7-2020

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Recommended Citation

Barry, Alexander J.; Triandafilou, Kristen M.; Stoykov, Mary Ellen; Bansal, Naveen K.; Roth, Elliot J.; and Kamper, Derek G., "Survivors of Chronic Stroke Experience Continued Impairment of Dexterity But Not Strength in the Nonparetic Upper Limb" (2020). *Mathematical and Statistical Science Faculty Research and Publications*. 46.
https://epublications.marquette.edu/math_fac/46

Archives of Physical Medicine and Rehabilitation, Vol. 101, No. 7 (July 2020): 1170-1175. DOI.

Survivors of Chronic Stroke Experience Continued Impairment of Dexterity But Not Strength in the Nonparetic Upper Limb

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Abstract

Objective

To investigate the performance of the less affected upper limb in people with stroke compared with normative values. To examine less affected upper limb function in those whose prestroke dominant limb became paretic and those whose prestroke nondominant limb became paretic.

Design

Cohort study of survivors of chronic stroke (7.2±6.7y post incident).

Setting

The study was performed at a freestanding academic rehabilitation hospital.

Participants

Survivors of chronic stroke (N=40) with severe hand impairment (Chedoke-McMaster Stroke Assessment rating of 2-3 on Stage of Hand) participated in the study. In 20 participants the prestroke dominant hand (DH) was tested (nondominant hand [NH] affected by stroke), and in 20 participants the prestroke NH was tested (DH affected by stroke).

Interventions

Not applicable.

Main Outcome Measure

Jebsen-Taylor Hand Function Test. Data from survivors of stroke were compared with normative age- and sex-matched data from neurologically intact individuals.

Results

When combined, DH and NH groups performed significantly worse on fine motor tasks with their nonparetic hand relative to normative data ($P<.007$ for all measures). Even the participants who continued to use their prestroke DH as their primary hand after the stroke demonstrated reduced fine motor skills compared with normative data. In contrast, grip strength was not significantly affected in either group of survivors of stroke ($P>.140$).

Conclusions

Survivors of stroke with severe impairment of the paretic limb continue to present significant upper extremity impairment in their nominally nonparetic limb even years after stroke. This phenomenon was observed regardless of whether the DH or NH hand was primarily affected. Because this group of survivors of stroke is especially dependent on the nonparetic limb for performing functional tasks, our results suggest that the nonparetic upper limb should be targeted for rehabilitation.

Life expectancy after stroke has been steadily increasing. Because of improvements in care and management after the stroke, the 1-year survival rate has increased substantially over the past decades.[1,2] Meanwhile, the average age of first-time stroke has been decreasing.[3,4] Together, these factors are leading to substantial lifespan durations post stroke.

Quality of life is likely to be affected by sensorimotor deficits resulting from the stroke. Up to two-thirds of all survivors of stroke experience chronic upper extremity impairment,[5,6] especially of the hand.[7] This will cause the majority of survivors of stroke to rely extensively on their nonparetic (ipsilesional) upper limb to perform functional tasks. A number of researchers have reported deficits in the nonparetic limb after stroke. The impairments include reduced task performance speed,[8,9] longer times to complete functional assessments,10, 11, 12, 13, 14 and reduced accuracy.[15] Presumably, functional deficits may be even greater in those individuals using the prestroke nondominant hand (NH) as the dominant hand (DH) post stroke.

Hence, there may be a vital role for therapeutic rehabilitation of the nonparetic hand. Therapy directly focused on the nonparetic hand, however, is relatively rare. While the lack of treatment may be partly attributable to reductions in available clinical treatment time (length of inpatient stays, for example, have decreased substantially over the last 25 years[4,16]), it may also arise from perceptions regarding the severity and significance of long-term deficits in the nonparetic hand.

In 2013, Kitsos et al published a comprehensive review of 27 studies looking at the ipsilesional hand following stroke,[17] with only 3 prior studies examining survivors of chronic stroke with standardized assessments (mean time post stroke 2-4.5y18, 19, 20). The review also demonstrated seemingly contradictory findings with a lack of consistency between speed, dexterity, strength, and functional ability. Furthermore, participants in these studies had a range of impairment levels in the paretic limb, potentially leading to an underestimation of the potential for deficits in the nonparetic upper limb. Sainburg and others have reported that the level of impairment in the nonparetic hand correlated with impairment level in the paretic hand.21, 22, 23, 24 Based on this literature, we believe examining survivors of stroke with more severe impairment of the paretic hand may provide the best indication of the extent of deficits in the nonparetic hand. Additionally, existing studies do not compare the prestroke NH (which post stroke has become the primarily used hand) with normative dominant data.

