UHASSELT

KNOWLEDGE IN ACTION

Faculteit Geneeskunde en Levenswetenschappen

master in de revalidatiewetenschappen en de kinesitherapie

Masterthesis

Assessment of somatosensory disorders after stroke: a systematic review of outcome measures and their psychometric properties

Toon Clement
Naomi Trekels

Eerste deel van het scriptie ingediend tot het behalen van de graad van master in de revalidatiewetenschappen en de kinesitherapie

PROMOTOR :
dr. Ilse LAMERS

COPROMOTOR :
Prof. dr. Peter FEYS

2016
2017

UHASSELT
KNOWLEDGE IN ACTION

www.uhasselt.be
Universiteit Hasselt
Campus Hasselt:
Martelarenlaan 42 | 3500 Hasselt
Campus Diepenbeek:
Agoralaan Gebouw D | 3590 Diepenbeek

UHASSELT

KNOWLEDGE IN ACTION

Faculteit Geneeskunde en Levenswetenschappen

master in de revalidatiewetenschappen en de kinesitherapie

Masterthesis

Assessment of somatosensory disorders after stroke: a systematic review of outcome measures and their psychometric properties

Toon Clement
Naomi Trekels

Eerste deel van het scriptie ingediend tot het behalen van de graad van master in de revalidatiewetenschappen en de kinesitherapie

PROMOTOR :
dr. Ilse LAMERS

COPROMOTOR :
Prof. dr. Peter FEYS

Assessment of Somatosensory Disorders after Stroke:
A Systematic Review of Outcome Measures and their Psychometric Properties

Outline

Patients with stroke often suffer from motor impairments, cognitive deficits as from somatosensory impairments. It's well known under clinicians that somatosensory is an important predictor for recovery of sensorimotor function (Winward, Halligan, & Wade, 1999). It is important to have standardized outcome measures with good psychometric properties in order to prove that a treatment is effective in clinical studies and practices.
The literature study of the master thesis is focused on providing an overview of the outcome measurements and their psychometric properties.

The most important findings of this literature review are the following:

- The Erasmus modification of the Nottingham Sensory Assessment is a reliable, inexpensive and feasible measure that gives an overall view of sensory impairments in stroke patients.

- Further research on the psychometric properties of somatosensory measurements in a stroke population is needed.

- Further research needs to focus on adapting existing somatosensory measurements to improve reliability, validity and responsiveness.

Toon Clement and Naomi Trekels
o.l.v.
Promotor: Dr. I. Lamers
Co-promotor: Prof. Dr. P. Feys
AJ 1617 Wetenschappelijke stage/ Masterproef deel 1

Context of the master thesis

This master thesis fits in the research domain of neurological rehabilitation. Patients suffering from stroke are often confronted with different types of impairments. Motor impairment, cognitive deficits, as well as somatosensory impairments are often present (Winward et al, 1999).

More specifically, the literature study of the master thesis is focused on the following research question: “What are the psychometric properties of clinical measures evaluating somatosensory disorders after stroke?”.
In the second part of this thesis, a research protocol is described that will investigate the reliability, validity and clinical utility of a robotic assessment measure to assess proprioception of the fingers in stroke patients.

This master thesis part 1 is part of our first master year at the UHasselt in Diepenbeek, and made by Toon Clement and Naomi Trekels. The literature search and writing was supervised by Dr. Ilse Lamers.
The research question was formed in cooperation with Dr. Ilse Lamers. The research strategy was done by Toon Clement and the data extraction and making of the frequency table was done by Naomi Trekels. Other editing aspects were performed in co-operation by the two students.

The design of the protocol is based on the study of Rinderknecht (2016) and made in cooperation with Dr. Ilse Lamers. The Rehabilitation Engineering Laboratory ETH of Zurich will lend the ReFlex, a ‘one degree-of-freedom’ robotic hand interface (Rinderknecht, Popp, Lambercy, & Gassert, 2016). This robot will be used in the experimental study. This study will take place in the MS center in Overpelt and the Hospital Jessa campus St. Ursula Herk-de-Stad.

TABLE OF CONTENTS

PART 1: OVERVIEW OF THE LITERATURE

1. Abstract

Background: It's well known under clinicians that somatosensory is an important predictor for recovery of sensorimotor function (Winward, Halligan, & Wade, 1999). It is important to have standardized outcome measures with good psychometric properties in order to prove that a treatment is effective in clinical studies and practices.

Methods: Two databases (PubMed and Web of Science) were consulted. The following research strategy was used: *(Somatosensory* OR *Sensation OR Sensory)* AND *(stroke OR poststroke)* AND *(Assessment* OR *Evaluation OR Outcome measures* OR *Validity* OR *Psychometrics* OR *Reliability* OR *Test-retest* OR *Responsiveness)* NOT *(Evoked potentials* OR *Nerve Stimulation* OR *Neurophysiology* OR *Dysphagia OR Robot* OR *Robotic* OR *Vestibular* OR *Medication* OR *Eye movements).*

Results: The psychometric properties of the Nottingham Sensory Assessment (NSA), was most frequently examined and showed moderate to high inter-rater reliability. The psychometric properties of the sensory scale of the Fugl-meyer assessment (FMA-s) was examined two times. Lastly the psychometric properties of the Rivermead Assessment of Somatosensory Performance (RASP) were two times investigated and showed high inter-rater reliability. Overall, moderate to high correlations were found between the different sensory outcomes.

Discussion and Conclusions: This review may help clinicians and researchers in making the selection of appropriate somatosensory measurements, despite the limited availability amount of studies investigating the psychometric properties of these measures.

Operationalization: This master thesis is a part of a broader research project, on the assessment of the impairments in patients with stroke and MS patients. The aim of our master thesis is to discuss the psychometric properties of somatosensory measurements in stroke patients.

Most important key words: Stroke, somatosensory impairments, psychometric properties

2. Introduction

Stroke is a common health problem worldwide (The World Health Report, 2008). The WHO expects an increase of stroke events from 1.1 million per year in 2000 to more than 1.5 million per year in 2025. This can be dued to the demographic changes of the modern society (Truelsen, Piechowski-Jòzwiak, Bonita, & Mathers, 2006). Research has showed that stroke is a multifactorial disease regulated by changeable (e.g., lifestyle) and unchangeable (e.g., sex and age) risk factors (Allen & Bayraktutan, 2008). Rehabilitation costs are very high, because of the long-term care, rehabilitation, nursing, and withdrawal from work. The annual cost of stroke is estimated to be between US $6.5 and 11.2 billion (Kaste, Fogelholm & Rissanen, 1998). Therefore, a cost-effective rehabilitation is crucial.

There are two types of stroke: ischemic and hemorrhagic. Ischemic stroke is caused by an obstruction within an artery and hemorrhagic stroke occurs when a degenerative artery ruptures. Both types of stroke can result in a variety of deficits (e.g., motor, sensory, cognitive, visual, balance, etc). Somatosensory deficits occur in around 70% of patients after stroke (Carey & Matyas, 2011).

In people with somatosensory impairments the primary or secondary somatosensory cortex, the thalamus, insula, posterior parietal cortex, or the cerebellum can be damaged. The somatosensory system is divided in three groups: exteroceptive, proprioceptive and higher cortical somatization (DeJong, 1979; Doyle, Bennett, Fasoli, &McKenna, 2010). Each group is subdivided in sets of somatosensory modalities such as light touch, pain, position sense, movement sense, and somatosensory discrimination sense (DeJong, 1979). Stereognosis is the most frequently impaired in stroke followed by proprioception. Tactile sensations are the least impaired (Connell, Lincoln, & Radford, 2007). The agreement between different somatosensory modalities is small within the same body area suggesting that the modalities are independent of each other and should all be tested. On the other hand, the agreement between different body areas for each somatosensory modality is high suggesting it is not necessary to evaluate all body parts, there was a redundancy between the wrist and hand or between the ankle and foot (Connell, Lincoln, & Radford, 2007).

Somatosensory deficits are correlated with worse motor outcome, lower activity level and a longer hospitalization (Broeks, Lankhorst, Rumping, & Prevo, 1999; Tyson, Hanley, Chillala, Selley, & Tallis, 2008; Sommerfeld & von Arbin, 2004; Blennerhassett, Matyas, & Carey, 2007; Hermsdörfer, Hagl, Nowak, & Marquardt, 2003; Meyer, Karttunen, Thijs, Feys, & Verheyden, 2014). Stroke patients without somatosensory deficits are more likely to reach independence in self-care function (Reding & Potes, 1988). Therefore, it is important to perform somatosensory assessment to determine the deficits and to provide directions for patient's rehabilitation. Standardized measures with good psychometric properties are needed to prove the effectiveness of a treatment in further studies. However, there is a lack of standardized somatosensory assessments in the current practice, despite these important prognostic contributors to recovery from stroke (Winward et al, 1999).

Therefore, a detailed overview of somatosensory outcome measurements and their psychometric properties in stroke is needed. To our knowledge no other review described the properties and clinical utility of outcome measures evaluating somatosensory impairments after stroke. The aim of this study is to discuss the psychometric properties of somatosensory measurements in stroke patients.

3. Methods

3.1. Research question

The main research question for this literature search is: “What are the psychometric properties of clinical measures evaluating somatosensory disorders after stroke?”.

3.2. Literature search

Two databases (PubMed and Web of Science) were consulted until April 2017. The following research strategy was used: (Somatosensory OR Sensation OR Sensory) AND (stroke OR poststroke) AND (Assessment OR Evaluation OR Outcome measures OR Validity OR Psychometrics OR Reliability OR Test-retest OR Responsiveness) NOT (Evoked potentials OR Nerve Stimulation OR Neurophysiology OR Dysphagia OR Robot OR Robotic OR Vestibular OR Medication OR Eye movements). After the removal of duplicates, all articles were screened by two independent reviewers. The full text was read when more information was necessary. If the full text was not available in the library of the university, the full text was requested by mail or using “Researchgate”. The references of the included articles were checked for additional articles. Fig. 1 gives an overview of the literature search strategy.

3.3. Selection criteria

The following selection criteria were used for the screening of the obtained articles:

(1) Are clinical standardized assessment measures evaluating somatosensory used?
(2) Are stroke patients included?
(3) Is the full text available?
(4) Written in English.
(5) Not published before 1990.
(6) Evaluating psychometric properties.

3.4. Quality assessment

To check the quality of the included studies evaluating psychometric proportions the same checklist as described in the systematic review of Lamers (2014) was used (appendix 1). Two independent reviewers practiced the use of the quality checklist on four articles by comparing them before screening. The other articles were divided between the reviewers. In case of doubt, the quality assessment was discussed together.

3.5. Data extraction

All included articles were searched in two parts. Firstly, an overview of outcome measures and the psychometric properties investigated for these outcome measures was made. Secondly, nineteen studies who evaluated the psychometric properties were extracted.

From these studies, the following data were extracted: study population, aim of the study and the psychometric properties of the outcome measures. The psychometric properties discussed in this review are reliability, validity and responsiveness. Reliability is the degree of consistency between repeated measurements. Inter-rater, intra-rater, test-retest reliability and internal consistency were described by using Cronbach alpha (α), Kappa value (κ) and Intra Class Correlation (ICC), Pearson correlation coefficient (ρ), Percent of Agreement (PA) and Standard Error of Measurement (SEM). Reliability was considered good when the values were very high (<0.90), high (0.70-0.89), moderate (0.50-0.69), and low (<0.49) (McDowell, 2006). ICC, Kappa value, Pearson correlation coefficient and percentage agreement were defined as very high (<0.90), high (0.70-0.89), moderate (0.50-0.69), and low (<0.49) (Portney & Watkins, 2009). Validity refers to the degree to which an outcome measures what it intended to measure. Validity was described by using Pearson correlation coefficient and Spearman correlation. Correlation coefficients were scored excellent (1.00), high (0.70), moderate (0.50) and low (0.30). Lastly, responsiveness is a measurement's ability to detect change over time (Portney & Watkins, 2009) and is described by using Standard Response of Mean (SRM) and Minimal Detectable Change (MDC). Standard response of mean was graded large (>0.80), moderate (0.50-0.80) and small (<0.50) (Cohen, 1988).

4. Results

The systematic literature search resulted in 980 articles of which 83 articles, met the inclusion criteria (Fig 1). Additionally, three articles were found through references, resulting in a total of 86 articles for data extraction after removing the duplicates between searches Pubmed and Web of science.

Extracted outcome measures were classified according to the modalities (proprioception, temperature, touch, vibration and stereognosis). Twenty-nine outcome measures were identified, seven on proprioception, txo on temperature, five on testing more than one modality, four on touch discrimination, five on touch threshold, one on vibration sense and five on stereognosis.
The psychometric properties of the Nottingham Sensory Assessment (NSA), the sensory scale of the Fugl-meyer assessment (FMA-s) and the Rivermead Assessment of Somatosensory Performance (RASP) were examined 6, 2 and 2 times.
There were also measurements found in the research strategy whose psychometric properties were not investigated. These measurements were still included to give a general view of their frequency.

Proprioception was measured the most by the wrist position sense test (WPST). Temperature was mostly measured by the quantitative sensory test (QST). The two-point discrimination test (TDT) was the most used outcome measure on the touch discrimination sense. Touch threshold sense was measured the most by the Semmes-Weinstein Enhanced Sensory Test (SWM) and the Von Frey Monofilaments.

