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Upper extremity disability after stroke. Psychometric properties of outcome measures and perceived ability to perform daily hand activities.

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Psychometric properties of outcome measures and perceived ability to perform daily hand activities

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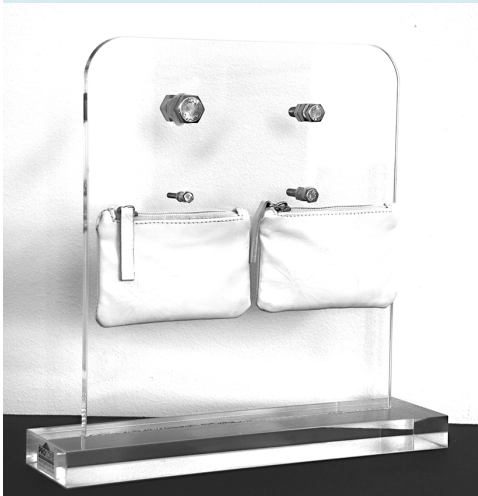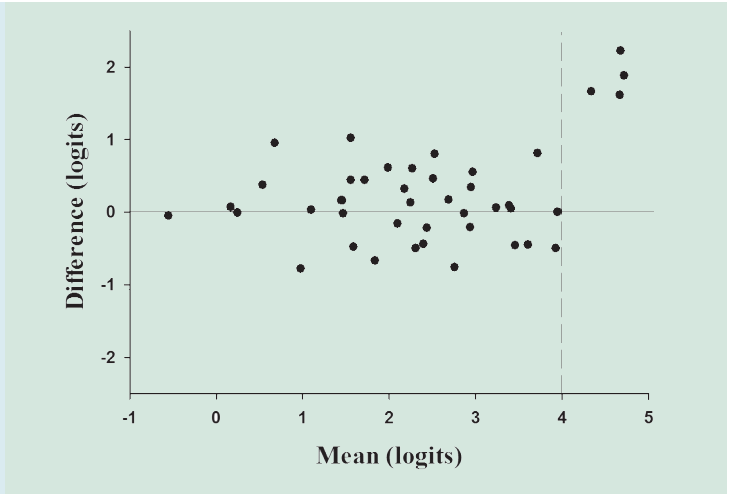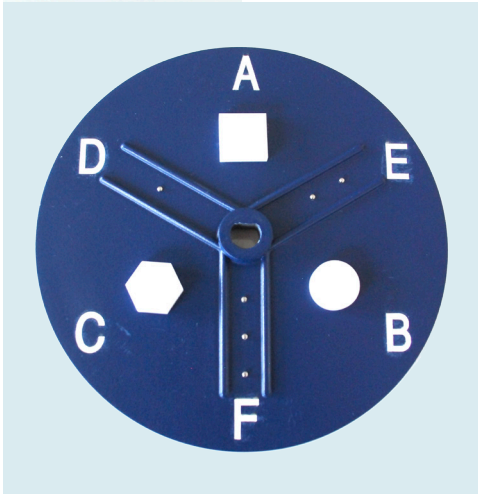
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AKADEMISK AVHANDLING

som med vederbörligt tillstånd av Medicinska fakulteten vid Lunds universitet för avläggande av doktorsexamen i medicinsk vetenskap kommer att offentligen försvaras i sal H01, Health Science Centre, Baravägen 3, Lund

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Psychometric properties of outcome measures and perceived ability to perform daily hand activities

Abstract:

Disability of the upper extremity is common after stroke. To be able to evaluate recovery and effects of interventions there is a need for stable and precise outcome measures. In order to design and target efficient rehabilitation interventions it is important to know which factors that affect the ability to perform daily hand activities. At the time when the studies in this thesis were planned there was limited knowledge of the psychometric properties of outcome measures for persons with mild to moderate impairments of the upper extremity after stroke. There was also a lack of knowledge of which daily hand activities these persons perceive difficult to perform and which factors are associated with the performance.

The overall aim of this thesis was to evaluate the psychometric properties of outcome measures for upper extremity after stroke, and to describe which daily hand activities persons with mild to moderate impairments in upper extremity after stroke perceive difficult to perform and identify associated factors with their performance.

In paper I – IV, between 43 and 45 participants were included. Muscle strength in the upper extremity, somatosensation (active touch), dexterity and self-perceived ability to perform daily hand activities were assessed twice, one to two weeks apart. In paper V, 75 participants were included and the evaluated measures of the upper extremity were used together with other stroke specific outcomes to cover important aspects of functioning and disability according to the International Classification of Functioning, Disability and Health (ICF). Test-retest analyses for continuous data were made with the Intraclass Correlation Coefficient (ICC), the Change in Mean, the Standard Error of Measurement (SEM) and the Smallest Real Difference (SRD) (Paper I, III and IV). For ordinal data the Kappa coefficient and the Elisabeth Svensson rank-invariant method were used (Paper II and III). For analyses of convergent validity the Spearman's correlation coefficient (rho) was calculated (Paper III). The ability to perform daily hand activities and the associations with potential factors were evaluated by univariate and multivariate linear regression models (Study V).

The results showed that outcome measures for isometric and isokinetic muscle strength, active touch, dexterity and self-perceived daily hand activities have high test-retest agreements and can be recommended for persons with mild to moderate impairments in the upper extremity after stroke (Paper I to IV). Isometric strength measurements had lower measurement errors than isokinetic measurements and might be preferred (Paper I). The outcomes of dexterity showed learning effects (Paper III) and the ratings of perceived daily hand activities (Paper IV) had relatively high random measurement errors which must be taken into account when recovery and effects of interventions are evaluated. The three evaluated dexterity measures were partly related and can complement each other (Paper IV). Daily hand activities that require bimanual dexterity were perceived most difficult to perform, and dexterity and participation were the strongest contributing factors for performing daily hand activities after stroke (Paper V).

In conclusion, this thesis has shown that outcome measures assessing functioning and disability of upper extremity after stroke are reliable and can be used in clinical settings and research. To increase the ability to perform daily hand activities, dexterity and perceived participation, in particular, should be considered in the assessments, goal-settings and rehabilitation after stroke.

Key words: Activities of Daily Living; Association; Dexterity; Muscle strength; Outcome assessment; Rehabilitation; Reproducibility of results, Self Report; Somatosensory disorders; Stroke; Touch perception; Upper extremity

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List of papers

Paper I: Ekstrand E, Lexell J, Brogårdh C. Isometric and isokinetic muscle strength in the upper extremity can be reliably measured in persons with chronic stroke. J Rehabil Med. 2015;47:706-13.

Paper II: Ekstrand E, Lexell J, Brogårdh C. Test-retest reliability of the Shape/Texture Identification test in people with chronic stroke. Clin Rehabil. 2015 Oct 1. pii: 0269215515608512. [Epub ahead of print]

Paper III: Ekstrand E, Lexell J, Brogårdh C. Test-retest reliability and convergent validity of three manual dexterity measures in persons with chronic stroke. PM R. 2016 Mar 10. pii: S1934-1482(16)00167-2. doi: 10.1016/j.pmrj.2016.02.014. [Epub ahead of print].

Paper IV: Ekstrand E, Lindgren I, Lexell J, Brogårdh C. Test-retest reliability of the ABILHAND questionnaire in persons with chronic stroke. PM R. 2014;6:324-31.

Paper V: Ekstrand E, Rylander L, Lexell J, Brogårdh C. Perceived ability to perform daily hand activities after stroke and associated factors: a cross-sectional study. Provisionally accepted for publication in BMC Neurology.

Abbreviations

ANOVA	Analysis of variance
BBT	Box and Block Test
CI	Confidence Interval
CIMT	Constraint Induced Movement Therapy
ESD	Early Supported Discharge
ICC	Intra-Class Correlation Coefficient
ICF	International Classification of Functioning, Disability and Health
LA	Less affected
LiSat	Life Satisfaction Questionnaire
LOA	Limits of agreement
MA	More affected
MAS	Modified Ashworth Scale
mSHFT	Modified Sollerman Hand Function Test
NHPT	Nine Hole Peg Test
PA	Percent agreement
RC	Relative Concentration
RP	Relative Position
RV	Relative Rank Variance
ROM	Range of Motion
SEM	Standard Error of Measurement
SD	Standard Deviation
SIS	Stroke Impact Scale
SHFT	Sollerman Hand Function Test
SRD	Smallest Real Difference
STI-test	Shape/Texture Identification Test

Introduction

The upper extremity

Functioning of the upper extremity is important for managing daily life in activities such as dressing, cooking and eating. With the upper extremities we can reach for different objects and perform power tasks when lifting and carrying heavy items. With the hands we can perform movements with precision when manipulating objects and tools in daily tasks. Moreover, the upper extremities are involved in postural control including dynamic balance as well as for everyday gestures and communication. The hands are also important for exploring and perceiving the world surrounding us and in emotional touch.

Movement control of upper extremity is complex and requires musculoskeletal and neural systems to contribute to movements in reaching, grasping and in-hand manipulations [1]. The movement control can be reduced by different injuries and disorders. Disability of the upper extremity is common after stroke and various functions such as muscle strength, somatosensation and dexterity can be impaired [2-4]. This can have a large impact on the ability to perform activities in daily life [5], especially those that require the use of both hands [6]. To assess disability of the upper extremity in a systematic and reliable manner is essential both in clinical practice and in research. An important aspect is the assessment of daily activities in order to identify areas of limitations in everyday life. It is also important to gain knowledge about factors that influence the performance of daily activities to adequately design and target efficient interventions for the upper extremity after stroke.

Movement control of the upper extremity

Movement control is achieved by the interaction of sensorimotor systems within the central nervous system. In motor control theories movements are explored based on how the nervous system produces purposeful, coordinated movements in interactions between the individual, the task and the environment [1]. Efficient reaching, grasping and in-hand manipulations rely on feedforward and feedback control mechanisms in order to perform smooth and well-timed movements [1, 7, 8]. In feedforward control, sensory information is used proactively in the movement planning prior to

movement initiation. During movements, information from mechanoreceptors in the skin and proprioceptors in the muscles, tendons and joints is processed [8, 9]. In feedback-control, the sensory input is compared to the intended action and the difference between the intended and actual performance is used to update the motor output and to correct errors during the movement execution [1, 7, 8].

Reaching involves the transportation of the upper extremity in space and requires flexibility of the shoulder complex. Stabilization of the shoulder is an important part of movement control in grasping and in dexterity tasks [1]. Grip formation is shaped during the transportation of the arm towards an object and the grip is adapted to the characteristics of the object before it is grasped [7]. In power grips the fingers and the thumb pads are directed toward the palm. Power grips include hook, spherical and cylindrical grips. In precision grips the thumb and the finger pads are directed towards each other in various positions such as the pinch, lateral pinch and tripoid grips [1].

Gross manual dexterity includes the ability to produce gross finger grips and releases while fine manual dexterity is the ability to perform grips that require large precision, coordination of finger movements and manipulation of objects in the hand [9]. Somatosensory input is shown to be essential for dexterity. Tactile mechanoreceptors in the glabrous skin of the hand respond to events of contact with an object and provide information about timing, size, location and direction of fingertip forces and also about the friction to the skin [10].

Dexterity task can be performed by one hand, unimanually, but can also require the use of both hands in bimanual tasks. The bimanual tasks can be symmetrical with both hands interacting in precision grips and manipulations or asymmetrical where one hand stabilizes the object and the other hand performs the parts of fine manual dexterity [1]. When an object is grasped it often needs to be adjusted in the hand by various in-hand manipulations such as translations, shifts and rotations [1, 10]. Translation involves moving objects between the fingertips and the palm as when a coin is picked up and then placed in the palm. In shifts, the object is held with the thumb opposed to the fingers and adjusted in position, for example when the pen grip is adjusted so the pen is held closer to the point for writing. In rotations an object is turned in the hand so it can be stabilized as when a fork is picked up and then rotated to get a proper grip suited for eating [1].

Thus, movement control in reaching, grasping and in-hand manipulations is complex and depends on sensorimotor control. Upper extremity disability is common after stroke and will often have a large impact on movements and the ability to manage daily life. To regain movement control and the ability to use the upper extremities in daily activities is therefore an important goal in the rehabilitation after stroke.

Upper extremity disability and recovery after stroke

Every year about 30 000 people suffer a stroke in Sweden [11]. Stroke is defined as an "acute neurological dysfunction of vascular origin with sudden or at least rapid occurrence of symptoms or signs corresponding to involvement of focal areas of the brain" [12]. There are two main types of stroke: ischemic (85%) and hemorrhagic (15%) [11]. Stroke is the most common cause of serious physical disabilities in adults in Sweden and often leads to a variety of sensorimotor impairments that affect movement control in the upper extremity. The prevalence of upper extremity disability is present in about 50% to 70% of the persons who have suffered a stroke in the acute phase and remains in about 50% of the persons after three months [2-4]. Thus, disability of the upper extremity is common and has been assigned as a top ten research priority relating to life after stroke [13].

The consequences after stroke can be classified according to the WHO model International Classification of Functioning, Disability and Health (ICF) [14, 15]. The ICF provides a framework for examining functioning and disability together with contextual personal and environmental factors. The term functioning refers to all body functions and structures, activities (execution of a task or action by an individual) and participation (engagement in life situations), while disability is similarly a term for impairments, activity limitations and participation restrictions [14].

Impairments of the upper extremity mainly affect the contralateral side (*more affected*). The assessment and the rehabilitation after stroke are therefore primarily directed towards this side in order to improve functioning of the upper extremities. However, minor impairments of the ipsilateral side (*less affected*) can also be present after a stroke [16].

