Available online at http://jbcp.shahed.ac.ir/

Journal of Basic and Clinical
PATHOPHYSIOLOGY

Volume 4, Number 2, Spring-Summer 2016

Correlation between lower and higher order sensory functions and manual dexterity in dominant and non-dominant hand of patients with idiopathic Parkinson's disease

Fatemeh Daneshjoo[1], Ghorban Taghizadeh[1]*, Akram Azad[1], Maryam Mehdizadeh[2], Mahbubeh Mandegary Najafabadi[1]

1. *Department of Occupational Therapy, School of Rehabilitation Sciences, Iran University of Medical Sciences, Tehran, Iran.*
2. *Department of Advanced Technology of Medicine, Iran University of Medical Sciences, Tehran, Iran*

Article info
Received: 15 June 2016
Revised: 20 July 2016
Accepted: 31 Aug 2016

p-ISSN:2322-1895
e-ISSN: 2345-4334

Key Words:
Manual dexterity
Sensory function
Parkinson's disease

ABSTRACT

Objective: To investigate the correlation between lower and higher order sensory functions and manual dexterity as well as to identify the sensory measures that could predict manual dexterity in patients with idiopathic Parkinson's disease (PD).

Materials and methods: In this cross-sectional study, 55 patients with idiopathic PD by mean age of 59.85 ± 11.89 years, and mean Hoehn and Yahr stage of 2.76 ± 1.37 were non-randomly selected. Lower order sensory function (i.e., light touch threshold), higher order sensory functions (i.e., tactile acuity, weight and texture discrimination, haptic performance and wrist proprioception) as well as gross and fine manual dexterity were measured in both hands.

Results: The results showed that light touch threshold and tactile acuity (measured by static two point discrimination (TPD) were not significantly associated with gross or fine manual dexterity in dominant or non-dominant hand. Tactile acuity (measured by moving TPD), weight discrimination and wrist proprioception were weakly correlated with gross and fine manual dexterity in both hands. A weak to moderate significant relation was found between texture discrimination and haptic performance and both type of manual dexterity in both hands. Haptic performance predicted the largest proportion of variance in the gross manual dexterity of both hands as well as fine manual dexterity of dominant hand.

Conclusion: This study showed the low to moderate correlation between higher order sensory functions and manual dexterity in patients with idiopathic PD. Haptic performance seems to be the most influential higher order sensory function associated with manual dexterity in these patients.

1. Introduction

Parkinson's disease (PD) is a neurodegenerative disease whose prevalence is about 1-2% in population over 65 years (1). One of the typical clinical symptoms of PD is bradykinesia that leads to a damage to motor functions requiring coordination, especially manual dexterity (2). Manual dexterity is defined as the ability to perform controlled, precise and coordinated movements with hands and fingers which is involved in many of activities of daily living (3). In addition to motor problems, higher-order sensory functions also may be affected in patients with PD including vibration, discriminative sense (4), proprioception, perception of object weight (5) and haptic performance (6).

***Corresponding Author:** *Ghorban Taghizadeh*
Department, Faculty of Rehabilitation Sciences, Iran University of Medical Sciences,Tehran, Iran.
Email: gh_taghizade@yahoo.com

Sensory information is needed for executing motor function, especially in manipulative tasks (7). Sensory problems lead to slow executing of motor tasks and patients exert excessive force in order to compensate this slowness which, in turn, results in the restriction of manipulative task (8). Higher-order sensory dysfunction may lead to abnormalities in sensorimotor integration and thus motor dysfunction including manual dexterity (9). Correlation between sensory and motor function of upper extremity using various measurement tools has been reported in different diseases such as stroke (10, 11), myelopathy (12), leprosy (8), diabetes (13), etc. However, only one study has investigated the correlation between sensory function (temporal discrimination threshold) and finger dexterity (coin rotation task) in patients with PD and reported low correlation (r=-0.43, P<0.01) (14). Lee et al (2010) only investigated one type of sensory function in index finger of the dominant hand of patients with PD while other types of sensory function may also be impaired in patients with PD and may affect motor function in these patients. On the other hand, conducting the correlation studies is very important for the following reasons. First, this kind of study may provide fruitful areas for future experimental researches. Second, these studies allow predicting the scores of one variable based on another variable (15). Therefore, the aim of this study was to investigate the correlation between lower and higher order sensory functions and manual dexterity as well as to identify the sensory measures which could predict manual dexterity in patients with idiopathic PD.