Psychometric properties

Table 2 presents the quality assessment of the studies investigating the psychometric properties. Overall the checklist questions were positively answered (> 6 times yes), indicating that all studies had sufficient methodologic quality to be included for this review. However, the sample size was not large enough ($\leq$ 20 participants) in five studies. Furthermore, there was often (11 times) not mentioned if there were any efforts made to address potential sources of bias. In seven studies the sample was not representative for the stroke population.
Table 5 gives an overview of the patient characteristics and aims of the studies investigating psychometric properties of outcome measures.

Reliability
All results regarding reliability were summarized in table 6.

Inter-rater reliability
High inter-rater reliability (ICC or κ or $r > 0.75$) was found for the position sense scale of the FMA-s, the Moving-Touch Pressure (MTP), the pressure and pinprick subtest of the Erasmus modification of the

Nottingham Sensory Assessment (Em-NSA), the RASP and the Sustained-Touch Pressure (STP), except for the passive subtest with light ball.

Moderate inter-rater reliability (κ = 0.50 to 0.75) was found for the light-touch, sharp-blunt discrimination, proprioception and two-point discrimination subtest of the Em-NSA and the stereognosis subtest of the revised Nottingham Sensory Assessment (rNSA).

Poor inter-rater reliability (ICC or κ < 0.50) was found for the light touch subtest of the FMA-s and the light touch, pressure, pinprick, temperature, tactile localization, bilateral simultaneous touch and detection of movement subtest of the rNSA.

Intra-rater reliability

There was overall high intra-rater reliability (ICC or κ or r or PA > 0.75) found for the AsTex, the FMA-s, the Hand Active Sensation Test (HASTe), the MTP, the pinprick subtest of the Em-NSA, the RASP, the Shape and Texture Identification test (STI-test^{TM}) and the two-point discrimination test.

There was moderate inter-rater reliability (κ = 0.50 to 0.75) for the light-touch, sharp-blunt discrimination and proprioception subtest of the Em-NSA and the STP.

Poor intra-rater reliability (κ < 0.50) was found for the two-point discrimination subtest of the Em-NSA.

Internal Consistency

There was high internal consistency (α = 0.82) between the 18 different items of the HASTe. Poor internal consistency (κ = -0.1 to 0.54) is found between the different somatosensory modalities tested in the rNSA. The pressure subtest of the rNSA scored consistently in all body areas with moderate to high consistency (κ = 0.42 to 0.96). On the other hand, the tactile localization subtest of the rNSA had slight to high consistency (κ = 0.07 to 0.77). Lastly, moderate to high level of agreement (κ = 0.72 to 0.95) was found between the total limb score and each individual anatomical site for all items of the RASP.

Validity

Correlation coefficients between sensory and other sensory modalities are provided in table 6. Overall, moderate to high (r or R^2 = 0.50 to 1) correlations were found between the different sensory outcomes, except for the correlation between The Brief Kinesthesia test and HASTE or the Semmes-Weinstein Enhanced Sensory Test (low correlation).

Correlation coefficients between somatosensory outcome measures and other outcome measures (e.g. motor activity and activities on daily living) are provided in table 7. Overall, low correlations were found between sensory and motor or other outcomes such as activity level and self-care independence. High

correlations (r, R^2, $\rho > 0.70$) were found between BKT and motor performance tests such as the Box and Blocks Test (BBT).

There is a low correlation (r, R^2, $\rho < 0.50$) between sensory tests (CSII, FMA-s, rNSA and RASP) and activities on daily living level or motor performance tests (e.g. Action Research Arm Test and Box to Block Test). MTP, STP, Em-NSA, Thumb finding test and Two- point discrimination test were low correlated with motor function, except for the threshold of touch which was moderate correlated.

Responsiveness

Only 3 studies (59, 50, 84) investigated responsiveness. These results are showed in table 9. Only the real (Standard response mean -SRM- and minimal detectable change -MDC-) change were reported for the AsTex, FMA-s and subtests tactile sensation, proprioception and stereognosis of the rNSA. There were no studies found who investigated the relevant change.

There was a high responsiveness (SRM= 0.83) for the subtest tactile sensation of the rNSA for patients whose baseline scores were below the maximum of any of the rNSA subscales (Wu et al, 2016). For the other subtests of proprioception and stereognosis there were moderate values of responsiveness (SRM = 0.50 to 0.80).

The FMA-s showed low responsiveness at each period (14 to 30, 30 to 90 and 90 to 180 days) of stroke recovery, except from the whole period of 14 to 180 days, there was moderate responsiveness (Lin, Hsueh, Sheu, & Hsieh, 2004). Moderate responsiveness was found for the AsTex (SRM= 0.57). The minimal detectable change in texture discrimination in the affected hand was estimated 0.38mm ($P < 0.05$).

Ceiling effects of the AsTex were observed in the less unaffected hand in two subacute stroke patients (8.3%) and one patient with chronic stroke (4.5%), also a floor effect seen in three patients of the subacute stroke population (12.5%) who couldn't perform the test.

5. Discussion

5.1. Reflection on the quality of the included studies

No validated quality checklist was available with regard to our research objective. Therefore a self-made checklist by Lamers (2014) was used. Most questions on the quality checklist were positively answered, indicating that all studies had sufficient methodologic quality to be included for this review. It was often (11 out of 19 times) not mentioned if there were any efforts made to address potential sources of bias. This can be seen as weaknesses of the included studies. None of the includes studies reported power analyse to determine the sample size. Therefore we introduced a criteria of a minimum sample size of twenty participants. Five studies did not meet this criterion. The results of seven studies cannot be generalized because they did not include the general population of stroke. For example, some of them included only chronic stroke patients. Two of them also included medical conditions such as traumatic brain injury, cerebral tumour, hydrocephalus, diabetes, PAD and other neurological conditions (Stolk-Hornsveld et al., 2006; Deshpande et al., 2010). However, there were no studies excluded because of the limited availability of studies investigating psychometric properties. Therefore results should be interpret with caution. Table 10 gives an overview of the strengths and weaknesses of the included studies.

5.2. Reflection on the findings in function of the research questions

The psychometric properties of the NSA were most frequently evaluated. All psychometric properties of the NSA are investigated, but the responsiveness is insufficiently documented. Although other measurements frequently occur among studies in this research strategy, their psychometric properties are not always investigated. For example, the touch threshold was frequently measured by the SWM and Von Frey Monofilaments, but the psychometric properties of these tests are never examined in stroke.

Assessing all modalities

Revised Nottingham sensory assessment scale (rNSA)

A large range of reliability scores in different body areas is found for each modality of the rNSA. The weak reliability scores may be due to the limited standardization of the protocol of the rNSA and the subjectivity of the examiner. The rNSA assumes that if sensation was present in the distal area of the limb, it would also be present proximally. This assumption for the protocol of the rNSA cannot be replied for the lower limb, because the subtest light touch of the ankle (κ= 0.16) and foot (κ= 0.46) is unreliable (Lincoln et al, 1998). In addition, the temperature subtest is also unreliable (κ= 0.10 to 0.53) and therefore should be omitted, although it is still frequently used in other studies.

Overall the rNSA has a moderate to high correlation with other somatosensory tests such as the FMA-s and RASP. There is a low correlation between ADL and motor performance tests. This can be explained

by the fact that patients with chronic stroke might learn other compensatory mechanisms, such as vision, for their limited somatosensory function. Another explanation can be that the NSA doesn't take account for the complex integration of the somatosensory system and the motor function. It is likely that an impaired score on a static light touch test doesn't correlate well with a dynamic grasping task.

There was only one study that investigated the responsiveness of the rNSA (Wu et al, 2016). The real change (e.g. Standard Response Mean) was only reported, and there was no study found that investigated the relevant change (e.g. Minimal Important Change). In the study only the pre-treatment scores below the maximum on any subscales of the rNSA were used to calculate the responsiveness. This can lead to an overestimation of the effect and wrong interpretation of the results.

There is also a significant ceiling-effect because 51.0% and 19.1% of the participants has achieved maximum scores on the proprioception and stereognosis subscales of the rNSA. This is probably due to the limited amounts of three categorical scores (absent, impaired and normal). Patients may have small somatosensory improvements but this is hard to distinguish within these scores. A larger, more subtle scoring is needed to prevent these floor- and ceiling-effects and to be able to detect little improvements. For example, the HASTe has a categorical scale with a range from zero to eighteen and the AsTex has a continuous scale. Both can be considered as alternatives.

Erasmus Modification of the Nottingham Sensory Assessment (EmNSA)

There was only one study investigating the reliability of the EmNSA (Stolk-Hornsveld et al., 2006). Overal there were high to moderate reliability except for the two-point discrimination subtest. However the two-point discrimination is not included on the definitive version of the EmNSA score sheet. In addition, the proprioception subtest was further standardized in comparison to the revised Nottingham Sensory Assessment (rNSA). This led to improved reliability. No special expensive equipment is required for the administration of the EmNSA. It is therefore a widespread used clinical assessment method for screening stroke population. The EmNSA only uses three categorical scales (absent, impaired and normal) and can only be used to give an overview of sensory impairments. Another limitation is that the reliability is only investigated in a small amount of stroke patients (Stolk-Hornsveld et al., 2006).

Fugl-Meyer Assessement (FMA-s)

The psychometric properties of the FMA-s were secondly most evaluated. The sensation subscale of the FMA evaluates light touch and position sense. There was only one study that investigated all psychometric properties of the FMA-s in patients with stroke. The correlation of the FMA-s with ADL and motor performance test was low. Low to moderate responsiveness and a significant ceiling effect was found for the FMA-s. This shows that the clinical use of the FMA-s in stroke patients is not recommended (Lin, Hsueh, Sheu, & Hsieh, 2004).

Rivermead Assessment of Somatosensory Performance (RASP)

The RASP assesses seven tests of somatosensory function and uses three custom-designed quantifiable pieces of equipment (Neurometer, Neurotemp and Two-point neurodiscriminator) that were especially developed for the RASP. High inter- and intra-rater agreement was found, but there were no individual scores for each subtest for inter-rater reliability reported, leaving a more specific interpretation impossible. On the sharp/dull subtest, the researchers introduced sham tests to identify and exclude patients whose performance might be considered affected by 'suggestibility', a lack of concentration and cognition. One study investigated the redundancy in the RASP. There is a high redundancy between anatomical areas. The study recommends that the palm of the hand, dorsum of the foot, thumb and the ankle should be the anatomical areas assessed at first. This will improve the usability of the RASP in clinical practice (Busse & Tyson, 2009). The RASP has a poor correlation with motor impairment and ADL. Responsiveness is not yet investigated for the RASP, hence clinical use is doubtful (Winward, Halligan, & Wade, 2002). Finally, the RASP also requires specific equipment and is relative expensive.

Touch and pressure

AsTex

The AsTex is a plastic strip printed with parallel vertical ridges and grooves that decline in width from left to right. Patients should slide their index finger along the surface and need to stop when the surface feels 'smooth'. The AsTex can be administered active or passive. Miller (2009) is the first study that documents normative values for texture discrimination of the fingertip. A minimum detectable change of 0.38 mm indicates a real change. This may be critical to keep track of the recovery and to evaluate which interventions are more effective (Miller, Martin, Wheat, & Goodwin, 2009).

Moving Touch-Pressure & Sustained Touch-Pressure (MTP & STP)

MTP evaluates the capacity to discriminate sensations in the hand generated by brushing movements. STP evaluates the manual ability to perceive a sustained touch pressure input by a light and heavy ball over time. Overall high intra-rater reliability is found for the MTP and STP (Dannnenbaum, Michaelsen, Desrosiers, & Levin, 2002). Moderate to high correlations were found between MTP, STP, HASTe and sensory outcomes, except for the Brief kinaesthesia Test. Again, poor correlations were found between the MTP, STP, Two-point discrimination test and motor function tests and ADL, except for the Brief kinaesthesia test. The major problem of the MTP and STP is the variability in the size of the skin surface stimulated by the brush and the amount of pressure applied to each brush and the speed of stimulus application. This leads to unstandardized measurements.

Proprioception

BKT

During the Brief kinaesthesia test, patients reproduce sliding movements of the index finger from a starting position to a target after being guided by the examiner. The BKT-score is the sum of the wrong distance from the target in centimetres for the two longest reaches. A primary limitation of the Brief kinaesthesia test is that poor reaching accuracy may be more due to limited motor function than impaired kinaesthetic function. Yet this limitation can be addressed by introducing a minimum score on a functional motor test. The major limitation is that the reliability is not yet investigated.

Stereognosis

Shape and texture identification test (STI test)

The Shape and texture identification test is used to assess stereognosis of the hand. It consists of two subtests: identification of shapes (cube, cylinder or hexagon) and identification of textures (one, two or three metal dots in a row). High reliability was found for the affected hand. The subtest shapes and texture showed respectively a moderate and high agreement. Other psychometric properties such as validity and responsiveness are not investigated. A negative of this test is that patients with no motor function in their affected hand cannot perform the test. Furthermore objects are not familiar to patients, compared to the subtest stereognosis of the rNSA (Ekstrand, Lexell, & Brogardh, 2016).