Paresis in the more affected upper extremity is the most common impairment after stroke and is due to a reduced ability to voluntarily activate motor neurons [17-19]. This will lead to weakness and difficulties to activate specific muscles for efficient reaching and to adequately stabilize the shoulder while grasping, lifting and manipulating objects. Reduced dexterity is caused by difficulties stabilizing the wrist and extending the fingers as well as problems regulating the force in the finger flexors to adapt the grip [20, 21]. Dexterity can also be reduced due to difficulties to perform independent finger movements and reduced timing in grip and lift tasks and when manipulating objects in the hand [22, 23].

Spasticity is prevalent in about 30% of persons with hemiparesis after stroke [24]. Clinically, spasticity can be seen as an increased resistance to passive movement with reduced ability to voluntarily move and control the upper extremity. The increased

muscle tone may also result in secondary complications in the musculoskeletal system such as shortening and weakening of muscles, reduced joint mobility and pain [25].

About half of the stroke survivors have persistent somatosensory impairments in the upper extremity [26, 27]. Somatosensory impairments after stroke has been shown to contribute to grip dysfunction, delayed grip formation, use of excessive grip force and difficulty to adapt the grip to suit the surface and configuration of different objects [26, 28-30]. This will lead to difficulties in lifting objects with precision grips as well as in-hand manipulations. If the grip force is too high, the object cannot be manipulated and if it is too low the object will be dropped [1]. Hand manipulations are less effective because impaired somatosensory input will reduce the ability to perform complex independent and coordinated finger movements [1]. Somatosensory impairments have also been shown to significantly decrease the spontaneous use of the upper extremity in daily tasks [31].

Reduced muscle strength, dexterity, spasticity and somatosensory impairments in the upper extremity limit the ability to perform daily activities with the upper extremities. However, other factors such as visual and perceptual disorders (including agnosia, apraxia and neglect), reduced cognitive function as well as low mood may also influence the performance [32]. Overall, it is shown that more than half of the persons six months after their stroke onset report problems to use their more affected hand in daily activities [5, 33].

Outcome of the upper extremity after stroke is determined by the site and size of the initial lesion and by the extent of the following recovery [15, 19]. In the first weeks after stroke recovery is primarily spontaneous and related to restitution of the ischemic penumbra and resolution of diaschisis [34]. Further recovery results from reorganization of the central nervous system, i.e. long term plasticity, and motor learning dependent processes [35]. Most recovery of upper extremity will occur within the first three months (acute and subacute phase) and after six months (chronic phase) further recovery seldom continues [2, 36, 37].

The severity of paresis in the upper extremity in the acute phase is shown to be the best predictor of prognosis of recovery [38-40]. Persons with mild to moderate upper extremity paresis have a much better prognosis and potential to recover [41]. Proximal shoulder and elbow motor function has been proven to be related to recovery of hand function after stroke [42] and the presence of early active finger extension has been shown to be important for regaining manual dexterity at six months after stroke [41, 43, 44]. Moreover, somatosensory function has also been shown to be an important predictor for recovery [45] and motor impairment that is accompanied by somatosensory loss results in decreased recovery of the upper extremity after stroke [46].

There are strong indications that training can affect brain plasticity and research has shown that training enhances cortical plasticity and thereby recovery [47]. Recovery after stroke can also occur through behavioral compensation. Persons with stroke learn to compensate for their deficits by using alternative strategies to achieve intended goals [48, 49]. However, after stroke there is also a risk to develop a learned non-use behavior, i.e. to predominantly use the less affected arm and hand and to ignore the more affected [50]. Restricted participation in society, can over time result in inactivity and increase the non-use behavior [14]. In rehabilitation of the upper extremity after stroke it is therefore important to consider all domains of the ICF in order to restore sensorimotor control and find ways to increase the ability to perform daily activities and to participate in life situations [15].

Rehabilitation of upper extremity after stroke

With increasing knowledge about recovery after stroke the importance of early, intensive training has been emphasized [47]. Persons with stroke benefit from treatment and rehabilitation in stroke units, i.e. organized multidisciplinary approach to treatment and care [51, 52]. The rehabilitation in the stroke unit should begin as soon as possible and the training should be as intensive as possible already from the very acute phase [47]. The multidisciplinary team is important in the stroke rehabilitation to assess functioning and disability, establish short-term and long-term goals together with the patient and involvement of carers [52]. Rehabilitation is often provided in a hospital setting but it has been shown that persons with mild to moderate stroke benefit from early supported discharge, i.e. early return home coordinated from the stroke unit with support and rehabilitation from a specialized multidisciplinary team [15]. Training can also be provided in outpatient settings in primary and community care individually or to groups of persons with stroke [25].

Different specific interventions are used to improve the functioning of the upper extremity after stroke, such as strength and somatosensory training, constraint-induced movement therapy (CIMT), task specific training, motor imagery, mirror therapy and virtual reality training. Strength training is practiced by resisted voluntary control to reduce the muscle weakness in the upper extremity. Resistance can be achieved by acting against gravity alone for weak muscles, by a therapist giving manual resistance or by using gym equipment [25, 53]. The somatosensation can be improved through somatosensory awareness in reaches, grips and manipulations and in training of texture discrimination, limb position sense and tactile object recognition [54, 55].

In CIMT the less affected hand is restrained from use by a mitt and the more affected hand is intensively trained by increasing task difficulty and by shaping techniques

[56-58]. Task specific training involves the practice of tasks in daily life. The task can be trained in part or as a whole task [59]. In repetitive task training the intensity and difficulty is progressed to enhance the performance [25].

Motor imagery is a training method that involves cognitive rehearsal in specific tasks by imagining the performance. The imagination is then often combined and followed by a movement [60]. Mirror therapy is based on visual stimulation to promote movement. A mirror is placed in the sagittal plane of a person to reflect the less affected side as if it were the more affected side. Thus, the movements of the less affected side give the illusion that it is the more affected side that is moving [61]. Virtual reality training is performed in a simulated practice environment that is created digitally using devices such as keyboards, motions sensors and 3D glasses. Virtual reality also gives the possibility to provide feedback on the movement performance and using goal attainment scores [62].

Interventions for somatosensory impairments, CIMT, task specific training, motor imagery, mirror therapy and virtual reality training are shown to be effective to improve functioning of upper extremity after stroke. Unilateral arm training may be more effective than bilateral arm training and it also seems that in general, more training is better than less [25].

The eventual goal of improved functioning of upper extremity is a restored ability to perform daily hand activities [25, 63, 64]. Despite that disability of upper extremity is common after stroke there was limited knowledge how it influence the ability to perform daily hand activities when the studies in this thesis were planned. More knowledge was therefore needed about which daily hand activities that are perceived difficult to perform and factors associated with the performance after stroke. Single factors that have been shown to be associated with the self-perceived performance of daily hand activities are motor function, strength, spasticity, somatosensation and dexterity, participation and life satisfaction [6, 65-72]. Gender, dominance of the affected upper extremity, vocational and social situations can affect overall functioning after stroke [73-77] and are therefore also important to consider. As several factors simultaneously influence the ability to use the hands in daily activities after stroke there is a need to understand how these factors together affect the performance. Most of the previous studies have evaluated how a single or a few factors are associated with the perceived ability to perform daily hand activities and thus, there was a need of more studies that take several factors into account simultaneously.

Taken together, rehabilitation after stroke should begin early and the training should be intensive. Evidence based interventions to improve functioning of the upper extremity should be used and factors that affect the ability to perform daily hand activities considered. In order to identify problems, to set goals, monitor recovery and to evaluate effects of rehabilitation interventions it is important to use outcome

measures that can capture important aspects of functioning and disability in the upper extremity after stroke.

Outcome measures for the upper extremity after stroke

A variety of outcome measures can be used to assess disability of the upper extremity after stroke. Arm muscle strength can be objectively measured by various dynamometers such as hand-held and isokinetic dynamometers. Hand-held dynamometers have been proven to have limited reliability [78], while isokinetic dynamometry is considered to be gold-standard for strength measurements in healthy subjects as well as in persons with neurological diseases [79, 80]. Isokinetic dynamometers enable measurements of both isometric and isokinetic muscle strength. Isometric measurements are performed in a stable and static position and therefore often easier to perform, whereas isokinetic measurements assess the dynamic torque development and therefore may better reflect activities in real life [81]. Grip strength is usually measured by hydraulic dynamometers in the clinical setting but these kinds of dynamometers have less precision when used for persons with weak hands [82, 83]. Today, electronic devices are available with high precision also for hand grips with low strength values [84]. Even if paresis is the most common impairment after stroke there was a lack of knowledge about the reliability of muscle strength measurements of the upper extremity when the studies in this thesis were planned. It has been shown that isokinetic strength measurements can be reliably assessed in healthy persons [85-87] but no study had evaluated isokinetic strength measurements in the upper extremity after stroke. Reliability of isometric strength measurements in the upper extremity has been evaluated but these studies had limitations of small sample sizes [68, 84, 88] and large variations or short intervals between test-retest occasions [68, 84]. More studies were therefore needed to evaluate the test-retest reliability of isometric and isokinetic muscle strength measurements of the upper extremity after stroke.

Somatosensory impairments in the upper extremity can be assessed by testing the ability to detect stimuli of light touch [89] and from monofilaments [90]. Sensory impairments can also be assessed by the ability to discriminate between different stimuli or positions of stimuli such as two-point discrimination [91] and joint proprioception [89]. These tests are performed passively (assess passive touch) and active hand movements are not permitted. However, in daily activities the somatosensory function is used during action, i.e. active touch, where proprioceptive and tactile input information is integrated throughout the intended movements. Active touch is essential in order to identify shapes, textures, sizes and in grasps and manipulations of different objects and also in the process of tactile learning after

stroke [29, 55]. The Shape Texture Identification Test (STI-test) is a standardized outcome measure for identification of shapes and textures and was originally developed for peripheral nerve injuries [92]. It is easy to perform and has shown robust psychometric properties in persons with peripheral nerve injuries and peripheral nerve diseases [92-94]. The STI-test has been used in clinical practice to assess active touch after stroke but no study was found that had evaluated the psychometric properties of the STI-test in this population.

Dexterity is usually assessed in tasks where speed is measured and/or quality of movement of different grips is assessed [9, 95]. Two quick and simple dexterity measures recommended after stroke [63, 96] are the Box and Block Test (BBT) [97] that assesses gross manual dexterity and the Nine Hole Peg Test [98] that assesses fine manual dexterity (NHPT). Although, the BBT and NHPT are commonly used for persons after stroke there was limited knowledge about the psychometric properties [99]. The Sollerman Hand Function Test (SHFT) [100] is another measure that assesses manual dexterity in 20 different tasks that replicate the main hand grips used in different daily hand activities. The SHFT has been shown to be reliable after stroke [101]. A short version of the SHFT, the modified SHFT (mSHFT) is developed where the three most sensitive and decisive items of manual dexterity are selected [102]. The mSHFT has been reported to have good psychometric properties in persons with peripheral nerve injuries [102] but knowledge of the psychometric properties was lacking for stroke. There was also limited knowledge about the relationship between different measures of manual dexterity and how they can complement or replace one another in persons with stroke.

An important issue in the assessment of the upper extremity is how the various impairments contribute to a decreased ability to perform daily hand activities. Outcome measures at the activity and participation level are necessary for determining if the rehabilitation interventions result in changes that are meaningful in daily life [63]. To understand the importance and impact of the decreased ability to perform daily hand activities in real life, patient-reported outcome measures are preferred [103]. Commonly used patient-reported measures for stroke are the ABILHAND Questionnaire [6], the Motor Activity Log [104] and the Stroke Impact Scale (SIS) [105]. The ABILHAND measures the self-perceived ability to perform daily bimanual hand activities and is validated for persons with stroke [6]. It has been highly recommended [106, 107] and used is several recent studies after stroke to assess recovery of the upper extremity and effects of interventions [61, 108-111]. However, no study had evaluated the test-retest reliability for persons with stroke.

Perceived participation and life satisfaction are also important to measure as they may relate to the upper extremity disability following stroke. Restrictions in participation and life satisfaction after stroke can be rated by patient-reported measures such as the

participation part (domain 8) of the Stroke Impact Scale [105] and the Life Satisfaction Questionnaire (LiSat-11) [112].

Although there are extensive international and national guidelines for stroke and the guidelines recommend the use of valid and reliable outcome measures, there was no consensus on which outcome to use for evaluating functioning and disability of the upper extremity after stroke [113-115]. In research, many different outcomes are currently utilized and it is therefore difficult to compare results and evaluate effects of interventions [107]. To be able to make recommendations and to agree on which outcomes to use it was important with increased knowledge about the psychometric properties of outcome measures for upper extremity after stroke.

Psychometric properties of outcome measures

The usefulness of any outcome measure, in clinical practice or research, depends mainly on its' psychometric measurements properties. Therefore the psychometrics of an outcome measure must be evaluated. The main quality concepts of an outcome measure are the reliability and validity [116]. In this thesis the psychometric evaluation is predominantly focused on the test-retest reliability but convergent validity is also considered.