To address these gaps, the current study examined strength and dexterity in the nonparetic upper limb of survivors of stroke with severe, chronic impairment of the paretic hand. In particular, we expressly recruited participants for whom the paretic limb was the dominant limb prestroke and an equivalent number for whom the paretic limb was the nondominant limb prior to the stroke. The obtained data were compared to age- and sex-matched normative data. We hypothesized that survivors of stroke who experienced primary impairment of their prestroke DH would exhibit substantial deficits in comparison with normative data for the DH, while individuals who were able to continue to use their prestroke dominant limb would not have these deficits. We expected that deficits would be observed in fine dexterity but not in gross hand strength because the former requires more complex motor control ability. The latter hypothesis was based on previous work that demonstrated a significant relationship between task complexity and ipsilateral motor activations.25, 26, 27, 28 We also anticipated a significant correlation between time post stroke and better overall performance; we surmised that a heavy reliance on the nonparetic hand would lead to improved control through repetitive practice.

Methods

Study design

This cross-sectional study follows the guidelines laid out by the Strengthening the Reporting of Observational Studies in Epidemiology Statement. A convenience sample of 40 survivors of stroke completed this protocol at the baseline assessment of a larger intervention study focused on the paretic hand. Participants were required to have chronic impairment of the contralesional (paretic) hand that resulted from a single, unilateral stroke incurred more than 6 months prior to enrollment. The hand impairment had to be severe, as indicated by a Stage of Hand rating of 2 or 3 on the Chedoke-McMaster Stroke Assessment.[29] We targeted equal numbers of subjects who primarily used their prestroke DH following stroke and those who primarily used their prestroke NH following the stroke. Each participant provided written informed consent, approved by the Northwestern University Institutional Review Board.

Evaluation

Each participant completed a single evaluation session at a freestanding, academic rehabilitation hospital. During the session, the participants were asked to use their nonparetic hand to perform a battery of assessments. One set measured manual dexterity: Jebsen-Taylor Hand Function Test (JTHFT),[10] 9-hole peg test (9HPT),[30] and box and blocks test (BBT).[31] The second set measured strength: maximum grip strength (GS), maximum lateral pinch strength (LPS), and maximum palmar pinch strength (PPS). Times to complete each of the 7 tasks of the JTHFT (writing, flipping cards, picking up small objects, simulating feeding, stacking checkers, picking up light objects, and picking up heavy objects) and the second 9HPT time were recorded. Performance on the BBT was quantified in terms of the number of blocks successfully moved within 1 minute. Maximum grip force was measured with a hand dynamometer,[a] while maximum lateral and palmar pinch were measured with a pinch gauge.[b]

Analysis

The collected data were compared to age- and sex-matched normative data found in the literature. These normative data were obtained for both the DH and NH. The normative metrics were total time and time to complete each task for the JTHFT,[10,32] total time to complete the 9HPT,[33] the number of blocks successfully moved for the BBT,[31] and peak force for the GS, LPS, and PPS.[34] The *Z* scores, representing the distance from the mean normalized by the standard deviation, were computed for each measure for each participant. The *Z* scores were signed such that a positive value indicates a worsened time or score, while a negative *Z* score indicates a score or time better than the normative mean. The 95% confidence intervals were determined from the calculated *Z* scores. The data for the DH group were compared with the normative values for the DH. The data for the NH group were compared with the normative values for both the NH and the DH. The latter comparison gauged functionality of the NH in terms of its new role as the predominantly used hand. Within the NH group, we also examined the effects of prestroke left-hand vs right-hand dominance on outcome measures.

The *z* scores of the outcome measures JTHFT, 9HPT, BBT, GS, LPS, and PPS were used to test significant difference from the normative values. Normal probability plots and the Kolmogorov-Smirnov tests were used to evaluate the normal distributions of the *z* scores. If no significant deviation from normal distribution was observed, 1-sample *t* tests were run with a null hypothesis of μ_z=0. Otherwise, nonparametric Wilcoxon signed rank test was used to test the null hypothesis of med_z=0. Note that the purpose of the standardized *z* scores is to facilitate visualization and comprehension; use of the *z* scores did not alter the values of the *t* statistics. To correct for the multiplicity of hypotheses, a Bonferroni correction was used such that the significance level was set to α=0.0083. As a secondary analysis, 1-sample *t* tests were also performed for each of the 7 individual items comprising the JTHFT to identify specific tasks that might be problematic for survivors of stroke to perform with their nonparetic upper limb. Additionally, Pearson correlation coefficients were computed to examine possible relationships or confounding variables between specific participant characteristics (time since stroke and the Fugl-Meyer Assessment of the Upper Extremity [FMUE][35]) and the *z* scores of the outcome measure values.

