Published in final edited form as:
Neurorehabil Neural Repair. 2006 September ; 20(3): 380–389. doi:10.1177/1545968305284528.

Individuals with the dominant hand affected following stroke demonstrate less impairment than those with the non-dominant hand affected

Jocelyn E Harris, O.T, PhD.[1,2] and **Janice J Eng, PhD, PT/OT**[1,2] **[Professor]**

[1]Department of Physical Therapy, University of British Columbia, Canada

[2]Rehabilitation Research Lab, G.F. Strong Rehab Centre, Vancouver, British Columbia, Canada

Abstract

Objective—The purpose was to determine if upper extremity impairment and function in individuals with chronic stroke is dependent upon whether the dominant or non-dominant hand is affected.

Methods—Ninety-three community-dwelling individuals with stroke. The Modified Ashworth Scale (tone), hand held dynamometry (isometric strength), monofilaments (sensation), Brief Pain Inventory (pain), Chedoke Arm and Hand Activity Inventory and Motor Activity Log (paretic arm use), and Reintegration to Normal Living Index (participation) were used to form impairment and function models.

Results—MANOVA models (DOMINANCE x SEVERITY) were created for impairment and function variables. There was a significant interaction and main effect of DOMINANCE for the impairment model (p=0.01) but not the function model (p=0.75). The dependent variables of tone, grip strength and pain were all significantly affected by DOMINANCE, indicating less impairment if the dominant hand was affected. All dependent variables except pain were affected by SEVERITY.

Conclusion—This study looked at the effect of the dominant hand being affected versus the non-dominant in individuals with chronic stroke. Individuals with the dominant hand affected demonstrated less impairment than those with the non-dominant hand affected. However, there was no effect of dominance on paretic arm use or performance in activities of daily living. Prospective studies to further explore the issue of hand dominance and post stroke function are suggested.

Keywords

Stroke; Upper extremity; Laterality; Rehabilitation

Correspondence address: Janice Eng, PhD, PT/OT, Professor, Department of Physical Therapy, University of British Columbia, 212-2177 Wesbrook Mall, Vancouver, BC, V6T 1Z3, Canada, Janice.Eng@ubc.ca.

INTRODUCTION

Hand dominance has been cited as an important factor in the performance of motor skills[1] with the dominant hand being used for many daily and recreational activities. Impairment of the dominant hand caused by conditions such as stroke, could compromise participation in many tasks. A large portion of individuals who have sustained a stroke have upper extremity impairment.[2,3] Studies report between 45–50% of individuals sustain a left hemisphere lesion and therefore right side paresis.[4–6] Since up to 80% of people are right hand dominant,[7] a significant proportion of individuals who experience a stroke will have their dominant hand affected. It is not known whether these individuals will gain better upper extremity outcome than those who had their non-dominant hand affected from stroke.

In healthy adults, potential differences in components of motor skill have been evaluated between the dominant and non-dominant hand. Speed, precision, and coordination[8–10] have been found to be superior in the dominant hand. However, researchers have found that reaction time is superior in the left hand of right-handers,[9,10] perhaps due to the role of the right hemisphere in visual spatial processing.[11] Muscle fatigue has been found to be greater in the non-dominant hand.[12,13] Different muscle activation and hand trajectories have been observed during reaching movements between the dominant and non-dominant hand.[14] Studies in healthy adults have shown that grip strength is approximately 10% greater for the dominant hand but only in right hand dominant individuals.[15,16]

It has been suggested that the advanced performance of the dominant hand may stem from motor programs and skills developed from extensive practice and experience associated with dominant hand use.[8–10,14] Bestelmeyer and Carey[9] also suggest the difference may be attributed to the non-dominant hand being less efficient in correcting movement errors and therefore less accurate. Other factors that may contribute to performance differences are an increased number of slow twitch Type-I muscle fibers (which are more resistant to fatigue) and a higher number of active motor units in the dominant hand.[12,13]

Hand dominance as a factor in motor and functional performance has been examined in some orthopedic and neurological conditions. Walsh et al.[17] found that a large portion (up to 35%) of individuals with hand injuries had to change handedness post injury and reported functional loss. Osteoarthritis is commonly found in hand joints and Caspi et al.[18] found greater clinical and radiographic changes in the dominant versus the non-dominant hand, indicating greater presence of degenerative changes. Their explanation for this finding was that the dominant hand is used extensively in manual tasks and is therefore more prone to develop arthritic bone changes. Following the onset of Parkinson's disease, individuals continued to perform faster finger tapping speed with their dominant hand compared to their non-dominant hand and this trend was even observed in individuals whose dominant hand was more affected by Parkinson's disease.[19]

No studies have examined the impact having the dominant verses the non-dominant hand affected post stroke has on impairment, activity (ADL), and participation. However, given the findings from studies on both the neurological and peripheral changes in arm function post stroke, we hypothesized that individuals with their dominant hand affected by the stroke would experience less impairment, greater performance in ADL, and higher ratings of participation compared to those with their non-dominant hand affected.

