Sensorimotor impairments of paretic upper limb correlates with activities of daily living in subjects with chronic stroke

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ABSTRACT: *The main objective of this study was to investigate the correlations between sensorimotor impairments of paretic upper limb and the hand functions of activities of daily living (ADLs) scores in persons with chronic stroke.*

This is a cross-sectional study with 19 chronic stroke survivors. Hand function was measured by the Jebsen-Taylor Hand Function Test (JTHFT). Impairments in upper extremity motor function were measured by upper limb items of Fugl-Meyer Assessment (FMA-UE). Forearm muscles strength, handgrip and pinch grip power were assessed using handheld dynamometers. Tactile sensation threshold was measured by monofilaments.

Significant differences were found between the affected and unaffected side in the total JTHFT scores, forearm muscle strength, handgrip and pinch grip ($p \leq 0.017$), but not the tactile sensation threshold. The total JTHFT scores were found to be correlated with total score of FMA-UE ($r_s = -0.789$), handgrip power ($r_s = -0.588$) and pinch grip power ($r_s = -0.657$) on the affected side, but not the tactile sensation. The total JTHFT scores were correlated with FMA-UE scores, handgrip and pinch grip of the affected side. This is the first study in documenting the correlation between the sensorimotor impairments and JTHFT scores in persons with chronic stroke. Our findings highlights the importance of including upper limb and grip strength training in stroke rehabilitation program in order to improve hand functions in activities of daily living in patients with chronic stroke.

KEY WORDS: STROKE, SENSORIMOTOR IMPAIRMENTS, HAND, UPPER LIMB, ACTIVITIES OF DAILY LIVING.

INTRODUCTION

Stroke is one of the major causes of disability and handicap in adults. It is well documented that stroke induces a wide range of disabilities and functional limitations and limitations in hand function always occur among stroke survivors. Wade et al (1983) conducted a study to measure the recovery of upper limb function in a group of stroke subjects. Only 27 out of 92 subjects achieved full recovery two years post-stroke. The underlying impairments which caused hand function loss in patients with stroke included muscle weakness, poor coordination and altered motor pattern (Ng and Shepherd 2000).

In addition to motor impairments, somatosensory deficits are found to be associated with the slower recovery and poorer performance of functional mobility in patients with stroke (Connell et al. 2008). The possible explanation is that afferent inputs ascending to the somatosensory cortex are required for acquiring motor skills which could be supported by direct anatomical projects had been found from somatosensory cortex to the motor, premotor and parietal cortices in monkeys (Jones et al. 1978), and these projections could modulate neuronal activity in the primary motor cortex (Farkas et al. 1999). Sensory deficits could also affect the motor functions in patients with stroke. Indeed, about 53% of stroke patients were reported to have impaired tactile sensation (Connell et al. 2008).

The Jebsen-Taylor Hand Function Test (JTHFT) is a standardized test measuring hand functions in activities of daily living (ADLs) (Jebsen et al 1969). In the original research by Jebsen et al (1969), JTHFT was used to assess subjects with a variety of disorders such as rheumatoid arthritis, hemiparesis and spinal cord injury. They found the test to have moderate inter-rater reliability (ICC = 0.60) (Jebsen et al 1969). The JTHFT was also capable of differentiating people with rheumatoid arthritis, spinal cord injury and hemiparesis from normal subjects (Jebsen 1969). Although the JTHFT is increasingly used in neurorehabilitation to evaluate the hand functions in patients with stroke,

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Table 1. Inclusion and exclusion criteria.

Inclusion criteria	Exclusion Criteria
1. Age between 55 and 75 years	1. Medical comorbidity
2. Previous history of stroke 1-10 years ago	2. Receptive dysphasia
3. Previous history of stroke 1-10 years ago	3. Pre-existing neurological disorders other than stroke
4. Discharged from all rehabilitation services at least 3 months before the commencement of this study	4. Cognitive impairment denoted by scoring <7 out of 10 on the Abbreviated Mental Test (AMT)
5. Able to understand instructions and give informed consent	

the relationship between sensorimotor impairments and the JTHFT scores had not been investigated before. Because major aim of stroke rehabilitation is to optimize patients' performances of motor tasks in activities of daily living, clinicians need a reliable and valid measurement that will establish patients' upper limb functions at baseline, to monitor patients' progress as a result of treatment. The objective of this study is to delineate possible association between sensorimotor impairments of upper limb (i.e. impairments in upper extremity motor function, muscle strength and tactile sensation of affected upper extremity) and hand functions in ADLs (ie, scores of JTHFT) in persons with chronic stroke. The results of the study will provide insight into the design and evaluation of therapeutic programs targeted at improving hand functions in activities of daily living in community-dwelling stroke patients.