Results

Participant information

A total of 40 participants completed the study, with 20 in the DH group and 20 in the NH group. Impairment of the paretic upper limb was severe, with FMUE averaging a mean of 15±6 of 66. Time post stroke ranged from 8 months to 26 years (table 1).

Table 1. Participant characteristics for each group

Variables	DH Group (n=20) (Mean ± SD)	NH Group (n=20) (Mean ± SD)
Age (y)	57.9±13.0	61.0±11.3
Time post stroke (y)	9.1±8.1	5.3±4.2
Chedoke-McMaster Hand Score	9 (stage 2)/11 (stage 3)	4 (stage 2)/16 (stage 3)
FMUE	14.1±7	16.6±5.4
Sex distribution	13 F/7 M	7 F/13 M
Lesion side	16 R /4 L	9 R/11 L

Abbreviations: F, female; L, left; M, male; R, right.

DH tested against normative dominant data

Substantial differences were apparent between scores for the nonparetic stroke hands and the normative scores. Despite maintaining use of their DH, the DH group (n=20) took significantly longer to complete the JTHFT (*t* value=2.5, $P<.001$) and the 9HPT (*t* value=2.5, $P<.001$) and moved significantly fewer blocks on the BBT (*t* value=3.8, $P<.001$) (table 2) than age- and sex-matched neurologically intact individuals. PPS was also significantly reduced (*t* value=1.0, $P<.005$). In contrast, the DH group displayed no significant difference in GS (*t* value=0.3, $P=.38$) or LPS (*t* value=0.2, $P=.532$).

Table 2. *Z* scores (±95% CI) compared with age- and sex-matched normative data

Outcome	DH vs Normative Dominant	NH vs Normative Nondominant	NH vs Normative Dominant
Average JTHFT time (s)	2.5±1.1† (9.0±1.1)	1.4±0.6† (11.8±1.2)	3.3±0.7†
Writing (s)	2.6±1.4† (20.8±4.2)	0.1±0.8 (37.7±8.4)	6.9±2.6†
Cards (s)	1.8±0.8† (6.6±1.0)	0.8±0.5* (6.6±0.8)	1.6±0.6†
Small objects (s)	1.9±1.2* (8.5±1.3)	1.5±0.7* (9.0±1.0)	2.1±0.8*
Simulated feeding (s)	3.2±1.3* (10.4±1.6)	2.1±1.1† (11.9±1.7)	4.6±1.7†
Checkers (s)	4.0±3.3 (7.2±2.3)	1.8±1.0† (7.1±1.3)	3.2±1.1†
Light objects (s)	2.3 ± 1.4† (4.8±0.7)	1.8±0.9† (5.1±0.6)	2.4±1.0†
Heavy objects (s)	1.9±0.9† (4.8±0.7)	1.9±0.9† (5.1±0.6)	2.2±0.8†
9HPT (s)	2.5±1.1† (25.8±3.5)	1.6±1.2 (25.7±2.82)	2.2±1.4*
BBT (blocks)	3.8±0.6† (47.9±4.1)	2.5±0.8* (51.1±5)	2.7±0.8†
GS (N)	0.3±0.7 (296.7±46.3)	−0.3±0.5 (328.3±45.8)	0.3±0.4
LPS (N)	0.2±0.7 (78.7±11.6)	0.6±0.4 (77.4±8.5)	0.8±0.5*
PPS (N)	1.0±0.6* (63.6±8.4)	1.0±0.5† (69.4±9.3)	1.2±0.6†

∗$P≤.0083$.
†$P≤.001$.

NH tested against normative nondominant data

For the NH group (n=20), comparisons with the normative data for the NH showed degraded performance in the NH group for the JTHFT (*t* value=1.4, *P*<.001), 9HPT (*t* value=1.6, *P*=.01), and BBT (*t* value=2.5, *P*<.001). Values for these measures were generally closer to the norm than for the DH comparison in the DH group but were still significantly worse than normative data. GS (*t* value=−0.3, *P*=.167) and LPS (*t* value=.6, *P*=.011) were not significantly different than the norm, but PPS was reduced (*t* value=1.0, *P*<.001).