METHODS

Participants

Ninety-three persons with chronic stroke (≥1 year post stroke) and residual upper extremity impairment were recruited on a voluntary basis from flyers in community centers and newspaper advertisements. Upper extremity impairment was first qualified if the individual answered ‘yes’ to having difficulty using their arm and or hand in daily activities during a phone screening interview. Subsequent arm impairment was quantified by demonstrating a deficit on any of the arm impairment scales. Inclusion criteria consisted of 1) only one incidence of stroke, 2) able to provide informed consent, 3) score of >23 on the Mini Mental Status Exam (Folstein et al. 1975), and 4) ≥50 year of age. Persons with 1) significant musculo-skeletal conditions, 2) neurological conditions other than incidence of stroke and 3) persons with receptive aphasia (as assessed from caregiver information or not able to follow a two step command “lift your left/right arm over your head”) were excluded from the study. Ethics approval was obtained from the local university and hospital review board. Participants took part in a 90-minute individual evaluation. An occupational therapist (JEH) with clinical experience in individuals with stroke and one trained research assistant assessed all participants.

Information on hand dominance was obtained by asking the individual which hand they preferred to use for writing and throwing a ball prior to the stroke. This information was then coded into 0 (dominant hand affected) or 1 (non-dominant hand affected). Arm motor recovery was measured using the upper extremity portion of the Fugl-Meyer Motor Impairment Scale (FMA).[20] The mean score of our sample (44.0) was used to classify the participants into two categories: 0 (severe impairment < 44) and 1 (mild impairment ≥ 44). Our distribution of FMA scores is consistent with other studies involving individuals with chronic stroke.[21,22]

Outcome Measures

Impairment Measures—The Modified Ashworth Scale (MAS)[23] was used to measure tone (i.e. resistance to passive movement) of the paretic elbow flexors. It is an ordinal scale ranging from 0 (normal) – 4 (rigid). The MAS includes a score of 1+ (slight increase in tone with minimal resistance through less than half range) which is distinctive from a score of 1 where the resistance is felt only at end range. For statistical purposes, coding of the MAS was recorded as the number assigned except for 1+, which was assigned a numerical value of 1.5. Inter-rater reliability has been found to be excellent (ICC=0.82–0.90).[23,25] Validity of the MAS has been studied by Pandyan et al.(2003)[26] and McCrea et al (2003)[27] who compared it to the resistive force during passive movement applied and measured by an isokinetic dynamometry system (r=0.51–0.91).

Isometric strength of the paretic arm was tested using a hand-held dynamometer. The average of three trials for all measures of strength was used to determine the final recorded score. High inter-rater reliability (ICC= 0.88–0.93), intra-rater reliability (ICC= 0.99),[28–30] and test-retest reliability (ICC=0.80–.98)[31] have been found for hand held dynamometry. Validity of hand held dynamometry by comparison to known weights (accuracy of 1–3%) [32] is excellent. Elbow and wrist flexion and extension, in addition shoulder flexion and abduction were assessed. The score from each muscle group tested was summed for a composite score for each subject. We have previously reported isometric strength in stroke and found similar average range and magnitude values of these upper extremity muscles in the paretic limb;[33] thus, one muscle group should not have undue weighting on the composite score. Grip strength of the paretic hand was determined using a Jamar dynamometer. Strength was measured and recorded in kilograms (kg) for both the arm and hand.

Sensation was assessed with a pressure aesthesiometer kit comprised of eight monofilaments. Sensation was measured on the dorsal lateral aspect of the index finger of the paretic hand. Filaments were presented from thick to fine and deformed to half its length. Once the individual is not able to detect the pressure the last monofilament felt is the score. Sham trials (where a filament was not administered but the subject was asked if they felt any pressure) were dispersed randomly within each filament. Inter-rater reliability (ICC=0.77–0.99)[34] and test-retest reliability (ICC= 0.69–0.71)[35,36] for monofilaments has been investigated with good results.

The Brief Pain Inventory (BPI)[37] was used to assess pain intensity and interference with function (e.g. household chores, walking, sleeping). Participants were asked to report whether they had pain of the paretic shoulder, arm, and hand only. Each item is rated on an eleven point ordinal scale (0= no pain and 10 = worst pain). Internal consistency (cronbach's alpha =0.89–0.95)[37,38] of the BPI has been found to be excellent. Validity of the BPI with a visual analog scale (r=0.66)[37] and the Pain Needs Assessment (r=0.60)[38] has been reported to be good.

Functional Measures—The Chedoke Arm and Hand Activity Inventory (CAHAI)[39] was used to evaluate the performance of the paretic arm in the completion of ADL. The assessor encourages the client to use both hands to complete each task. The CAHAI consists of 13 tasks of daily living (e.g. pouring, buttoning, zipping). Scoring is done on a 7-point ordinal scale (1 = total assistance and 7 = complete independence). Scoring is based on the percentage of contribution to each task by the paretic arm/hand. For example, an individual would score 7 on the jar opening tasks if they are able to hold the jar in their non-paretic hand and open it with the paretic hand. A score of 3 means they are able to use the paretic hand to stabilize and manipulate but require hand over hand guidance (50–74% contribution of the paretic arm). High internal consistency (Cronbach's alpha = 0.98),[39] excellent inter-rater reliability (ICC = 0.98), construct validity (r=0.81–0.93),[40] and face and content validity have been reported.[41]

The Motor Activity Log (MAL)[42] was used to measure each participant's perception of how much and how well they use their paretic arm during ADL. It is a semi-structured interview that consists of 30 ADL items (e.g. brushing teeth, buttoning a shirt, eating). Scoring is completed using two scales: 1) Amount of Use scale (0 = paretic arm is not used and 5 =

paretic arm is used as much as prior to the stroke) and 2) Quality of Movement scale (0 = movement quality is poor and 5 = movement quality is as before the stroke). The MAL has been used as an outcome measure to evaluate arm use by individuals with stroke.[43,44] The MAL is also a useful measure because it evaluates the amount of paretic arm use during ADL, unlike traditional ADL measures in which compensation from the non-paretic arm can play a large role in performance. The MAL has been shown to have high internal consistency (Cronbach's alpha ≥ 0.88), and reasonable construct validity (Spearman's rho = 0.63) in persons with stroke.[45] The MAL has good inter-rater reliability (ICC = 0.90–0.94).[44,45]