METHOD

This study was a cross-sectional clinical trial. Nineteen community-dwelling stroke patients were recruited through a local self-help group. Inclusion and exclusion criteria are listed in table 1. The characteristics of subjects are summarised in tables 2 and 3. The study protocol was approved by the ethics committee of the university, and all subjects provided written informed consent after thorough explanation of the study prior to data collection. The study was conducted according to the Declaration of Helsinki for human experiments. All assessment was explained and administered in Chinese.

OUTCOME MEASURES

(1) Jebsen-Taylor Hand Function Test (JTHFT)

The JTHFT consists of seven subtests: writing, cards turning, lifting small objects, simulated feeding, stacking checkers, picking up light cans and picking up heavy cans. The time for completing each subtest was recorded. The total JTHFT score was calculated by adding the time scores of all subtests. Higher scores indicated slower performance of tasks. Subjects were allowed a maximum of 180 seconds to complete each subtest. If the subject could not complete the task within the time allowed, 180 seconds was taken as the time for completing the task (Eliasson et al 2006) as higher scores indicated slower performance of tasks while lower scores indicated better performance.

(2) Fugl-Meyer Assessment of Upper Extremity (FMA-UE)

Fugl-Meyer Assessment (FMA) is a well-accepted validated test for assessing impairments of motor function in people suffering hemiparesis due to cerebrovascular injuries such as stroke. It was originally developed to assess both upper and lower limb motor functions and balance (Fugl-Meyer et al 1975). Only the upper limb items of FMA (FMA-UE) were used in the present study in order to evaluate upper-extremity motor impairment including reflexes, voluntary control of isolated

Table 2. Descriptive statistics of demographic data.

Characteristics	(n=19)
Age (years)	62.0±6.59
Gender (M/F)	12/7
Weight (kg)	64.57±12.00
Height (m)	1.61±0.11
Dominant hand (L/R)	0/19
Education (Primary school or below/secondary 1-3/ secondary 4-7/ university or above)	7/6/4/2
Episodes of stroke	1.32±0.582
Years since stroke	5.37±0.34
Stroke side (L/R)	12/7
Type of stroke (hemorrhagic/ischemic)	6/13

Table 3: Demographic characteristics of subjects.

No	Age (y)	Gender	Dominant hand	Weight (kg)	Height (m)	Education level (*)	Episodes of stroke	Years since stroke	Stroke side	Type of stroke(^)
1	71	Male	Right	65.3	1.61	2	1	2	Left	U
2	57	Female	Right	58.5	1.53	2	1	1	Left	H
3	65	Male	Right	73.5	1.71	3	1	3	Left	I
4	56	Female	Right	35.8	1.25	1	1	8	Right	H
5	60	Male	Right	58.0	1.60	3	1	3	Left	I
6	65	Male	Right	66.0	1.64	2	2	3	Right	I
7	73	Male	Right	59.9	1.62	2	3	6	Left	I
8	76	Female	Right	47.1	1.51	1	1	2	Right	I
9	56	Male	Right	73.5	1.62	2	1	4	Left	I
10	58	Male	Right	79.5	1.76	3	1	10	Right	H
11	62	Male	Right	80.0	1.67	1	2	4	Left	I
12	62	Female	Right	51.0	1.53	1	1	7	Left	I
13	57	Male	Right	62.5	1.70	2	1	3	Right	H
14	56	Female	Right	64.1	1.60	1	2	14	Right	I
15	55	Male	Right	68.0	1.67	1	1	5	Right	I
16	58	Male	Right	65.0	1.60	4	1	7	Left	H
17	67	Female	Right	78.0	1.61	4	1	7	Left	I
18	55	Male	Right	84.0	1.66	3	1	4	Left	H
19	69	Female	Right	57.0	1.60	1	2	10	Left	I