NH tested against normative dominant data

The NH group also exhibited impairment in the nonparetic hand when comparing performance with the normative DH. JTHFT (*t* value=3.3, *P*<.001), 9HPT (*t* value=2.2, *P*=.005), and BBT (*t* value=2.7, *P*<.001) were all significantly different from normative values. PPS (*t* value=1.2, *P*<.001) and LPS (*t* value=0.8, *P*=.002) were significantly reduced, although GS was not (*t* value=0.3, *P*=.140). Overall, GS was the only measure that did not exhibit deficits. The level of impairment of the NH was generally greater when compared with normative data for the DH hand than when compared with normative data for the NH. In particular, the relative JTHFT scores were significantly worse for the normative dominant than for the normative nondominant comparisons (*P*<.001).

Individual JTHFT Items

For individual measures of the JTHFT, all tasks performed with the nonparetic hand took significantly longer than the normative mean except for NH in comparison with the normative NH for writing (see table 2). Notably, the NH components for feeding and writing in comparison with the normative data for the DH were relatively the worst for the set of tasks, with *z* scores of 6.9 and 4.8, respectively. Surprisingly, the average *z* score for DH feeding, simulating a task performed every day by subjects with this hand for most of their lives, reached a value of 3.2.

NH tested between right/left prestroke hand dominance

Within the NH group, because the participants were almost evenly split in terms of handedness prestroke (9 left/11 right), a secondary analysis on the effect of prestroke handedness was performed. For JTHFT and 9HPT, participants with prestroke right-hand dominance tended to perform better with their poststoke adaptations (left hand tested) than those with prestroke left-hand dominance (right hand tested) (table 3) although not significantly (JTHFT: *t* value=2.0, *P*=.057; 9HPT: *t* value=1.3, *P*=.229).

Table 3. *Z* scores (±95% CI) compared with age- and sex-matched normative data, separated by hand dominance

Outcome	Left Hand Tested (n=9)	Right Hand Tested (n=11)
JTHFT (s)	0.9±0.6 (10.4±1.3)	1.9±0.9* (12.9±1.8)
9HPT (s)	0.9±1.2 (23.2±2.8)	2.3±2.1 (27.7±4.7)
BBT (blocks)	2.0±0.7* (55.6±7.1)	3.0±1.3* (47.3±7.3)
GS (N)	−0.4±0.8 (340.7±84.2)	−0.3±0.58 (317.6±61.4)
LPS (N)	0.7±0.8 (77.0±15.3)	0.5±0.6 (77.4±12.0)
PPS (N)	1.1±0.8 (69.4±16.0)	0.9±0.7 (69.8±13.9)

∗*P*≤.001.

Correlation measures

Correlation analysis showed relationships between the amount of impairment in the paretic limb and deficits in the nonparetic limb (table 4). For DH participants, FMUE score for the paretic limb negatively correlated with the nonparetic JTHFT (ρ=−0.494, P=.027) and PPS (ρ=−0.529, P=.016) z scores. As FMUE score increases (indicating less impairment in the paretic limb), the time required to complete the JTHFT on the nonparetic side decreases (indicating better performance) relative to the normative data. For NH participants, FMUE of the paretic limb negatively correlated with nonparetic BBT z score computed relative to normative data for both the NH (ρ=−0.640, P=.002) and the DH (ρ=−0.638, P=.002). Time post stroke was not correlated with any outcome measure.

Table 4. Pearson correlation coefficients for nonparetic *z* scores vs paretic FMUE

Correlation	DH vs Normative Dominant	NH vs Normative Nondominant	NH vs Normative Dominant
JTHFT *z* score vs FMUE	−0.494*	−0.284	−0.206
9HPT *z* score vs FMUE	−0.244	−0.284	−0.330
BBT *z* score vs FMUE	0.296	−0.640*	−0.638*
GS *z* score vs FMUE	−0.146	0.304	0.300
LPS *z* score vs FMUE	−0.306	−0.055	−0.125
PPS *z* score vs FMUE	−0.529*	0.116	0.178

∗P≤.05.

Discussion

A total of 40 survivors of stroke with severe, chronic impairment of the paretic hand and arm participated in the assessment of task performance and strength with the nonparetic limb. Scores were compared with normative values for the matching age and sex. The analysis revealed substantial deficits in task performance but not strength. These deficits were apparent despite the fact that the survivors of stroke had been, on average, primarily reliant on their nonparetic hand for more than 7 years. We had expected to see positive correlations between time post stroke and improvement in outcomes because of the amount of practice amassed through primary use of the nonparetic hand. We found no significant correlations, however, between performance and years post stroke.