Validity

Validity refers to the degree to which a test measures what it is intended to measure. Validation is a process of determining that it is possible to make valid statements about an individual based on the scores of the test. There are three main types of validity estimates: content validity, criterion validity and construct validity [116]. Content validity is the extent to which the domains or items within a measure includes important aspects of the construct that they will be used to measure. The criterion validity can be established by concurrent or predictive validation when a gold standard outcome measure already exists (criterion measure). To evaluate the concurrent validation, a test is correlated with the gold standard measure. In the case when the criterion not will be available until in the future, for example the outcome of a diagnostic tests, predictive validation is used. The construct validity estimates whether a test measures the intended construct and that the test results behave as expected. Convergent and discriminant validity are the two subtypes of validity that make up construct validity. Convergent validity evaluates how closely an outcome measure is related to other measures of the same underlying construct and divergent validity evaluates that measures that are not supposed to be related are, in fact, unrelated [116].

Reliability

Reliability is the overall consistency of an outcome measure and this means that it produces similar results under consistent conditions. There are several types of reliability estimates such as the test-retest reliability, intra-rater reliability, inter-rater reliability and internal consistency. Test-retest reliability assesses the degree to which test scores are consistent from one test occasion to the next. This is the case when repeated assessments are made of a single rater (intra-rater reliability) or by the same person who answers a questionnaire under the same testing conditions. Inter-rater reliability assesses the degree of agreement between two or more raters in their assessments. Internal consistency reliability assesses the consistency of results across items within a test [116].

In this thesis the test-retest reliability was evaluated for several outcome measures of upper extremity and is therefore more detailed described. Test-retest reliability is the evaluation of agreement and measurement error of repeated measurements on two or more occasions [117]. Test-retest reliability provides assurance that the test measures the outcome in a stable and precise way each time it is used. A better reliability indicates that the precisions is better and consequently a better possibility to detect changes over time and after interventions both in the clinical setting and in research.

When the test-retest is evaluated the individuals measured must be the targeted population that the test is intended for [117]. It is important in repeated measurements that they are performed under the same conditions and the test situation therefore needs to be standardized and the test protocols thoroughly described. The time period between administrations should be long enough to prevent fatigue, learning effects and recall bias [118] and yet short enough to assure a stable condition. [119]. An interval between 2 to 14 days is common to use [116], but will depend on the variable being measured.

Test-retest reliability of continuous data

The Intraclass Correlation Coefficient [120] is commonly used to evaluate agreement in a test-retest evaluation. In a test-retest evaluation it is also important to detect systematic and random measurement errors. Systematic measurement errors can be calculated by the Change in Mean [117] and random measurement errors by the Standard Error of Measurement [121] and the Smallest Real Difference [122]. The test-retest data can also be displayed visually by Bland Altman graphs [123].

Intraclass Correlation Coefficient (ICC) [120] is commonly used to estimate the retest agreement for continuous normal distributed data. The reliability measured by the ICC is defined as the ratio of variability between individuals to the total variability. The total variability is the variability between the individuals and the measurement error (variability between individuals) [116]. The closer the ratio is to 1.0, the higher

the reliability and the lower is the error. An ICC of 0.95 means that an estimated 95% of the observed score variance is due to the variability between the individuals. The balance of the variance (1 – ICC = 5%) is then attributable to the measurement error. The ICC coefficient can be interpreted according to Fleiss [124] where values less than 0.4 represent poor agreement; 0.4 to 0.59 fair; 0.60 to 0.75 good; and values larger than 0.75 represent excellent agreement. As the ICC values are sensitive to the spread of the measurements between the individuals, the magnitude of the ICC will be dependent on the variability between the individuals [117, 125]. That is, if the individuals differ little from each other, the ICC values will be lower than if the individuals differ a lot from each other. Therefore, the interpretation of the ICC according to a standard should be used with caution and complemented by an analysis of the systematic and random measurement errors [126].

The Change in Mean [117] (mean difference) can be used to evaluate the systematic measurement error, i.e. if there is a systematic change between the two test occasions. The systematic change is a nonrandom change and occurs if the individuals systematically perform higher (or lower) scores in test occasion two. A systematic change can result from factors such as learning, change in behavior or fatigue. To discover a systematic change in the mean a 95% confidence interval for the mean difference of the two test occasions is formed [117]. If the 95% confidence interval does not include zero, this indicates a significant systematic change in the mean. If the measure shows systematic change in the mean it is important to analyze the cause. A systematic increase of the scores in a test-retest assessment can be due to a learning effect between the test occasions. A learning effect could be minimized by including trial practices before the test is performed. When using an outcome measure that is prone to learning it is also recommended to include more than one baseline assessment [117].

The Standard Error of Measurement (SEM) [121] is used to quantify the size of the random measurement error for a group of persons. The SEM quantifies the precision of the measurement and can be considered as the "typical error" [127]. The SEM has the same units as the measurement scores and gives a value that can be used to define the difference needed between separate measures to be considered a real improvement or deterioration for a group of persons. The SEM can be calculated as the square root of the mean square error term from the ANOVA (analysis of variance), i.e. the variability within individuals [128, 129]. The SEM represents the noise around the mean difference, the random measurement error, and is therefore separated from the systematic measurement error [130]. The measurement error according to SEM can also be expressed as a percentage value, SEM%. The SEM is then divided by the grand mean, i.e. mean of all the measurements from test occasion 1 and 2, and multiplied by 100 to give a percentage value [117]. The SEM% is independent of the units of measurements and therefore more easily interpreted. In stroke studies values about SEM% less than 10% have been suggested as acceptable [99, 131].

The Smallest Real Difference (SRD) [122] is used to quantify the random measurement error for a single person. The SRD can be used to evaluate if the difference, for example before and after an intervention, for a single individual measured represents a real change. If the difference lies outside the SRD, this represents a clinically important change and consequently, if the difference is within the SRD this does not represent a real change. The SRD is formed by using the SEM and multiplying it by $\sqrt{2}$ and 1.96 to include 95% of the observations of the difference between the two measurements [117]. The SRD can, as the SEM, be expressed as a relative value of the grand mean, the SRD% [117]. In stroke studies a SRD% less than 30% is suggested as acceptable [99]. The sample size in reliability studies in neurology for continuous data has been recommended to amount to at least 30 participants to be able to form useful SRDs and SRD% [132].

Bland Altman graphs [123] can be used to express the test-retest data visually. The difference between the two measurements is represented on the y-axis and mean of the two measurements is represented on the x-axis for each of the participants in the sample. To illustrate the difference between systematic change and random measurement errors the mean difference and the 95% confidence interval for the mean difference together with the 95% limits of agreement (LOA) (mean difference ± 1.96 standard deviation of the difference) can be included in the Bland and Altman graph [133].

Test-retest reliability of ordinal data

The evaluation of the test-retest reliability of ordinal data is usually made by Kappa statics [134]. The Elisabeth Svensson rank-invariant method [135] can be used to evaluate the agreement and also the systematic and random disagreements.

The Kappa coefficient [134] is used to determine the retest agreement for ordinal data obtained from clinical rating scales and self-report questionnaires and is equivalent to the ICC. The Kappa coefficient is the proportion of agreement beyond that is expected by chance. It is calculated as the achieved beyond chance agreement (observed agreement minus the chance agreement) as a proportion of the possible beyond chance agreement (1 minus the chance agreement). The Kappa coefficient can be weighted to reflect the magnitude of the difference between repeated measurements and is recommended for ordinal scales [119]. Linear and quadratic weights are commonly used [136]. The Kappa coefficient ranges from 0 to 1, that is from agreement no better than chance to perfect agreement. The strength of the Kappa coefficient can be interpreted as <0.4 poor, 0.40 to 0.60 fair, 0.61 to 0.80 as good and >0.75 represent excellent agreement [124].

As the Kappa coefficient is a measure of agreement it does not indicate if there are systematic or random disagreements between the test occasions. To broaden the analysis, the Kappa coefficient can be complemented by analysis of the Elisabeth

Svensson rank-invariant method [135]. The Svensson method has also the advantage that it is not sensitive, as the Kappa coefficient, to the spread of the ratings in the scale.

The Elisabeth Svensson rank-invariant method [135] provides information about the agreement and systematic and random disagreements of the paired data in a test-retest situation. The agreement is calculated as the percentage of the paired observations that has the same score. The Svensson method estimates the systematic disagreement as the Relative Position (RP) and the Relative Concentration (RC) [135, 137]. The RP explains the degree of systematic change in position (higher/lower) in the scale between two test occasions. A positive RP value indicates that the participants have higher scores on the second test occasion than on the first. The RC expresses the degree of systematic shift in concentration (centered/dispersed) and a positive value indicates that the scores are more centered at the second test occasion. Possible values of RP and RC range from -1 to 1 and zero values indicate a lack of systematic disagreement. The RP and RC values are calculated together with 95% confidence intervals. Statistically significant values are indicated by a 95% confidence interval that does not cover zero. The random disagreement is expressed as the Relative Rank Variance [135, 137]. The Relative Rank Variance ranges from 0 to 1 and the higher the value, the more dispersed is the test-retest measurements. The RV is also calculated together with a 95% confidence interval and significant values are indicated by a 95% confidence interval that does not cover zero.

Taken together, psychometric properties are important to evaluate to assure that outcome measures used in the clinical setting and in research measures what they are intended to measure and that the measurements are stable and precise. The choice of statistical methods should be based on the type of data. The evaluation of reliability ought to be made both regarding the agreement and the systematic and random measurement errors or disagreements of the repeated measurements. Knowledge about measurement errors is essential for determining if real changes have occurred when evaluating changes over time and effects after interventions for a group of individuals and a single individual.

Rationale for the thesis

Impairments of the upper extremity are common after stroke which may affect movement control and the ability to perform daily hand activities. Persons with mild to moderate disability in their upper extremity are an important group in the stroke population as these persons have the potential to recover and to improve functioning of the upper extremity. To be able to follow the recovery and effects of interventions for upper extremity after stroke, valid and reliable outcome measures are needed. At the time when the studies in this thesis were planned there was limited knowledge of the psychometric properties of outcome measures for muscle strength, somatosensation, dexterity and perceived ability to perform daily hand activities for persons with mild to moderate impairments of the upper extremity after stroke. There was also a lack of knowledge of which daily hand activities these persons perceive difficult to perform and which factors are associated with the performance. A greater knowledge would improve the ability to design and target efficient rehabilitation interventions and develop more effective interventions in the future for persons with disability of the upper extremity after stroke. With this background an overall aim and specific aims were developed.

Aims

Overall aim

The overall aim of this thesis was to evaluate psychometric properties of outcome measures for upper extremity after stroke, and to describe which daily hand activities persons with mild to moderate impairments in upper extremity after stroke perceive difficult to perform and to identify associated factors with the performance.

Specific aims

- To evaluate the test-retest reliability of strength measurements in the upper extremity (isometric shoulder abduction, isometric elbow flexion and isokinetic elbow extension/flexion and isometric hand grip) in persons with chronic stroke and to assess the measurements errors in order to define limits for the smallest change that indicates a real change, both for a group of individuals and a single individual.

- To evaluate the test-retest reliability of the Shape/Texture Identification test as an outcome measure of active touch of the hand in persons with chronic stroke.

- To evaluate the test-retest reliability and convergent validity of the Box and Block Test, the Nine Hole Peg Test and the modified Sollerman Hand Function Test as measures of manual dexterity in persons with mild to moderate impairments in the upper extremity after stroke.

- To assess the test-retest reliability of the ABILHAND Questionnaire as a measure of daily activities involving the use of the hand in persons with chronic stroke and to define limits for the smallest change that indicates a real change, both for a group of individuals and for a single individual.

- To evaluate a) which daily activities persons with mild to moderate impairments of the upper extremity after stroke perceive difficult to perform and b) how several factors (age, gender, social and vocational situation, affected hand, upper extremity pain, spasticity, muscle strength, somatosensation, manual dexterity, perceived participation and life satisfaction) are associated with the self-perceived performance.

Methods

Participants

Persons with stroke (ischemic or hemorrhagic) admitted to the Department of Neurology and Rehabilitation Medicine at Skåne University Hospital were recruited from April 2012 to August 2015. They were identified through cooperation with physiotherapists and occupational therapists working in the stroke rehabilitation units serving the acute neurology wards at Skåne University Hospital. A flow chart of the inclusions is shown in Figure 1.
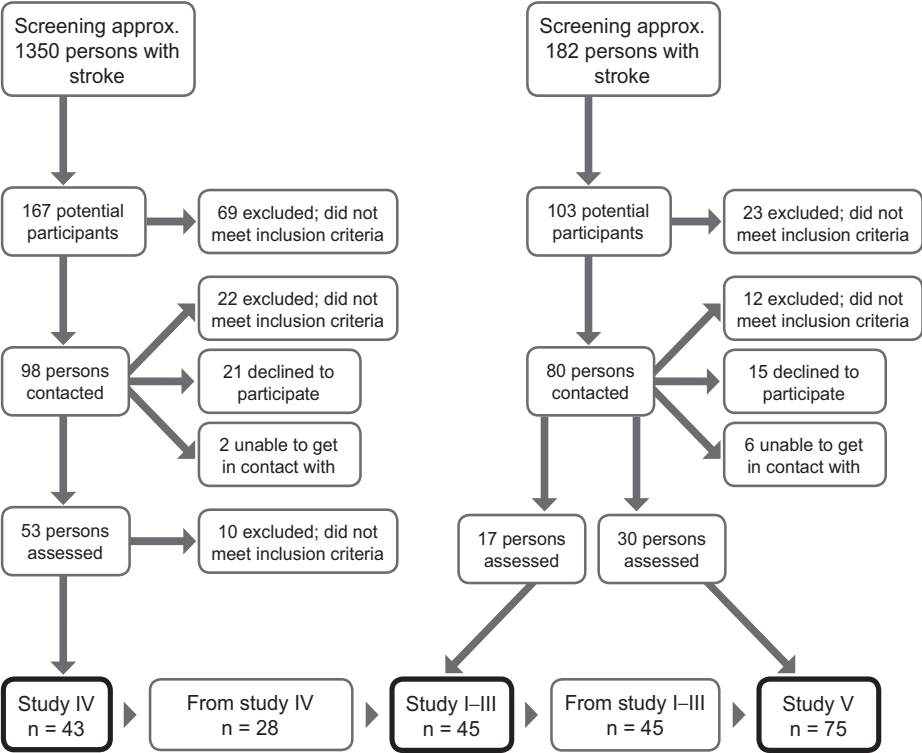
Figure 1.
Flow chart of inclusions in Study I to V.