* 1: Primary school or below / 2: Secondary Grade 1-3 / 3: Secondary Grade 4-7 / 4: University or above ^ H: Haemorrhagic / I: Ischemic / U: Unknown

movement, and coordination. Subjects were first given instructions and demonstrations before performing the tasks. Their performances were observed and rated by a trained tester in accordance with the criteria set in Fugl-Meyer's original study in 1975 (Fugl-Meyer et al 1975). Individual marks for all items were then totalled. Total score ranges between 0 and 66, with lower score indicating worse motor function. Duncan et al (1983) reported excellent intra-rater (r = 0.995-0.996) and inter-rater (r = 0.098-0.995) reliability in subjects with chronic stroke. Test-retest reliability was also reported to be excellent (ICC = 0.97). Good correlations were also reported between FMA-UE and Arm Motor Ability Test (functional ability r = 0.94, quality of movement r = 0.94) (Chae et al 2003).

(3) Maximal isometric muscle strength

The Nicholas Hand Held Dynamometer was used to measure upper limb muscle strength. Excellent test-retest reliability was reported for healthy subjects (ICC = 0.820-0.995) (Magnusson et al 1990). Maximum isometric strength of elbow and wrist flexors and extensors were tested on both affected and unaffected upper limbs. Testing position was listed in table 4. Subjects were instructed to gradually increase force against the tester until maximal contraction was achieved. Maximum contraction was maintained for approximately 5 seconds. Five trials were performed on each muscle group. One minute of rest was given between each trial to minimize the effect of fatigue. The results of the five trials were first averaged. The averaged values were then normalized by body weight for analysis.

(4) Handgrip and pinch grip strength

The Jamar Hydraulic Hand Dynamometer was used to measure handgrip force and pinch grip force. Excellent inter-rater reliability was reported in handgrip force (ICC = 0.996-0.998, $p<0.05$) and pinch grip force (ICC = 0.949-0.990, $p<0.05$) in healthy subjects (Lindstrom-Hazel et al 2009). Testing positions are listed in table 4.

(5) Tactile sensation

Semmes-Weinstein Monofilaments was used to evaluate the sensation threshold to light touch. Excellent inter-rater reliability (ICC = 0.999) (Novak et al 1993) was reported using monofilament in assessing tactile sensation deficits.

Table 4: Muscle strength testing positions

Action	Position	Dynamometer placement
Elbow flexion	Supine Shoulder: 30° abduction Elbow: 90° flexion Forearm: Supinated	1cm proximal to wrist on flexor surface of forearm
Elbow extension	Supine Shoulder: 30° abduction Elbow: 90° flexion Forearm: Supinated	1cm proximal to wrist on extensor surface of forearm
Wrist flexion	Sitting Elbow: 90° flexion Forearm: Supported & supinated Wrist: Neutral Fingers: Relaxed	Just proximal to 3rd metacarpal head on palmar side
Wrist extension	Sitting Elbow:90° flexion Forearm: Support & pronated Wrist: Neutral Fingers: Flexion	Just proximal to 3rd metacarpal head on dorsal side
Handgrip	Sitting Elbow: 90° Flexion Forearm: Neutral & without support	/
Pinch grip	Sitting Elbow: 90° Flexion Forearm: Neutral & without support	/

Three sites were chosen for the test: tip of index finger, centre of palm, and 1 cm proximal to MCPJ of middle finger on the dorsal side. These points were chosen because they occupy sites involved in many hand activities. Starting with stiffness of 4.31, the monofilament was applied perpendicularly to subject's skin until the monofilament started to bend then held in this position for approximately 1 second. Subjects were instructed to answer "Yes" once they felt the pressure. If there was no response, the procedure was repeated five times for each monofilament stiffness. The monofilament was applied in a descending order until the subject no longer felt the stimulus. The previous filament was applied again to reconfirm the sensory threshold. The lower the scores represent the better sensation.

