Assessment of behavioral tasks performed by hemiplegic patients with impaired dexterity post stroke

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Abstract. – **Disability continues to be one of the leading reasons individuals affected by stroke are left incapable of performing daily activities. Due to the staggering number of disabled adults suffering post-stroke neurological damage, there is a critical need for creating and monitoring effects of successful, intensive stroke therapies. Behavioral assessments are useful tools by which to examine the effectiveness of these stroke therapies as they allow for the investigation of multiple variables, including task performance time, performance quality, and degree of motor function. The purpose of this review is to discuss various behavioral assessments commonly administered during stroke rehabilitation. Developing a battery of standardized behavioral tests would create an instrument to assess therapies, and therefore, ensure the most successful therapies stay in practice to help the recovery of individuals suffering from impaired dexterity due to stroke.**

Key Words
Disability, Stroke, Stroke-therapies, Behavioral tasks.

Introduction

Human manipulatory skills require some of the most complex levels of brain function and interactions, subtended by central representations that include widely distributed neural networks across cortical and subcortical structures. Consequently, dexterous behaviors used during daily routine and vocation are often impaired to varying degrees in patients with brain damage. A major goal of rehabilitation research is to determine how neurological problems in specific patient groups affect normal mechanisms that govern the performance of simple movements.

Overall, it is the loss of independence due to a physical impairment that is the greatest cost to stroke survivors and to the community[1]. Despite intensive rehabilitative efforts, the functional outcome of patients with initially severe hemiparesis is very poor[2]. It has been estimated that only 5% of patients with complete paralysis regain full arm function[3] and 30-66% of survivors never regain any use of the affected arm[4,5]. Although the loss of skilled arm function is related to the location of the stroke[6], the extent and location of damage are not entirely predictive of eventual function[7,8].

Weakness and loss of dexterity account for most of the disability experienced following a stroke. Although both are apparent simultaneously, recovery of strength does not ensure recovery of dexterity[9]. Carefully designed experiments have shown that loss of dexterity can occur independently of weakness, slowness of muscle activation, excessive co-contraction, and spasticity[9]. However, when contributions of strength and dexterity to functional recovery are compared, strength tends to make a greater impact on motor recovery than dexterity[9].

Features commonly associated with impaired dexterity in the hemiplegic upper limb include the loss of individuated finger movement[10], altered muscle properties due to contracture[11], slowing of coordinated movements[12], increased sensation of heaviness or effort when moving[13], and reduced command of aimed and ballistic movements[14]. These features are independent of visuospatial disorders, such as apraxia, agnosia, and neglect, which are common following right hemisphere damage[15]. Gradual recovery of dexterity can occur following a stroke, although it is often incomplete. Functionally beneficial reorganization within the corticospinal system can occur provided approximately 20% of cortical pyramidal cells are spared[16]. Damage to the posterior limb of the internal capsule, which contains the densest projections from the primary

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motor cortex (M1), is strongly correlated with poor motor outcome, emphasizing the importance of the integrity of the corticospinal tract for the recovery of fine motor functions of the upper limb[6]. Sensory deficits resulting from somatosensory cortex lesions are also associated with deficits in fine motor skill[17] and may contribute to the overall motor deficit independently, or as a function of, the extensive connections between M1 and a number of somatosensory areas in the parietal cortex[17].

Investigation of Hemiplegic Upper Limb Function

Traditionally, assessment of upper limb motor function following stroke has relied on qualitative descriptions of muscular control, strength, and overall tone[18]. Over time, a wide range of upper limb assessment scales have been developed to quantify deficits in function and to provide a means of documenting recovery during rehabilitation. Each of these tests has limitations in terms of sensitivity, time required for completion, ceiling and floor effects, equipment required, and/or consideration given to pre-morbid hand preferences. The following assessments are organized according to the degree of motor recovery evaluated. Third order tests are the most comprehensive, evaluating performance time, quality of movement, and overall motor performance. Second order assessments and first order assessments appraise only two or one of the three aforementioned criteria, respectively, but are often combined in order to more thoroughly trend functional recovery and performance over the course of rehabilitation. The following battery of behavioral assessments serves as an overview of common tests employed in stroke rehabilitation in order to guide assessment selection based on a number of factors including elements evaluated, time required for task completion, patient population limitations, and overall clinical applicability.