In Table 1 an overview of the study design, participants and inclusion and exclusion criteria are shown. A total of 45 persons (8 women and 37 men) were included in study I, II and III. The inclusion criteria were stroke onset at least 6 months prior to study enrollment and mild to moderate impairments in the upper extremity after stroke. The exclusion criteria were inability to understand test instructions due to impaired cognition and/or communication and other diseases or disorders that could affect the upper extremity function. The mean age was 65 years (SD 7) and the mean time from stroke onset was 44 months (SD 28).

In study IV a sample of 43 persons (11 women and 32 men) was included based on the same criteria as in study I to III. Their mean age was 64 years (SD 8) and their mean time from stroke onset was 16 months (SD 8).

In Study V the inclusion criteria were stroke onset at least 4 months prior to study enrollment and mild to moderate impairments of the upper extremity after stroke. The exclusion criteria were the same as in study I to IV. The 45 persons participating in study I to III were included plus another 30 persons to a total of 75 participants (21 women and 54 men). Their mean age was 66 years (SD 8) and their mean time from stroke onset was 33 months (SD 26).

Table 1.
Overview of study design, inclusion and exclusion criteria and sample in Study I to V.

Design	Study I, II and III	Study IV	Study V
	Cross sectional	Cross sectional	Cross sectional
Inclusion criteria	Stroke onset at least 6 months prior to study enrollment and mild to moderate impairments of the upper extremity after stroke.		Stroke onset at least 4 months prior to study enrollment and mild to moderate impairments of the upper extremity after stroke.
Exclusion criteria	Inability to understand test instructions due to impaired cognition and/or communication and other diseases that could affect the upper extremity function.		
Sample	45 participants 8 women, 37 men	43 participants 11 women, 32 men	75 participants 21 women, 54 men
Mean age (yrs)	65 (SD 7; 44 to 76)	64 (SD 8; 45 to 81)	66 (SD 8; 44 to 85)
Stroke type, n (%)	Ischemic: 32 (71) Hemorrhagic: 13 (29)	Ischemic: 34 (79) Hemorrhagic: 9 (21)	Ischemic: 58 (77) Hemorrhagic: 17 (33)
Right sided paresis, n (%)	25 (56)	24 (56)	37 (49)
Right sided handedness, n (%)	42 (93)	41 (95)	71 (95)
Months post stroke (SD; range)	44 (28; 10 to 116)	16 (8; 6 to 36)	33 (26; 4 to 116)

Assessments and outcome measures

Descriptive and demographic data of age, gender, time since stroke, type of stroke, side of paresis, hand dominance, social and vocational situation and presence of perceived upper extremity pain were collected before the assessments in all studies. The main outcome measures used in the five studies are shown in Table 2.

Table 2.
Overview over the main outcome measures used in Study I to V.

	Study I	Study II	Study III	Study IV	Study V
Arm strength, Biodex dynamometer	X				
Grip strength, Grippit dynamometer	X				X
Spasticity, Modified Ashworth Scale					X
Light touch, Fugl-Meyer Assessment		X			
Proprioception, Fugl-Meyer Assessment		X			
Active touch, Shape Texture/Identification test (STI-test)		X			X
Dexterity, Box and Block Test (BBT)			X		
Dexterity, Nine Hole Peg Test (NHPT)			X		
Dexterity, modified Sollerman Hand Function Test (mSHFT)			X		X
Daily hand activities, ABILHAND Questionnaire				X	X
Participation, Stroke Impact Scale (SIS) Participation					X
Life Satisfaction, Life Satisfaction Questionnaire (LiSat, global satisfaction)					X

Muscle Strength

In study I a test-protocol was developed for isometric and isokinetic muscle strength measurements. The muscle strength was measured in the arm (shoulder and elbow) and in the hand.

Arm strength (isometric shoulder abduction and elbow flexion and isokinetic elbow extension/flexion) was measured with a Biodex System 3 PRO dynamometer (Biodex Medical Systems Inc., NY, USA, www.biodex.com) (Study I). During the measurements, the participants were sitting in the Biodex chair (Figure 2) with the joint lines aligned with the dynamometer movement axis. Prior to each measurement the participants practiced the movement to warm-up and to become familiar with the

procedures. The isometric strength measurements were performed twice with a rest interval of 60 seconds. The isokinetic strength measurements included three trials of reciprocal extension and flexion at 60°/s. The highest maximal voluntary contraction was recorded as the highest peak torque in Newton meters (Nm).

Figure 2
The Biodex dynamometer

Grip strength was measured with the electronic computerized dynamometer Grippit (Catell AB, Hägersten, Sweden, www.catell.se) (Figure 3) (Study I and V). The participants were seated by a table with the forearm resting on a foam cushion in neutral position. The grip strength measurements were repeated three times (each contraction lasting 3 seconds with 60 seconds rest interval). The highest voluntary contraction was recorded as the maximal grip strength (isometric) in Newton (N).

For further details on the muscle strength test protocol and measurement procedures see Paper I.
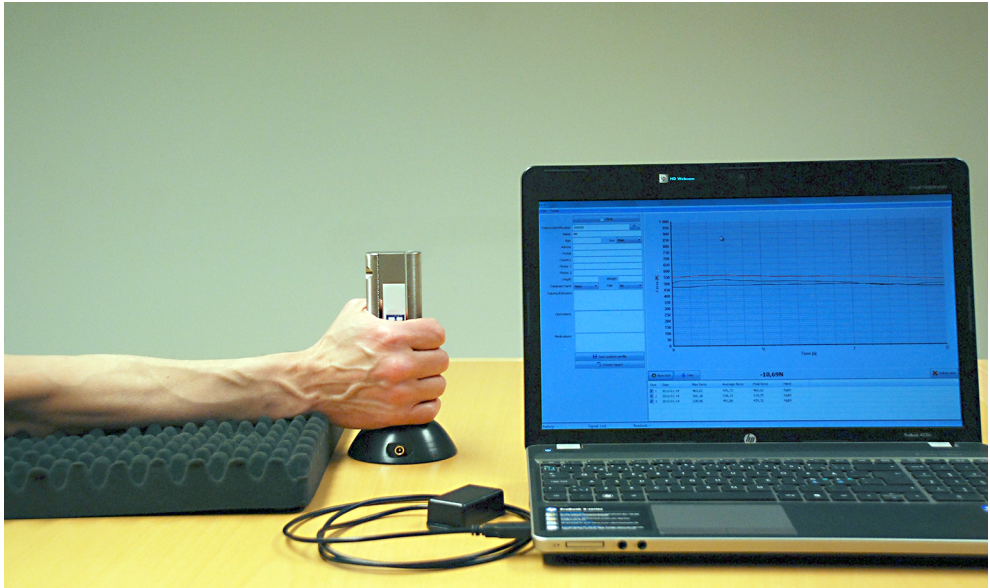
Figure 3
The Grippit dynamometer

Spasticity

Spasticity was assessed with the Modified Ashworth Scale [138] (Study V). It is a 6-point ordinal scale from 0 to 5 where 0 indicates normal tone and 5 indicates rigid tone. Spasticity was considered present if the participants had a score larger than 1 point in the shoulder abductors, elbow flexors, elbow extensors or wrist flexors.

Light touch and proprioception

Sensory function, light touch and proprioception, in the upper extremity were assessed according to the Fugl-Meyer Assessment of Sensorimotor Function [89] (Study II). Light touch was assessed by stroking a cotton swab on the hands/fingers and on the forearm/upper arm, and classified as normal (2 points), diminished or increased (1 point) or absent (0-point). Proprioception was assessed in the wrist and thumb and rated as 2 points for 4/4 attempts correct, 1 point for 3/4 attempts correct and 0 points for less than 3/4 correct.

Active touch

Active touch of the hand was assessed by the The Shape/Texture Identification Test (STI-test) [92] (Össur Nordic AB, Uppsala, Sweden, www.ossur.se) (Figure 4) (Study II and V). The STI-test includes three shapes (cube, cylinder or hexagon) and three textures (one, two or three raised metal dots placed in a row) in three difficulty levels (decreasing sizes). According to the standardized test instructions [92], the participants were seated behind a screen and identified the shapes (presented randomly size for size) by the index finger. Thereafter the textures are presented and identified in the same way. The score of the STI-test ranges from 0 to 6 points per hand and a higher score indicates better somatosensory function [92].

Figure 4
The Shape/Texture Identification Test

Dexterity

In Study III dexterity was assessed as gross and fine manual dexterity, by using three different outcome measures: the Box and Block Test (BBT), the Nine Hole Peg Test (NHPT) and the modified Sollerman Hand Function Test (mSHFT). The mSHFT was also used in Study V.

Gross manual dexterity was assessed by the Box and Block Test (BBT) [97] (Reha-Stim Medtec GmbH & Co., Berlin, Germany, www.reha-stim.de/cms) (Figure 5). The BBT consists of a box divided by a partition into two equal-sized compartments and 100 wooden blocks (2.5 cm). The maximum number of wooden blocks, one at a time, should be moved across the partition in the middle of the box within 60 seconds. One practice trial should be performed before the actual test. The score is recorded as the number of blocks that is transported during 60 seconds. The higher the number of blocks per minute, the better is the performance of gross manual dexterity.
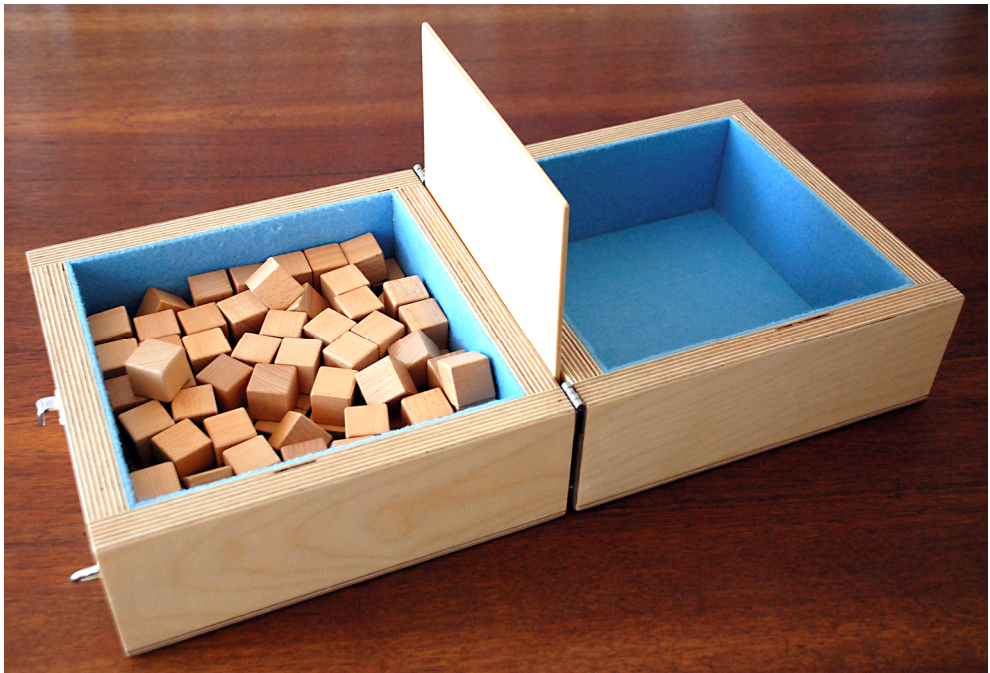
Figure 5
The Box and Block Test

Fine manual dexterity was assessed by the Nine Hole Peg Test (NHPT) [98] (Reha-Stim Medtec GmbH & Co., Berlin, Germany, www.reha-stim.de/cms) (Figure 6). NHPT consists of a square board with nine holes and a container with nine pegs. The

pegs are to be picked up and put into the pegboard, one at a time, and thereafter returned back to the container. One practice trial should be performed before the actual test. The time taken to complete the test is recorded. The shorter the time, the better is the performance of fine manual dexterity.
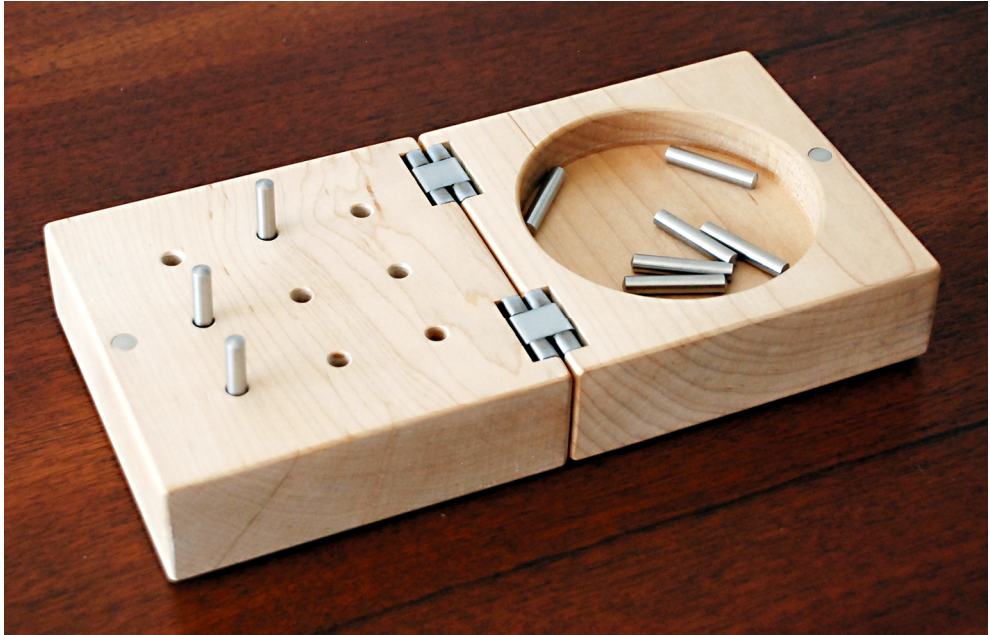
Figure 6
The Nine Hole Peg Test