The Reintegration to Normal Living (RNL)[46] Index was used to measure perception of involvement in life situations. The RNL consists of 11 items with an emphasis on participation in activities and the community (e.g. "I participate in social activities with my family, friends and/or business acquaintances as is necessary or desirable to me.", "I am able to participate in recreational activities as I desire and "I assume a role in my family which meets my needs"). Items are scored on a three point ordinal scale (1 = not able to participate as desired and 3 = able to fully participate as desired). Good inter-rater reliability (ICC =0.62) and internal consistency (Cronbach's alpha = 0.90–0.95)[46] has been found as was good validity (r=0.72) with the Spitzer Quality of Life Index.[47]

Test re-test reliability for the measures used in this study was established using fifteen of the participants with a one week interval between testing (ICC = 0.86–0.98).

Statistical Analysis

Descriptive statistics were used for all variables. Data were evaluated using multivariate analysis (MANOVA). Since the severity of arm motor recovery could interact with the effect of whether the dominant or non-dominant hand was affected, we used a two factor model which could quantify the main effects and interactions of these two variables. Independent factor one (dominant versus non-dominant hand affected) was called DOMINANCE and independent factor two (FMA <44 or ≥44) was called SEVERITY. A 2x2 MANOVA assessed these independent factors on six dependent impairment variables (arm strength, grip strength, pain, tone, and sensation; i.e. impairment model). A second 2x2 MANOVA assessed these factors on three function variables (CAHAI, MAL, and RNL; i.e. function model). Significant MANOVAS were followed by post hoc univariate analysis (ANOVA) of the dependent variables. Homogeneity was tested using the Levene Statistic. Effect size for each MANOVA model was produced using Eta squared ($\acute{\eta}^2$). A value of $p \leq 0.05$ was considered significant. SPSS statistical software 11.5 for Windows was used for all analyses.

RESULTS

Participant characteristics and descriptive statistics can be found in Table 1. Forty (43%) individuals experienced right side paresis. Forty-two (45%) of the participants had the dominant arm affected by the stroke. Eight (9%) of the participants were left-handed. Fifty-seven (61%) participants were classified as mildly impaired (≥44 FMA) with 36 (39%) classified as severely impaired (<44 FMA). Test re-test reliability for the measures used in this study was established using fifteen of the participants with a one week interval between testing (ICC = 0.86–0.98).

No significant difference was found for impairment variables of strength, grip, tone, and sensation ($p>0.05$) between participants with right versus left hemisphere lesion. However pain was significantly different ($p=0.02$) between right and left hemisphere lesion. Individuals with right hemisphere lesion reported more pain. There was no significant difference found for function variables ($p>0.05$) between participants whose right versus left hemisphere was the site of injury. Homogeneity (dominant versus non-dominant affected) was not significant.

The MANOVA for the impairment model demonstrated a significant DOMINANCE x SEVERITY interaction (Table 2). There was a significant main effect for both DOMINANCE and SEVERITY (Table 2). The post-hoc tests showed that the dependent variables of tone, grip strength, and pain were all significantly affected by DOMINANCE, indicating less impairment if the dominant hand was affected (Table 3). Post hoc results for SEVERITY (Table 4) indicated that individuals were significantly more impaired in all variables (arm strength, grip strength, tone, and sensation, $p< 0.0001$) except pain, in the lower score FMA group (<44). The effect size for the impairment models were large ($\acute{\eta}^2$ =0.20–0.78) based on Cohen’s categories for ANOVA effect size measures.[48]

The MANOVA for the function model showed no significant interaction for DOMINANCE x SEVERITY (Table 2). There was a significant main effect of SEVERITY but not for DOMINANCE (Table 2). Post hoc results revealed all dependent variables were significantly affected by SEVERITY (Table 4). The effect size for the function models ranged from small ($\acute{\eta}^2$ =0.01) to large ($\acute{\eta}^2$ =0.78).

DISCUSSION

We found both an interaction and main effect for DOMINANCE in the impairment model. The interaction effect suggests that individuals who are severely or mildly impaired with the dominant hand affected show less impairment than those with the non-dominant hand affected. Having the dominant hand affected post stroke may have a protective effect against impairment. However, we did not find an interaction or main effect of DOMINANCE for the function model. Though DOMINANCE impacts impairment it is not translated into better arm performance in activities of daily living.

The propensity to use the dominant hand may lead to a better pre-stroke neuromuscular condition of the dominant hand (e.g., stronger muscles, more efficient motor unit recruitment) compared to the non-dominant hand. In fact, Tanaka et al.[13] suggests that the increased use of the dominant hand may produce a ‘training effect’ giving it an advantage over the non-dominant hand. Priori et al.[49] studied the issue of handedness in healthy individuals using transcranial magnetic stimulation, and found that the threshold required to produce movement was higher in the non-dominant hand. This suggests differences in motor cortical output for dominant and non-dominant hand movement. Therefore, if the dominant hand is affected by the stroke it may demonstrate less impairment immediately following the stroke due to its protective effect. Additionally, if the dominant hand has been affected by the stroke, individuals may be more motivated to use their dominant hand during recovery since they are not used to using their non-dominant hand for daily tasks. Provins[1] concluded that there is a preference to utilize the dominant arm more often during daily activities and this is reflected by better arm pointing accuracy, movement speed, and precision when using the dominant hand in healthy adults.[1,12,13] In contrast, if the non-dominant hand is affected, individuals may have little motivation to use this hand in daily tasks making it difficult to promote the use of the non-dominant hand in therapy. Annet[8] indicated that healthy individuals appear to be reluctant to work hard at a task when forced to use the non-dominant hand. The issue of motivation to use the non-dominant affected hand could be addressed by using treatment approaches that incorporate forced use of the impaired arm.