DATA ANALYSIS

Results were analysed using SPSS 16.0.0 for Windows. Mann-Whitney U test was used to identify differences in measures between affected and unaffected arms. The distribution of data was checked using a Kolmogorov-Smirnov test of normality. As the data was not normally distributed, Spearman's Rho was used to assess the correlations between different outcome measures. Level of significance was set at $\alpha = 0.05$. For Spearman's Rho statistics, r_s = 0.00-0.25 were classified as showing little or no correlation; r_s = 0.25-0.50 as fair; r_s = 0.50-0.75 as moderate to good; and $r_s > 0.75$ as good to excellent.

RESULTS

Subjects

Nineteen patients with stroke, an average of 62.0 ± 6.6 years old (16 men; all right-hand dominant), post-stroke 5.4 ± 0.3 years participated in the study. Their demographic data and level of functional mobility of our subjects was shown in Table 2.

The Jebsen-Talyor Hand Function Test

The total JTHFT scores and scores of all subtests showed significant differences between affected and unaffected sides ($p<0.001$). Total JTHFT scores of the unaffected side (68.61 ±16.99) were lower than those of the affected side (347.07 ±354.49) (Table 5).

Maximum Isometric Muscle Strength

Comparing affected side with unaffected side, all measurements of elbow and wrist muscle strength showed significant difference ($p = 0.017$) for normalized wrist extensor, $p<0.001$ for all others). All measures of maximum isometric strength on the unaffected side were stronger than those on the affected side (Table 5).

Handgrip and Pinch Grip Strength

Significant differences were found between affected and unaffected sides in both handgrip and pinch grip strength ($p<0.001$ for both grips). In both handgrip and pinch grip strength, the strength of the affected sides were significantly weaker than the unaffected sides, with the unaffected sides more than twice as strong as the affected sides for both

Table 5: Mean values of JTHFT, tactile sensation, muscle strength and FMA (n=19).

Parameters	Unaffected arm	Affected arm	*p*
JTHFT:			
Total JTHFT score	68.608±16.993	347.072±354.497	<0.001
Subtest 1 - writing test	26.843±13.877	78.008±46.651	<0.001
Subtest 2 - page turning	6.987±2.082	39.102±52.068	<0.001
Subtest 3 - lifting small objects	9.232±2.620	48.992±54.424	<0.001
Subtest 4 - simulated feeding	9.087±2.280	47.419±60.691	<0.001
Subtest 5 - stacking checkers	6.233±1.924	61.571±73.475	<0.001
Subtest 6 - picking up light cans	4.965±1.150	34.906±55.784	<0.001
Subtest 7 - picking up heavy cans	5.262±1.263	37.075±59.836	<0.001
FMA total score	/	47.050±12.886	/
Muscle strength (normalized):			
Elbow flexion	0.179±0.481	0.116±0.042	<0.001
Elbow extension	0.150±0.425	0.088±0.040	<0.001
Wrist flexion	0.117±0.037	0.068±0.043	<0.001
Wrist extension	0.136±0.053	0.093±0.049	0.017
Handgrip	0.444±0.972	0.171±0.079	<0.001
Pinch grip	0.102±0.434	0.045±0.034	<0.001
Tactile sensation:			
1cm proximal to MCPJ	3.105±0.709	3.513±0.793	0.075
Centre of palm	3.330±0.695	3.442±0.766	0.908
Tip of index finger	3.195±0.552	3.407±0.898	0.729

measures. Ranges for normalized handgrip on the affected and unaffected sides were 0.06-0.33Nkg^{-1} and 0.30-0.74Nkg^{-1}, whereas ranges for normalized pinch grip were 0.00-0.13Nkg^{-1} and 0.05-0.25Nkg^{-1} respectively (table 5).

Tactile sensation

On the three points assessed no differences between sides were found (p = 0.908 for palm, p = 0.729 for index finger), though the difference between the two sides at MCPJ approaches statistical significance (p = 0.075) (Table 5).