Dexterity in common daily activities was assessed by the modified Sollerman Hand Function test (mSHFT) [102] (Catell AB, Hägersten, Sweden, www.catell.se) (Figure 7). In the mSHFT the three most sensitive and decisive tasks of manual dexterity are selected from the 20-item original SHFT [100, 101]. These three tasks are strongly correlated with the result of the total score of the complete test (Spearman's rho 0.96 (p<0.001) [102]. The mSHFT includes item number 4: picking up 4 coins in different sizes from a purse (pulp pinch (tip to tip) grip); item number 8: putting 4 nuts in decreasing size on bolts (pulp, lateral or tripoid pinch grip); and item number 10: doing up 4 buttons in decreasing sizes (pulp or lateral pinch grip). The ability to grasp the object correctly, the time to complete the item and quality of movement is assessed on 5 point scale (0 to 4 points). The upper time limit is 60 seconds for each item. Any divergence with regard to the permitted handgrips of the test manual lowers the score. The sum score ranges between 0 to 12 points for each hand (where 12 indicate normal dexterity) [102].
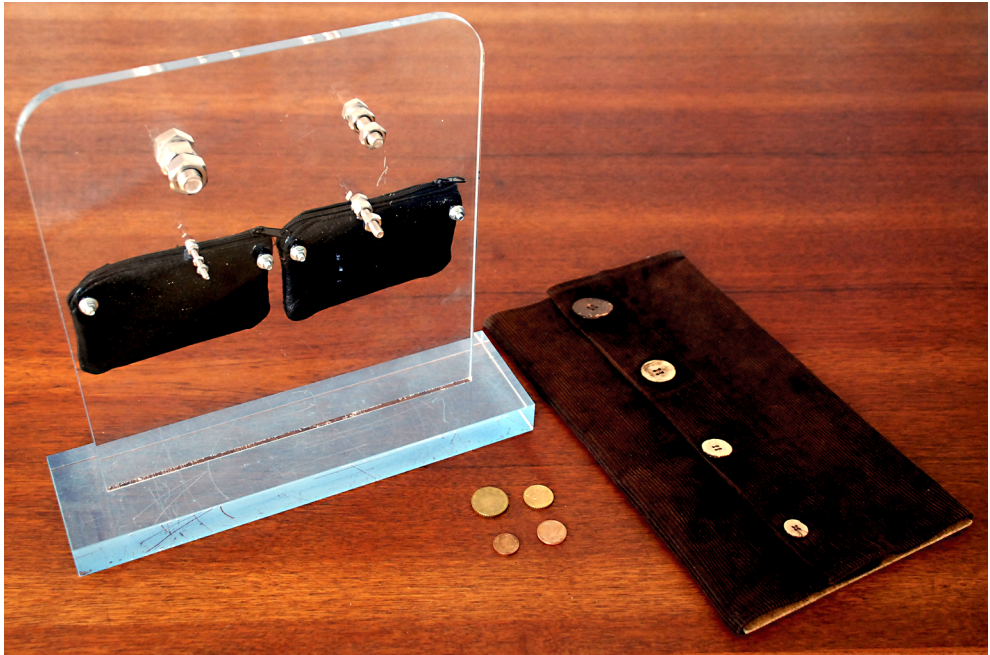
Figure7
The modified Sollerman Hand Function Test

Daily hand activities

Perceived ability to perform daily hand activities was assessed with the ABILHAND Questionnaire (stroke version) (Study IV and V) [6]. The ABILHAND consists of 23 common bimanual activities that are rated as impossible (0 point), difficult (1 points) or easy (2 points). Items not attempted within the last three months are set as not applicable. The items are ordered hierarchically, from the most difficult items to the easiest ones and they are also rated according to the level of bimanual involvement: A) breakable into unimanual sequences; B) requires stabilization with the affected upper extremity; and C) require bimanual digital activity (fine manual dexterity). The ABILHAND is Rasch validated, which means that ordinal data are converted into an unidimensional interval scale, and presented in logits (i.e. log odds units) that ranges from plus to minus around zero as the center of the scale [139]. The higher the logit value, the better the self-perceived ability to use the upper extremities in daily hand activities. In this thesis, the Swedish version of the ABILHAND was used [140]. The logits were obtained by entering the raw scores into an online data analysis module (www.rehab-scales.org) based on the calibration of the scale established for chronic stroke patients [6].

Participation

Perceived participation was assessed by the Stroke Impact Scale 3.0 (SIS; Swedish version) [105] (Study V). SIS is an interview-based questionnaire that consists of eight domains that assess different aspects of the impact of stroke on the self-perceived health. SIS is administered in an interview and scored on a 5-point scale from 1 (limited all of the time) to 5 (limited none of the time). One of the domains addresses perceived participation, SIS Participation, and can be used as a separate scale. It includes the impact of stroke on work, social activities, quiet recreations, active recreations, role as a family member, religious activities, life control and ability to help others. The mean for the eight items is calculated as a composite score and converted into a percentage value (from 0 to 100) [141]. SIS has been shown to be reliable and valid in stroke [105, 142].

Life Satisfaction

Perceived Life Satisfaction was assessed by the Life Satisfaction Questionnaire (LiSat-11) [112] (Study V). LiSat-11 is an interview-based reported questionnaire that assesses global satisfaction in 11 items; one item about life as a whole and 10 domain specific items about satisfaction in vocation, economy, leisure, life, contacts, sexual life, ADL, family life, partner relationship, somatic health, psychological health. The item assessing the global satisfaction (life as a whole) has been used in prior studies in stroke [143] as a measure of life satisfaction and was included in Study V. The LiSat-11 score for each item ranges from 1 (very dissatisfying) to 6 (very satisfying). The response options were dichotomized into two categories; dissatisfying (score 1 to 4) and satisfying (score 5 to 6) according to Fugl-Meyer et al. [112].

Statistics

Descriptive statistics, such as frequencies, means and standard deviations (SD) and medians and minimum and maximum (min-max) were presented for demographic data and clinical characteristics of the participants in all studies. Differences between the test-retest scores were presented as frequencies and percent (Study II, III and IV). The distribution of the participants' ratings (easy, difficult, impossible or not applicable) of the ABILHAND score was presented in percent (Study V).

An overview of the statistical methods used in the thesis is presented in Table 3.

Table 3.
Statistical methods used in Study I to V

	Study I	Study II	Study III	Study IV	Study V
Intraclass correlation coefficient (ICC)	X		X	X	
Change in Mean	X		X	X	
Standard Error of Measurement (SEM)/SEM%	X		X	X	
Smallest Real Difference (SRD)/SRD%	X		X	X	
Bland and Altman graphs	X			X	
Kappa coefficient (quadratic weights)		X	X		
The Elisabeth Svensson rank-invariant method		X	X		
Spearman's correlation coefficient			X		X
Univariate linear regression					X
Multivariate linear regression					X

Test-retest reliability analyses for continuous data were made with the Intraclass Correlation Coefficient (ICC), the Change in Mean, the Standard Error of Measurement (SEM) and the Smallest Real Difference (SRD) (Study I, III and IV). The data were also presented in Bland Altman graphs (Study I and IV). For ordinal data the Kappa coefficient (quadratic weights) and the Elisabeth Svensson rank-invariant method were used (Study II and III). For analyses of convergent validity the Spearman's correlation coefficient (rho) was calculated (Study III). Correlations between the potential factors (Study V) were also calculated using the Spearman correlation (rho) to investigate the strength of their associations. The associations between the ability to perform daily hand activities and potential factors were evaluated by univariate and multivariate linear regression models (Study V). The multivariate regression building was performed with a stepwise selection strategy where the model was evaluated at each step (i.e. the model was expanded from one to two variables, from two to three variables, etc.). A generous inclusion criteria ($p \leq 0.20$) was used to not exclude any potential variable in the early stages.

The statistical software programs used were SPSS version 20 to 23, MedCalc version 15 (www.medcalc.org) and the Elisabeth Svensson program (www.oru.se/esi/svensson). P-values <0.05 were considered significant.

Ethical considerations

The persons included in this thesis were identified via the stroke units and rehabilitation clinics at the Skane University Hospital. They were informed about the study and those persons who were interested in participating were provided further information in a letter. The letter included information about the purpose of the study, the test procedures and the right to withdraw from the studies at any time without giving any reason. The persons were then contacted per telephone and the information was repeated verbally. Thereafter the inclusion and exclusion criteria were verified and the persons were asked if they wanted to participate in the study. Before the study enrollment each individual gave his or her written consent to participate.

The clinical examinations, the assessments and questionnaires are accepted methods that were not considered to be associated with any discomfort for the participants. As many assessments were performed during each test occasion the study protocol was carefully planned with several pauses to avoid fatigue. The participants were also offered refreshments during a longer halftime break. To assure that all participants understood the test instructions these were given in a structured and pedagogic way and repeated if necessary.

When persons are contacted and asked to participate in assessments and interviews there is always a certain risk for intrusion of personal integrity. More tests may result in that the participants will be more focused on their diagnosis, symptoms and problems. Questions about perceived participation and life satisfaction can cause serious thoughts. The assessments and interviews were therefore performed in a calm environment and time was included for the participants to reflect and ask questions. If needed, the participants were also able to get advice and guidance to treatment.

The principles of the Declaration of Helsinki were followed and all studies in this thesis were approved by the Regional Ethical Review Board, Lund, Sweden (Dnr 2012/591).

Results

Psychometric properties of outcome measures

The test-retest reliability for the outcome measure with continuous data is presented in Table 4 and for the outcome measures with ordinal data in Table 5.

Table 4

Test-retest reliability of continous data of the upper extremity

	ICC	đ (T2-T1)	95% CI for đ	SEM%	SRD%
Isometric arm strength					
Shoulder abduction (newton meter) MA[a]	0.97	0.1	-1.3 to 1.4	9	26
Shoulder abduction (newton meter) LA[a]	0.97	-0.9	-2.0 to 0.2	6	16
Elbow flexion (newton meter) MA[a]	0.97	1.1	-0.2 to 2.3	8	21
Elbow flexion (newton meter) LA[a]	0.97	-0.4	-1.7 to 0.8	6	16
Isokinetic arm strength					
Elbow extension (newton meter) MA[b]	0.92	1.8	0.6 to 2.9	13	35
Elbow extension (newton meter) LA[a]	0.92	1.6	0.3 to 2.7	9	26
Elbow flexion (newton meter) MA[b]	0.95	1.3	0.3 to 2.4	9	26
Elbow flexion (newton meter) LA[a]	0.95	0.4	-0.8 to 1.6	7	21
Isometric grip strength					
Grip strength (newton) MA[a]	0.96	6.2	-3.2 to 15.6	9	26
Grip strength(newton) LA[a]	0.95	3.9	-7.4 to 15.2	8	21
Dexterity					
BBT (no of blocks) MA[a]	0.98	1.2	0.5 to 2.5	6	16
BBT (no of blocks) LA[a]	0.85	3.4	2.6 to 4.2	6	16
NHPT (seconds) MA[c]	0.99	-3.4	-5.0 to -1.8	9	24
NHPT (seconds) LA[a]	0.93	-0.7	-1.1 to -0.3	4	12
Daily hand activities					
ABILHAND (logits)[c]	0.91	0.1	-0.1 to 0.2	15	42

MA: more affected upper extremity; LA: less affected upper extremity; ICC: Intraclass Correlation Coefficient; đ bar: Change in Mean; CI: confidence interval; SEM%: Standard Error of Measurement in percent of the grand mean; SRD%: Smallest Real Difference in percent of the grand mean; BBT: Box and Block Test; NHPT: Nine Hole Peg Test;. Sample of [a]45, [b]44, [c]39 participants.

Table 5

Test-retest of ordinal data of the upper extremity

	Kappa	PA% 1-point	Systematic disagreement	Random disagreement
Active touch				
STI-test MA[a]	0.94	93	No	No
STI-test LA[a]	0.55	96	No	No
Dexterity				
mSHFT MA[a]	0.95	82	Yes	No
mSHFT LA[a]	0.59	85	Yes	No
MA: more affected upper extremity; LA: less affected upper extremity; Kappa: Kappa coefficient (quadratic weights); PA% 1-point: percent agreement with at most 1 point difference; STI-test: Shape/Texture Identification Test, mSHFT: modified Sollerman Hand Function Test. [a]Sample of 45 participants.				