We found that if the dominant hand was affected by the stroke, individuals had less tone (MAS) than if the non-dominant hand was affected. Tone, defined as the degree of resistance given by a joint when being passively moved through range of motion, can result from both hyper-reflexia and mechanical/viscoelastic changes in the muscles and connective tissues.[49] The viscoelastic (peripheral) changes may be influenced by rehabilitation techniques. Some clinicians may avoid using the affected arm and hand if tone is present based on the theory of Neurodevelopment Treatment (NDT) as it advocates the inhibition of movements which may increase tone.[50] However, the tendency to use the dominant hand in daily activities, even if affected by the stroke, may limit some of the neuromuscular and mechanical changes which contribute to increased tone. Thus, it is possible that a greater use of the affected hand may diminish tone and facilitate movement.

Grip strength demonstrated a significant main (DOMINANCE) effect in the impairment model. These findings suggest that the individual with the dominant hand affected will have greater grip strength. Grip strength has been shown to be a significant factor of functional recovery.[51,52] However, having the dominant hand affected did not impact functional measures. Thus those with stronger grip strength due to dominance showed no greater functional independence over those with the non-dominant hand affected. In the chronic stage of recovery, individuals may have developed ways to cope with grip strength impairment and thus are able to complete functional tasks regardless of which hand is affected. The impact of hand dominance at the sub-acute stage, when adaptation and compensation have not occurred, may demonstrate different results than individuals with chronic stroke. Individuals may still benefit from grip strength and gripping activities (e.g. grasp/release, turning, pushing/pulling) during rehabilitation to minimize joint stiffness, increase/maintain range of motion, and help prevent shoulder-hand syndrome.

Pain scores were affected by the factor of DOMINANCE as individuals with their dominant hand affected reported less pain regardless of severity of motor impairment. The greater pre-stroke conditioning of the dominant arm may make it less prone to the mechanisms that can cause pain. Although individuals reported only mild levels of pain and pain interference with daily activities, it is still an important issue in stroke rehabilitation.[53] The reduced pain when the dominant arm is affected may occur because individuals attempt to utilize their dominant hand more frequently after stroke and thus minimize secondary joint changes that often produce pain (i.e. shoulder capsulitis, contractures, and subluxation). This suggests the importance of movement of the affected arm during rehabilitation.

There was a confounding factor with the assessment of pain and its relation to DOMINANCE. We found a significant difference in pain scores between individuals with right versus left hemisphere lesion; persons with right hemisphere lesion had higher pain scores. It is possible that the greater pain is associated with the impaired sensory (e.g., spatial neglect and altered pain perception)[54,55] associated with right hemisphere lesions. Since right hemisphere lesions would typically result in left arm impairment, it is not possible to separate the mechanisms due to hemisphere side and pain from secondary joint changes resulting from the inactivity of the non-dominant arm. A large sample which had sufficient power to assess the factors of hand dominance post-stroke (dominant versus non-dominant hand affected), right versus left handedness prior to stroke, and lesion side (right versus left hemisphere lesion) could help to partition the effects of these factors.

In our study, pain was the only variable to differ between right and left hemisphere lesions. Hemispheric specialization in humans, where one side of the brain is dominant for certain functions, has been explored. The left hemisphere appears dominant for motor aspects of upper extremity movement that include planning, sequencing, and modifying, whereas the right hemisphere is involved in visuospatial and sensory aspects.[56–58] This suggests that side of lesion would impact different aspects of upper extremity movement. Sudies have found that the left motor cortex was activated during both ipsilateral and contralateral movement regardless of hand dominance but substantially more in right hand dominant individuals.[59–62] It was also found that the right motor cortex was activated during contralateral movement but equally for right and left hand dominant individuals. Findings from these studies suggest hemispheric asymmetry for upper extremity movement and that hand dominance is related to activation of the motor cortices, particularly the left motor cortex. Left hemispheric lesions result in both contralateral and ipsilateral arm movement deficits, however, right lesions result in mostly contralateral deficits.[60]

Despite the studies which have found differences in motor cortical activation between right and left hemisphere lesions following stroke during upper extremity movements,[63–65] our results did not show any hemisphere effect on muscle strength, tone, sensation or arm function. Although the neurophysiological evidence would suggest that impairment might depend on which hemisphere was affected by stroke, others have not found consensus on hemipheric effects on physical measures of impairment and function. Some studies have reported poorer functional outcomes for right hemisphere lesions for muscle strength,[66] motor skills,[67] and measures of ADL,[66,68] although others have reported no effect of lesion on impairment[68] and ADL measures.[67,69] Further investigation on how lesion location and side affects functional recovery of arm movement is needed. This would help to specify individuals who would benefit from certain treatment interventions (i.e. constraint induced therapy, bilateral therapy) based on lesion location and side

In contrast to our findings of a DOMINANCE effect with impairment measures, we found no effect on measures of function. Those with the dominant hand affected showed no advantage on scores of function over those with the non-dominant hand affected. Once tasks become more complex (e.g. dressing, eating, and bathing), persons with stroke may begin to use compensatory strategies including adaptive equipment, thus minimizing the effect of hand dominance. This may be more apparent in individuals with chronic stroke. It is also evident in ADL tasks that bimanual movement and coordination are often used and the required contribution of the dominant hand is not as substantial as in unilateral tasks. It is possible that individuals with the dominant hand affected have become proficient in using the non-paretic or non-dominant hand for activities decreasing the effect of the paretic dominant hand. Studies to determine the impact of hand dominance on function at earlier stages of stroke recovery may demonstrate different results than compared to individuals in the chronic stage.