Combined modalities

HASTe

The HASTe is a functional measure of haptic perception of the hand. To complete the HASTe, patients need to use one hand to explore objects with a different weight and texture without vision. These object properties influence grip and load forces during grasping and lifting. A minimal motor function is necessary to complete the HASTe. The HASTe is a measure of the integrated ability to use the hand to obtain sensory information and therefore differs from for example the STP and Two-point discrimination test. Secondly it evaluates the entire hand, in comparison to the AsTex and BKT. The HASTe is a continuous scale that provides clinicians with more precise information about performance than a categorical measure like the rNSA (Williams, Basso, Case-Smith, & Nichols-Larsen, 2006). Finally, a weakness of the HASTe is the relative long administration time.

5.3. Reflection on the strengths and weaknesses of the literature study

A strength of this review is that other measurements, of which the psychometric properties were not investigated yet, were also included to give a provisional summary of the frequency of usage. Our research strategy was meant to give a clear overview of all the psychometric properties of somatosensory measurements. Thereby the review might not have included all articles that used

somatosensory measurements, because this was not the primary aim of the research. A clear description of the inclusion and exclusion criteria was used.
First, studies that used robotic instruments were not included in this review because they are not widely applicable yet and because of the lack of commercial availability. Therefore, recently developed technologic measurements were not described in this review. The second weakness is that there are often only one or two studies that are investigating the same measurement, which makes it harder to compare results of this measurement. In general, the sample sizes of the included studies were small. Eleven studies did not mention if there were any efforts made to address potential sources of bias, which can be seen as a weakness to the quality of the included studies. Another weakness is the limited number of studies that investigated psychometric properties of somatosensory measurements, especially for validity and responsiveness. There is a lack of correlation between different sensory measurements. There were also no values found of the area under the receiver operating characteristic curve (AUC) and the smallest real change (SRC).

5.4. Recommendations for further research and clinical practice

In order to improve future research on the psychometric properties of somatosensory measurements in a stroke population, several recommendations can be made. First, further research on the clinical properties of existing somatosensory measurements are necessary, because not all psychometric properties are fully documented. Secondly, further research needs to focus on adapting some tests, such as the rNSA, EmNSA, RASP and FMA-s, to improve the reliability, validity or responsiveness in stroke. For example, responsiveness of the RASP in stroke patients need to be investigated. In addition, recommendations are to determine which modality should be tested in each body part to achieve reliable and valid outcome measurements. Research needs to determine if a larger range of scores is plausible to detect little improvements of sensory recovery.

There are some new tests available that take the active behavioural aspect of somatosensation more into account, such as the AsTex, HASTe and Brief Kinaesthesia Test. Yet not all psychometric properties of these new tests are investigated, especially the correlation with other sensory and motor function tests.

Another major limitation of these clinical measurements is subjectivity of the examiner. Recent research suggests this can be resolved using robotic approaches (Rinderknecht et al., 2016). The reliability, validity and clinical utility of a robotic assessment measure in stroke patients will be investigate in the second part of this thesis. This study will be focus on evaluating the proprioception, an essential modality in activities of daily living (Rinderknecht et al., 2016).

Although the limited data, following recommendations can be made. First, the EmNSA is recommended as screening measure to give an overview of all sensory impairments in stroke, because this version is the most standardized compared to the rNSA. However the subtest stereognosis is not represented in

the EmNSA, therefore the stereognosis subtest of the rNSA could be added. It's important to keep in mind the responsiveness of the EmNSA and rNSA is weak or not reported. In addition a few tests can be added to obtain more information about the somatosensory function of one modality. The AsTex can be used to examine the touch threshold of a patient. Because of its continuous scale, it can offer more detailed information. If the reliability will be proven in future research, the Brief Kinaesthetic Test could test the proprioception in further detail.

6. Conclusion

This review may help clinicians and researchers in making the selection of appropriate somatosensory measurements, despite the limited availability amount of studies investigating the psychometric properties of these measures. No clear recommendations regarding a golden standard can be made yet.

7. List of references

(*) articles investigating psychometric properties

1. Ahmed, M. M. H., Kondeva, M., Al-Saed, M., Ramar, S. V., & Eyadeh, A. A. (2008). Our experience with posturography in hemiparetic patients after stroke in Kuwait. *Kuwait Medical Journal, 40*(1), 47-52.
2. Allen, C. L., & Bayraktutan, U. (2008). Risk factors for ischaemic stroke. *Int J Stroke, 3*(2), 105-116. doi:10.1111/j.1747-4949.2008.00187.x
3. Blennerhassett, J. M., Matyas, T. A., & Carey, L. M. (2007). Impaired Discrimination of Surface Friction Contributes to Pinch Grip Deficit After Stroke. *Neurorehabil Neural Repair, 21*(3), 263-272. doi:10.1177/1545968306295560
4. Bohls, C., & McIntyre, A. (2005). The effect of ice stimulation on sensory loss in chronic stroke patients - a feasibility study. *Physiotherapy, 91*(4), 237-241. doi:10.1016/j.physio.2005.02.001
5. (*) Borstad, A., Altenburger, A., Hannigan, A., LaPorte, J., Mott, R., & Nichols-Larsen, D. S. (2015). Design, Fabrication, and Administration of the Hand Active Sensation Test (HASTe). *J Vis Exp*(103). doi:10.3791/53178
6. (*) Borstad, A., & Nichols-Larsen, D. S. (2016). The Brief Kinesthesia test is feasible and sensitive: a study in stroke. *Braz J Phys Ther, 20*(1), 81-86. doi:10.1590/bjpt-rbf.2014.0132
7. Borstad, A. L., Bird, T., Choi, S., Goodman, L., Schmalbrock, P., & Nichols-Larsen, D. S. (2013). Sensorimotor training and neural reorganization after stroke: a case series. *J Neurol Phys Ther, 37*(1), 27-36. doi:10.1097/NPT.0b013e318283de0d
8. Bowden, J. L., Lin, G. G., & McNulty, P. A. (2014). The prevalence and magnitude of impaired cutaneous sensation across the hand in the chronic period post-stroke. *PLoS One, 9*(8), e104153. doi:10.1371/journal.pone.0104153
9. Broeks, J. G., Lankhorst, G. J., Rumping, K., & Prevo, A. J. (1999). The long-term outcome of arm function after stroke: results of a follow-up study. *Disabil Rehabil, 21*(8), 357-364.
10. Brogardh, C., & Sjolund, B. H. (2006). Constraint-induced movement therapy in patients with stroke: a pilot study on effects of small group training and of extended mitt use. *Clin Rehabil, 20*(3), 218-227. doi:10.1191/0269215506cr937oa
11. (*) Busse, M., & Tyson, S. F. (2009). How many body locations need to be tested when assessing sensation after stroke? An investigation of redundancy in the Rivermead Assessment of Somatosensory Performance. *Clin Rehabil, 23*(1), 91-95. doi:10.1177/0269215508097296
12. Byl, N., Roderick, J., Mohamed, O., Hanny, M., Kotler, J., Smith, A., . . . Abrams, G. (2003). Effectiveness of sensory and motor rehabilitation of the upper limb following the principles of neuroplasticity: patients stable poststroke. *Neurorehabil Neural Repair, 17*(3), 176-191. doi:10.1177/0888439003257137

13. Byl, N. N., Pitsch, E. A., & Abrams, G. M. (2008). Functional outcomes can vary by dose: learning-based sensorimotor training for patients stable poststroke. *Neurorehabil Neural Repair, 22*(5), 494-504. doi:10.1177/1545968308317431
14. Cambier, D. C., De Corte, E., Danneels, L. A., & Witvrouw, E. E. (2003). Treating sensory impairments in the post-stroke upper limb with intermittent pneumatic compression. Results of a preliminary trial. *Clin Rehabil, 17*(1), 14-20. doi:10.1191/0269215503cr580oa
15. Carey, L. M., & Matyas, T. A. (2005). Training of somatosensory discrimination after stroke: facilitation of stimulus generalization. *Am J Phys Med Rehabil, 84*(6), 428-442.
16. Carey, L. M., & Matyas, T. A. (2011). Frequency of discriminative sensory loss in the hand after stroke in a rehabilitation setting. *J Rehabil Med, 43*(3), 257-263. doi:10.2340/16501977-0662
17. Carey, L. M., Matyas, T. A., & Oke, L. E. (1993). Sensory loss in stroke patients: effective training of tactile and proprioceptive discrimination. *Arch Phys Med Rehabil, 74*(6), 602-611.
18. Carey, L. M., Matyas, T. A., & Oke, L. E. (2002). Evaluation of impaired fingertip texture discrimination and wrist position sense in patients affected by stroke: comparison of clinical and new quantitative measures. *J Hand Ther, 15*(1), 71-82.
19. (*) Carey, L. M., Oke, L. E., & Matyas, T. A. (1997). Impaired touch discrimination after stroke: A quantitative test. *Journal of Neurologic Rehabilitation, 11*(4), 219-232.
20. Chen, J. C., Liang, C. C., & Shaw, F. Z. (2005). Facilitation of sensory and motor recovery by thermal intervention for the hemiplegic upper limb in acute stroke patients: a single-blind randomized clinical trial. *Stroke, 36*(12), 2665-2669. doi:10.1161/01.STR.0000189992.06654.ab
21. Cohen J: Statistical Power Analysis for the Behavioral Sciences. Second edition. Hillsdale, NJ: Lawrence Earlbaum Associates; 1988.
22. Colomer, C., E, N. O., & Llorens, R. (2016). Mirror therapy in chronic stroke survivors with severely impaired upper limb function: a randomized controlled trial. *Eur J Phys Rehabil Med, 52*(3), 271-278.
23. (*) Connell, L. A., Lincoln, N. B., & Radford, K. A. (2008). Somatosensory impairment after stroke: frequency of different deficits and their recovery. *Clin Rehabil, 22*(8), 758-767. doi:10.1177/0269215508090674
24. Connell, L. A., McMahon, N. E., & Adams, N. (2014). Stroke survivors' experiences of somatosensory impairment after stroke: An Interpretative Phenomenological Analysis. *Physiotherapy, 100*(2), 150-155. doi:10.1016/j.physio.2013.09.003
25. (*) Dannenbaum, R. M., Michaelsen, S. M., Desrosiers, J., & Levin, M. F. (2002). Development and validation of two new sensory tests of the hand for patients with stroke. *Clin Rehabil, 16*(6), 630-639. doi:10.1191/0269215502cr532oa
26. de Almeida Oliveira, R., Cintia Dos Santos Vieira, P., Rodrigues Martinho Fernandes, L. F., Patrizzi, L. J., Ferreira de Oliveira, S., & Pascucci Sande de Souza, L. A. (2014). Mental practice and mirror therapy associated with conventional physical therapy training on the hemiparetic upper limb in poststroke rehabilitation: a preliminary study. *Top Stroke Rehabil, 21*(6), 484-494. doi:10.1310/tsr2106-484

27. de Diego, C., Puig, S., & Navarro, X. (2013). A sensorimotor stimulation program for rehabilitation of chronic stroke patients. *Restor Neurol Neurosci, 31*(4), 361-371. doi:10.3233/rnn-120250
28. DeJong, R. N. (1979). *The Neurologic Examination.* Philadelphia, PA: Harper & Row.
29. (*) Deshpande, N., Metter, E. J., & Ferrucci, L. (2010). Validity of clinically derived cumulative somatosensory impairment index. *Arch Phys Med Rehabil, 91*(2), 226-232. doi:10.1016/j.apmr.2009.10.006
30. Dohle, C., Pullen, J., Nakaten, A., Kust, J., Rietz, C., & Karbe, H. (2009). Mirror therapy promotes recovery from severe hemiparesis: a randomized controlled trial. *Neurorehabil Neural Repair, 23*(3), 209-217. doi:10.1177/1545968308324786
31. Doyle, S., Bennett, S., Fasoli, S. E., & McKenna, K. T. (2010). Interventions for sensory impairment in the upper limb after stroke. *Cochrane Database Syst Rev*(6), Cd006331. doi:10.1002/14651858.CD006331.pub2
32. Doyle, S., Bennett, S., & Gustafsson, L. (2013). Occupational therapy for upper limb post-stroke sensory impairments: a survey. *British Journal of Occupational Therapy, 76*(10), 434-442. doi:10.4276/030802213x13807217284143
33. Duff, M., Chen, Y., Cheng, L., Liu, S. M., Blake, P., Wolf, S. L., & Rikakis, T. (2013). Adaptive mixed reality rehabilitation improves quality of reaching movements more than traditional reaching therapy following stroke. *Neurorehabil Neural Repair, 27*(4), 306-315. doi:10.1177/1545968312465195
34. (*) Ekstrand, E., Lexell, J., & Brogardh, C. (2016). Test-retest reliability of the Shape/Texture Identification testTM in people with chronic stroke. *Clin Rehabil, 30*(11), 1120-1127. doi:10.1177/0269215515608512
35. G. Broeks, J., Lankhorst, G. J., Rumping, K., & Prevo, A. J. H. (1999). The long-term outcome of arm function after stroke: results of a follow-up study. *Disabil Rehabil, 21*(8), 357-364. doi:10.1080/096382899297459
36. (*) Gaubert, C. S., & Mockett, S. P. (2000). Inter-rater reliability of the Nottingham method of stereognosis assessment. *Clin Rehabil, 14*(2), 153-159. doi:10.1191/026921500677422368
37. Halligan, P. W., Marshall, J. C., Hunt, M., & Wade, D. T. (1997). Somatosensory assessment: can seeing produce feeling? *J Neurol, 244*(3), 199-203. doi:10.1007/s004150050073
38. Harris, J. E., & Eng, J. J. (2006). Individuals with the dominant hand affected following stroke demonstrate less impairment than those with the nondominant hand affected. *Neurorehabil Neural Repair, 20*(3), 380-389. doi:10.1177/1545968305284528
39. Harris, J. E., & Eng, J. J. (2007). Paretic upper-limb strength best explains arm activity in people with stroke. *Phys Ther, 87*(1), 88-97. doi:10.2522/ptj.20060065
40. Hasan, M., Whiteley, J., Bresnahan, R., MacIver, K., Sacco, P., Das, K., & Nurmikko, T. (2014). Somatosensory change and pain relief induced by repetitive transcranial magnetic stimulation in patients with central poststroke pain. *Neuromodulation, 17*(8), 731-736; discussion 736. doi:10.1111/ner.12198