Battery of Behavioral Assessments

Third Order

Motor assessments evaluating performance time, movement quality, and motor performance

Test Évaluant la performance des Membres supérieurs des Personnes Âgées (TEMPA)

The Test Évaluant la performance des Membres supérieurs des Personnes Âgées (TEMPA) is an assessment of performance time, motor performance, and quality of movement. The TEMPA is composed of four unilateral and five bilateral tasks, which represent activities of daily living (ADLs). Each task is measured using a 0 to 3 scale, where 0 denotes successful completion of the task and 3 represents an inability to complete the task even with assistance. A task analysis section of the TEMPA allows the participant to quantify the difficulty of the task according to several dimensions: strength, range of motion, precision of gross movement, and precision of fine movement [19].

The TEMPA is a valuable tool, as it assesses three different dimensions of motor function. However, the TEMPA was originally designed for geriatric individuals and thus does not take into account the specific difficulty a stroke survivor may face while completing the tasks. Most tasks of the TEMPA tend to be too difficult for subjects who have experienced a moderate or even mild stroke [20], limiting its applicability in this population.

Wolf Motor Function Test (WMFT)

Used mostly in investigating effectiveness of constraint-induced motor therapy (CIMT), the Wolf Motor Function Test (WMFT) is a frequently employed tool that quantifies upper extremity motor function in individuals recovering from stroke. The WMFT is an assessment of performance time and strength of movement and is generally composed of 2 strength tasks and 15 performance tasks, all arranged in order of complexity. The WMFT gives two scores: a motor function score and a time score. The functional ability for each task is ranked on a 5-point scale, with a score of 1 representing no movement of the participating arm and a score of 5 representing normal movement[21]. Most of the tasks are reliable, although there are 3 tasks involving precise movement of the elbow that have proven to be unreliable[20]. Unreliable tasks can easily be dropped, making for a shorter overall assessment of less than 30 minutes. However, all 17 tasks can also be employed to create a wider range of task assessments. The WMFT allows clinicians and researchers to detect slight differences in motor function, as the assessment is sensitive to subtle variances in motor quality. Furthermore, the WMFT is useful in assessing both single-joint and coordinated movements, movement speed, and requires a very simple set-up of items to be run[20]. Since the measure evaluates gradient of proximal to distal function, it can be used to compare abilities across individuals with wide-ranging impairments. As such, it allows for the study of mildly affected patients who show very subtle deficits of finger movements/dexterity to those severely affected who may only manifest residual function of the proximal shoulder and upper arm.

Arm Motor Ability Test

The Arm Motor Ability Test (AMAT) is yet another assessment tool that makes particular effort to quantify the ease of completing ADLs. Like the WMFT, the AMAT measures limb functional ability, quality of movement, and task performance time. The aforementioned criteria are measured by a set of 17 compound tasks, each composed of one to three subtasks. The subtasks are completed continuously and consist of both unilateral and bilateral movements. Each task is divided and rated in two indices: functional ability and quality of movement, both rated on a 0- (no movement) to 5- (normal movement) point scale[22]. Placing a time limit on each task gives the AMAT a performance time component as well. Although the AMAT takes into account many important factors of motor assessment, it fails to be as sensitive as the WMFT[20]. The assessment focuses largely on hand-dependent tasks and should not be used for subjects who have little to no hand control[23]. Clinical administration of the AMAT might also pose a problem due to its fairly long run time of ~40 minutes, which may fatigue the patient[23].