There was an effect of SEVERITY on measures of impairment and function. Individuals in the severe FMA range (<44) had significantly greater impairment, except for pain. Severe motor impairment as measured by the FMA did not appear to affect pain scores. The issue of pain is complex and could be due to a number of neurogenic or secondary musculoskeletal conditions. Severity did have a negative effect on measures of function, with individuals demonstrating more difficulty in ADL, less use of and satisfaction with the paretic arm in daily tasks, and a decrease in participation (RNL) scores. These results are not surprising since severity of motor impairment has been found to negatively effect functional recovery post stroke.[3,21, 70,71]

Limitations

Our findings can only be generalized to community dwelling individuals in the chronic stage of stroke recovery. However, over half of the individuals who have sustained a stroke are discharged home,[1] with a significant portion having residual motor impairment.[2,3] We did not collect information on lesion location or size. This limits our ability to generalize to specific stroke populations and the possible impact lesion location may have on handedness post stroke. However, we found that several impairment variables were different when separated by DOMINANCE, but were not significant when separated by right and left hemisphere lesion.

CONCLUSION

If the dominant hand was affected post stroke, individuals demonstrated less impairment but not function. We explored peripheral changes post stroke that could contribute to the dominant hand having less impairment. Our findings suggest that re-enforcement of paretic arm use in both unilateral and bilateral tasks may lessen impairment and reduce musculoskeletal changes post stroke.

Acknowledgments

This work was supported from an operating grant from the Canadian Institutes of Health Research (CIHR), the RX&D Health Research Foundation Special Research Allowance Program and career scientist awards to JJE from CIHR (MSH-63617)and the Michael Smith Foundation for Health Research, and a CIHR Doctoral Award and Strategic Training Fellowship in Rehabilitation Research from the CIHR Musculoskeletal and Arthritis Institute to JEH.

References

1. Provins KA. The specificity of motor skill and manual asymmetry; a review of the evidence and its implications. J Mot Behavior. 1997; 29:183–193.
2. Parker VM, Wade DT, Hewer LR. Loss of arm function after stroke: measurement, frequency, and recovery. Int J Rehabil Med. 1986; 8:69–73.
3. Wade DT. Measuring arm impairment and disability after stroke. Int Disabil Studies. 1989; 11:89–92.
4. Brosseau L, Raman S, Fourn L, Coutu-Walkulczyk G, Tremblay LE, Pham M, beaudoin P. Recovery time of independent poststroke abilities: part 1. Top Stroke Rehabil. 2001; 8:60–71. [PubMed: 14523753]
5. Macciocchi SN, Diamond PT, Alves WM, Mertz T. Ischemic stroke: relation of age, lesion location, and initial neurological deficit to functional outcome. Arch Phys Med Rehabil. 1998; 79:1255–1257. [PubMed: 9779680]
6. Sze K, Wong E, Or KH, Lum CM, Woo J. Factors predicting stroke disability at discharge: a study of 793 Chinese. Arch Phys Med Rehabil. 2000; 81:876–80. [PubMed: 10895998]
7. Annett M. Laterality and types of dyslexia. Neurosci Biobehav Rev. 1996; 20:631–6. [PubMed: 8994202]
8. Annett M. Five tests of hand skill. Cortex. 1992; 28:583–600. [PubMed: 1478086]
9. Bestelmeyer PEG, Carey D. Processing bias towards the preferred hand: valid and invalid cueing of left-versus right-hand movements. Neuropsychologia. 2004; 42:1162–1167. [PubMed: 15178168]
10. Kauranen K, Vanharanta H. Influence of age, gender, and handedness on motor performance of upper and lower extremities. Percept Mot Skills. 1996; 82:515–525. [PubMed: 8724924]
11. Barthelemy S, Boulinguez P. Manual reaction time asymmetries in human subjects: the role of movement planning and attention. Neuroscience Letters. 2001; 315:41–44. [PubMed: 11711210]
12. Farina D, Kallenberg LAC, Merletti R, Hermens H. Effect of side dominance on myoelectric manifestations of muscle fatigue in the human upper trapezium muscle. Eur J Appl Physiol. 2003; 90:480–488. [PubMed: 12898269]
13. Tanaka M, McDonagh MJN, Davies CTM. A comparison of the mechanical properties of the first dorsal interosseous in the dominant and non-dominant hand. Eur J Appl Physiol. 1984; 53:17–20.
14. Sainburg RL, Kalakanis D. Differences in control of limb dynamics during dominant and nondominant arm reaching. J Neurophysiol. 2000; 83:2661–2675. [PubMed: 10805666]
15. Incel NA, Ceceli E, Durukan PB, Erdem HR, Yorgancioglu ZR. Grip strength: effet of hand dominance. Singapore Med J. 2002; 43:234–237. [PubMed: 12188074]
16. Peterson P, Petrick M, Connor H, Conklin D. Grip strength and hand dominance: challenging the 10% rule. Am J Occup Ther. 1989; 43:444–447. [PubMed: 2750859]
17. Walsh WW, Belding NN, Taylor E, Nunley JA. The effect of upper extremity trauma on handedness. AJOT. 1993; 47:787–795. [PubMed: 8116769]
18. Caspi D, Flusser G, Farber I, Ribak J, Leibovitz A, Habot B, Yaron M, Segal R. Clinical, radiologic, demographic, and occupational aspects of hand osteoarthritis in the elderly. Semin Arthritis Rheum. 2001; 30:321–331. [PubMed: 11303305]
19. Nutt JG, Lea ES, Van Houten L, Schuff RA, Sexton GJ. Determinants of tapping speed in normal control subjects and subjects with Parkinson's disease; differing effects of brief and continued practice. Mov Disord. 2000; 15:843–849. [PubMed: 11009189]
20. Fugl-Meyer A, Jaasko L, Leyman I, Olsson S, Steglind S. The post-stroke hemiplegic patient: A method for evaluation of physical performance. Scand J Rehabil Med. 1975; 7:13–31. [PubMed: 1135616]
21. Desrosiers J, Malouin F, Bourbonnais D, Richards CL, Rochette A, Bravo G. Arm and leg impairments and disabilities after stroke rehabilitation: Relation to handicap. Clin Rehabil. 2003; 17:666–673. [PubMed: 12971712]
22. van der Lee J, Snels I, Beckerman H, Lankhorst G. Exercise therapy for arm function in stroke patients: A systematic review of randomized controlled trials. Clin Rehabil. 2001; 15:20–31. [PubMed: 11237158]