41. Hedman, L. D., & Sullivan, J. E. (2011). An initial exploration of the perceptual threshold test using electrical stimulation to measure arm sensation following stroke. *Clin Rehabil, 25*(11), 1042-1049. doi:10.1177/0269215511399475
42. Helliwell, S. (2009). Does the Use of a Sensory Re-Education Programme Improve the Somatosensory and Motor Function of the Upper Limb in Subacute Stroke? A Single Case Experimental Design. *British Journal of Occupational Therapy, 72*(12), 551-558. doi:10.4276/030802209X12601857794853
43. Hermsdörfer, J., Hagl, E., Nowak, D. A., & Marquardt, C. (2003). Grip force control during object manipulation in cerebral stroke. *Clinical Neurophysiology, 114*(5), 915-929. doi:http://dx.doi.org/10.1016/S1388-2457(03)00042-7
44. Hill, V. A., Fisher, T., Schmid, A. A., Crabtree, J., & Page, S. J. (2014). Relationship between touch sensation of the affected hand and performance of valued activities in individuals with chronic stroke. *Top Stroke Rehabil, 21*(4), 339-346. doi:10.1310/tsr2104-339
45. Jang, S. H. (2011). Contra-lesional somatosensory cortex activity and somatosensory recovery in two stroke patients. *J Rehabil Med, 43*(3), 268-270. doi:10.2340/16501977-0654
46. Jang, S. H., Chang, C. H., Kim, S. H., Jung, Y. J., & Hong, J. H. (2015). Thalamic Reorganization in Chronic Patients With Intracerebral Hemorrhage: A Retrospective Cross-Sectional Study. *Medicine (Baltimore), 94*(34), e1391. doi:10.1097/md.0000000000001391
47. Jang, S. H., & Lee, M. Y. (2013). Correlation between somatosensory function and cortical activation induced by touch stimulation in patients with intracerebral hemorrhage. *Int J Neurosci, 123*(4), 248-252. doi:10.3109/00207454.2012.755968
48. Kaste, M., Fogelholm, R., & Rissanen, A. (1998). Economic burden of stroke and the evaluation of new therapies. *Public Health, 112*(2), 103-112. doi:http://dx.doi.org/10.1038/sj.ph.1900422
49. Kattenstroth, J. C., Kalisch, T., Kowalewski, R., Tegenthoff, M., & Dinse, H. R. (2013). Quantitative assessment of joint position sense recovery in subacute stroke patients: a pilot study. *J Rehabil Med, 45*(10), 1004-1009. doi:10.2340/16501977-1225
50. Kessner, S. S., Bingel, U., & Thomalla, G. (2016). Somatosensory deficits after stroke: a scoping review. *Top Stroke Rehabil, 23*(2), 136-146. doi:10.1080/10749357.2015.1116822
51. Krewer, C., Hartl, S., Muller, F., & Koenig, E. (2014). Effects of repetitive peripheral magnetic stimulation on upper-limb spasticity and impairment in patients with spastic hemiparesis: a randomized, double-blind, sham-controlled study. *Arch Phys Med Rehabil, 95*(6), 1039-1047. doi:10.1016/j.apmr.2014.02.003
52. Kumar, A., Bhoi, S. K., Kalita, J., & Misra, U. K. (2016). Central Poststroke Pain Can Occur With Normal Sensation. *Clin J Pain, 32*(11), 955-960. doi:10.1097/ajp.0000000000000344
53. Lamers, I., Kelchtermans, S., Baert, I., & Feys, P. (2014). Upper limb assessment in multiple sclerosis: a systematic review of outcome measures and their psychometric properties. *Arch Phys Med Rehabil, 95*(6), 1184-1200. doi:10.1016/j.apmr.2014.02.023

54. Lee, K. B., Kim, J. S., Hong, B. Y., Kim, Y. D., Hwang, B. Y., & Lim, S. H. (2015). The motor recovery related with brain lesion in patients with intracranial hemorrhage. *Behav Neurol, 2015*, 258161. doi:10.1155/2015/258161
55. Lee, K. B., Kim, J. S., Hong, B. Y., & Lim, S. H. (2017). Clinical recovery from stroke lesions and related outcomes. *J Clin Neurosci, 37*, 79-82. doi:10.1016/j.jocn.2016.11.008
56. Lee, K. B., Lim, S. H., Kim, K. H., Kim, K. J., Kim, Y. R., Chang, W. N., . . . Hwang, B. Y. (2015). Six-month functional recovery of stroke patients: a multi-time-point study. *Int J Rehabil Res, 38*(2), 173-180. doi:10.1097/mrr.0000000000000108
57. Leibowitz, N., Levy, N., Weingarten, S., Grinberg, Y., Karniel, A., Sacher, Y., . . . Soroker, N. (2008). Automated measurement of proprioception following stroke. *Disabil Rehabil, 30*(24), 1829-1836. doi:10.1080/09638280701640145
58. Lima, N. M., Menegatti, K. C., Yu, E., Sacomoto, N. Y., Scalha, T. B., Lima, I. N., . . . Honorato, D. C. (2015). Sensory deficits in ipsilesional upper-extremity in chronic stroke patients. *Arq Neuropsiquiatr, 73*(10), 834-839. doi:10.1590/0004-282x20150128
59. (*) Lin, J. H., Hsueh, I. P., Sheu, C. F., & Hsieh, C. L. (2004). Psychometric properties of the sensory scale of the Fugl-Meyer Assessment in stroke patients. *Clin Rehabil, 18*(4), 391-397. doi:10.1191/0269215504cr737oa
60. (*) Lincoln, N. B., Crow, J. L., Jackson, J. M., Waters, G. R., Adams, S. A., & Hodgson, P. (1991). The unreliability of sensory assessments. *Clin Rehabil, 5*(4), 273-282. doi:10.1177/026921559100500403
61. (*) Lincoln, N. B., Jackson, J. M., & Adams, S. A. (1998). Reliability and Revision of the Nottingham Sensory Assessment for Stroke Patients. *Physiotherapy, 84*(8), 358-365. doi:http://dx.doi.org/10.1016/S0031-9406(05)61454-X
62. Lindgren, I., Ekstrand, E., & Brogardh, C. (2016). Measurement variability of quantitative sensory testing in persons with post-stroke shoulder pain. *J Rehabil Med, 48*(5), 435-441. doi:10.2340/16501977-2180
63. Lindgren, I., Ekstrand, E., Lexell, J., Westergren, H., & Brogardh, C. (2014). SOMATOSENSORY IMPAIRMENTS ARE COMMON AFTER STROKE BUT HAVE ONLY A SMALL IMPACT ON POST-STROKE SHOULDER PAIN. *J Rehabil Med, 46*(4), 307-313. doi:10.2340/16501977-1274
64. Liu, W., Lipsitz, L. A., Montero-Odasso, M., Bean, J., Kerrigan, D. C., & Collins, J. J. (2002). Noise-enhanced vibrotactile sensitivity in older adults, patients with stroke, and patients with diabetic neuropathy. *Arch Phys Med Rehabil, 83*(2), 171-176.
65. Lynch, E. A., Hillier, S. L., Stiller, K., Campanella, R. R., & Fisher, P. H. (2007). Sensory retraining of the lower limb after acute stroke: a randomized controlled pilot trial. *Arch Phys Med Rehabil, 88*(9), 1101-1107. doi:10.1016/j.apmr.2007.06.010
66. Mann, G. E., Burridge, J. H., Malone, L. J., & Strike, P. W. (2005). A pilot study to investigate the effects of electrical stimulation on recovery of hand function and sensation in subacute stroke patients. *Neuromodulation, 8*(3), 193-202. doi:10.1111/j.1525-1403.2005.05238.x

67. McDowell I. (2006). *Measuring health: a guide to rating scales and questionnaires.* New York: Oxford Univ Pr.
68. (*) Meyer, S., De Bruyn, N., Lafosse, C., Van Dijk, M., Michielsen, M., Thijs, L., . . . Verheyden, G. (2016). Somatosensory Impairments in the Upper Limb Poststroke: Distribution and Association With Motor Function and Visuospatial Neglect. *Neurorehabil Neural Repair, 30*(8), 731-742. doi:10.1177/1545968315624779
69. Meyer, S., Karttunen, A. H., Thijs, V., Feys, H., & Verheyden, G. (2014). How Do Somatosensory Deficits in the Arm and Hand Relate to Upper Limb Impairment, Activity, and Participation Problems After Stroke? A Systematic Review. *Phys Ther, 94*(9), 1220-1231. doi:10.2522/ptj.20130271
70. (*) Miller, K. J., Phillips, B. A., Martin, C. L., Wheat, H. E., Goodwin, A. W., & Galea, M. P. (2009). The AsTex: clinimetric properties of a new tool for evaluating hand sensation following stroke. *Clin Rehabil, 23*(12), 1104-1115. doi:10.1177/0269215509342331
71. Parsons, S. L., Mansfield, A., Inness, E. L., & Patterson, K. K. (2016). The relationship of plantar cutaneous sensation and standing balance post-stroke. *Top Stroke Rehabil, 23*(5), 326-332. doi:10.1080/10749357.2016.1162396
72. Penta, M., Tesio, L., Arnould, C., Zancan, A., & Thonnard, J. L. (2001). The ABILHAND questionnaire as a measure of manual ability in chronic stroke patients: Rasch-based validation and relationship to upper limb impairment. *Stroke, 32*(7), 1627-1634.
73. Portney, L. G., & Watkins, M. P. (2009). *Foundations of clinical research: Applications to practice.* Upper Saddle River, N.J: Pearson/Prentice Hall.
74. Pumpa, L. U., Cahill, L. S., & Carey, L. M. (2015). Somatosensory assessment and treatment after stroke: An evidence-practice gap. *Aust Occup Ther J, 62*(2), 93-104. doi:10.1111/1440-1630.12170
75. Raghavan, P., Geller, D., Guerrero, N., Aluru, V., Eimicke, J. P., Teresi, J. A., . . . Turry, A. (2016). Music Upper Limb Therapy-Integrated: An Enriched Collaborative Approach for Stroke Rehabilitation. *Front Hum Neurosci, 10*, 498. doi:10.3389/fnhum.2016.00498
76. Reding, M. J., & Potes, E. (1988). Rehabilitation outcome following initial unilateral hemispheric stroke. Life table analysis approach. *Stroke, 19*(11), 1354-1358.
77. Rinderknecht, M. D., Popp, W. L., Lambercy, O., & Gassert, R. (2016). Reliable and Rapid Robotic Assessment of Wrist Proprioception Using a Gauge Position Matching Paradigm. Frontiers in Human Neuroscience, 10, 316. http://doi.org/10.3389/fnhum.2016.00316
78. Roosink, M., Renzenbrink, G. J., Buitenweg, J. R., van Dongen, R. T., Geurts, A. C., & Ijzerman, M. J. (2011). Somatosensory symptoms and signs and conditioned pain modulation in chronic post-stroke shoulder pain. *J Pain, 12*(4), 476-485. doi:10.1016/j.jpain.2010.10.009
79. Roosink, M., Van Dongen, R. T., Buitenweg, J. R., Renzenbrink, G. J., Geurts, A. C., & MJ, I. J. (2012). Multimodal and widespread somatosensory abnormalities in persistent shoulder pain in the first 6 months after stroke: an exploratory study. *Arch Phys Med Rehabil, 93*(11), 1968-1974. doi:10.1016/j.apmr.2012.05.019
80. Rosamond, W., Flegal, K., Furie, K., Go, A., Greenlund, K., Haase, N., . . . Hong, Y. (2008). Heart disease and stroke statistics--2008 update: a report from the American Heart Association Statistics

Committee and Stroke Statistics Subcommittee. *Circulation, 117*(4), e25-146. doi:10.1161/circulationaha.107.187998