Second Order

Motor Assessment Evaluating Motor Performance and Performance Time

Jebsen-Taylor Functional Hand Test

The Jebsen-Taylor Functional Hand Test (JTT) is composed of 7 unilateral tasks and evaluates patients on the performance of these tasks and the time it takes to complete them. The assessment lacks the ability to record quality of movement, an essential attribute when determining the efficacy of stroke rehabilitation. In addition, Sears and Chung[24] found that the JTT is not suitable to quantify motor recovery in patients affected by any type of hand-related motor impairment, limiting its applicability to the wide realm of patients with impaired dexterity. The Jebsen-Taylor Functional Hand Test takes approximately 15 minutes to run and is fairly easy to administer, though the equipment can be quite bulky[24].

Motor Assessments Evaluating Movement Quality and Motor Performance

Chedoke-McMaster Stroke Assessment

The Chedoke-McMaster Stroke Assessment (CMSA) is a two-part test composed of a physical impairment segment and a disability inventory. The physical impairment segment is a multidimensional test used to rate the physical impairments of a patient's arm, hand, leg, foot, shoulder pain, and postural control. Five of the aforementioned six dimensions are measured by quantifying motor impairments according to a seven point scale relative to the seven stages of motor recovery as established by Twitchell and Brunnstrom[25]. This excludes shoulder pain, which is measured by severity. The scales for each dimension range from a score of 1 (most impairment) to 7 (no impairment), leading to a total possible score of 42 (7 points for each dimension)[26]. This test assesses the ability of the patient to produce pressure and force against a therapist's arm, and extend, flex, and rotate the limb. Changes in disability are measured with the disability inventory segment of the CMSA. Designed to be used with the Uniform Data System for Medical Rehabilitation (UDS) and Functional Independence Measure (FIM), the disability inventory consists of a gross motor function index (maximum score of 70) and a walking index (maximum score of 30 and is scored by conducting a 2-minute walking test) yielding a total possible score of 100 overall. The Chedoke-McMaster Stroke Assessment is a valuable tool that is precise to the stroke population and is effective in evaluating the progress of an individual's stroke-recovery. However, the limited assessment of hand function combined with the 2-part scoring system creates an unnecessarily complex assessment[27].

Fugl-Meyer Assessment – Upper Extremity Component

Rather than exclusively testing upper limb function, the Fugl-Meyer Assessment (FMA) tests impairment of the upper and lower extremities, balance, and sensation[28]. It has undergone extensive psychometric testing and is sensitive to change after intervention[18]. The 66-point upper limb section is commonly used in isolation to measure motor recovery. It consists of 33 items scored on a 3-point scale and coordination/speed. Validity[29] and reliability[30] have been established in multiple studies. Both the Action Research Arm Test (ARAT; see below) and the FMA are sensitive to motor changes in chronic stroke[5]. While empirical measures of function and impairment are important in clinical studies, the ability of patients to use their affected upper limb for daily activities, or real-world use, is a primary focus for rehabilitation. An important advantage of FMA lies in the acute stage of post-stroke rehabilitation, where its relation with ADLs is stronger than other tests, such as ARAT.

First Order

Motor Assessment Evaluating Only Performance Time

Nine-Hole Peg Test

The 9-HPT, also known as the Nine-Hole Peg Test, is a timed assessment aimed to evaluate fine manual dexterity. The test takes an average of about 10 minutes and is conducted in two to three trials for each hand, each trial alternating between the damaged and normal hand. Within 50 seconds, the subject must pick up and place 9 pegs into 9 separate holes spaced 50 mm apart in a board, and reverse the process by removing the pegs[31]. The scoring system of the 9-HPT is based on how many pegs are placed into the board per second, a significant loss of function being quantified by the task taking more than eighteen seconds to complete[31]. In general, the 9-HPT is easy to administer, a good assessment to quantify performance time, and clinically applicable. However, this simple task does not take into account the performance and quality of movement and, therefore, must be used in combination with other tasks to comprehensively diagnose a patient's stroke recovery. Patients with excessive hand impairment who are unable to grip the pegs will not be able to participate, limiting the 9-HPT's applicability in this population.