23. Bohannon R, Smith MB. Interrater reliability of a modified ashworth scale of muscle spasticity. Phys Ther. 1987; 67:206–207. [PubMed: 3809245]
24. Allison SC, Abraham LD, Peterson CL. Reliability of the Modified Ashworth Scale in the assessment of flexor muscle spasticity in patients with traumatic brain injury. Int J Rehabil Res. 1996; 19:67–78. [PubMed: 8730545]
25. Sloan RL, Sinclair E, Thompson J, Taylor S, Pentland B. Inter-rater reliability of the Modified Ashworth Scale for spasticity in hemiplegic patients. Int J Rehabil Res. 1992; 15:158–161. [PubMed: 1526704]
26. Pandyan AD, Price CIM, Barnes MP, Johnson GR. A biomechanical investigation into the validity of the Modified Ashworth Scale as a measure of elbow spasticity. Clin Rehab. 2003; 17:290–294.
27. McCrea PH, Eng JJ, Hodgson AJ. Linear spring-damper model of the hypertonic elbow: reliability and validity. J Neurosci Methods. 2003; 128:121–128. [PubMed: 12948555]
28. Bohannon RW. Internal consistency of dynamometer measurements in healthy subjects and stroke patients. Percept Mot Skills. 1995; 81:113–114.
29. Bohannon R. The clinical measurement of strength. Clin Rehabil. 1987; 1:5–16.
30. Mathiowetz V. Comparison of Rolyan and Jamar dynamometers for measuring grip strength. Occupational Ther Int. 2002; 9:201–209.
31. Ottenbacher KJ, Branch LG, Ray L, Gonzales VA, Peek MK, Hinman MR. The reliability of upper-and lower-extremity strength testing in a community survey of older adults. Arch Phys Med Rehabil. 2002; 83:1423–1427. [PubMed: 12370879]
32. LaStayo P, Hartzel J. Dynamic versus static grip strength: how grip strength changes when the wrist is moved, and why dynamic grip strength may be a more functional measurement. J Hand Ther. 1999; 12:212–8. [PubMed: 10459529]
33. McCrea PH, Eng JJ, Hodgson AJ. Time and magnitude of torque generation is impaired in both arms following stroke. Muscle Nerve. 2003; 28:46–53. [PubMed: 12811772]
34. Novak CB, Mackinnon SE, Williams JI, Kelly L. Establishment of reliability in the evaluation of hand sensibility. Plast Reconstr Surg. 1993; 92:311–322. [PubMed: 8337282]
35. Halar EM, Hammond MC, LaCava EC, Camann C, Ward J. Sensory perception threshold measurement: an evaluation of semiobjective testing devices. Arch Phys Med Rehabil. 1987; 68:499–507. [PubMed: 3619613]
36. Sieg KW, Williams WN. Preliminary report of a methodology for determining tactile location in adults. Occ Ther J Res. 1986; 6:195–206.
37. Cleeland CS, Ryan KM. Pain assessment: global use of the Brief Pain Inventory. Ann Acad Med Singap. 1994; 23:129–138. [PubMed: 8080219]
38. Tyler EJ, Jensen MP, Engel JM, Schwartz L. The reliability and validity of pain interference measures in persons with cerebral palsy. Arch Phys Med Rehabil. 2002; 83:236–239. [PubMed: 11833028]
39. Barreca S, Gowland C, Stratford P, Torresin W, Huijbregts M, Van Hullenaar S, et al. Development of the Chedoke Arm and Hand Activity Inventory: Item Selection. Phys Can. 1999 Summer;:209–211.
40. Barreca S, Gowland C, Stratford P, Huijbregts M, Griffiths J, Torresin W, Dunkley M, Miller P, Masters L. Development of the Chedoke Arm and Hand Activity Inventory: theoretical constructs, item generation, and selection. Top Stroke Rehabil. 2004; 11:31–42. [PubMed: 15592988]
41. Barreca SR, Stratford PW, Lambert CL, Masters LM, Streiner DL. Test-retest reliability, validity, and sensitivity of the Chedoke Arm and Hand Activity Inventory: a new measure of upper limb function for survivors of stroke. Arch Phys Med Rehabil. 2005; 86:1616–1622. [PubMed: 16084816]
42. Taub E, Miller NE, Novack TA, Cook EW III, Fleming WC, Nepomuceno CS, Connell JS, Crago JE. Technique to improve chronic motor deficit after stroke. Arch Phys Med Rehabil. 1993; 74:347–354. [PubMed: 8466415]
43. Miltner W, Bauder H, Sommer M, Dettmers C, Taub E. Effects of contraint-induced movement therapy on patients with chronic motor deficits after stroke. Stroke. 1999; 30:586–592. [PubMed: 10066856]