81. Saeys, W., Vereeck, L., Truijen, S., Lafosse, C., Wuyts, F. P., & Van de Heyning, P. (2012). Influence of sensory loss on the perception of verticality in stroke patients. *Disabil Rehabil, 34*(23), 1965-1970. doi:10.3109/09638288.2012.671883
82. (*) Sanford, J., Moreland, J., Swanson, L. R., Stratford, P. W., & Gowland, C. (1993). Reliability of the Fugl-Meyer assessment for testing motor performance in patients following stroke. *Phys Ther, 73*(7), 447-454.
83. Schaechter, J. D., van Oers, C. A., Groisser, B. N., Salles, S. S., Vangel, M. G., Moore, C. I., & Dijkhuizen, R. M. (2012). Increase in sensorimotor cortex response to somatosensory stimulation over subacute poststroke period correlates with motor recovery in hemiparetic patients. *Neurorehabil Neural Repair, 26*(4), 325-334. doi:10.1177/1545968311421613
84. Scholz, D. S., Rohde, S., Nikmaram, N., Bruckner, H. P., Grossbach, M., Rollnik, J. D., & Altenmuller, E. O. (2016). Sonification of Arm Movements in Stroke Rehabilitation - A Novel Approach in Neurologic Music Therapy. *Front Neurol, 7*, 106. doi:10.3389/fneur.2016.00106
85. Sens, E., Knorr, C., Preul, C., Meissner, W., Witte, O. W., Miltner, W. H., & Weiss, T. (2013). Differences in somatosensory and motor improvement during temporary functional deafferentation in stroke patients and healthy subjects. *Behav Brain Res, 252*, 110-116. doi:10.1016/j.bbr.2013.05.048
86. Seo, J. P., & Jang, S. H. (2014). RECOVERY OF AN INJURED MEDIAL LEMNISCUS PATHWAY IN A PATIENT WITH INTRACEREBRAL HAEMORRHAGE. *J Rehabil Med, 46*(5), 475-478. doi:10.2340/16501977-1796
87. Smania, N., Montagnana, B., Faccioli, S., Fiaschi, A., & Aglioti, S. M. (2003). Rehabilitation of somatic sensation and related deficit of motor control in patients with pure sensory stroke. *Arch Phys Med Rehabil, 84*(11), 1692-1702.
88. Sommerfeld, D. K., Johansson, H., Jonsson, A. L., Murray, V., Wessari, T., Holmqvist, L. W., & von Arbin, M. (2011). Rivermead mobility index can be used to predict length of stay for elderly persons, 5 days after stroke onset. *J Geriatr Phys Ther, 34*(2), 64-71. doi:10.1519/JPT.0b013e3181ffb70d
89. Sommerfeld, D. K., & von Arbin, M. H. (2004). The impact of somatosensory function on activity performance and length of hospital stay in geriatric patients with stroke. *Clin Rehabil, 18*(2), 149-155. doi:10.1191/0269215504cr710oa
90. (*) Stolk-Hornsveld, F., Crow, J. L., Hendriks, E. P., van der Baan, R., & Harmeling-van der Wel, B. C. (2006). The Erasmus MC modifications to the (revised) Nottingham Sensory Assessment: a reliable somatosensory assessment measure for patients with intracranial disorders. *Clin Rehabil, 20*(2), 160-172. doi:10.1191/0269215506cr932oa
91. Sullivan, K. J., Tilson, J. K., Cen, S. Y., Rose, D. K., Hershberg, J., Correa, A., . . . Duncan, P. W. (2011). Fugl-Meyer assessment of sensorimotor function after stroke: standardized training procedure for clinical practice and clinical trials. *Stroke, 42*(2), 427-432. doi:10.1161/strokeaha.110.592766

92. Truelsen, T., Piechowski-Jozwiak, B., Bonita, R., Mathers, C., Bogousslavsky, J., & Boysen, G. (2006). Stroke incidence and prevalence in Europe: a review of available data. Eur J Neurol, 13(6), 581-598. doi:10.1111/j.1468-1331.2006.01138.x
93. Tyson, S. F., Hanley, M., Chillala, J., Selley, A. B., & Tallis, R. C. (2008). Sensory loss in hospital-admitted people with stroke: characteristics, associated factors, and relationship with function. *Neurorehabil Neural Repair, 22*(2), 166-172. doi:10.1177/1545968307305523
94. Valentini, M., Kischka, U., & Halligan, P. W. (2008). Residual haptic sensation following stroke using ipsilateral stimulation. *J Neurol Neurosurg Psychiatry, 79*(3), 266-270. doi:10.1136/jnnp.2007.120279
95. (*) Williams, P. S., Basso, D. M., Case-Smith, J., & Nichols-Larsen, D. S. (2006). Development of the Hand Active Sensation Test: reliability and validity. *Arch Phys Med Rehabil, 87*(11), 1471-1477. doi:10.1016/j.apmr.2006.08.019
96. Winters, C., Kwakkel, G., Nijland, R., & van Wegen, E. (2016). When Does Return of Voluntary Finger Extension Occur Post-Stroke? A Prospective Cohort Study. *PLoS One, 11*(8), e0160528. doi:10.1371/journal.pone.0160528
97. Winward, C. E., Halligan, P. W., & Wade, D. T. (1999). Current practice and clinical relevance of somatosensory assessment after stroke. *Clin Rehabil, 13*(1), 48-55. doi:10.1177/026921559901300107
98. (*) Winward, C. E., Halligan, P. W., & Wade, D. T. (2002). The Rivermead Assessment of Somatosensory Performance (RASP): standardization and reliability data. *Clin Rehabil, 16*(5), 523-533. doi:10.1191/0269215502cr522oa
99. Winward, C. E., Halligan, P. W., & Wade, D. T. (2007). Somatosensory recovery: a longitudinal study of the first 6 months after unilateral stroke. *Disabil Rehabil, 29*(4), 293-299. doi:10.1080/09638280600756489
100. Wolny, T., Saulicz, E., Gnat, R., & Kokosz, M. (2010). Butler's neuromobilizations combined with proprioceptive neuromuscular facilitation are effective in reducing of upper limb sensory in late-stage stroke subjects: a three-group randomized trial. *Clin Rehabil, 24*(9), 810-821. doi:10.1177/0269215510367561
101. WorldHealthOrganization-WHO. The World Health Report 2008: Primary Health care: now more than ever. Geneva; 2008 [cited 2010 Sept 7]. Available from: http://ww.who.org.
102. (*) Wu, C. Y., Chuang, I. C., Ma, H. I., Lin, K. C., & Chen, C. L. (2016). Validity and Responsiveness of the Revised Nottingham Sensation Assessment for Outcome Evaluation in Stroke Rehabilitation. *Am J Occup Ther, 70*(2), 7002290040p7002290041-7002290048. doi:10.5014/ajot.2016.018390
103. Wu, C. Y., Huang, P. C., Chen, Y. T., Lin, K. C., & Yang, H. W. (2013). Effects of mirror therapy on motor and sensory recovery in chronic stroke: a randomized controlled trial. *Arch Phys Med Rehabil, 94*(6), 1023-1030. doi:10.1016/j.apmr.2013.02.007
104. Yeldan, I., Huseyinsinoglu, B. E., Akinci, B., Tarakci, E., Baybas, S., & Ozdincler, A. R. (2015). The effects of very early mirror therapy on functional improvement of the upper extremity in acute stroke patients. *J Phys Ther Sci, 27*(11), 3519-3524. doi:10.1589/jpts.27.3519

10. Appendices part I – overview of the literature

Table 1: Overview of number of hits for different combinations of search terms

	Key-words and Mesh-terms in PubMed	Hits from 1990-01-01 to 2016-12-31	Hits from 1990-01-01 to 2017-04-30
#1	Somatosensory [Title/Abstract]	20696	21142
#2	Somatosensory disorder [Mesh]	15392	15593
#3	Sensation [Title/Abstract]	25000	25572
#4	Sensory [Title/Abstract]	125340	128204
#5	Stroke [Title/Abstract]	168648	173650
#6	Poststroke [Title/Abstract]	3634	3769
#7	Evoked potentials [Title/abstract]	18665	18957
#8	Neurophysiology [Title/abstract]	4580	4772
#9	Nerve stimulation [Title/abstract]	13346	13588
#10	Robot [Title/abstract]	11420	11869
#11	Robotic [Title/abstract]	17470	18292
#12	Vestibular [Title/abstract]	22838	23325
#13	Medication [Title/abstract]	150154	154252
#14	Eye movements [Title/abstract]	11967	12262
#15	Outcome measures [Title/abstract]	125509	128507
#16	Assessment [Title/abstract]	665163	684967
#17	Evaluation [Title/abstract]	792769	812253
#18	Psychometrics [Title/abstract]	1883	2057
#19	Reliability [Title/abstract]	112906	116114
#20	Test-retest [Title/abstract]	18578	19145
#21	Validity [Title/abstract]	122130	125470
#22	Responsiveness [Title/abstract]	69327	70476
#23	(#1 OR #2 OR #3 OR #4)	171575	175080
#24	(#5 OR #6)	169298	174206
#25	(#7 OR #8 OR #9 OR #10 #11 OR #12 OR #13 OR #14)	260564	267432
#26	(#15 OR #16 OR #17 OR #18 #19 OR #20 OR #21 OR #22)	2399042	2443440
#27	#23 AND #24 NOT#25 AND #26	632	649

	Key-words and Mesh-terms in Web of Science	Hits from 1990-01-01 to 2016-12-31	Hits from 1990-01-01 to 2017-05-29
#1	Somatosensory [Topic]	28065	28,654
#2	Sensation [Topic]	37635	38,809
#3	Sensory [Topic]	185315	190,148
#4	Stroke [Topic]	240603	248,627
#5	Poststroke [Topic]	6246	6,515
#6	Evoked potentials [Topic]	58661	59,793
#7	Neurophysiology [Topic]	10290	10,514
#8	Nerve stimulation [Topic]	53508	54,453
#9	Robot [Topic]	140340	146,640
#10	Robotic [Topic]	83437	87,441
#11	Vestibular [Topic]	24244	24,802
#12	Medication [Topic]	201538	209,047
#13	Eye movements [Topic]	46248	47,536
#14	Outcome measures [Topic]	330424	343,046
#15	Assessment [Topic]	1116485	1,160,353
#16	Evaluation [Topic]	1464660	1,514,235
#17	Psychometrics [Topic]	4791	5,038
#18	Reliability [Topic]	388411	402,663
#19	Test-retest [Topic]	20300	21,028
#20	Validity [Topic]	305051	315,728
#21	Responsiveness [Topic]	94643	96,616
#22	(#1 OR #2 OR #3)	233791	239,943
#23	(#4 OR #5)	241520	249,571
#24	(#6 OR #7 OR #8 OR #9 #10 OR #11 OR #12 OR #13)	578621	598,906
#25	(#14 OR #15 OR #16 OR #17 OR #18 #19 OR #20 OR #21)	3226244	3,339,930
#26	#22 AND #23 NOT #24 AND #25	781	805

Table 2: Reason of exclusion

Reason of exclusion	Number of studies	Autor(s), year
Review	4	(Borstad & Nichols-Larsen, 2014; Carey, Lamp, & Turville, 2016; Doyle, Bennett, Fasoli, & McKenna, 2010; Sullivan & Hedman, 2008)
Spanish	1	(Diaz-Arribas, Pardo-Hervas, Tabares-Lavado, Rios-Lago, & Maestu, 2006)
Animals	25	(Komotar et al., 2007; Balkaya & Endres, 2010; Balkaya, Krober, Gertz, Peruzzaro, & Endres, 2013; Balkaya, Krober, Rex, & Endres, 2013; J. L. Chen, M. Chopp, & Y. Li, 1999; B. Wali, T. Ishrat, D. G. Stein, & L. Sayeed, 2016; Dong & Fong, 2016; De Vloo, Morlion, van Loon, & Nuttin, 2017;Demers, McPherson, & Juul, 2005; S. M. Fleming & Schallert, 2011; Freret et al., 2006; A. J. Hunter et al., 2000; H. S. Kim et al., 2014; Knapp et al., 2015; Linden, Fassotte, Tirelli, Plumier, & Ferrara, 2014; Marshall & Ridley, 1996; Mendez-Gallardo & Robinson, 2010; Menezes et al., 2017; Pindolia et al., 2012; Schallert, Fleming, Leasure, Tillerson, & Bland, 2000; Soleman, Yip, Leasure, & Moon, 2010; Tajima et al., 2014; S. Wang et al., 2013; Wei, Ren, Chen, & Zhao, 2012; Yousuf, Atif, Sayeed, Wang, & Stein, 2016;)
Robots	4	(Coscia, Monaco, Capogrosso, Chisari, & Micera, 2011; Fluet, Lambercy, & Gassert, 2011;Liu, Ma, Gu, Wu, & Lv, 2016; Yu, Wang, Liu, & Ieee, 2014)
No stroke population (Multiple sclerosis, Cerebral palsy, Spinal cord injury, etc.),	95	(Arboix, Massons, Garcia-Eroles, Oliveres, & Targa, 2000; Assaad-Khalil, Zaki, Rehim, et al., 2015; Antonic et al., 2013; Auld, Boyd, Moseley, Ware, & Johnston, 2012; Barone et al., 1991; Bastounis, Bakoylannis, et al., 2007; Beric, 1993; Birbeck et al., 2010; Blomqvist, Wester, Sundelin, & Rehn, 2012; Boccard, Pereira, & Aziz, 2015; Bonilla et al., 2012; Boninger, Impink, Cooper, & Koontz, 2004; Borisoff, Elliott, Hocaloski, & Birch, 2010; Bowden & McNulty, 2013; Brady & Garcia, 2009; Breningstall, 1999; Brogardh, Johansson, Nygren, & Sjolund, 2010; Buchanan, Darrow, Monsivais, Nadasdy, & Gjini, 2014; N. Byl, Zhang, Coo, & Tomizuka, 2015; P. Chen, Ward, Khan, Liu, & Hreha, 2016; Claydon & Krassioukov, 2006; Colagiuri, Cull, & Holman, 2002; Cooper & Rose, 2000; Corriveau, Hebert, Raiche, & Prince, 2004; Corriveau, Hebert, Raiche, & Prince, 2004; Culp et al., 2013; Daviet, Salle, et al., 2002; de Kloet, Gijzen, Braga, Meesters, Schoones, & Vlieland, 2015; Dohare, Garg, Jain, Nath, & Ray, 2008; Donat et al., 2016; Ferrel-Chapus, Hay, Olivier, Bard, & Fleury, 2002; Forsberg et al., 2004; Foster, DeMark, Spigel, Rose, & Fox, 2016; Fusco et al., 2009; Hanbali, Fuller, Leeds, & Sawaya,