Muscle strength

The test-retest agreements, the ICCs, for the arm and hand muscle strength measurements (n=45) ranged from 0.92 to 0.97 (Table 4) (Paper I). Three isokinetic measurements showed systematic measurement errors, Changes in Mean, indicating learnings effects. The random measurement errors for a group of individuals, SEM%, ranged from 6% to 9% for isometric arm strength, 7% to 13% for isokinetic arm strength, and 8% to 9% for isometric grip strength. The random measurement errors for a single individual, SRD%, ranged from 16% to 26% for isometric arm strength, 21% to 35% for isokinetic arm strength, and 21% to 26% for isometric grip strength, respectively.

Active touch

The agreement according to the Kappa coefficient for the STI-test (n=45) was 0.94 for the more affected hand and 0.55 for the less affected hand (Table 5) (Paper II). Most participants (93% to 96%) had at most 1 point difference (PA% 1 point) in the total sum score between the two test occasions. The two subtests (identification of shapes and identification of textures) showed no systematic or random disagreements according to the Elisabeth Svensson rank-invariant method.

Dexterity

The ICCs for BBT and NHPT (n=45) ranged from 0.85 to 0.99 (Table 4) (Paper III). Significant Changes in Mean were found for BBT and NHPT, indicating learning effects. The random measurement errors for a group of individuals, SEM%, ranged from 4% to 9% and for a single individual, the SRD%, from 12% to 24%.

The Kappa coefficient for the mSHFT (n=45) was 0.95 for the more affected hand and 0.59 for the less affected hand (Table 5) (Paper III). The percent agreement for those who had at most 1-point difference between the two test occasions (PA 1-point) ranged from 82% to 85%. The mSHFT showed significant systematic disagreements according to the Svensson method, indicating learning effects.

The convergent validity for the three dexterity tests (Paper III) showed that the correlations (Spearman's rho) for the more affected hand was highest between the NHPT and the mSHFT (-0.68) and lower between NHPT and mSHFT (-0.57) as well as between the BBT and the mSHFT (0.41) (n=39). The correlations (rho) for the less affected hand ranged from 0.44 to 0.48 between all measures (n=45).

Daily hand activities

Most participants rated the same response option for the 23 items on the ABILHAND Questionnaire at the two test occasions (Paper IV). When the test-retest reliability of the ABILHAND logit score was evaluated four outliers, with high mean logit scores (>4.0) and large differences, were identified in the total sample of 43 persons (Figure 8). The results for the sample of 39 participants showed an ICC of 0.91, a SEM% of 15% and a SRD% of 42% (Table 4).
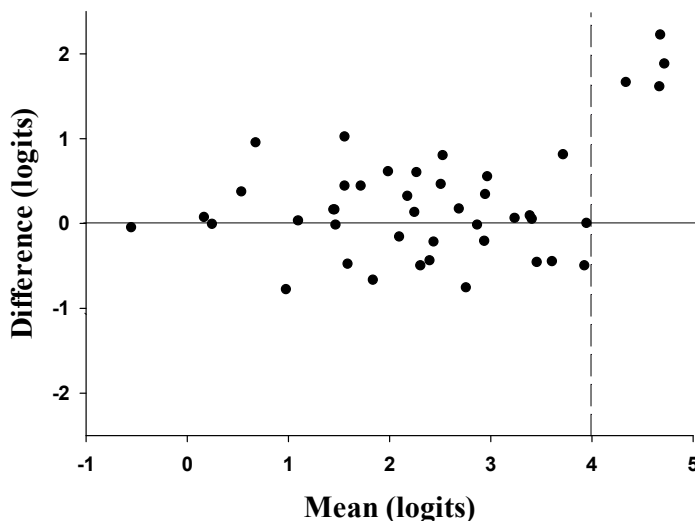
Figure 8
The Bland and Altman graph shows the difference (logits) between the measurements from the two test occasions (test 2 minus test 1) plotted against the mean (logits) of the two test occasions for the ABILHAND (n=43). Four participants (outliers) had high means (>4.0) and large differences in logits between the two test occasions (located to the right of the vertical dashed line).

Perceived ability to perform daily hand activities and associated factors

Bimanual tasks that required a high level of fine manual dexterity (level C) were perceived as the most difficult to perform according to the ratings of ABILHAND Questionnaire (Paper V) (Table 6). Between 40% and 61% of the participants perceived that eight items were difficult or impossible to perform: '*hammering a nail*'; '*filing one's nails*'; '*threading a needle*'; '*wrapping up gifts*'; '*cutting meat*'; '*tearing open a pack of chips*'; '*buttoning a shirt*' and '*cutting one's nails*'. All but one of these items, '*buttoning up a skirt*', were classified as requiring level C. Thirteen items were perceived as easy and most of these items only required stabilization with the more affected hand (level B) or could be breakable into unimanual sequences (level A). Five items (level B) and were perceived as easy by 60% to 84% of the participants and five items (level A) were perceived as easy by 63% to 95% of the participants. Two of the items, '*shelling hazel nuts*' and '*sharpening a pencil*', were not attempted within the last three months (not applicable) for a majority of the participants.

Table 6.
Distribution (%) of perceived ability to perform the 23 items in the ABILHAND Questionnaire

Nr	Items	Impossible	Difficult	Easy	NA	Level
1	Hammering a nail	19	28	31	23	C
2	Threading a needle	23	31	15	32	C
3	Peeling potatoes	13	35	51	1	C
4	Cutting one's nails	19	42	39	0	C
5	Wrapping up gifts	16	35	23	27	C
6	Cutting meat	9	41	48	1	C
7	Filing one's nails	8	33	31	28	C
8	Peeling onions	12	29	51	8	C
9	Shelling hazel nuts	0	9	20	71	C
10	Opening a screw-topped jar	5	23	71	1	C
11	Fastening the zipper of a jacket	3	37	60	0	B
12	Tearing open a pack of chips	15	41	40	4	C
13	Buttoning up a shirt	12	45	41	1	A
14	Sharpening a pencil	0	4	41	55	C
15	Taking the cap off a bottle	1	21	76	1	B
16	Spreading butter on a slice of bread	1	27	72	0	A
17	Fastening a snap (jacket, bag)	3	12	84	1	B
18	Buttoning up trousers	4	29	65	1	B
19	Opening mail	0	6	84	0	B
20	Pulling up the zipper of trousers	2	16	80	1	A
21	Squeezing toothpaste on a tooth brush	0	8	92	0	A
22	Unwrapping a chocolate bar	1	32	63	4	A
23	Washing one's hands	0	5	95	0	A

Items ranked from 1 to 23: from more difficult to less difficult. NA: not applicable. Level A: the item is breakable into unimanual sequences; level B: the item requires stabilization with the affected hand; level C: the item requires bimanual dexterity. Due to truncation the percentage values do not add up to 100% for all items.

Factors potentially associated with perceived ability to perform daily hand activities included in the linear regression analysis were: age, gender, social situation (living together with another vs living alone), vocational situation (working vs not working), affected hand (dominant vs non-dominant), upper extremity pain (present vs not present), spasticity (MAS), grip strength (Grippit), active touch (STI-test), manual dexterity (mSHFT), participation (SIS Participation) and life satisfaction (LiSat-life as a whole) (Paper V).

The bivariate correlations (Spearmans rho) between the factors with continuous or ordinal data were generally low (rho<0.5) with the exception for the correlation between dexterity and active touch (rho=0.68).

The factor that showed the strongest association with perceived ability to perform daily hand activities was dexterity, explaining 39% of the variance (p<0.001). A one unit increase in dexterity corresponded to 0.32 increased logit score of daily hand activities (i.e. a β-coefficient of 0.32) in the univariate model. The final multivariate regression model (Table 7) included the three factors; dexterity (p<0.001), participation (p=0.002) and grip strength (p=0.180). The explained variance increased from 39% to 48% when participation was added to the model. Grip strength only contributed slightly (1% increased explained variance) and was added due to the generous inclusion criterion (p≤0.20). The β-coefficient for dexterity changed from 0.32 in the univariate to 0.26 in the multivariate model and perceived participation (per 10 units increase) changed from 0.39 to 0.26.

Table 7.
Factors associated with perceived ability to perform daily hand activity (logits) in the final multivariate linear regression model for the 75 participants with stroke.

Factors	β-value (95% CI)	p-value	Explained variance[d] (%)
Dexterity (per unit increase)[a]	0.26 (0.16 to 0.35)	<0.001	
Participation (per 10 units increase)[b]	0.26 (0.10 to 0.42)	0.002	
Grip strength (newton, per 10 units increase)[c]	0.02 (-0.01 to 0.05)	0.180	
Dexterity			39
Dexterity + participation			48
Dexterity + participation + grip strength			49
Data obtained by: [a]the modified Sollerman Hand Function Test; [b]the Stroke Impact Scale domain Participation; and [c]the Grippit dynamometer. [d]Explained variances after successive addition of determinants.			

General discussion

The studies in this thesis have focused on evaluating psychometric properties of outcome measures for upper extremity and factors associated with the ability to perform daily hand activities in persons with mild to moderate impairments of the upper extremity after stroke. The results show that outcome measures of muscle strength in upper extremity, active touch of the hand, manual dexterity and perceived daily hand activities can be reliably measured. The daily hand activities perceived most difficult to perform were bimanual tasks requiring a high level of fine manual dexterity and dexterity and perceived participation were the strongest contributors for the ability to perform daily hand activities.

Psychometric properties of the outcome measures

Test-retest reliability of continuous data

The muscle strength measurements (Paper I), the BBT and NHPT (Paper III) and the ratings of the ABILHAND Questionnaire (Paper IV), showed excellent agreements based on the ICC according to Fleiss (>0.75) [124]. This is in line with previous test-retest reliability studies of muscle strength measurements in the upper extremity after stroke [88, 99], in persons with neuropathies [144] and in healthy individuals [85-87, 145, 146] even if different electronic dynamometers have been used. This is also in agreement with test-retest evaluations of dexterity measures after stroke [99], in persons with neurologic conditions [147, 148], neuropathies [144] and in healthy individuals [97, 149]. The test-retest reliability of ABILHAND has not previously been evaluated after stroke but the ICC is in line with prior studies in persons with rheumatoid arthritis [150, 151] and systemic sclerosis [152].

A Change in Mean was found for the isokinetic muscle strength measurements (Paper I) and the dexterity measures BBT and NHPT (Paper III). The participants performed better the second test occasion compared to the first test occasion and this indicates learning effects. Effects of learning are probably due to that these tests are relatively difficult to perform. Thus, when evaluating isokinetic muscle strength and manual dexterity over time or after interventions, more than one baseline assessment is recommended to reduce the effect of learning.

It has been suggested that acceptable limits for random measurement errors for upper extremity after stroke are SEM%<10% and SRD%<30% [99, 131]. The random measurement errors for the isometric muscle strength (Paper I) were within these limits in line with previous studies in stroke [68, 84, 99]. The isokinetic arm strength measurements had higher random measurement errors than the isometric ones. Isokinetic strength measurements are valuable as they reflect the dynamic force development and reciprocal movements in real life but as isometric strength measurements yield smaller measurement errors they might be preferred when muscle strength after stroke is evaluated. However, the choice of the measurement mode always depends on the research question.

The random measurement errors for the dexterity measures BBT and NHPT (Paper III) were within acceptable limits and in agreement with prior studies in persons with neuropathies [144]. The random measurement errors for BBT is in line with a prior study in stroke by Chen et al. [99] but a higher SRD% value, 54%, for the more affected hand was reported for the NHPT in that study. However, the sample in the study by Chen et al. included a larger proportion of persons with spasticity (50% compared to 30% in the sample of Paper III). Persons with spasticity in the study by Chen et al. had generally higher random measurements errors than those with no spasticity which could explain the larger variability [99].

The ratings of the ABILHAND (Paper IV) showed relatively high random measurement errors and this must be taken into account when recovery and effects of interventions are evaluated in the clinical setting. The ABILHAND is a highly recommended outcome measure [107] and has the advantage that it captures a person's self-perceived ability to perform bimanual daily hand activities. It is also Rasch validated that enables the ordinal data to be converted into logits (interval data) and the items to be hierarchically ordered [6]. The bimanual items in the ABILHAND could also be useful in the clinical assessment and treatment planning in the rehabilitation of the upper extremity after stroke.

Taken together, the muscle strength measurements, the BBT, the NHPT and the ABILHAND can be reliable to use for persons with mild to moderate impairments of the upper extremity after stroke. However, learning effects for isokinetic measurements, the BBT and NHPT and also the higher measurement errors for isokinetic measurements and ABILHAND must be considered when following changes over time and effects of interventions.

Test-retest reliability of ordinal data

The STI-test (Paper II) and the mSHFT (Paper III) showed excellent agreement for the more affected hand based on the Kappa coefficient according to Fleiss [153]. The Kappa coefficient of the STI-test for the more affected hand was in agreement with previous studies in peripheral nerve injuries [92] and neuropathies [144]. As the test-

retest reliability of the mSHFT has not been evaluated before it is not possible to compare the results of Paper III to other studies.

For the less affected hand the Kappa coefficients for the STI-test and the mSHFT were only fair. The Kappa coefficient is influenced by the prevalence of the scores in the cells of the contingency table [125]. As the prevalence of scores was concentrated to the higher end of the scale for the less affected hand this resulted in a higher agreement expected by chance and consequently a lower Kappa value [119].