Our results concerning task performance concur with prior studies describing longer times to complete the JTHFT[9,10,12] and the 9HPT.[11,14,36] While a number of these studies examined survivors of stroke in the acute or subacute phase of recovery, we observed these deficits in individuals years after the stroke, in agreement with Wetter et al.[13] Intriguingly, even survivors of stroke who continued to use their prestroke DH as their DH after the stroke showed substantial impairment in fine motor control, as indicated by scores on the JTHFT, the 9HPT, and the BBT. Times to complete the simulated feeding and checkers tasks of the JTHFT especially revealed these deficits—survivors of stroke took longer to complete these common tasks by 3-4 standard deviations. The prestroke nondominant group also exhibited significant impairment in the nonparetic limb, based on results of the JTHFT, 9HPT, and BBT. Impairment becomes readily apparent when comparing values with respect to normative values for the DH. For example, z scores for writing and simulated feeding, exceeding 6 and 4, respectively, were more than twice as great as the z scores with respect to the nondominant normative data.

In contrast, we saw no deficits in GS and limited compromise of LPS. While strength deficits in the nonparetic hand have been noted during the acute[9,11] and subacute phases[37] by some researchers, others reported normal force levels in both the subacute and chronic phases.[11] Thus, force deficits may resolve with time, although McCrea et al observed reduced maximum torque development in the more proximal arm (shoulder and elbow) in survivors of stroke at the chronic phase of recovery.[38] Weakness in the nonparetic limb that results from the stroke may be mitigated by the use of alternative neural pathways that can produce more gross movements, such as maximum grip force production. For example, Xu et al hypothesized that the recruitment of reticulospinal pathways led to the restoration of strength in the paretic hand following a stroke.[39] However, fine motor control, which is not typically associated with the reticulospinal pathway, had a very different recovery trajectory. The significant reductions seen in PPS may be attributable to deficits in manual dexterity required to produce and properly direct this force or by an impaired corticospinal tract.[40]

Our NH group was fairly evenly split between those who had experienced a stroke in the right hemisphere and those with left-hemisphere lesions. While the results were not statistically significantly different, the group with lesions in the right hemisphere (nonparetic right hand) tended to perform more poorly on dexterity but not strength assessments than those with left-hemisphere lesions. These results are in accordance with a study by Cunha et al examining survivors of stroke with mild or moderate impairment of the paretic limb.[41] The investigators reported greater loss of dexterity but not strength in individuals with right-hemisphere lesions and surmised that the additional deficits may have arisen from damage to areas associated with visuospatial processing that are located in the right hemisphere.[41] Semrau et al observed that among survivors of stroke in the subacute phase of recovery, individuals with right-hemisphere lesions were more likely to exhibit coordination deficits in the nonparetic arm than individuals with left-hemisphere lesions,[42] although Sunderland et al saw greater upper limb impairment in subjects with left-hemisphere injury during the acute phase of recovery.[9]

The significant deficits in dexterity that we saw across participants, including those who continued to use their prestroke DH as their poststroke DH, suggest possible brain alterations affecting both hemispheres in response to the stroke. Mooney et al measured lower gamma-aminobutyric acid concentrations in the contralesional as well as the ipsilesional M1 in survivors of stroke with chronic impairment, although the effect on function is not clear.[43] Van Dokkum et al described greater activation of the rolandic operculum by survivors of stroke in the subacute phase of recovery during reaching movements with the nonparetic arm compared with neurologically intact survivors of stroke.[44] The involvement of this area in internal movement representation and imagery suggests possible compensation for visual or proprioceptive limitations.[45] Further studies are needed to identify the sources of impairment for the nonparetic limb.

Study limitations

This study aimed to quantify the amount of impairment in the nonparetic limb of severely impaired survivors of stroke (Stage of Hand score 2 or 3 on the Chedoke-McMaster Stroke Assessment). It may be beneficial to look at these same outcomes with all levels of impairment. This should include age- and sex-matched controls for comparisons. The study size is still relatively small; for results that are more definitive, a larger number of participants is required.

Conclusions

Current poststroke clinical practice is rarely focused on the nonparetic hand despite the fact that this hand will assume most of the functional tasks after stroke, especially in individuals with significant impairment of the paretic hand. We observed substantial deficits in dexterity of the nonparetic limb in our cohort of survivors of stroke, even years after the stroke, despite typically heavy reliance on this limb because of the extent of impairment in the paretic limb. Significant deficits were observed regardless of whether the prestroke dominant limb was ipsilesional or contralesional. Therefore, it may be beneficial to investigate therapy focused either solely on the nonparetic arm or on the nonparetic upper extremity in concert with the paretic side.

Suppliers

a. Hand dynamometer; Jamar Technologies.

b. Pinch gauge; B&L Engineering.

Acknowledgment
We thank Ning Yuan, MS, for his assistance with data collection.

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