2. Materials and Methods

2.1. Participants

In this non-experimental cross-sectional study, 55 patients with idiopathic PD (48 male, 7 female) with a mean age of 59.85 ± 11.89, mean time since diagnosis of 7.96 ± 5.33 years and mean Hoehn and Yahr stage of 2.76 ± 1.37 were non-randomly selected from clinic of motor disorders in Hazrat Rasoul hospital, Tehran, Iran. The main inclusion criteria were the following: having PD according to the neurologist diagnosis, having an acceptable level of cognitive function (i.e., score of more than 23 on the Mini Mental Status Examination (MMSE) (16), having the ability to read and write, not having non-rectified vision problems with eyeglasses based on patient report, not having other neurological diseases such as stroke, orthopedic problems such as fracture and tendon injuries in upper extremity or diabetes according to the patient or physician report. In the case of inability to perform the tests or lack of cooperation in the execution of the tests, subjects were excluded. All patients signed a written consent form approved by the Ethics Committee of Iran University of Medical Sciences to participate in the study.

2.2. Instruments

A demographic questionnaire was used to record age, sex, dominant and more affected hand, stage of the disease according to the Hoehn and Yahr Scale and time since diagnosis of PD. Lower order sensory function was measured by Weinstein enhanced sensory test while higher order sensory function was evaluated by two-point discrimination, hand active sensation test, haptic object recognition test and wrist position sense test as described following.

2.3. Weinstein enhanced sensory test (WEST)

Light touch thershold was assessed using the WEST with five filaments indicating six different force levels which were applied to the skin. Evaluation was performed in a quite room and closed eyes condition. Participants were seated at the table in front of the examiner and placed the tested hand on the examiner's hand in a supinated position. First, the test procedure was explained to them and then they were asked to verbally report when they felt the touch of their skin with the filament. Testing was started by the lightest filament. The number of this filament was recorded if the patient reported two of the three touch. Otherwise, the test was repeated by the thicker filament. To minimize the possibilty of guessing the answer, ramdom order of the tests and time intervals between them were considered. Three location of fingers palm (thumb, index and little finger) were assessed on both hands. Scoring of the test was done based on 0-5 scale as suggested by Rosen and Lundborg. The mean score of three fingers in each hand was used for the analysis (17).

2.4. Two-point discrimination (TPD)

Tactile acuity of thumb, index and middle finger of both dominant and non-dominant hand were measured by static and moving two-point discrimination (STPD and MTPD, respectively). TPD determines the minimum distance between two stimulus points applied on the skin that could be perceived as separate points. The test was conducted using DiskCriminator. In MTPD, DiskCriminator was moved from proximal to distal along the long axis of finger's distal phalanx (18). TPD score of each thumb, index and middle finger as well as the mean score of these fingers were used for statistical analysis.

2.5. Hand active sensation test (HAST)

Weight and texture discrimination were evaluated by the HAST following the procedure developed by Williams et al. (19). Briefly, the test consisted of 9 familiar objects with the same shape and size while their weight and texture were different. The HAST requires a subject to manually explore the objects by one hand across 18 trials and match them twice, once based on weight and once based on texture without describing the manner of matching. Both dominant and non-dominant hand were tested. Test score was determined by total number of correct matches (0-18) for each hand. This measure has a good test-retest reliability (19). Each score of weight and texture discrimination and sum of them (i.e., total score of HAST) were considered for statistical analysis.

2.6. Haptic object recognition test (HORT)

Haptic performance was assessed using the HORT as described (20). HORT included five various groups of unfamiliar cubic objects (1.5×2.7×4.7) which are made from LEGO bricks. Objects of each group had a particular number of rectangular bricks in different positions on the sides. To facilitate visual identification of these constructional differences, they were highlighted by color. One sample of each group was placed on the table in front of the subject. First, subjects were allowed to be familiarized with sample objects by visual and unimanual haptic exploration. Then they were asked to explore a total of 17 objects placed in a fabric sac only by unimanual haptic exploration and determine the group of each explorated object by placing it in a box behind the particular sample on the table. Three consecutive trials of this process were performed for each of dominant and non-dominant hand and the score of the test was determined by an average number of errors in three trials. A good accuracy has been reported for this test (21).