Box and Block Test

The Box and Block Test (BBT) is a valuable measure of manual dexterity by administering a manual task, once for each upper limb. The assessment requires the patient to transport as many 2.54 cm^3 blocks from one section to another within 1 minute[32]. The BBT is a useful assessment and is comparable to the 9-HTP. However, while the pegs in the 9-HPT are all uniformly sized, the blocks in the BBT vary in size. A disadvantage of administering the BBT is that a measure of the responsiveness to change is not established and a patient's performance can vary due to various factors such as age or experience. Thus, this examination is useful as a one-time assessment of motor function but less suitable to trend rehabilitation over time[32].

Finger Tapping Task

The Finger Tapping Task (FTT) is an evaluation tool that is most commonly used for the assessment of psychogenic movement disorders but was recently shown also to be applicable for the motor assessment of Parkinson's and stroke patients[33]. With the ability to quantify motor impairments, the FTT is a time-variable task that scores the patient's finger tapping rate. The FTT is a useful measurement as it can be adjusted to the ability of the patient and is relatively easy to administer. However, subjects can easily manipulate this task by slowing down or speeding up the rate of task completion[33], thereby limiting its evaluative utility[34].

Motor Assessments Evaluating Only Motor Performance

Frenchay Arm Test

The Frenchay Arm Test is composed of five tasks, each of which is scored on a pass or fail basis. The test is designed to evaluate a patient's ability to perform functional tasks involving the impaired hand[31]. Although the Frenchay Arm Test is an effective and clinically applicable tool to determine motor impairment with a completion time of approximately 3 minutes, it is still missing the ability to rate performance time and movement quality [22, 23].

Motricity Index (Upper Extremity Subscale)

The Motricity Index is an evaluation tool used to assess motor deficits by examining a movement at three joints of the upper extremity: pinch grasp, elbow flexion, and shoulder abduction. Each movement is graded on a scale of 0 to 33, leading to a maximum total score of 100 after an additional point is added for the completion of all three upper extremity movements. The Motricity Index is an easily administered assessment, takes approximately 5 minutes to complete[35], and is clinically applicable. However, the Motricity Index does not provide a physician or therapist with the necessary tools to fully evaluate an impaired arm, as it only tests the strength of the movement and not the quality or performance time of the task. Moreover, because it is based on the Medical Research Council grades of muscle strength, the Motricity Index revolves around the assumption that participants are able to perform isolated movements, movements that stroke survivors are typically unable to complete[23].

Action Research Arm Test (ARAT)

The ARAT is based on the Carroll test of upper extremity function[36] and consists of 19 movements grouped into four subtests: grasp, grip, pinch and gross arm movement[37]. Items are organized hierarchically and scored on a four-point scale, with a maximum total score of 57 points. Although not designed specifically for stroke patients, its use with this population has been validated[37], and intra-rater and retest reliability have been established[5,37]. To detect a clinically meaningful change, the measurement error of the ARAT must be smaller than the estimated minimal clinically important difference in scores, with an increase in a score of 5.7 points suggesting a clinically relevant change in function[5]. ARAT is noted to be more responsive to interventional studies compared to FMA and carries higher responsiveness ratios even in the chronic stroke patients.

Grip Strength/Grip Force/Grip-Lift Task

Objective measurement of grip ability is simple to measure and useful for detecting early recovery and predicting final functional outcome post-stroke[31]. Consisting of a single task that can specifically evaluate grip strength, grip force, and the ability to lift something, the highest score from three successive trials is indicative of functional recovery and recommended for reproducible results[38]. Completion of the grip tasks requires muscle strength, muscle control, and adequate sensory feedback for accurate performance. Investigation of impairments in manipulative grip force control in stroke patients has been undertaken comprehensively by Hermsdorfer et al[15]. Rather than using an apparatus that could be gripped and lifted from a surface, they developed a lightweight instrumented object that was not physically connected to external devices. Compared with age-matched healthy subjects, chronic cerebral stroke patients with mild to moderate paresis used excessive grip force when holding and transporting the object despite a reduction in maximal grip strength. Although there were some delays in responding to force changes in a grip perturbation task and decreased speed of movement during object transport, the feed forward mechanisms required for the cyclic vertical movements were intact, suggesting that anticipatory control was preserved. Significant correlations between the delay in the perturbation task and increased grip force and delay in achieving peak grip force during object transport led the authors to conclude that impaired sensibility and sensorimotor processing accounted for force control deficits in stroke patients[15]. Improvements in the hardware and software required to construct a grip-lift apparatus have led to the suggestion that grip control may be easily included in clinical examination of hand function following cerebral lesions[15]. The examination is brief, non-invasive, easy for patients to complete, and overall helpful in directing therapeutic intervention[15].