To expand our analysis the STI-test and the mSHFT were also evaluated by the percent agreement and analysis of disagreements according to the Elisabeth Svensson rank-invariant method [135]. The analysis of the percent agreement of the STI-test and the mSHFT in Paper II and III showed that most of the participants (≥82%) scored at most 1-point difference in the total sum score between the two test occasions for both hands. The percent agreement was slightly higher for the less affected than the more affected hand.

The Elisabeth Svensson analysis of the STI-test (Paper II) did not show any significant systematic or random disagreements. The Svensson analysis of the mSHFT (Paper III) did not show any significant random disagreements between the two test occasions but significant systematic disagreements were revealed, indicating learning effects. This is in line with the analysis of the Change in Mean of the other two dexterity measures, BBT and NHPT. Therefore, more than one baseline assessment is also recommended for the mSHFT to reduce the effects of learning.

Taken together, the STI-test and the mSHFT are reliable to use for persons with mild to moderate impairments of the upper extremity after stroke. The mSHFT showed learning effects which must be considered when changes over time and effects after interventions are evaluated.

Validity

The evaluation of the convergent validity showed high correlations for the more affected hand between the mSHFT and the NHPT, whereas the correlations were adequate between the NHPT and the BBT, and between the BBT and the mSHFT (Paper III) [154]. This suggests that the three measures of dexterity are related but cannot fully complement one another. The BBT mainly requires grips and releases, i.e. gross manual dexterity, and could therefore be preferred for persons with moderate impairments of the more affected upper extremity. The NHPT requires a higher level of fine manual dexterity with precision grips and translations and rotations when performing the in-hand manipulations and is more suitable for persons with milder impairments of the upper extremity. The mSHFT had a high correlation to the NHPT implying that it also measures fine manual dexterity and is most suitable for persons with milder impairments of upper extremity. As the

mSHFT has the advantage of reflecting activities in daily life it could be an appropriate alternative to the NHPT.

Perceived ability to perform daily hand activities and associated factors

The ratings of the ABILHAND (Paper V) showed that eight of the 23 bimanual items were perceived as difficult or impossible to perform. All of those items were tasks classified as requiring a high level of bimanual dexterity (level C) (Table 6) [6] except for one item. The items that were rated as easy were primarily breakable into unimanual sequences (level A) or only required stabilization with the affected upper extremity (level B). As ability to perform bimanual activities is an important goal in the rehabilitation after stroke [64] the ratings of the items in the ABILHAND could be helpful for the patients in their goal setting. The different levels of the items of ABILHAND may in turn be useful in the analysis of bimanual involvement and manual dexterity demands in order to target the underlying sensorimotor functions to achieve the intended goals.

Dexterity and participation were the strongest contributors for performing daily hand activities and should therefore be considered in the assessment, goal-setting and rehabilitation after stroke. Grip strength was included as the third determinant in the final model but just contributed slightly (1%). In a previous study by Harris and Eng [66] several potential factors such as muscle strength, spasticity, somatosensation and pain were included in the multivariate analyses. The study showed that muscle strength in the upper extremity and spasticity were the strongest contributing factors for the ability to use the hands in daily activities among persons in the chronic phase after stroke. However, in that study dexterity was not included in the analysis. Therefore, the results of Paper V are difficult to fully compare with the study by Harris and Eng. Altogether though, the findings suggest that increased manual dexterity is important for the performance of daily hand activities in persons with milder impairments, whereas strength is more important for persons with severe impairments.

Furthermore, somatosensation measured as active touch, was the factor that showed the second highest explanatory value in the univariate analyses but was not included in our multivariate model due to the high correlation to dexterity (rho=0.68). Somatosensation, measured as passive touch, has in a previous study been found to have somewhat lower correlations to dexterity (rho=0.33 to 0.34) in persons with mild impairments in the upper extremity after stroke [155]. An accurate dexterity relies on active touch to coordinate and adjust the movements of the hand [21, 29]. Paper V indicates that active touch might be an important factor for explaining

dexterity for persons with mild to moderate impairments of the upper extremity after stroke.

Methodological considerations

Number of participants

The sample sizes for the reliability analysis of continuous data in Paper I, II and III were >30 participants which is considered as sufficient when test-retest reliability is evaluated in neurological samples [156]. There is no accepted method to decide the sample size when using ordinal data in test-retest studies but it is suggested that the sample size should be larger than when continuous data is evaluated [157]. A sample of 45 persons was used in Paper II and III which we considered to be sufficiently large for the reliability analyses of the ordinal data in the STI-test and the mSHFT. However, future studies ought to evaluate and to determine the sample sizes for methods of ordinal data such as Kappa statistics and the Elisabeth Svensson rank-invariant method.

Choice of outcome measures

The outcome measures in Paper I to IV were chosen to measure several aspects of functioning and disability of the upper extremity such as muscle strength, somatosensation, dexterity and perceived ability to perform daily hand activities. The choice was also based on that the outcome measures are commercially available so that clinicians can easily get access to and use recommended outcomes. The test burden after stroke is large as disability can be due to various impairments and activity limitations. Therefore, outcomes were mainly chosen that were relatively easy, non-fatiguing and time-efficient to perform.

Isokinetic dynamometry is considered gold-standard [79, 80] and therefore these muscle strength measurements were chosen in Paper I. As no test protocol for arm strength measurements of upper extremity after stroke was found in the literature a test protocol was carefully developed. Isometric arm strength measurements were included as these are easy to perform and isokinetic measurements as they better reflect muscle strength in action. For grip strength, a new electronic hand grip dynamometer that is commercially available, portable and easy to use was included for measurements of grip strength.

The STI-test [92] was initially developed for persons with peripheral nerve injuries but has been used in the clinical setting for stroke. The STI-test measures active touch, important for movement control in grips and in-hand manipulations and has the advantage of being standardized which is difficult in the assessment of somatosensation [158]. The STI-test is also easy to use and commercially available and was therefore included as a measure of active touch.

Three tests were chosen that assess different aspects of dexterity. The BBT [97] assesses gross manual dexterity and NHPT [98] assesses fine manual dexterity. They are commercially available and commonly used and recommended after stroke [63, 96]. The mSHFT [102] is the only commercially available version of the Sollerman test. The mSHFT is easy and time-efficient to use and also reflects grips used in daily tasks. [102]. These three dexterity test were therefore included as outcome measures of dexterity.

The ABILHAND Questionnaire [6] for stroke is highly recommended for assessing perceived ability to perform daily hand activities [107]. It is easy to use and available via the internet on www.rehab-scales.org. Compared to the Motor Activity Log [104], also commonly used as a self-perceived measure of daily hand activities after stroke, the ABILHAND has the advantage to mainly assess bimanual tasks. As the ability to perform bimanual activities is considered as an important goal in stroke rehabilitation [64], bimanual tasks should be assessed. The ABILHAND was therefore included as an outcome measure of the perceived ability to perform bimanual daily activities.

In Paper V, the previously evaluated outcome measures were included together with stroke specific outcomes to cover important aspects of functioning and disability. Grip strength was used as a measure of the muscle strength of the entire upper extremity as grip strength has been found to be highly correlated to arm strength in persons with mild to moderate impairments in the upper extremity after stroke [159]. The mSHFT [102] was chosen as an outcome of dexterity as it showed good psychometric properties in Paper III and is well suited to use in this population. To cover aspects of participation and life satisfaction the SIS Participation [105] and LiSat (life as a whole) [112] were also included.

Reliability

In this thesis several statistical methods were used to thoroughly evaluate the reliability. The ICC is a measure of agreement and sensitive to the spread of the measurements between the individuals (relative test-retest reliability) [117]. The Kappa coefficient is also sensitive to the number of categories in the variable and also to the prevalence of scores in the contingency table [125]. Thus, the ICC and the Kappa coefficient are insufficient as single measures of reliability. Therefore, it was important to broaden the evaluation of continuous data with analyses of systematic

and random measurement errors within the individuals (absolute test-retest reliability) and ordinal data of analyses of percent agreement and systematic and random disagreements. The evaluation of the size of systematic and random measurement errors and disagreements is valuable as they have different impacts on the quality of a measure. Identified systematic measurement errors or disagreements can be explained and adjusted for whereas large random measurement errors or disagreements could be a sign of poor quality of an outcome measure [117].

The interpretations of the reliability coefficients can be done according to several standards. We used the limits for excellent agreement according to Fleiss [124] (>0.75) in this thesis both for continuous and ordinal data (Paper I to IV). More conservative limits are proposed by Landis and Koch [160] and Altman [161] (>0.80). However, the ICCs in this thesis were all above 0.80 and the Kappa coefficients for the more affected hand were also above 0.80. As limits for interpretations are arbitrarily set they are recommended to be used with caution [126].

Analysis of random measurement errors of continuous data can be made with various estimates [117]. The 95% LOA are normally presented in a Bland and Altman graph [123]. The SEM and SRD provide values of the smallest change that indicate a real change for a group and a single individual and have been suggested as more practical estimates of the measurement errors [126, 127]. They are easy to interpret and together they distinguish between limits to evaluate changes over time and effects of interventions for a group compared to a single individual [116]. The SEM and SRD can also be expressed as a percentage value of the grand mean, the SEM% and the SRD% [117], which makes it possible to compare the measurement errors across studies.

The Elisabeth Svensson rank-invariant method [135] is a newer approach to analyze the reliability of ordinal data and has the advantage that the systematic and random disagreements can be evaluated. However, the Svensson method has the disadvantage of being difficult to compare to other studies as it is yet not commonly used. In the Svensson method the agreement is evaluated as the absolute percent agreement. However, in ordinal scales the absolute percent agreement (same score at both test occasions) could be moderate when in fact most persons only have one point difference. We therefore also used the PA% 1-point, i.e. the percent agreement of the persons with at most 1 point difference between the two test occasions. In this thesis (Paper II and III) we have shown that it could be preferable to use several statistical methods to evaluate the test-retest reliability, as is proposed for continuous data [117], also for ordinal data.

Study designs and measurement procedures

In the muscle strength test protocol (Paper I) reciprocal isokinetic strength measurements were included as they better reflect movements in real life than isometric strength measurements. However, instead of performing reciprocal isokinetic movements, separate movements of dynamic elbow extension and flexion might have been preferred to decrease the measurement errors. Future test-retest reliability studies are needed to evaluate different modes of performances of isokinetic strength measurements in the upper extremity after stroke.

The STI-test, as a measure of active touch, showed larger deficits of somatosensory function compared to assessments of passive touch (Paper II). However, even if all participants had preserved motor function of the more affected hand it cannot be excluded that difficulties to identify the shapes and textures might not only have been due to a reduced somatosensory function but also to a reduced motor function of the hand. More knowledge is therefore desired about different assessments of passive and active touch and their relations when measuring somatosensory function in persons with stroke.

All dexterity tests showed learning effects. Yet, trial practices were included according to the test instructions for the BBT and NHPT [97, 98] and the mean of multiple assessments was used as the score as is recommended [144, 162]. However, the test instructions of the mSHFT do not propose any trial practices and the actual assessment is only performed once, i.e. the score is based on one performance [100]. This raises the question if trial practices and using the mean of several tests are useful for reducing learning effects of dexterity measures. More knowledge is needed about the optimal number of preceding trial practices, number of assessments and whether the mean or the highest value should be used when assessing dexterity after stroke.

The ABILHAND is mainly focused on tasks performed by the hands close to the body and does not assess tasks such as reaching for objects further away, lifting or carrying. Thus, all aspects of upper extremity activities in daily life are not included. Moreover, four outliers were identified in the sample with high differences in the logits score in the test-retest evaluation. Changes in the ends of a Rasch scale leads to greater changes in logits compared with changes of the center of the scale (around zero) as the standard errors are larger at the end of the logits scale [163]. To decrease this variability at the end of the scale it has been suggested to add more difficult items to extend the scale and thereby increase the precision [163].

It cannot be excluded that other factors than those included in Paper V may be of importance for the ability to perform daily hand activities after stroke. However, it is difficult to include too many assessments without causing fatigue in persons with stroke. As the study had a cross-sectional design it is not possible to state that the causality directly results from the factors included in the linear region models. Reverse

causality might also have been present. It is therefore suggested that future prospective studies evaluate how various potentially associated factors influence daily hand activities after stroke in several points over time.

Strengths and limitations

A strength in this thesis is that several outcome measures for the upper extremity after stroke were psychometrically evaluated in Paper I to IV. In Paper V, the evaluated measures of the upper extremity were then used together with other stroke specific outcomes to cover important aspects of functioning and disability after stroke according to the ICF. In all studies the test situations were carefully standardized, the test protocols were thoroughly described and one examiner performed all assessments. In the test-retest measurements the participants were in a stable phase after stroke and tested at the same location, the same time and day of the week at both test occasions. A one-week interval (Paper I to III) or a two-week interval (Paper IV) between the test occasions was chosen to avoid fatigue, minimize learning effects and recall bias.

This thesis has also some limitations. Aspects of perceived participation and life satisfaction were included in Paper V, but these outcome measures have not been evaluated for the sample of persons with mild to moderate impairment of the upper extremity after stroke. However, ratings of perceived participation and life satisfaction were collected twice and will be analyzed in future studies. Furthermore, when recruiting persons with mild to moderate impairments in the upper extremity after stroke more men were found as possible participants and agreed to participate in the studies. Only persons with mild to moderate impairments of the upper extremity without major cognitive impairments or difficulties to communicate after stroke were included in the five studies. Thus, this is a selected group of persons with stroke and the results can therefore not be generalized to the whole stroke population.