2.7. Wrist position sense test (WPST)

Wrist proprioception was evaluated by WPST following the procedure described by Carey et al. (22). Briefly, the examiner moved the subjects wrist to the predetermined wrist position (10 position for flexion and 10 position for extension) in a random order using the lever of apparatus. The apparatus design was so that the subject did not see his/her wrist position or moving the lever by the examiner. After each movement, subjects showed perceived angle of his/her wrist, then the error was determined by comparing the angle of the lever to the angle showed by subject. Mean error of 20 position was calculated as an index of proprioceptive discriminative ability.

2.8. Box and block test (BBT)

Gross manual dexterity was measured by BBT. The participants were asked to move wooden blocks from one campartment of the box to the another using one hand as quickly as possible. Test was conducted for both dominant and non-dominant hand and the score of each hand was calculated by the number of blocks that the subject moved in 60 seconds by that hand (23). This test demonstrate a high reliability and good validity (24).

2.9. Purdue Pegboard test (PPT)

Fine manual dexterity was assessed by PPT. The square pegboard carries two parallel columns of hole, one on the right side and another on the left side, and pegs were placed in two containers at the top of the pegboard. The subject was asked to pick the pegs with one hand, one by one, and placed them in the holes. They were given 30 seconds to complete the test for each dominant and non-dominant hand. High test-retest reliability has been reported for PPT (25).

2.10. Procedure

First, patients completed the demographic questionnaire and then sensory and motor functions were evaluated. All evaluations were performed by one trained examiner in a single day and in drug On-phase (1 hour after Levodopa administration) (26). In order to avoid fatigue, rest periods between evaluations were given to the patients. Participants wore a blindfold to close eyes in sensory tests during which visual depriviation was required. The sequense of evaluations was randomly selected.

2.11. Statsitical Analysis

Normal distribution of the data was investigated by the Shapiro-Wilks test (p>0.05). Approximate nonlinear transformation (i.e., natural log) was used to transform the variables that were not normally distributed. Pearson product moment correlations and Spearman rank order were used to test the correlation between different measures of sensory function and manual dexterity. Strength of the correlation was determined based on Munro's descriptive terms as following: r values of 0.00-0.25, 0.26-0.49, 0.50-0.69, 0.70-0.89 and 0.90-1.00 indicates little (if any correlation), low, moderate, high and very high correlation, respectively (15). A simultaneous multiple regression analysis was used to determine which sensory performance variables that showed significant correlation with manual dexterity could be the best predictor of the variance in manual dexterity.

3. Results

3.1. Participants' characteristics

Table 1 shows demographic data of the subjects participated in this study. All patients with idiopathic PD were right-handed. The number of patients with more affected right hand and patients with more affected left hand was approximately equal. Most subjects (36.4%) were in the stage 2 of the disease progression level based on Hoehn and Yahr scale.

Table 1. Characteristics of patients with idiopathic Parkinson's disease

variable		Mean(SD)
Age (year)		59.85(11.89)
Time since diagnosis (year)		7.96(5.33)
Mini Mental Status Examination		27.26(10.67)
Variable		Frequency (%)
Sex	Male	48 (87.3)
	Female	7 (12.7)
Dominant hand	Right	55 (100)
	Left	0(0)
More affected hand	Right	26 (47.3)
	Left	25 (45.5)
	Both	4 (7.2)
Stage of disease	1	14 (25.5)
	1.5	7 (12.7)
	2	20 (36.4)
	2.5	8 (14.5)
	3	6 (10.9)

Legend: SD= Standard deviation, %=percent.

3.2. Correlation between sensory and motor function in the dominant hand of patients with idiopathic PD

The results of the current study showed that there was not a significant correlation between light touch threshold and BBT as well as PPT. Also, there was not a significant correlation between STPD in thumb, index and middle finger as well as the mean of STPD in these fingers and BBT as well as PPT. A low significant correlation was found between MTPD in thumb, index, middle finger and the mean of MTPD in these fingers and BBT. The same results were found for correlation between MTPD and PPT with the exception of MTPD in middle finger. Texture subtest of HAST was moderately correlated with BBT while the weight subtest of HAST was weakly correlated with BBT. Also, texture, weight subtest and total score of HAST were weakly correlated with PPT. The results of this study showed a moderate significant correlation between HORT and both BBT and PPT. Moreover, there was a low correlation between WPST and both BBT and PPT (Table 2).