		2001; Harel et al., 2013; Jang, Park, & Kwon, 2016; Jaspers, Byblow, Feys, & Wenderoth, 2015; Jensen, Kvale, & Baerheim, 2008; Katayama et al., 2001; Klein et al., 2004; Koch, Thomas, Tschope, & Ritz, 1993; Koniakgriffin, Ludingtonhoe, & Verzemnieks, 1995; R. Kumar et al., 2016; Landi et al., 2002; Liao, Yang, Wu, & Wang, 2014; Lindroth, Sullivan, & Silkwood-Sherer, 2015; Lipsitz, Jonsson, Kelley, & Koestner, 1991; Lofgren, Lenholm, Conradsson, Stahle, & Franzen, 2014; Maenpaa, Jaakkola, Sandstrom, Airi, & von Wendt, 2004; Miloro & Repasky, 2000; Murphy et al., 2015; S. Nadeau, Arsenault, Gravel, & Bourbonnais, 1999; Nelson & Wu, 2017; Ness & Field-Fote, 2009; Overholser & Schubert, 1993; Pardasaney et al., 2013; Pastre et al., 2011; Phillips, Robertson, Killen, & White, 2012; Phua, McGarvey, Ngu, & Ing, 2005; Pinol, Ramirez, Salo, Ros, & Blanch, 2013; Porosinska, Pierzchala, Mentel, & Karpe, 2010; Pullicino, Benedict, Capruso, Vella, WithiamLeitch, et al., 1996; Rasche, Rinaldi, Young, & Tronnier, 2006; Rolland et al., 2004; Romkes & Schweizer, 2015; Rossignol & Rossignol, 2006; Ruffieux et al., 2013; Rutner, Ziccardi, & Janal, 2005; Sauvaget, Yamada, Fujiwara, Sasaki, & Mimori, 2002; Schott & Korbus, 2014; Schroder et al., 2007; Sharma et al., 2015; Shepard & Bracken, 1999; Sinanovic et al., 2015; Smart, Wand, & O'Connell, 2016; So et al., 2011; Sousa et al., 2009; Stratton et al., 2000; B. H. Svensson, Christiansen, & Jepsen, 1992; E. Svensson & Hager-Ross, 2006; Svensson, Graven-Nielsen, & Arendt-Nielsen, 1998; Tamburella, Scivoletto, & Molinari, 2014; Tay et al., 2006a; Teunissen, Eurelings, Notermans, Hop, & van Gijn, 2000; Thimineur, Sood, Kravitz, Gudin, & Kitaj, 1998; D. M. Thompson, 2003; Thoumie, Lamotte, Cantalloube, Faucher, & Amarenco, 2005; Tuttolomondo et al., 2013; Uszynski, Purtill, Donnelly, & Coote, 2016; Wasner, Schattschneider, Binder, & Baron, 2003; Wittich, Barstow, Jarry, & Thomas, 2015; Wudel, Novis, Baker, Kim, & Moyer, 2016; Yancosek & Howell, 2011; J. F. Yang et al., 2013; L. Y. Yang et al., 2015; Zhang, Meng, Lu, Liu, & Huang, 2017; Zuniga, 2015)
No somatosensory measurements.	751	(Ab Patar et al., 2014; Abbasi-Kesbi, Nikfarjam, & Memarzadeh-Tehran, 2017; Abode-Iyamah et al., 2016; Ackerley, Carlsson, Wester, Olausson, & Wasling, 2014; Adachi, Hosoya, & Yamaguchi, 1996; Adinolfi et al., 2015; Afzal, Oh, Choi, & Yoon, 2016; Aichner, Adelwohrer, & Haring, 2002; Alcan, Canal, & Zinnuroglu, 2017; Allison, Shenton, Bamforth, Kilbride, & Richards, 2016; O. P. Almeida, Alfonso, Yeap, Hankey, & Flicker, 2013; Q. J. Almeida, Black, & Roy, 2002; Altamura et al., 2007; Altmann, Thommessen, Ronning, Reichenbach, & Fure, 2014; Alves-Pinto et al., 2015; Aman, Elangovan, Yeh, & Konczak, 2014; Amort et al., 2011; Anderson, Smith, Ido, & Frankel, 2013; Androfagina, Kuznetsova, & Svetkina, 2015; Aoyagi, Liu, Tsujiuchi, Tsuji, &

		Chino, 1997; Appasamy et al., 2015; Appelros & Terent, 2004; Aprile, Briani, Pazzaglia, Cecchi, Negrini, Padua, et al., 2015; Aruin, 2005; Ashioti et al., 2009; Assenza et al., 2009; Aviv et al., 1997; Azouvi, Jacquin-Courtois, & Luaute, 2016; Backus et al., 2014; Badke, Sherman, Boyne, Page, & Dunning, 2011; O. N. Bae et al., 2013; S. Bae & Kim, 2017; Baggerly, 1991; Bagley, Hudson, Forster, Smith, & Young, 2005; Bai, Cui, Zou, & Lao, 2013; Bailey, Riddoch, & Crome, 2000; Balucani et al., 2015; Baratta & Solomonow, 1992; Bard, Fleury, & Ferrel, 2002; Baron, Binder, & Wasner, 2010; Barrass, 2008; Barreca, Finlayson, Gowland, & Basmajian, 1999; Barrett et al., 2006; Bartha-Doering, Deuster, Giordano, Zehnhoff-Dinnesen, & Dobel, 2015; Baskett, Marshall, Broad, Owen, & Green, 1996; Baumann, Le Bihan, Chau, & Chau, 2014; Bavinzski et al., 1997; Bayouk, Boucher, & Leroux, 2006; Beaulieu & Schneider, 2013; Belousova, Tokareva, Gorodetskaya, Kalenikova, & Medvedev, 2016; Bensmail, Robertson, Fermanian, & Roby-Brami, 2010; Ben-Shabat, Matyas, Pell, Brodtmann, & Carey, 2015; Berglund, Harju, Kosek, & Lindblom, 1999; Bergmann et al., 2015; Bernard, Balkaya, & Rex, 2016; Bernhardt, Ellis, Denisenko, & Hill, 1998; Berthezene et al., 1998; Beslac-Bumbasirevic, Paden, Jovanovic, & Stefanovic-Budimkic, 2012; Bhagavatula et al., 2016; Bhatt et al., 2016; Bittar et al., 2005; Blackburn, Riemann, Myers, & Lephart, 2003; Blasi, Whalen, & Ayata, 2015; Blennerhassett, Carey, & Matyas, 2006, 2008; Blennerhassett, Gyngell, & Crean, 2010; Bode, Heinemann, Semik, & Mallinson, 2004; Boespflug et al., 2014; Bohannon & Walsh, 1991; Bohil, Alicea, & Biocca, 2011; Bohra et al., 2015; Bonaiuti, Rebasti, & Sioli, 2007; Bonan et al., 2004; Boonsinsukh, Panichareon, & Phansuwan-Pujito, 2009; Boothby & Roberts, 1995; Borlongan, Cahill, & Sanberg, 1995; Borsook, 2012; Bosveld & Field-Fote, 2015; Bouhassira et al., 2005; Bracci et al., 2007; Bradley et al., 1998; Bradt, Magee, Dileo, Wheeler, & McGilloway, 2010; Braem, Honore, Rousseaux, Saj, & Coello, 2014; Braga et al., 2013; Brandt, Steinke, Thie, Pessin, & Caplan, 2000; Bright & Murphy, 2013; Brin, 2009; Broega et al., 2010; J. G. Broeks, G. J. Lankhorst, K. Rumping, & A. J. Prevo, 1999; Brogardh & Sjolund, 2006; D. L. Brown, Lisabeth, Garcia, Smith, & Morgenstern, 2004; S. H. Brown, Lewis, McCarthy, Doyle, & Hurvitz, 2010; Brumley & Robinson, 2004; Bu et al., 2007; Buck et al., 2004; Bugnicourt, Garcia, Canaple, Lamy, & Godefroy, 2011; Burton & Sinclair, 1994; Bustamante, Brevis, Canales, Millon, & Pascual, 2016; Butts et al., 2016; Buxbaum, Dawson, & Linsley, 2012; Buxbaum et al., 2004; C et al., 2005; Cakir et al., 2012; Callaway, Knight, Watkins, Beart, & Jarrott, 1999; Camps-Renom et al., 2015; Canavero & Bonicalzi, 2007; Carello, Silva, Kinsella-Shaw, & Turvey, 2008; J. R. Carey et

		al., 2014a; L. M. Carey & Seitz, 2007; Carlozzi et al., 2017; Cassidy, O'Connor, & O'Keane, 2004; Cattaneo et al., 2016; Chae et al., 2009; Chai, Zhang, Xue, Liu, & Wang, 2014; Chan, Chung, Gomez, Seyone, & Baylon, 1994; Chandroth, Sharkey, & Sharkey, 1999; Chantsoulis et al., 2016; Chanubol et al., 2012; Danckert et al., 2004; Chapman et al., 2003; Charles & Gordon, 2005; Charness, 1995; C. C. Chen et al., 2016; C. M. Chen, Hou, & Holodny, 2008; I. C. Chen et al., 2000; J. Chen, M. Chopp, & Y. Li, 1999; J. Chen et al., 2001; N. Chen, Yuan, Cheung, & Huang, 1998; W. H. Chen, Yang, & Yin, 2017; Cheng & Hong, 1995; Cheng, Wang, Chung, & Chen, 2004; Chien, Hu, Tang, Sheu, & Hsieh, 2007; Chin et al., 2013; Cho, Yeon, Kim, & Chung, 2016; Choi et al., 2017; J. Chung, Kim, & Yang, 2016; S. M. Chung & Song, 2016; Cikajlo & Krpic, 2014; Cioni & Meglio, 2007; Clark, Ashford, Burt, Aycock, & Kimble, 2006; Colomer, Noe, & Llorens, 2016; Committeri et al., 2007; Corey-Bloom, Galasko, Hofstetter, Jackson, & Thal, 1993; Coreybloom, Galasko, Hofstetter, Jackson, & Thal, 1993; F. W. Costa et al., 2013; Cramer & Crafton, 2006; Criado, Lingelbach, Ledesma, & Lucas, 2002; Crosbie, McDonought, Lennon, McNeill, & Ieee, 2006; Croy, Drechsler, Hamilton, Hummel, & Olausson, 2016; Cruice, Worrall, & Hickson, 2006; Cruice, Worrall, Hickson, & Murison, 2003; J. J. Cunningham, Halum, Butler, & Postma, 2007; L. L. Cunningham et al., 1996; David, Dinse, Mainka, Tegenthoff, & Maier, 2015; Davies, Kidd, Stone, & MacMahon, 1995; Daviet et al., 2001; Daviet, Preux, et al., 2002; A. S. Davis, Pass, Finch, Dean, & Woodcock, 2009; M. F. Davis, Lay, & Frostig, 2013; Dawson, Hsu, Liu, Dawson, & Wamsley, 1994; de Bode, Mathern, Bookheimer, & Dobkin, 2007; de Campos, Kukke, Hallett, Alter, & Damiano, 2014; De Geyter, Stoop, Sarre, De Keyser, & Kooijman, 2013; De Geyter et al., 2012; de Kloet, Gijzen, Braga, Meesters, Schoones, & Vliet Vlieland, 2015; de Kloet, Gijzen, Braga, Meesters, Schoones, & Vlieland, 2015; K. K. de Menezes et al., 2015; K. K. P. de Menezes et al., 2015; C. B. de Oliveira, de Medeiros, Frota, Greters, & Conforto, 2008; R. de Oliveira, E. W. Cacho, & G. Borges, 2006; R. de Oliveira, E. W. A. Cacho, & G. Borges, 2006; R. A. de Oliveira et al., 2014; R. A. A. de Oliveira, de Andrade, Machado, & Teixeira, 2012; R. A. A. de Oliveira et al., 2014; De Wit et al., 2007; De Witte, Wilssens, Engelborghs, De Deyn, & Marien, 2006; Deltombe, De Wispelaere, Gustin, Jamart, & Hanson, 2004; Demaerschalk et al., 2012; Desrosiers, Bourbonnais, Bravo, Roy, & Guay, 1996; Desrosiers, Noreau, Rochette, Bravo, & Boutin, 2002; Detre, 2006; Dettmers, Benz, Liepert, & Rockstroh, 2012; Dewald, Given, & Rymer, 1996; Dietrich, Marienhagen, Schalke, Bogdahn, & Schlachetzki, 2004; DiFrancisco-Donoghue, Jung, Geisel, & Werner, 2015; Dimitrijevic, 2008; Dimwamwa &