44. Liepert J, Baude H, Miltner W, Taub E, Weiller C. Treatment-induced cortical reorganization after stroke in humans. Stroke. 2000; 31:1210–1216. [PubMed: 10835434]

45. Van der Lee J, Beckerman H, Knol DL, de Vet HCW, Bouter LM. Clinimetric properties of the Motor Activity Log for the assessment of arm use in hemiparetic patients. Stroke. 2004; 35:1410–1414. [PubMed: 15087552]

46. Wood-Dauphinee SL, Opzoomer A, Williams JI, Marchand B, Spitzer WO. Assessment of global function: The Reintegration to Normal Living Index. Arch Phys Med Rehabil. 1988; 69:583–590. [PubMed: 3408328]

47. Wood-Dauphinee SL, Williams JI. Reintegration to normal living index as a proxy to quality of life. J Chron Dis. 1987; 40:491–499. [PubMed: 3597654]

48. Cohen, J. Statistical Power Analysis for the Behavioral Sciences. 2. Mahwah, NJ: Erlbaum;

49. Katz RT, Rymer WZ. Spastic hypertonia: mechanisms and measurement. Arch Phys Med Rehabil. 1989; 70:144–155. [PubMed: 2644919]

50. Bobath, B. Adult Hemiplegia: Evaluation and Treatment. Oxford, England: Heinemann Medical; 1999.

51. Mercier C, Bourbonnais D. Relative shoulder flexor and handgrip strength is related to upper limb function after stroke. Clin Rehabil. 2003; 18:215–221.

52. Boissy P, Bourbonnais D, Carlotti MM, Gravel D, Arsenault BA. Maximal grip force in chronic stroke subjects and its relationship to global upper extremity function. Clin Rehab. 1999; 13:354–362.

53. Ratnasabapathy Y, Broad J, Baskett J, Pledger M, Marshall J, Bontia R. Shoulder pain in people with stroke: a population-based study. Clin Rehabil. 2003; 17:304–311. [PubMed: 12735538]

54. Beschin N, Cazzani M, Cubelli R, Sala SD, Spinazzola L. Ignoring left and far: an investigation of tactile neglect. Neuropsychologia. 1996; 34:41–49. [PubMed: 8852692]

55. Sterzi R, Bottini G, Celani MG, Righetti E, Lamassa M, Ricci S, Vallar G. Hemianopia, hemianaesthesia and hemiplegia after right and left hemisphere damage: a hemispheric difference. J Neurol Neurosurg Psychiatry. 1993; 56:308–310. [PubMed: 8459249]

56. Haaland KY, Prestopnik JL, Knight RT, Lee R. Hemispheric asymmetries for kinematic and positional aspects of reaching. Brain. 2004; 127:1145–1158. [PubMed: 15033898]

57. Sabate M, Gonzalez B, Rodriquez M. Brain lateralization of motor imagery: motor planning asymmetry as a cause of movement lateralization. Neuropsychologia. 2004; 42:1041–1049. [PubMed: 15093143]

58. Winstein CJ, Pohl PS. Effects of unilateral brain damage on the control of goal-directed hand movements. Exp Brain Res. 1995; 105:163–174. [PubMed: 7589312]

59. Civardi C, Cavalli A, Naldi P, Varrasi C, Cantello R. Hemispheric asymmetries of cortico-cortical connections in human hand motor areas. Clin Neurophysiol. 2000; 111:624–629. [PubMed: 10727913]

60. Kim S, Ashe J, Hendrick K, Ellermann JM, Merkle H, Ugurbil K, Georgopoulos AP. Functional magnetic resonance imaging of motor cortex: hemispheric asymmetry and handedness. Stroke. 1993; 261:615–617.

61. Triggs WJ, Subramanium B, Rossi F. Hand preference and transcranial magnetic stimulation asymmetry of cortical motor representation. Brain Res. 1999; 835:324–329. [PubMed: 10415389]

62. Ziemann U, Hallett M. Hemispheric asymmetry of ipsilateral motor cortex activation during unimanual motor tasks: further evidence for motor dominance. Clin Neurophysiol. 2001; 112:107–113. [PubMed: 11137667]

63. Debaere F, Van Assche D, Kiekens C, Verschueren SMP, Swinnen SP. Coordination of upper and lower limb segments:deficits on the ipsilesional side after unilateral stroke. Exp Brain Res. 2001; 141:519–529. [PubMed: 11810145]

64. Guliani C, Purser J, Light K, Genova P. Impairments in arm control in subjects with left and right hemisphere stroke. NeuroRehabil. 1997; 9:71–87.