Clinical implications and future research

The use of valid and reliable outcome measures to assess functioning and disability of the upper extremity after stroke is essential in order to follow recovery, provide accurate documentation, assist goal setting and facilitate the evaluation of rehabilitation interventions. A thorough knowledge of the psychometric properties of outcome measures for upper extremity after stroke will enable having consensus and making recommendations on which outcome measures to use in clinical guidelines and in research. This thesis has contributed to increased knowledge about psychometric properties of outcome measures of upper extremity muscle strength, somatosensation, manual dexterity and perceived ability to perform daily hand activities in persons with mild to moderate impairments of the upper extremity after stroke.

This thesis has also increased the knowledge about which daily hand activities that are perceived difficult to perform and which factors that are associated with the performance in persons with mild to moderate impairments of the upper extremity after stroke. This knowledge is important in order to design and target efficient rehabilitation interventions and develop new effective interventions in the future for persons with upper extremity disability after stroke.

Outcome measures for upper extremity

Even though muscle weakness is the most common impairment after stroke there is limited evidence for interventions of strength training for the upper extremity [25]. One reason for this might be a lack of studies using reliable muscle strength test protocols for the upper extremity [53]. This thesis has shown that muscle strength in the arm can be reliable measured by isokinetic dynamometry and grip strength can be reliably measured by an electronic grip strength dynamometer. This test protocol could therefore be used to evaluate upper extremity muscle strength in the clinical setting and in future research. However, isokinetic dynamometry is not always available for clinicians in stroke rehabilitation and can be difficult and time-

consuming to perform. Grip strength measures are easier and quicker to obtain and could therefore be used as a proxy for the muscle strength in the entire upper extremity for persons with mild to moderate impairments of the upper extremity after stroke [159]. However, the choice of measures depends on the objective with the measurements.

Somatosensation is traditionally assessed in the clinical setting by passive assessments of light touch and proprioception [158, 164]. However, these tests are poorly standardized [158] and might also underestimate the somatosensory impairments. Somatosensation used in tasks in daily life require active touch and active touch is therefore important to measure. This thesis has shown that active touch can be reliably measured by the STI-test in persons with mild to moderate impairments of the upper extremity after stroke. Active touch was also shown to be associated to dexterity in the correlation analyses in Paper V. The STI-test could therefore be valuable to add to the somatosensory assessment after stroke both in the clinical practice and in research. Future studies are needed to further investigate how different modes of somatosensation is associated to manual dexterity and also influence the performance of daily hand activities after stroke.

This thesis has also shown that the BBT, NHPT and mSHFT are reliable to use as outcome measures of dexterity for persons with stroke. The BBT may be preferred for persons with moderate impairments of the upper extremity and the NHPT and the mSHFT for persons with milder impairments. The mSHFT has the advantage to reflect tasks in daily life important for the ability to perform daily hand activities after stroke. The mSHFT is therefore recommended to use in the clinical practice and research. However, the mSHFT is mainly focused on evaluating different grips used in dexterity tasks. To be able to perform manipulations there is also a need to accomplish in-hand manipulations such as translations, shifts and rotations in the hand. It would therefore be desirable to develop an outcome measure that includes different grips and in-hand manipulations commonly used in activities in real life.

The ABILHAND assesses the ability to perform bimanual activities in real life and is therefore a valuable tool in the patient's goal setting and in the evaluation of rehabilitation interventions after stroke. The different levels of ABILHAND may in turn be useful in the analysis of bimanual involvement and the underlying sensorimotor functions could then be practiced to increase movement control and goal achievements. Even though this thesis has shown that the ABILHAND Questionnaire has an acceptable reliability consideration must be taken to the relatively high random measurement errors in repeated measurements. As the ABILHAND was developed for more than 15 years ago [6] it is suggested that the ABILHAND should be revised and updated in future research.

How to increase movement control and the ability to perform daily hand activities

This thesis has shown that dexterity is important for the perceived ability to perform daily hand activities. At the stroke onset it is therefore of outmost importance to minimize the brain damage in order to increase recovery of the upper extremity and preserve dexterity [32]. In rehabilitation after stroke there is evidence for CIMT and task specific training which involves practice of activities in daily life [25]. However, to avoid compensation when tasks are difficult to perform it is essential to practice the underlying sensorimotor functions. This suggests that more focus ought to be given to interventions targeting dexterity such as the practice of grip formations, coordination of finger movements as well as translations, shifts and rotations in the hand in order to increase movement control.

In order to achieve movement control in dexterity tasks the shoulder function is important for stabilizing the upper extremity while grasping and performing precision tasks. Shoulder abduction is an early predictor of good hand function after stroke [41] and important for elbow joint control in active movements [165]. Increased emphasis on proximal upper extremity stabilization has been recommended to increase the effects of CIMT [166] while reaching, grasping and manipulating objects. Shoulder stabilization should therefore be practiced in conjunction with dexterity to improve the ability to perform daily hand activities.

Active touch is also an important factor for movement control of the hand and ought to be assessed and practiced in order to improve dexterity and daily hand activities. Somatosensory training should therefore be considered after stroke and include texture discrimination, object recognition and somatosensory awareness in grasping and in-hand manipulations [25].

Perceived participation was also shown to be of importance for the perceived ability to perform daily hand activities. Usually most of the rehabilitation is given in the first months after stroke. Yet, a recent large European multicenter study found that upper extremity function and daily activities for persons with stroke deteriorates over time [167]. More interventions and follow-ups in later phases after stroke are therefore needed with emphasis on maintaining and finding new ways to participate in meaningful activities. That is, there is a need for more long-term rehabilitation planning in order to uphold the ability to perform daily hand activities over time.

Despite that several potential factors were included in the multivariate analyses in this thesis the ability to perform daily hand activities was not fully explained. This implies that other factors also are important to consider and that in the rehabilitation after stroke the ability to perform daily activities must be assessed and practice *per se*. More research is also needed to evaluate the training effects of muscle strength,

somatosensation and dexterity and how these interventions can be integrated to improve the ability to perform activities of the upper extremity in real life after stroke.

Conclusions

This thesis has shown that in persons with mild to moderate impairments of the upper extremity after stroke:

- Isometric and isokinetic muscle strength can be reliably measured. Isokinetic strength measurements have the advantage of reflecting dynamic strength in real life. However, as isometric strength measurements showed lower measurement errors they might be preferred when muscle strength after stroke is evaluated.

- Active touch can be reliably measured with the STI-test. As active touch reflects the somatosensory function in action when exploring shapes and textures and when grasping and manipulating objects, the STI-test could be valuable to add to the somatosensory assessment after stroke.

- Dexterity can be reliable measured with the BBT, the NHPT and the mSHFT. As all three tests showed learning effects in repeated assessments, more than one baseline assessment is recommended when evaluating changes of dexterity over time or after interventions. The BBT may be preferred for persons with moderate impairments of the upper extremity and the NHPT and the mSHFT for persons with milder impairments. As the mSHFT has the advantage of reflecting activities in daily life it may be a suitable alternative to the NHPT.

- Self-perceived daily hand activities can be reliably rated with the ABILHAND Questionnaire. The relatively high random measurement errors must be taken into account when recovery and effects of interventions are evaluated.

- Daily hand activities that are perceived most difficult to perform are bimanual tasks that require fine manual dexterity. Dexterity and participation are important contributing factors for performing daily hand activities and should be considered in the rehabilitation after stroke.

Populärvetenskaplig sammanfattning

Förmågan att kunna använda armen och handen i vardagen beror på ett komplext samspel mellan olika kroppsfunktioner såsom muskelstyrka, känsel och finmotorik som i sin tur påverkar förmågan att utföra olika vardagsaktiviteter. Nedsatt funktion i arm och hand är vanligt hos personer som insjuknat i stroke, dvs i en hjärninfarkt (blodpropp i hjärnan) eller i en hjärnblödning. Framförallt kan förmågan att utföra tvåhandsaktiviteter påverkas och det finns risk att ett 'icke-användar-beteende' utvecklas, dvs. att personerna inte använder armen och handen i den utsträckning som de egentligen skulle kunna. Ett viktigt mål i rehabiliteringen efter stroke är därför att förbättra funktions- och aktivitetsförmågan i armen och handen.

För att kunna följa återhämtningen av funktions- och aktivitetsförmågan i armen och handen och utvärdera effekter av rehabilitering är det viktigt att använda utfallsmått med god mätkvalitet. God mätkvalitet innebär att utfallsmåtten ska mäta det som avses (validitet) och att mätningen är tillförlitlig, dvs. ger liknande resultat vid upprepade mätningar under samma förhållanden (reliabilitet). Även om det finns omfattande internationella och nationella riktlinjer för stroke saknas konsensus om vilka utfallsmått som bör användas för armen och handen, vilket gör det svårt att jämföra resultat och utvärdera effekterna av olika behandlingsmetoder. Således behövs mer kunskap om mätkvaliteten för utfallsmått som mäter funktions- och aktivitetsförmågan i armen och handen efter stroke. För att kunna förbättra funktions- och aktivitetsförmågan i armen och handen i rehabiliteringen efter stroke är det också viktigt få ökad förståelse för vilka dagliga aktiviteter som är svåra att utföra och vilka faktorer som påverkar utförandet.

Det övergripande syftet med detta avhandlingsarbete var att utvärdera mätkvaliteten för utfallsmått som mäter styrka, känsel och finmotorik samt självskattad förmåga att utföra vardagliga tvåhandsaktiviteter hos personer med nedsatt arm- och handfunktion efter stroke. Därutöver var syftet att öka kunskapen om vilka vardagliga tvåhandsaktiviteter som upplevs svåra att utföra och vilka faktorer som har betydelse för utförandet.

I delstudie I till III deltog 45 personer och i delstudie IV deltog 43 personer som insjuknat i stroke. I delstudie I till III mättes deltagarna med en veckas mellanrum och i delstudie IV med två veckors mellanrum.

I delstudie I utvärderades reliabilitet för mätningar av styrka i armen och handen. Styrkan mättes både i en statisk position och under en rörelse. Studien visade att det fanns en god reliabilitet för mätning av muskelstyrka i skuldra, armbåge och hand. De statiska mätningarna var mer reliabla och kan därför vara att föredra.

I delstudie II utvärderades reliabilitet för bedömningsinstrumentet Shape/Texture Identification Test (STI-test) som mäter aktiv känsel i handen genom att former och ytor i olika storlekar ska identifieras. Studien visade att känsel efter stroke kan mätas reliabelt med STI-testet.

I delstudie III utvärderades reliabilitet och samtidig validitet (relationen mellan utfallsmåtten) för tre test som mäter finmotorik: Box and Block Test; Nine Hole Peg Test och modifierat Sollerman Hand Function Test. Alla tre testen visade på en god reliabilitet men också på läreffekter, dvs. deltagarna förbättrade systematiskt sina resultat vid andra testtillfället. Därför rekommenderas att mer än en baslinjemätning genomförs när effekter av rehabilitering utvärderas. De tre finmotoriska utfallsmåtten var delvis relaterade men mäter också olika aspekter av finmotorisk förmåga. Box and Block Test kan rekommenderas för personer med måttliga funktionsnedsättningar medan Nine Hole Peg Test och modifierat Sollerman Hand Function Test är mer lämpade för personer med lättare funktionsnedsättningar i armen och handen efter stroke.

I delstudie IV utvärderades reliabilitet för frågeformuläret ABILHAND, som mäter självskattad förmåga att utföra vardagliga tvåhandsaktiviteter. Studien visade att ABILHAND hade en acceptabel reliabilitet för personer med lätt till måttlig funktionsnedsättning i armen och handen efter stroke.

I delstudie V studerades vilka vardagliga aktiviteter som uppfattas som svåra att utföra samt vilka faktorer som påverkar utförandet, i en undersökningsgrupp om 75 personer. Studien visade att de aktiviteter som kräver en god finmotorik upplevdes svårast att utföra. Finmotorik och upplevd delaktighet i sociala sammanhang var de två faktorer som bidrog mest till förmågan att kunna utföra dagliga tvåhandsaktiviteter.

Sammanfattningsvis visar studierna i denna avhandling att muskelstyrka i armen och handen (delstudie I), aktiv känsel i handen (delstudie II), finmotorik (delstudie III) och vardagliga tvåhandsaktiviteter (delstudie IV) kan mätas reliabelt efter stroke. Finmotorik och delaktighet i meningsfulla sammanhang (delstudie V) verkar vara viktiga faktorer för förmågan att kunna utföra vardagliga aktiviteter med händerna och bör därför noggrant bedömas och beaktas i rehabiliteringen hos personer med lätt till måttlig nedsättning av funktions- och aktivitetsförmågan i armen och handen efter stroke.

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Upper extremity disability after stroke

Psychometric properties of outcome measures and perceived ability to perform daily hand activities

Impairments of the upper extremity are common after stroke which may affect movement control and the ability to perform daily hand activities. To be able to follow recovery and effects of interventions, valid and reliable outcome measures are needed. At the time when this thesis was planned there was limited knowledge of the psychometric properties of outcome measures for muscle strength, somatosensation, dexterity and perceived ability to perform daily hand activities for persons with mild to moderate impairments of the upper extremity after stroke. There was also a lack of knowledge which daily hand activities these persons perceive difficult to perform and which factors are associated with their performance. A greater knowledge would improve the ability to design and target efficient rehabilitation interventions for persons with disability of the upper extremity after stroke and to evaluate effects of interventions. With this background the five studies in this thesis were designed.

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