Ashworth Scale

One of the methods that have been proposed for measuring muscle spasticity involves manually moving a limb through the range of motion to passively stretch specific muscle groups. Ashworth[39] has described a five-point ordinal scale for grading the resistance encountered during such passive muscle stretching. Ashworth's scale grades spasticity as follows: 0 = normal muscle tone; 1 = slight increase in muscle tone, "catch" when limb moved; 2 = more marked increase in muscle tone, but limb easily flexed; 3 = considerable increase in muscle tone; and 4 = limb rigid in flexion or extension. As Ashworth's scale assigns grades to a manually determined resistance of muscle to passive stretching, it measures spasticity as defined herein.

Barthel Index

The Barthel Index was first published[40] in 1965, and was designed to assess change in functional status in rehabilitation patients with neurologic or musculoskeletal impairments. The Barthel Index assesses 10 ADLs. Eight items are related to self-care activities: feeding, transfer from chair to bed and back, grooming, toileting, bathing, dressing, bowel, and bladder continence. Two items pertain to mobility: walking or propelling a wheelchair, and ascending/descending stairs. It is scored on a 3-point weighted scale, with the weighted scores summed to give a total score from 0 (total dependence) to 100 (total independence).

Motor Activity Log

The Motor Activity Log (MAL) was developed to measure improvement in motor activity[41]. Most researchers investigating the effect of CIMT use additional outcome measures other than the MAL, such as the aforementioned Wolf Motor Function Test, the Arm Motor Activity Test, the Fugl-Meyer Assessment scale, or the Action Research Arm test, which are all performance measures. The MAL consists of a semi-structured interview for the patient to assess the use of the paretic arm and hand during activities of daily

Table I. Third order assessments evaluating performance time, movement quality, and motor performance.

THIRD ORDER ASSESSMENTS				
Assessment	**Tasks**	**Measurements**	**Run Time**	**Reference**
TEMPA	4 unilateral 5 bilateral	Performance time Movement quality Motor performance	~44 minutes	Desrosiers et al (1995) Feys et al (2002)
WMFT	2 strength 15 performance		~30 minutes	Lang et al (2008) Morris et al (2001)
AMAT	17 compound 1-3 subtasks each		~40 minutes	Kopp et al (1997) Morris et al (2001) Chae et al (2002)

Test Évaluant la performance des Membres supérieurs des Personnes Âgées (TEMPA), Wolf Motor Function Test (WMFT), Arm Motor Ability Test (AMAT)

living. Two scores are given for each activity, 1 for the amount of use (AOU) and 1 for the quality of movement (QOM) of the paretic arm. The questions concern activities performed during the past week or, occasionally, the past year[41]. After an initial screening question to verify that the activity at issue has been performed during the time-frame at issue, the patient is asked how much the affected arm participated in this activity. Possible scores range from 0 (never use the affected arm for this activity) to 5 (always use the affected arm for this activity). To measure QOM, the patient is asked how well the affected arm helped during this activity. Possible scores range from 0 (inability to use the affected arm for this activity) to 5 (ability to use the affected arm for this activity just as well as before the stroke).

Conclusions

The astonishing number of disabilities resulting from stroke leaves affected individuals unable to function independently. Stroke rehabilitation techniques have been designed to train post-stroke patients to use their affected limbs in hopes of regaining partial or full recovery of movement. Early stroke rehabilitation is critical for enhancing motor recovery, but the optimal time window for specific neurorehabilitation has yet to be elucidated. The intensity and duration of the rehabilitation strategy are also important factors that influence effectiveness. Although the evidence base for stroke rehabilitation continues to grow, future studies must be conducted to ascertain the optimal time, intensity, and duration for specific rehabilitation techniques and to facili-

Table II. Two classes of second order assessments evaluating two of the three functional motor movement categories: motor performance, performance time, movement quality.

