television; FOB - Flock of Birds tracking system.

Figure 2.

Overlap images showing locations of lesions for the (A) right and (B) left hemisphere damaged groups; Color scale of magenta to yellow shows increasing overlap. (C) Comparison of movement duration between the controls and stroke groups in reaching to targets near the midline with their contralesional arm, and (D) ipsilesional arm. LHD = Left Hemisphere Damage, RHD = Right Hemisphere Damage, L = left hand, R = right hand.

Figure 3.

(A) Comparison of mean right arm preference (ratio of right arm reaches to left arm reaches) across the three groups (control, LHD, RHD) for all targets. (B) Comparison of contralesional arm reaches between LHD and RHD patients to all targets, and (C) to midline targets (the 4 targets located on the midline of the body). LHD - Left Hemisphere Damage; RHD - Right Hemisphere Damage.

Figure 4.

Reach Frequency to each target for each group: (A) Control, (B) LHD and (C) RHD (Dark shade: right arm reach frequency; Lighter shade: left arm reach frequency). The RF midline depicts the Reach Frequency midline for each group, and the shaded region beneath the RF midline represents the 95% confidence interval.

Table 1

Demographic information of subjects

	Control Subjects	LHD	RHD
n	16	7	7
Age (years)	59.37 ± 6.11	65.42 ± 6.6	61.85 ± 11.39
Education	15.3 ± 2.49	16.0 ± 3.05	14.0 ± 3.05
Fugl Meyer score	N/A	60.57 ± 3.95	58.29 ± 5.88
Lesion volume (cm ³)	N/A	114.47 ± 132.30	120.81 ± 79.82
Years post-stroke	N/A	3.52 ± 2.01	4.88 ± 6.54