Correlations with the JTHFT

No significant correlation was found between the total JTHFT scores and age, weight, height, education level, number of episodes of stroke and years since stroke. Significant moderate negative correlations were also found between the total JTHFT scores with normalized handgrip (r_s = -0.588, p = 0.008) and normalized pinch grip (r_s = -0.657, p = 0.002) strength on the affected side. There was no significant correlation found among the total JTHFT scores, tactile sensation and maximum isometric muscle strength of flexor and extensor of elbow and wrist. Strong significant correlations were found between the total JTHFT score on the affected side and total FMA score under Spearman's analysis (r_s = -0.789, p<0.001). The sub-scores of JTHFT were also found to have significant correlations with all but Part I of FMA. Strength of these correlations ranged from fair to good (r_s = -0.482 – -0.716). No significant correlation was found between total JTHFT score and muscle strength, grip strength and tactile sensation on the unaffected side (Table 6).

Table 6: Correlation between total JTHFT score and other measures on ipsilateral side.

Parameters		Spearman p	*p*
Affected hand	**FMA**		
	Total FMA score	-0.789*	<0.001
	Part I reflexes	0.232	0.339
	Part II flexor & extensor synergies	-0.606*	0.006
	Part III mixing synergies	-0.660*	0.002
	Part IV out of synergy	-0.482*	0.037
	Part VI wrist	-0.716*	0.001
	Part VII hand	-0.661*	0.002
	Part VIII coordination	-0.599*	0.007
	Muscle strength (normalized)		
	Elbow flexion	0.047	0.847
	Elbow extension	-0.249	0.304
	Wrist flexion	-0.284	0.238
	Wrist extension	-0.042	0.864
	Handgrip	-0.588*	0.008
	Pinch grip	-0.657*	0.002
	Tactile sensation		
	1cm proximal to MCPJ	0.375	0.114
	Centre of palm	0.342	0.152
	Tip of index finger	0.158	0.518
Unaffected hand	**Muscle strength (normalized)**		
	Elbow flexion	0.288	0.232
	Elbow extension	0.084	0.732
	Wrist flexion	0.337	0.158
	Wrist extension	0.225	0.355
	Handgrip	0.333	0.163
	Pinch grip	0.188	0.442
	Tactile sensation		
	1cm proximal to MCPJ	0.351	0.141
	Centre of palm	0.241	0.320
	Tip of index finger	0.214	0.378

DISCUSSION

Our study is the first study to delineate possible association between sensorimotor impairments of upper limb (i.e. impairments in upper extremity motor function, muscle strength and tactile sensation of affected upper extremity) and hand functions in ADLs (ie, scores of JTHFT) in persons with chronic stroke

Muscle strength

The results obtained from the present study are consistent with previous findings that there is a significant difference in strength between sides of the stroke subjects (Chae et al 2003). In a review on clinical and physiological studies with stroke patients, the loss of muscle strength following stroke could be due to decreased capacity to activate motor units, reduced number of functioning motor units, reduced motor units firing rate and increased co-contraction of the antagonists during movement (Ng and Shepherd 2000).

Results of this study show that the JTHFT scores have a moderate to good correlation with normalized pinch grip (r = -0.657, p<0.01) and handgrip (r = -0.588, p<0.01), but not with elbow and wrist muscle strength. This could be explained by the fact that JTHFT focuses mainly on evaluating fine motor hand functions instead of gross motor functions. Effective muscle contraction of hand muscles, as indicated by hand and pinch grip strength, is essential for good hand function. Elbow and wrist muscles however, are less involved in fine hand functions. Consistent with previous findings (Sunderland et al 1989), our results support the view that grip strength could also be an important indicator of upper extremity function in persons with chronic stroke. Sunderland et al (1989) reported that grip strength has a good prognostic value for persons with acute stroke. It was found that subjects with better grip strength at one month tended to have a better upper limb function at six months, and grip strength was a valid predictor of upper limb function.