Table 2. Correlation between sensory and fine motor function in dominant hand of patients with idiopathic Parkinson's disease

Variable			Box & block test			Purdue pegboard test (unimanual subtest)		
			Correlation	$P_{(V)}$	R^2	Correlation	$P_{(V)}$	R^2
Weinstein enhanced sensory test			-0.15	0.26	0.02	-0.07	0.60	0.005
Two-point discrimination	Static	Thumb finger	-0.15	0.28	0.02	-0.02	0.89	0.0004
		Index finger	-0.19	0.17	0.04	-0.15	0.29	0.02
		Middle finger	-0.05	0.73	0.003	0.15	0.26	0.02
		Mean	-0.19	0.17	0.04	-0.23	0.09	0.05
	Moving	Thumb finger	-0.37	0.005	0.14	-0.36	0.006	0.13
		Index finger	-0.40	0.003	0.16	-0.30	0.03	0.09
		Middle finger	-0.36	0.008	0.13	-0.21	0.12	0.04
		Mean	-0.38	0.004	0.14	-0.32	0.02	0.10
Hand active sensation test		Texture	0.57	0.000	0.32	0.41	0.002	0.17
		Weigh	0.43	0.001	0.18	0.38	0.005	0.14
		Total	0.56	0.000	0.31	0.42	0.001	0.18
Haptic object recognition test			-0.64	0.000	0.41	-0.50	0.000	0.25
Wrist position sense test			-0.31	0.02	0.10	-0.31	0.02	0.10

Multiple regression analysis showed that BBT was significantly correlated with HORT and total score of HAST (which explained 40 % and 31 % of variance, respectively) while it did not show significant association with mean score of MTPD and WPST. Multiple regression analysis also indicated that PPT was only significantly associated with HORT (which explained 32 % of variance) (Table 4).

3.3. Correlation between sensory and motor function in non-dominant hand of patients with idiopathic PD

Light touch threshold was not significantly associated with BBT and PPT. Also, STPD in thumb, index and middle finger as well as the mean of STPD in these fingers was not significantly correlated with BBT and PPT. There was a weak significant correlation between MTPD in thumb, index and middle finger as well as the mean of MTPD in these fingers and both of BBT and PPT. Also, texture, weight subtests and total score of HAST were weakly correlated with both BBT and PPT. A moderate significant correlation was found between HORT and BBT while there was a weak significant association between HORT and PPT. Moreover, a low

significant correlation was found between WPST and both BBT and PPT (Table 3).

Table 3. Correlation between sensory and fine motor function in non-dominant hand of patients with idiopathic Parkinson's disease

Variable			Box & block test			Purdue pegboard test (unimanual subtest)		
			Correlation	$P_{(V)}$	R^2	Correlation	$P_{(V)}$	R^2
Weinstein Enhanced Sensory Test			0.01	0.94	0.0001	-0.05	0.70	0.003
Two-point discrimination	Static	Thumb finger	-0.17	0.22	0.03	0.15	0.29	0.02
		Index finger	-0.17	0.21	0.03	0.13	0.34	0.02
		Middle finger	-0.16	0.26	0.03	0.21	0.13	0.04
		Mean	-0.24	0.08	0.06	0.12	0.41	0.01
	Moving	Thumb finger	-0.30	0.02	0.09	-0.33	0.02	0.11
		Index finger	-0.41	0.002	0.17	-0.29	0.03	0.08
		Middle finger	-0.43	0.001	0.18	-0.39	0.003	0.15
		Mean	-0.38	0.004	0.14	-0.32	0.02	0.10
Hand active sensation test		Texture	0.43	0.001	0.18	0.37	0.006	0.14
		Weight	0.32	0.02	0.10	0.37	0.006	0.14
		Total	0.46	0.000	0.21	0.47	0.000	0.22
Haptic object recognition test			-0.58	0.000	0.34	-0.43	0.001	0.18
Wrist position sense test			-0.30	0.03	0.09	-0.37	0.006	0.14

Multiple regression analysis indicated that BBT was only significantly associated with HORT (which explained 41 % of variance). Beside, PPT was significantly correlated with the mean score of MTPD and total score of HAST (which explained 28 % and 31 % of variance, respectively) while it did not show significant association with HORT and WPST (Table 4).