		Johnson, 2015; Dobkin, 1999, 2007; Dobkin, Firestine, West, Saremi, & Woods, 2004; Doyle, Bennett, & Gustafsson, 2013; S. D. Doyle & Bennett, 2014; Dozono, Hachisuka, Wada, & Hachisuka, 2015; Dromerick & Reding, 1995; du Jardin et al., 2013; C. Duclos, Nadeau, & Lecours, 2008; N. C. Duclos, Maynard, Abbas, & Mesure, 2013, 2014; Duff et al., 2010; Duffin et al., 2012; Duncan, Goldstein, Matchar, Divine, & Feussner, 1992; Dunn et al., 2013; Dunn et al., 2015; Durisko, McCue, Doyle, Dickey, & Fiez, 2016; Eby et al., 2017; Edwards et al., 2006; Edwardson et al., 2017; Elwan, Hashem, Helmy, el Tamawy, et al., 1994; Elwan, Hashem, Helmy, Eltamawy, et al., 1994; Elwan et al., 1995a; Elwan et al., 1995b; Emery, 2003; Epstein & Moran, 2006; Essick, James, & McGlone, 1999; Essick, Phillips, & Trotman, 2007; Etzi, Spence, Zampini, & Gallace, 2016; Fahim, 2003; Y. Fang et al., 2003; Y. N. Fang et al., 2003; Faraji, Gomez-Palacio-Schjetnan, Luczak, & Metz, 2013; Faria-Fortini et al., 2016; Faria-Fortini, Michaelsen, Cassiano, & Teixeira-Salmela, 2011; Feezor et al., 2007; Ferrante, Rana, & Ferrante, 2004; Ferreiro, dos Santos, & Conforto, 2010; Fischer et al., 2010; M. K. Fleming, Newham, Roberts-Lewis, & Sorinola, 2014; Flossmann, Redgrave, Briley, & Rothwell, 2008; Fong et al., 2011; K. N. Fong et al., 2013; Foong et al., 2008; Forss, Hietanen, Salonen, & Hari, 1999; Fridriksson et al., 2016; Fugate, Robinson, Rabinstein, & Wijdicks, 2011; Gaber, Parsons, & Gautam, 2011; Gabriel, Kowalske, & Holavanahalli, 2009; Gallien et al., 2003; Gan, Sacco, Kargman, Roberts, Boden-Albala, et al., 1997; Gan, Sacco, Kargman, Roberts, BodenAlbala, et al., 1997; Gandiga, Hummel, & Cohen, 2006; Gandolfi, Geroin, Ferrari, E, et al., 2016; Gandolfi, Geroin, Ferrari, La Marchina, et al., 2016; Garcia, Sedeno, Murcia, Couto, & Ibanez, 2017; Gardner, Palmer, Hamalainen, & Warren, 1992; Gatti, Tettamanti, Lambiase, Rossi, & Comola, 2015; Gerlai, Thibodeaux, Palmer, Campagne, & Van Bruggen, 2000; Gerlai, Thibodeaux, Palmer, van Lookeren Campagne, & Van Bruggen, 2000; Ghandehari & Izadi, 2009; Ghasemi, Rowe, Shah, Venkatesan, & England, 2016; Ghaziani et al., 2017; Giaquinto, Mascio, & Fraioli, 2002; Giraldo-Cadavid et al., 2017; Giraldo et al., 2013; Goliwas et al., 2015; Gong, Zhang, Cui, Yang, & Sun, 2009; Goodyear & Douglas, 2009; Gorson, Pessin, DeWitt, & Caplan, 1996; Gorst et al., 2016; Gotoh, Terayama, & Amano, 2001; Greenspan, Joy, McGillis, Checkosky, & Bolanowski, 1997; P. Gulde, C. M. L. Hughes, & J. Hermsdorfer, 2017; Guo, Ye, Kauffman, & Doub, 2009; Habekost & Rostrup, 2006; Hackney, Hall, Echt, & Wolf, 2012; Hakim-elahi, 1991; J. Y. Han et al., 2016; L. Han, Law-Gibson, & Reding, 2002; Hancock, Lay, Davis, & Frostig, 2013; Handschu, Poppe, Rauss, Neundorfer, & Erbguth, 2003; Hanger et al., 2000; Hanks, Rapport,

		Millis, & Deshpande, 1999; Hansson, 2004; Hantikainen, Riesen-Uru, Raemy-Rothl, & Hirsbrunner, 2006; Hara, 2015; Hara, Obayashi, Tsujiuchi, & Muraoka, 2013; S. Harada et al., 2014; T. Harada, Okajima, & Takahashi, 2010; Harnish, Neils-Strunjas, Lamy, & Eliassen, 2008; A. L. Harris, Elder, Schiff, Victor, & Goldfine, 2014; P. Harris & Ferrin, 2014; Hartman-Maeir, Soroker, & Katz, 2001; Hartman-Maeir, Soroker, Ring, & Katz, 2002; Hartman, Lekic, Rojas, Tang, & Zhang, 2009; Hayakawa, Kazami, Fujimoto, Kikuchi, & Kohyama, 2009; Heales, Bergin, Vicenzino, & Hodges, 2016; Heath, Almeida, Roy, Black, & Westwood, 2003; Hebert et al., 2009; Hegland, Davenport, Brandimore, Singletary, & Troche, 2016; Hegyi & Szigeti, 2012; Hemsley & Balandin, 2014; Hertza, Davis, Barisa, & Lemann, 2012; Hesse et al., 1994; E. J. Heyer & Adams, 1996; G. Heyer, Groene, & Martus, 2002; Hicks, MacLellan, Chernenko, & Corbett, 2008; Hinman, 2000; Hirel et al., 2017; Hodl et al., 2008; Hoffmann, Sacco, Mohr, & Tatemichi, 1997; Hoge, 2012; I. K. Hong, Choi, & Lee, 2012; J. H. Hong & Jang, 2010; Hoo, Paul, Chae, & Wilson, 2013; Hosseini, Sharafkhah, Koohi-Hosseinabadi, & Semsar-Kazerooni, 2016; A. L. Hsu, Tang, & Jan, 2003; H. W. Hsu et al., 2013; H. Y. Hsu et al., 2012; Hu et al., 2014; H. Huang, Ingalls, Olson, Ganley, Rikakis, & He, 2005; S. Huang et al., 2012; Y. C. Huang et al., 2011; Y. C. Huang, Liang, Pong, Leong, & Tseng, 2010; Hudson, Semenenko, & Lumb, 2000; Huh, Park, Jung, Oh, & Choi, 2015; Hummelsheim, Amberger, & Mauritz, 1996; Hung et al., 2014; Hunter, Crome, Sim, Donaldson, & Pomeroy, 2006; Hunter, Crome, Sim, & Pomeroy, 2008; S. M. Hunter et al., 2011; Hurvitz, Conti, & Brown, 2003; Huzmeli, Yildirim, & Kilinc, 2017; C. R. Innes et al., 2007; Innes, Jones, Anderson, Hollobon, & Dalrywple-Alford, 2009; C. R. H. Innes et al., 2007; Inoue et al., 2013; Ishibashi, Kuroiwa, Endo, Okeda, & Mizusawa, 2003; Ishida et al., 2011; Israely & Carmeli, 2016; Jack, Piggott, & Paterson, 1994; Jackman & Iadecola, 2015; Jagadesham, Aparajita, & Gough, 2008; Jamali, Fujioka, & Ross, 2014; Jang, Ahn, et al., 2005; Jang et al., 2004; Jang, Kim, Cho, Choi, & Cho, 2007; Jang, Son, Lee, & Hong, 2013; Jang, You, et al., 2005; Janssen et al., 2012; Jenkins, Norton, Hampton, & Weeks, 2016; H. K. Jeong, Lee, Kim, & Heo, 2005; J. Jeong, Park, Lee, & Eun, 2014; B. Johansson, Starmark, Berglund, Rodholm, & Ronnback, 2010; K. Johansson, Lindgren, Widner, Wiklund, & Johansson, 1993; J. Y. Jung, Glasgow, Scott, & Ieee, 2008; S. H. Jung, Ahn, et al., 2005; S. H. Jung, You, et al., 2005; Kainerstorfer, Sassaroli, Hallacoglu, Pierro, & Fantini, 2014; Kalra, 2010; Kamano, 2003; Kangas & Tate, 2006; M. Karaca, E. Kilic, B. Yazici, S. Demir, & J. de la Torre, 2002; Karkare, Taly, Sinha, & Rao, 2011; Karppa, Syrjala, Tolonen, & Majamaa, 2003; Katayama, Fukaya, & Yamamoto, 1998; Kato,

		Tanaka, Sugihara, & Shimizu, 2015; Katz, Hartman-Maeir, Ring, & Soroker, 1999; Kayamori et al., 1997; Kayiran, Dursun, Dursun, Ermutlu, & Karamursel, 2010; Kazmierski, Stelagowski, Kasielska-Trojan, Bogusiak, & Glabinski, 2014; Kemppainen et al., 1999; Khateb et al., 2009; Khositseth et al., 2004; Kidd, 2009; Kiers, Brumagne, van Dieen, & Vanhees, 2014; J. S. Kim, 2001, 2014; J. S. Kim, Choi-Kwon, Kwon, & Kwon, 2009; J. S. Kim & Choi, 2002; Y. Kim, Bulea, & Damiano, 2016; Kimberley, Khandekar, & Borich, 2008; Kimberley, Schmidt, Chen, Dykstra, & Buetefisch, 2015; Kitatani et al., 2016; Klit, Hansen, Marcussen, Finnerup, & Jensen, 2014; Kluding & Gaiewski, 2009; Kohyama, Kobayashi, Hatakeyama, & Suzuki, 2000; Koike et al., 2015; Kollmansberger & Berger, 1994; Kondo, Hosokawa, Soma, Iwata, & Maltais, 2001; Kondrakhov, Zakharova, Fadeeva, & Tanyashin, 2016; Kong, Chua, & Lee, 2011; Kong, Woon, & Yang, 2004; Kononen et al., 2005; Kostic, Popovic, & Popovic, 2013; Kowalczewski, Gritsenko, Ashworth, Ellaway, & Prochazka, 2007; Kraft et al., 2015; Kramer et al., 1997; Kress, Minati, Ferraro, & Critchley, 2011; J. Ku et al., 2003; Kucukdeveci et al., 2000; Kujala, Tervaniemi, & Schroger, 2007; Kunkel, Potter, & Mamode, 2017; Kurillo, Zupan, & Bajd, 2004; Kuroiwa & Okeda, 2003; Kusoffsky, Apel, & Hirschfeld, 2001; Kvarnstrom, Karlsten, Quiding, & Gordh, 2004; Lafosse et al., 2005; Lai et al., 2001; Lakshminarayanan, Wang, Webster, & Seo, 2017; Laloux, Richelle, Jamart, Decoster, & Laterre, 1995; Lampl, Gilad, Eshel, & Sarovapinhas, 1995; Larson, Feigon, Gagliardo, & Dvorkin, 2014; Lay, Davis, Chen-Bee, & Frostig, 2011; E. J. Lee et al., 2005; K. B. Lee, Kim, Hong, & Lim, 2017; K. B. Lee, S. H. Lim, E. H. Ko, et al., 2015; M. Y. Lee et al., 2012; S. H. Lee et al., 2015; T. H. Lee & Lee, 2012; Lefaucheur et al., 2004; Lemberg, Kirchberger, Stucki, & Cieza, 2010; Lemke, Rugh, Van Sickels, Bays, & Clark, 2000; Leocani et al., 2007; Levin & Panturin, 2011; Li, Rema, & Ebner, 2005; K. C. Lin et al., 2014; S. I. Lin, 2005; Liebermann, Ploner, Kraft, Kopp, & Ostendorf, 2013; Liepert, Busching, Sehle, & Schoenfeld, 2016; Liepert, Greiner, Nedelko, & Dettmers, 2012; Liguz-Lecznar, Zakrzewska, Daniszewska, & Kossut, 2014; Lim et al., 2008; N. Lima et al., 2015; N. M. Lima, K. C. Menegatti, E. Yu, N. Y. Sacomoto, T. D. Oberg, et al., 2015; F. Lin et al., 2016; K. C. Lin, 1996; K. C. Lin, Huang, Chen, Wu, & Huang, 2014; S. I. Lin, Hsu, & Wang, 2012; Linaro, Couto, & Giugliano, 2015; Lindgren, Lexell, Jonsson, & Brogardh, 2012; Lindley et al., 1993a; Lindley et al., 1993b; Lisa, Jughters, & Kerckhofs, 2013; D. F. Liu, Zhao, Lu, Yao, & Liao, 2013; H. Liu, L. Song, & T. Zhang, 2014; J. L. Liu & Bai, 2007; S. Y. Liu et al., 2009; Liutkiene, Stropus, Dabuzinskiene, & Pilmane, 2007; Loken, Evert, & Wessberg, 2011; Lopez-Valdes et al., 2014; Lori et al., 2002; Lou et al., 2004; Luehr et al.,