Tactile sensation

It was surprising to note that that there was no difference in tactile sensation over the 3 selected sites between affected and unaffected hands, because sensory deficit is frequently reported by persons with stroke (Connell et al. 2008). The estimates of prevalence in somatosensory impairment after stroke varied widely from (Connell et al. 2008), and may due to heterogeneity in study populations, the number of somatosensory modalities and body areas assessed. Our results contrasted with the study of Sommerfeld and Arbin, (2004), which found that 39 out of 77 subjects with acute stroke had impaired tactile sensation assessed by light touch with cotton wool. No significant correlation was found between tactile sensation with cotton wool and the total scores of JTHFT for both sides, suggesting that deficits in tactile sensation did not affect hand function. This contradicted the result of a previous study by Ebied et al, (2004), which found significant correlation between impaired tactile sensation induced by artificial cutaneous sensation block and writing ($p = 0.02$). Continuous feedback from afferent input was important for the automatic fine adjustment of hand movement and, the ability to adjust force and direction of movements accurately was essential for performing fine hand functions (Connell et al. 2008). In our study, the three sites tested for tactile sensation may not represent the whole picture of sensory deficiency in individuals with stroke. In addition, different subject types, different assessment method may also affect the result of study.

Correlations between JTHFT and FMA-UE

Significant correlations were found between total JTHFT score and all but the first and fifth items of FMA-UE. These items of FMA-UE examined upper limb reflexes while the JTHFT examines the functional capacity of hands. One previous study (Woodbury et al 2007) suggested that the reflex items of FMA-UE differed from the rest of the test. While the majority of FMA-UE items assessed voluntary movements, the reflex items were assessing involuntary responses (Woodbury et al 2007). Since all items in the JTHFT involved subjects performing voluntary movements, it was reasonable that there was no correlation between the JTHFT and reflex items of FMA-UE. Similar results with poor correlation between severity of spasticity and motor functions in stroke patients had been found in some previous studies (Ng and Hui-Chan 2005). Our negative results may also be due to small sample size and/or to the adoption of compensatory strategy by our stroke subjects, such as increased trunk side flexion to accomplish the upper limb motor tasks.

Strongest correlations were found between total the JTHFT score and sixth and seventh items of FMA-UE ($r_s = -0.716$ and $r_s = 0.661$ respectively) which assessed wrist mobility and prolonged isometric muscle contraction, as well as hand functions and grips. The sixth and seventh items of FMA-UE are similar in task nature of the JTHFT and also to hand function, as most hand functions such as writing and picking up objects involves the movement of joints of wrist and hand. In addition, strong significant correlation was found between the total JTHFT scores and most items of FMA-UE. This could be explained by a number of testing items (ie, the sixth and seventh items) between both measurements

Limitations

Our study did have several limitations. As majority of the subjects recruited in this study were quite active and have a relatively high functional status, results obtained in this study might not be generalized to persons with acute stroke or persons with lower mobility level. Further studies might need to recruit subjects with different functional level. The number of subjects that participated in this study was relatively small. This study was a cross-sectional study, and it did not prove any causality between the JTHFT score and level of different impairments. We only measured tactile sensation in the present study, whether pin-pick sensation or proprioception generating similar result would need further investigation. In addition, a few subjects with more arm impairment could not complete some items of JTHFT within the 180 seconds time limit. A score of 180 seconds was given as suggested by Eliasson et al (2006), and this might overestimate the ability of the subjects. All subjects in this study are right-handed, they may never have used the left hand to write. Therefore the measure of writing speed on the left side (JTHFT Item 1) may not really be measuring their functional ability.

Isometric muscle strength measured in this study may not be functional in our assessment protocol, as most ADL tasks involve movement of joints whilst muscle force is exerted. Previous study showed that shoulder flexors strength had a moderate to excellent correlation with paretic upper limb function (Mercier and Bourbonnais 2004). The present study, however, did not measure muscle strength of shoulder muscles due to limited time, and further studies could include shoulder muscle strength as one of the measurements.

CONCLUSION

The present study showed that there was a significant difference in hand functions in ADLs, handgrip, pinch grip and maximum isometric strength between affected and unaffected sides, but not tactile sensation. The total JTHFT score was strongly correlated to the total score and all subtests of FMA-UE except measurement of reflex (ie, the first and fifth items). Moderate correlation was also identified between the total JTHFT scores and normalized handgrip and pinch grip on the affected side. These findings indicate that motor recovery and muscle strength of the hands are important for hand function in activities of daily living in persons with chronic stroke. It is important for physiotherapist in designing appropriate intervention in improving muscle strength of upper extremity, pinch grip and handgrip in order to improve hand functions in ADLs in patients with chronic stroke.

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