Table 4. A summary table of simultaneous multiple regression analyses, with hand function tests as the dependent variable and the hand sensory measures as the independent variable in patients with Parkinson' disease

Dependent variables		Independent variables	R	R^2	Adjusted R^2	β coefficient	P value for β coefficient
Dominant hand	Box & block	Haptic object recognition	0.73	0.53	0.49	-0.40	0.001
		Hand active sensation (total score)				0.31	0.01
		Moving two-point discrimination (mean score)				-0.19	0.08
		Wrist position sense				-0.006	0.96
	Purdue Pegboard	Haptic object recognition	0.58	0.34	0.29	-0.32	0.03
		Hand active sensation (total score)				0.21	0.14
		Moving two-point discrimination (mean score)				-0.20	0.14
		Wrist position sense				-0.02	0.88
Non-dominant hand	Box & Block	Haptic object recognition	0.64	0.41	0.37	-0.41	0.002
		Hand active sensation (total score)				0.21	0.12
		Moving two-point discrimination (mean score)				-0.15	0.22
		Wrist position sense				-0.04	0.72
	Purdue Pegboard	Haptic object recognition	0.61	0.37	0.32	-0.19	0.17
		Hand active sensation (total score)				0.31	0.02
		Moving Two-Point Discrimination (mean score)				-0.28	0.03
		Wrist position sense				-0.009	0.94

4. Discussion

To the best of authors' knowledge, this is the first study that investigated the correlation between lower and higher order sensory function and manual dexterity in both dominant and non-dominant hand of patients with idiopathic PD. The results of the current study showed that there was no significant correlation between the light touch threshold as well as tactile acuity based on STPD in both dominant and non-dominant hand and gross and fine manual dexterity in patients with idiopathic PD. However, tactile acuity based on MTPD, wrist proprioception, texture and weight discrimination as well as haptic performance in both dominant and non-dominant hand was significantly correlated with gross and fine manual dexterity in these patients. After doing multiple regression analysis for sensory function variables which showed significant correlation with manual dexterity, the results indicated that the haptic performance had the most important effect on gross dexterity in both dominant and non-dominant hand (40 % and 41 % of variance, respectively) as well as fine manual dexterity (32 % of variance) in dominant hand while combination of weight and texture discrimination had the most effect on fine manual dexterity in non-dominant hand (31 % of variance). As most of the previous studies have investigated the correlation between sensory and motor function of hand in diseases other than PD and most of them have used different measuring tools compared to the current study (8, 10-12) and because of progressive nature of PD, the possibility of comparing the results of this study with previous studies is limited. However, the results of this study is in accordance with Lee et al. (2010) who reported the significant low correlation between sensory function (temporal discrimination threshold) and finger dexterity (coin rotation task) in patients with PD (14).

These results indicated that the more need of higher-order processing for sensory functions, the greater will be their correlation with dexterity performance. For example, WEST which measures the detection of light touch needs lower sensory processing compared to two-point discrimination and HORT which measure the discriminative performance. Previous studies also reported that hand function needs more fine reception acuity and judgment compared to detection (27-29). The current study found the same correlation between sensory and motor function in both dominant and non-dominant hand. This result could be explained by the fact that the number of patients who their dominant hand was the more affected hand (47.3%) was approximately equal to ones who their non-dominant hand was the more affected hand (45.5%). Moreover, sensory and motor functions as well as and also the correlation between them were investigated separately in dominant and non-dominant hand. However, pooled data of dominant and non-dominant hand has been reported in previous studies (30, 31) , so it is impossible to compare this result with them.

In this study, PPT and BBT were used as a measure of fine and gross motor dexterity, respectively. Previous studies have reported that the level of correlation between sensory and motor function is proportional to the size of objects used in motor tests that means the larger the object, the lower will be the correlation (8, 31). However, the level of correlation between gross motor dexterity and sensory function was not only lower but also it was slightly higher than fine motor dexterity. This contrary result may be due to the nature of PD which requires more investigation in future studies.