SECOND ORDER ASSESSMENTS				
Assessment	**Tasks**	**Measurements**	**Run Time**	**Reference**
JTT	7 unilateral	Motor Performance Performance Time	~15 minutes	Sears & Chung (2010)
CMSA	Impairment Inventory: 6 subscales Disability Inventory: 2 subscales	Movement Quality Motor Performance	~60 minutes	Brunnstrom (1996) Levin et al (2004) Gowland et al (1993)
FMA	17 compound 1-3 subtasks each		~40 minutes	Kopp et al (1997) Morris et al (2001) Chae et al (2002)

Jebsen-Taylor Functional Hand Test (JTT), Chedoke-McMaster Stroke Assessment (CMSA), Fugl-Meyer Assessment – Upper Extremity Component (FMA)

Table III. Two classes of first order assessments evaluating one of the three functional motor movement categories: motor performance, performance time, movement quality

FIRST ORDER ASSESSMENTS				
Assessment	**Tasks**	**Measurements**	**Run Time**	**Reference**
9-HPT	1 task: 2-3 trials per hand	Performance Time	~10 minutes	Sunderland et al (1989)
Finger Tapping Rate	1 task		Variable	Criswell et al (2010) Heller et al (1987)
BBT	1 task		1 minute	Cohen et al (2010)
Frenchay-Arm Test	5 tasks	Motor Performance	~3 minutes	Kopp et al (1997) Chae et al (2002)
Motricity Index	6 movements		~5 minutes	Collin & Wade (1990) Chae et al (2002)
ARAT	19 movements: 4 subtests		~10 minutes	Carroll (1965) Lyle (1981) Van der Lee (2001)
Grip Force/ Strength/Lift	1 task		Variable	Hermsdorfer et al (2003) Hermsdorfer & Mai (1996) Grichting et al (2000) Wenzelburger et al (2005) Hammer & Lindmark (2003)

Nine-Hole Peg Test (9-HPT), Box and Block Test (BBT), Action Research Arm Test (ARAT)

tate the translation of basic scientific evidence into routine clinical practice.

Many stroke therapies are not suited for all levels of disability, as some techniques require retention of certain hand and wrist movements, an ability that is available only to a few patients with minimal deficits. The subtle inclusion and exclusion criteria that accompany participation in rehabilitation programs requires that the correct individuals be chosen so maximum benefit can be observed. Furthermore, motor improvement must be examined and evaluated during the course of a stroke therapy in order to quantitatively and qualitatively describe functional recovery and effectively characterize improvement over time. The aforementioned batteries of behavioral assessments serve as both a clinical and experimental tool to evaluate motor recovery in post-stroke patients and aid in therapy selection and monitoring individuals during the rehabilitation process. Each order of assessments varies in application and sensitivity to change, and provides an approximation of certain milestones in functional recovery that can be achieved with proper and careful rehabilitation techniques. With a comprehensive view of the motor recovery process in the human brain and use of behavioral assessments, significant therapeutic steps can be taken to decrease the number of disabilities resulting from stroke and increase functional recovery of individuals suffering from post-stroke motor impairments.

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Conflict of interest

The Authors declare that they have no conflict of interests.