65. Zemke AC, Heagerty PJ, Lee C, Cramer SC. Motor cortex organization after stroke is related to side of stroke and level of recovery.

66. Waller S, Whitall J. Hand dominance and side of stroke affect rehabilitation in chronic stroke. Clin Rehabil. 2005; 19:544–551. [PubMed: 16119411]

67. Bernspang B, Fisher AG. Differences between persons with right or left cerebral vascular accident on the assessment of Motor and Process Skills. Arch Phys Med Rehabil. 1995; 76:1144–1151. [PubMed: 8540792]

68. Shelton F, Reding MJ. Effect of lesion location on upper limb motor recovery after stroke. Stroke. 2001; 32:107–112. [PubMed: 11136923]

69. Macciocchi SN, Diamond PT, Alves WM, Mertz T. Ischemic stroke: relation of age, lesion location, and initial neurologic deficit to functional outcome. Arch Phys Med Rehabil. 1998; 79:1255–1257. [PubMed: 9779680]

70. Ween JE, Alexander MP, D'Esposito M, Roberts M. Factors predictive of stroke outcome in a rehabilitation setting. Neurology. 1996; 47:388–392. [PubMed: 8757009]

71. Nakayama H, Jorgensen HS, Raaschou HO, Olsen TS. Recovery of upper extremity function in stroke patients: The Copenhagen Stroke Study. Arch Phys Med Rehabil. 1994; 75:394–398. [PubMed: 8172497]

Table 1

Descriptive Statistics (N=93)

Variable	n	Mean(standard deviation)	Range
Sex (M/F)	61/32		
Age		68.7(9.4)	50–93
Time Since Stroke (yrs)		5.1(4.1)	1–27
Dominance (R/L)	85/8		
Side of Paresis (R/L)	40/53		
Dominance Affected/Unaffected	42/51		
Stroke Type (Ischemic/Hemorrhagic)	34/18		
Fugl-Meyer Upper Extremity Motor Scale (0–66)		43.9(21.1)	4–66
Modified Ashworth Scale Elbow (0–4)		1.0(1.1)	0–4
Arm Strength(kg)		45.4(29.4)	0.0–132.5
Grip Strength(kg)		13.0(11.1)	0.0–43.7
Sensation (1–8)		4.1(2.2)	1–8
Brief Pain Inventory Total (0–120)		9.9(17.3)	0–88
Chedoke Arm and Hand Activity Inventory (13–91)		62.1(31.8)	13–91
Motor Activity Log Total (0–5)		3.1(1.6)	0–5
Reintegration to Normal Living Index (11–33)		29.2(3.6)	19–33

Table 2

MANOVA results for DOMINANCE and SEVERITY

Impairment Model	**MANOVA**
Main effect of DOMINANCE	[*]λ = 0.84, p=0.01
Main effect of SEVERITY	λ = 0.13, p<0.0001
Interaction of DOMINANCE x SEVERITY	λ = 0.84, p=0.01
Function Model	
Main effect of DOMINANCE	λ = 0.99, p=0.72
Main effect of SEVERITY	λ = 0.22, p<0.0001
Interaction of DOMINANCE x SEVERITY	λ = 0.99, p=0.75

[*] λ = Wilks lambda

Table 3

MANOVA post-hoc results for DOMINANCE

IMPAIRMENT MODEL		**Mean**	**95% CI**	**P value**
Arm Strength	D[*]	48.0	47.7–57.0	0.23
	ND	44.4	35.8–53.0	
Grip	D	13.5	10.8–16.2	0.04
	ND	9.8	7.3–12.3	
Pain	D	4.8[†]	0.4–10.0	0.02
	ND	13.6	8.7–18-4	
MAS score	D	0.7	0.54–0.98	0.02
	ND	1.5	0.90–2.0	
Sensation	D	4.5	3.9–5.1	0.49
	ND	4.2	3.7–4.7	
FUNCTION MODEL				
Chedoke Arm and Hand Activity Inventory	D	62.7	52.0–72.0	0.41
	ND	61.6	53.0–71.0	
Motor Activity Log	D	2.9	2.6–3.2	0.45
	ND	2.7	2.4–3.0	
Reintegration to Normal Living Index	D	28.7	27.6–29.8	0.45
	ND	29.3	28.2–30.3	

[*] D = dominant hand affected, ND = non-dominant hand affected

[†] A lower score indicates less pain

Table 4

MANOVA post-hoc results for SEVERITY

IMPAIRMENT MODEL		**Mean**	**95% CI**	**P value**
Arm Strength	SV*	34.2	31.2–52.2	
	MI*	48.5	33.5–60.7	0.0001
Grip	SV	4.6	1.7–7.4	
	MI	18.7	16.4–21.0	0.0001
Pain	SV	8.3	2.8–13.9	
	MI	10.0	5.6–14.5	0.64
MAS score	SV	3.3	2.9–3.8	
	MI	0.34	0.04–0.7	0.0001
Sensation	SV	5.5	4.8–6.1	0.0001
	MI	3.2	2.7–3.7	
FUNCTION MODEL				
Chedoke Arm and Hand Activity Inventory	SV	27.2	22.1–32.3	0.0001
	MI	84.2	80.2–88.2	
Motor Activity Log	SV	1.5	1.1–1.8	0.0001
	MI	4.1	3.9–4.9	
Reintegration to Normal Living Index	SV	28.1	26.9–29.3	0.03
	MI	29.8	28.9–30.8	

* SV- severely impaired (FM<44), MI – mildly impaired (FM≥44)