Although higher order sensory performances of hand including wrist proprioception, tactile acuity in moving form, haptic performance and object recognition were significantly correlated with fine and gross manual dexterity in patients with idiopathic PD, the level of correlation was generally low to moderate and the high correlation was not found. One possible explanation for this result may be the time dependency of both fine and gross manual dexterity tests used in this study which mainly show the speed of motor function. Nevertheless, sensory defects not only affects speed of motor function but also other aspects of motor function including direction, force and accuracy (32). Therefore, high correlation may be found using tests which measure other aspects of motor function. Moreover, both dexterity tests are conducted in open eyes condition, thus the somatosensory deficits may be compensated by vision in these tests. Scalha et al. (2011) also reported the higher correlation between sensory function and motor function of upper extremity which tested in closed eye condition. They have explained this finding by the role of visual cues in compensating the possible sensory deficits of hand and help in organization of information obtained from affected hand (10). Another possible explanation may be the time since PD diagnosis (which its mean was 7.96 years) and progressive nature of PD. It has been shown that if sensory deficits occur gradually, gradual adaptation and compensation for them is possible which has also been observed in patients with diabetes (13) and leprosy (33). The compensation may take place by enhancing the pressure of finger on the holding object which stimulating deeper afferent fibers resulting in more sensory and motor feedbacks (30). Moreover, it seems possible that these results are due to the stage of disease progression in patients participated in this study. All participants being in the initial stages of disease progression and sensory function may not be severely affected in these stages which may result in lack of high correlation between sensory and motor function in these patients. Lack of matched healthy subjects to compare the results and investigating this correlation in advanced stages of PD were the limitations of this study, so it is suggested that they should be considered in the future studies.

Conclusion

This study showed the significant low to moderate correlation between gross and fine manual dexterity and higher order sensory functions including tactile acuity, wrist proprioception, texture and weight discrimination as well as haptic performance in patients with idiopathic PD. Haptic performance seems to be the most influential higher order sensory function associated with manual dexterity in these patients.

Acknowledgement

This work was supported by Iran University of Medical Sciences, Tehran, Iran. The authors declare that there is no conflict of interest.

References

1. Liu CC, Li CY, Lee PC, Sun Y. Variations in Incidence and Prevalence of Parkinson's Disease in Taiwan: A Population-Based Nationwide Study. Parkinson's disease 2016.
2. Foki T, Pirker W, Geißler A, Haubenberger D, Hilbert M, Hoellinger I, et al. Finger dexterity deficits in Parkinson's disease and somatosensory cortical dysfunction. Parkinsonism & Related Disorders 2015;21(3):259-65.
3. Liubicich ME, Magistro D, Candela F, Rabaglietti E, Ciairano S. Physical Activity, Fine Manual Dexterity and a Coach's Self-Efficacy in a Physical Activity Program for Older Persons Living in Residential Care Facilities. Psychology 2012;3(05):384.
4. Nolano M, Provitera V, Estraneo A, Selim MM, Caporaso G, Stancanelli A, et al. Sensory deficit in Parkinson's disease: evidence of a cutaneous denervation. Brain 2008;131(7):1903-11.
5. Maschke M, Tuite PJ, Krawczewski K, Pickett K, Konczak J. Perception of heaviness in Parkinson's disease. Movement disorders 2006;21(7):1013-8.
6. Lyoo C, Ryu Y, Lee M, Lee M. Striatal dopamine loss and discriminative sensory dysfunction in Parkinson's disease. Acta neurologica Scandinavica 2012;126(5):344-9.
7. Kalisch T, Tegenthoff M, Dinse HR. Improvement of sensorimotor functions in old age by passive sensory stimulation. Clinical Intervention in Aging 2008;3(4):673-90.
8. Melchior H, Vatine J-J, Weiss PL. Is there a relationship between light touch-pressure sensation and functional hand ability? Disability and rehabilitation 2007;29(7):567-75.
9. Lee HM, Koh S-B. Many faces of Parkinson's disease: non-motor symptoms of Parkinson's disease. Journal of Movement Disorders 2015;8(2):92.
10. Scalha TB, Miyasaki E, Lima NMFV, Borges G. Correlations between motor and sensory functions in upper limb chronic hemiparetics after stroke. Arquivos de Deuro-psiquiatria 2011;69(4):624-9.
11. Wagner JM, Lang CE, Sahrmann SA, Hu Q, Bastian AJ, Edwards DF, et al. Relationships between sensorimotor impairments and reaching deficits in acute hemiparesis. Neurorehabilitation and Neural Repair 2006;20(3):406-16.
12. Doita M, Sakai H, Harada T, Nishida K, Miyamoto H, Kaneko T, et al. The influence of proprioceptive impairment on hand function in patients with cervical myelopathy. Spine 2006;31(14):1580-4.
13. Casanova J, Casanova J, Young M. Hand function in patients with diabetes mellitus. Southern Medical Journal 1991;84(9):1111-3.
14. Lee MS, Lyoo CH, Lee MJ, Sim J, Cho H, Choi YH. Impaired finger dexterity in patients with parkinson's disease correlates with discriminative cutaneous sensory dysfunction. Movement Disorders 2010;25(15):2531-5.
15. Domholt E. Rehabilitation research. Elsevier Saunders 2nd ED 2008.
16. Godefroy O, Fickl A, Roussel M, Auribault C, Bugnicourt JM, Lamy C, et al. Is the Montreal Cognitive Assessment superior to the Mini-Mental State Examination to detect poststroke cognitive impairment? A study with neuropsychological evaluation. Stroke; A Journal of Cerebral Circulation 2011;42(6):1712-6.
17. Schreuders TA, Selles RW, van Ginneken BT, Janssen WG, Stam HJ. Sensory evaluation of the hands in patients with Charcot-Marie-Tooth disease using Semmes-Weinstein monofilaments. Journal of Hand Therapy 2008;21(1):28-35.
18. Ross RG. Rehabilitation of the Hand and Upper Extremity. Journal of Hand Therapy 2002;15(4):380.
19. Williams PS, Basso DM, Case-Smith J, Nichols-Larsen DS. Development of the Hand Active Sensation Test: reliability and validity. Archives of physical medicine and rehabilitation 2006;87(11):1471-7.
20. Kalisch T, Tegenthoff M, Dinse HR. Repetitive electric stimulation elicits enduring improvement of sensorimotor performance in seniors. Neural plasticity 2010.
21. Norman JF, Crabtree CE, Norman HF, Moncrief BK, Herrmann M, Kapley N. Aging and the visual, haptic, and cross-modal perception of natural object shape. Perception 2006;35(10):1383-95.
22. Carey LM, Oke LE, Matyas TA. Impaired limb position sense after stroke: a quantitative test for clinical use. Archives of Physical Medicine and Rehabilitation 1996;77(12):1271-8.