References

1) Pang MY, Harris JE, Eng JJ. A community-based upper-extremity group exercise program improves motor function and performance of functional activities in chronic stroke: a randomized controlled trial. Arch Phys Med Rehabil 2006; 87: 1-9.
2) Nakayama H, Jorgensen HS, Raaschou HO, Olsen TS. Compensation in recovery of upper extremity function after stroke: the Copenhagen Stroke Study. Arch Phys Med Rehabil 1994; 75: 852-857.
3) Richards L, Pohl P. Therapeutic interventions to improve upper extremity recovery and function. Clin Geriatr Med 1999; 15: 819-832.
4) 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.
5) Van der Lee JH, Wagenaar RC, Lankhorst GJ, Vogelaar TW, Deville WL, Bouter LM. Forced use of the upper extremity in chronic stroke patients: results from a single-blind randomized clinical trial. Stroke 1999; 30: 2369-2375.
6) Wenzelburger R, Kopper F, Frenzel A, Stolze H, Klebe S, Brossmann A, Kuhtz-Buschbeck J, Golge M, Illert M, Deuschl G. Hand coordination following capsular stroke. Brain 2005; 128: 64-74.
7) Feys H, Hetebrij J, Wilms G, Dom R, De Weerdt W. Predicting arm recovery following stroke: value of site of lesion. Acta Neurol Scand 2000; 102: 371-377.
8) Kwakkel G, Kollen BJ, van der Grond J, Prevo AJ. Probability of regaining dexterity in the flaccid upper limb: impact of severity of paresis and time since onset in acute stroke. Stroke 2003; 34: 2181-2186.
9) Canning CG, Ada L, Adams R, O'Dwyer NJ. Loss of strength contributes more to physical disability after stroke than loss of dexterity. Clin Rehabil 2004;18: 300-308.
10) Lang CE, Schieber MH. Reduced muscle selectivity during individuated finger movements in humans after damage to the motor cortex or corticospinal tract. J Neurophysiol 2004; 9: 1722-1733.
11) O'Dwyer NJ, Ada L, Neilson PD. Spasticity and muscle contracture following stroke. Brain 1996; 119: 1737-1749.
12) McCombe WS, Whitall J. Fine motor control in adults with and without chronic hemiparesis: baseline comparison to nondisabled adults and effects of bilateral arm training. Arch Phys Med Rehabil 2004; 85: 1076-1083.
13) Rode G, Rossetti Y, Boisson D. Inverse relationship between sensation of effort and muscular force during recovery from pure motor hemiplegia: a single-case study. Neuropsychologia 1996; 34: 87-95.
14) Platz T, Bock S, Prass K. Reduced skilfulness of arm motor behaviour among motor stroke patients with good clinical recovery: does it indicate reduced automaticity? Can it be improved by unilateral or bilateral training? A kinematic motion analysis study. Neuropsychologia 2001; 39: 687-698.
15) Hermsdorfer J, Laimgruber K, Kerkhoff G, Mai N, Goldenberg G. Effects of unilateral brain damage on grip selection, coordination, and kinematics of ipsilesional prehension. Exp Brain Res 1999; 128: 41-51.
16) Rossini PM, Calautti C, Pauri F, Baron JC. Post-stroke plastic reorganisation in the adult brain. Lancet Neurol 2003; 2: 493-502.
17) Nudo RJ, Friel KM, Delia SW. Role of sensory deficits in motor impairments after injury to primary motor cortex. Neuropharmacology 2000; 39: 733-742.
18) Poole JL, Whitney SL. Motor assessment scale for stroke patients: concurrent validity and interrater reliability. Arch Phys Med Rehabil 1988; 69: 195-197.
19) Desrosiers J, Hebert R, Bravo G, Dutil E. Upper extremity performance test for the elderly (TEMPA): normative data and correlates with sensorimotor parameters. Test d'Evaluation des Membres Superieurs de Personnes Agees. Arch Phys Med Rehabil 1995; 76: 1125-1129.
20) Morris DM, Uswatte G, Crago JE, Cook EW, 3rd, Taub E. The reliability of the wolf motor function test for assessing upper extremity function after stroke. Arch Phys Med Rehabil 2001; 82: 750-755.
21) Lang CE, Edwards DF, Birkenmeier RL, Dromerick AW. Estimating minimal clinically important differences of upper-extremity measures early after stroke. Arch Phys Med Rehabil 2008; 89: 1693-1700.
22) Kopp B, Kunkel A, Flor H, Platz T, Rose U, Mauritz KH, Gresser K, McCulloch KL, Taub E. The Arm Motor Ability Test: reliability, validity, and sensitivity to change of an instrument for assessing disabilities in activities of daily living. Arch Phys Med Rehabil 1997; 78: 615-620.
23) Chae J, Yang G, Park BK, Labatia I. Muscle weakness and cocontraction in upper limb hemiparesis: relationship to motor impairment and physical disability. Neurorehabil Neural Repair 2002; 16: 241-248.
24) Sears ED, Chung KC. Validity and responsiveness of the Jebsen-Taylor Hand Function Test. J Hand Surg Am 2010; 35: 30-37.
25) Brunnstrom S. Motor testing procedures in hemiplegia: based on sequential recovery stages. Phys Ther 1966; 46: 357-375.
26) Levin MF, Desrosiers J, Beauchemin D, Bergeron N, Rochette A. Development and validation of a scale for rating motor compensations used for reaching in patients with hemiparesis: the reaching performance scale. Phys Ther 2004; 84: 8-22.
27) Gowland C, Stratford P, Ward M, Moreland J, Torresin W, Van Hullenaar S, Sanford J, Barreca S, Vanspall B, Plews N. Measuring physical impairment and disability with the Chedoke-McMaster Stroke Assessment. Stroke 1993; 24: 58-63.
28) Fugl-Meyer AR, Jaasko L, Leyman I, Olsson S, Steglind S. The post-stroke hemiplegic patient. 1. a method for evaluation of physical performance. Scand J Rehabil Med 1975; 7: 13-31.
29) Dettmann MA, Linder MT, Sepic SB. Relationships among walking performance, postural stability, and functional assessments of the hemiplegic patient. Am J Phys Med 1987; 66: 77-90.
30) Sanford J, Moreland J, Swanson LR, Stratford PW, Gowland C. Reliability of the Fugl-Meyer assessment for testing motor performance in patients following stroke. Phys Ther 1993; 73: 447-454.
31) Sunderland A, Tinson D, Bradley L, Hewer RL. Arm function after stroke. An evaluation of grip strength as a measure of recovery and a prognostic indicator. J Neurol Neurosurg Psychiatry 1989; 52: 1267-1272.
32) Corben LA, Tai G, Wilson C, Collins V, Churchyard AJ, Delatycki MB. A comparison of three measures