23. Slota GP, Enders LR, Seo NJ. Improvement of hand function using different surfaces and identification of difficult movement post stroke in the Box and Block Test. Applied Ergonomics 2014;45(4):833-8.
24. Desrosiers J, Bravo G, Hébert R, Dutil E, Mercier L. Validation of the Box and Block Test as a measure of dexterity of elderly people: reliability, validity, and norms studies. Archives of Physical Medicine and Rehabilitation 1994;75(7):751-5.
25. Mehdizadeh H, Taghizadeh G, Ashayeri H. Test-retest reliability of the Purdue Pegboard test in drug on-phase for patients with Parkinson's disease. Koomesh 2010;11(3):190-8, En27.
26. Morris S, Morris ME, Iansek R. Reliability of measurements obtained with the Timed "Up & Go" test in people with Parkinson disease. Physical therapy 2001;81(2):810-8.
27. Fess EE. Documentation: Essential elements of an upper extremity assessment battery. Rehabilitation of the hand: Surgery and Therapy 1995; 1:185-214.
28. Novak CB, Mackinnon SE, Kelly L. Correlation of two-point discrimination and hand function following median nerve injury. Annals of Plastic Surgery 1993;31(6):495-8.
29. Weinstein S. Fifty years of somatosensory research: from the Semmes-Weinstein monofilaments to the Weinstein Enhanced Sensory Test. Journal of Hand Therapy 1993;6(1):11-22.
30. Dannenbaum RM, Michaelsen SM, Desrosiers J, Levin MF. Development and validation of two new sensory tests of the hand for patients with stroke. Clinical Rehabilitation. 2002;16(6):630-9.
31. Dellon ES, Keller KM, Moratz V, Dellon AL. Validation of cutaneous pressure threshold measurements for the evaluation of hand function. Annals of Plastic Surgery 1997;38(5):485-92.
32. Hudspeth AJ, Jessell TM, Kandel ER, Schwartz JH, Siegelbaum SA. Principles of neural science 5nd ED; 2013.
33. Yawalkar S. Leprosy for medical practitioners and paramedical workers.Novartis Foundation for Sustainable Development 8nd ED; 2009