of upper limb function in Friedreich ataxia. J Neurol 2010; 257: 518-523.
33) Criswell S, Sterling C, Swisher L, Evanoff B, Racette BA. Sensitivity and specificity of the finger tapping task for the detection of psychogenic movement disorders. Parkinsonism Relat Disord 2010; 16: 197-201.
34) Heller A, Wade DT, Wood VA, Sunderland A, Hewer RL, Ward E. Arm function after stroke: measurement and recovery over the first three months. J Neurol Neurosurg Psychiatry 1987; 50: 714-719.
35) Collin C, Wade D. Assessing motor impairment after stroke: a pilot reliability study. J Neurol Neurosurg Psychiatry 1990; 53: 576-579.
36) Carroll D. A quantitative test of upper extremity function. J Chronic Dis 1965; 18: 479-91.
37) Lyle RC. A performance test for assessment of upper limb function in physical rehabilitation treatment and research. Int J Rehabil Res 1981; 4: 483-492.
38) Hammer A, Lindmark B. Test-retest intra-rater reliability of grip force in patients with stroke. J Rehabil Med 2003; 35: 189-194.
39) Ashworth B: Preliminary trial of carisoprodal in multiple sclerosis. Practitioner 1964; 192: 540-542.
40) Mahoney FI, DW Barthel. Functional evaluation: the Barthel Index. Maryland State Medical J 1965; 14: 61-65.
41) Uswatte G, Taub E. Constraint-induced movement therapy: New approaches to outcome measurement in rehabilitation. In: D.T. Stuss, G. Winocur, I.H. Robertson (Eds.), Cognitive rehabilitation: Cambridge, UK: Cambridge University Press. A comprehensive approach, 1999; pp. 215-229.