		2016; Lundquist & Nielsen, 2014; Lundstrom, Smits, Terent, & Borg, 2009; Luvizutto et al., 2016a; P. Lyden et al., 2009; P. D. Lyden, Lu, Levine, Brott, & Broderick, 2001; P. D. Lyden, Lu, Levine, Brott, Broderick, et al., 2001; Machado, Baker, Plow, & Malone, 2013; Maeshima & Osawa, 2007; Magrinelli, Zanette, & Tamburin, 2013; Malcharek et al., 2015; Malouin, Pichard, Bonneau, Durand, & Corriveau, 1994; Malouin, Richards, Durand, & Doyon, 2008; Mansfield, Mochizuki, Inness, & McIlroy, 2012; Mao et al., 2015; Maravita et al., 2003; Marigold & Eng, 2006; Marigold, Eng, Tokuno, & Donnelly, 2004; Martin, Johnston, & Sadowsky, 2012; Martinez-Diaz, Garcia, Hernandez, & Aranda-Abreu, 2015; Martins, De Sousa, Barbosa, De Menezes, & Costa, 2011; Martinsson, Eksborg, & Wahlgren, 2003; Matjacic, 2007; Matjacic, Rusjan, Stanonik, Goljar, & Olensek, 2005; Matovic, Glinac, & Saric, 2010; Matsuura, Harada, & Tokuyama, 2016; Mattana, Effiong, & Myssiorek, 1997; Mattingley et al., 2004; Max et al., 2004; McCarthy, Otto, & Rao, 2011; McKay, 2012; Melchior, Vatine, & Weiss, 2007; Meldrum, Pittock, Hardiman, Dhuill, et al., 2004; Meldrum, Pittock, Hardiman, Ni Dhuill, & O'Regan, 2004; K. K. P. Menezes et al., 2016; Metz, 2016; Meyer, De Bruyn, Lafosse, et al., 2016; Micera, Keller, Lawrence, Morari, & Popovic, 2010; Michaud, 2002; Migliaccio et al., 2014; Mihejeva, Vetra, & Riga Stradins, 2012; K. C. Miller, Long, & Edwards, 2015; K. J. Miller, Galea, Goodwin, & Wheat, 2004; Mittrach et al., 2008; Modo et al., 2000; Mokudai et al., 2000; Moncayo, Devuyst, Van Melle, & Bogousslavsky, 2000; Moon, Pyun, Tae, & Kwon, 2016; Morch, Gazerani, Nielsen, & Arendt-Nielsen, 2013; Mori et al., 2013; Most et al., 2015; Moulin et al., 1995; Moyanova, Kortenska, Kirov, Itzev, & Usunoff, 2008; Moyanova et al., 2007; Muller-Oerlinghausen et al., 2004; Munoz, Chavarriaga, Villada, Lopez, & Ieee, 2014; S. Nadeau, Gravel, Arsenault, Bourbonnais, & Goyette, 1997; S. E. Nadeau, 2002; Nakatsuka et al., 2011; Nathan, Prost, Guastello, Jeutter, & Reynolds, 2012; Navalon et al., 2014; Neppe, Chen, Davis, Sawchuk, & Geist, 1992; Nelles et al., 1999; Nhan et al., 2004; Nicholson, 2004; Niimi, Ichinose, Saegusa, Nakata, & Morita, 1997; T. Nijboer, van de Port, Schepers, Post, & Visser-Meily, 2013; T. C. W. Nijboer, Ruis, van der Worp, & De Haan, 2008; Nilsen & DiRusso, 2014; Nishihira et al., 2014; Nitz & Gage, 1995; Norton & Corbett, 2000; Nwachuku et al., 2015; Nymark et al., 1998; O'Brien, Parsons, & Anderson, 2012; Odding, Valkenburg, Stam, & Hofman, 2001; Ohhashi & Inoya, 2013; Okawara & Usuda, 2015; Oken, Yavuzer, Ergocen, Yorgancioglu, & Stam, 2008; G. R. Oliveira et al., 2008; Omary, Chernoguz, Lasri, & Leker, 2013; Opheim, Danielsson, Alt Murphy, Persson, & Sunnerhagen, 2015; Opsommer, Zwissig, Korogod, & Weiss, 2016; Orfei et al., 2007; Osterberg & Boivie, 2010;

		Ostrzenski, 2012; Owen, Green, Stein, & Aziz, 2006; Ozen, Orhan, Gorur, & Ozturk, 2006; Padua, Aprile, et al., 2008; Padua, Pareyson, et al., 2008; Page, Harnish, Lamy, Eliassen, & Szaflarski, 2010; Palacios-Navarro, Albiol-Perez, & Garcia, 2016; Pallesen, Buhl, & Roenn-Smidt, 2016; Pandey & Abubacker, 2006; Papavasileiou et al., 2013; Papuc et al., 2013; J. Park, White, Stevinson, Ernst, & James, 2002; S. W. Park, Wolf, Blanton, Winstein, & Nichols-Larsen, 2008; T. H. Park et al., 2013; Patel, Duncan, Lai, & Studenski, 2000; Pearce, Stolwyk, New, & Anderson, 2016; Pedersen, Vinter, & Olsen, 2004; Pendlebury et al., 2015; Pereira & Aziz, 2014; Perez-Lazaro et al., 2005; Perivier et al., 2016; Petersen, Brennum, & Dahl, 1997; Petrarca, Rossi, Bollea, Cappa, & Castelli, 2011; Petrilli et al., 2002; Pettersen, Stien, & Wyller, 2007; Phipps, 1991; Picard & Smith, 1992; Pillai & Mikulis, 2015; Pinedo-Otaola & de la Villa, 2000; Pinedo et al., 2014; Pirotte et al., 2005; Pittaccio et al., 2013; Pittaccio et al., 2009; Pizzamiglio, Guariglia, Antonucci, & Zoccolotti, 2006; Planton et al., 2012; Platz et al., 2005; Plow, Malone, & Machado, 2013; Plow, Pascual-Leone, & Machado, 2012; Plummer, Morris, & Dunai, 2003; Polanowska et al., 2014; Pollock et al., 2014; Popovic & Popovic, 2013; Posl, Cieza, & Stucki, 2007; Pozet et al., 2016; Prasertsakul, Kaimuk, Charoensuk, & Ieee, 2014; Pundik, Falchook, McCabe, Litinas, & Daly, 2014; Pundik et al., 2015; Punt & Riddoch, 2006; Rath, He, Nordling, & Wienecke, 2017; Reese et al., 2000; Reissman & Dhaher, 2015; Rijntjes et al., 2005; Rinderknecht, Gross, Leuenberger, Lambercy, & Gassert, 2015; Rink et al., 2010; Ro et al., 2007; Roan & Bell, 2017; Robinson, Shumway-Cook, Matsuda, & Ciol, 2011; Rode et al., 2015; Roerdink, Geurts, de Haart, & Beek, 2009; Rogind, Christensen, Danneskiold-Samsoe, & Bliddal, 2005; Roosink, Renzenbrink, et al., 2011a; Roosink, Renzenbrink, et al., 2011b; Roosink; Roosink, Van Dongen, et al., 2012; Rosa, Marques, Demain, & Metcalf, 2015; Rose, Bakal, Fung, Farn, & Weaver, 1994; Rosini, Pretegiani, Guideri, Cerase, & Rufa, 2013; Rossini & Dal Forno, 2004; Roszkowski, Drabik, Grajkowska, Jurkiewicz, & Daszkiewicz, 2003; Rousseaux, Allart, Bernati, & Saj, 2015; Rousseaux, Buisset, Daveluy, Kozlowski, & Blond, 2008, 2009; Rowbotham, Petersen, & Fields, 1998; Rowland, Cooke, & Gustafsson, 2008; Rudberg, Furner, & Cassel, 1992; Saevarsson, 2013; Sale & Franceschini, 2012; Salhab, Sarraj, & Saleh, 2016; Salles et al., 2017; Samuelsson, Soderfeldt, & Olsson, 1996; Saposnik, de Tilly, & Caplan, 2008; Sasaki, Matsunaga, Tomite, Yoshikawa, & Shimada, 2012; Sathian, Greenspan, & Wolf, 2000; Sato et al., 2012; Schaffert, Gehret, & Mattes, 2012; Schallert & Woodlee, 2003; Schlieper & Dinse, 2012; Schneider & Olshaker, 2012; Schuster, Lussi, Wirth, & Ettlin, 2012; Seghier et al., 2016;

		Sejdic, Jeffery, Vanden Kroonenberg, & Chau, 2012; N. J. Seo, Fischer, Bogey, Rymer, & Kamper, 2011; Sezer, Yavuzer, Sivrioglu, Basaran, & Koseoglu, 2007; Sgandurra et al., 2011; S. Shafqat, J. C. Kvedar, M. M. Guanci, Y. C. Chang, & L. H. Schwamm, 1999; Shapira et al., 2004; Shapira et al., 2006; Sheean, 2006; Sheffler & Chae, 2015; Shindo et al., 2011; Shivasharan et al., 2013; Sibley, Beauchamp, Van Ooteghem, Straus, & Jaglal, 2015; Sibley, Straus, Inness, Salbach, & Jaglal, 2011; Silva et al., 2010; Silver et al., 2006; Singh, Hummel, Gerber, Landis, & Iannilli, 2015; Skidmore, Rogers, Chandler, Jovin, & Holm, 2007; J. M. Smith et al., 2007; N. A. Smith & Clarke, 2012; P. S. Smith, Dinse, Kalisch, Johnson, & Walker-Batson, 2009; Smits, Jiskoot, & Papma, 2014; Solomon, Barohn, Bazan, & Grissom, 1994; Sommerfeld & von Arbin, 2001, 2004; Son, Ko, Lee, & Kim, 2012; S. M. Son et al., 2012; Sone et al., 2015; Y. B. Song et al., 2014; Song, Chung, & Hwang, 2013; Y. C. Song, Kang, Dong, & Chen, 2016; Soroker, 2003; Soyuer & Ozturk, 2007; Spark et al., 2011; Spilker et al., 1997; Spratt, Tomkins, Pepperall, McLeod, & Calford, 2014; Srivastava et al., 2008; Starr et al., 2011; Sterr, 2004; Sterr et al., 2013; Sterr, Freivogel, & Voss, 2002; Sterr, Szameitat, Shen, & Freivogel, 2006; Stewart, Cauraugh, & Summers, 2006; Suetterlin & Sayer, 2014; J. Sullivan et al., 2015; J. E. Sullivan & Hedman, 2005, 2007; K. J.; Sumikura, Andersen, Drewes, & Arendt-Nielsen, 2003; Suriya-amarit, Gaogasigam, Siriphorn, & Boonyong, 2014; Suttipong & Sindhu, 2012; Suzuki et al., 2006; P. Szabo, Enikov, & Asme, 2017; Takahashi et al., 2007; Takami, Fujita-Hamabe, Harada, & Tokuyama, 2011; Takatori, Okada, Shomoto, & Shimada, 2009; Takatori, Shomoto, & Shimada, 2009; Talley Watts, Zheng, Garling, Frohlich, & Lechleiter, 2015; P. M. S. Tan et al., 2017; E. Tanaka, Saegusa, & Yuge, 2013; H. Tanaka et al., 2012; M. Tanaka, Chonan, Jiang, & Hikita, 1998; T. Tanaka, Sugihara, Nara, Ino, & Ifukube, 2005; T. Tanaka, Yamada, & Inagaki, 2011; Tarczy-Hornoch & Repka, 2004; Tarkowski, Naver, Wallin, Blomstrand, & Tarkowski, 1995; Tarola & Phillips, 2015; Tashiro, Shiokawa, Aono, Maeno, & Ieee, 2009; Taskin et al., 2006; Taub, Munz, & Tasker, 1997; Tecchio et al., 2007; Thaller & Hughes, 2014; Thatcher, North, & Biver, 2005; Thomas et al., 2005; H. E. Thompson, Robson, Lambon Ralph, & Jefferies, 2015; H. E. Thompson, Robson, Ralph, & Jefferies, 2015; Thulborn, Carpenter, & Just, 1999; Thurman, Stevens, & Rao, 2008; "TIA offers a warning sign that a stroke may be on its way," 2007; Ting et al., 2011; Tinga et al., 2016; Tobinick, 2011; Tobinick, Kim, Reyzin, Rodriguez-Romanacce, & DePuy, 2012; Torre et al., 2013; Toth, 2003; Townend, Traves, & Crimmins, 2005; Tremolizzo, Sala, Zoia, & Ferrarese, 2012; Triandafilou & Kamper, 2014; Tsuboi, Ohka, &

		Yussof, 2014; Tu et al., 2017; Tuke, 2008; Tuor et al., 2001; Tuor et al., 2007; Tyson, Chillala, Hanley, Selley, & Tallis, 2006; Tyson, Hanley, Chillala, Selley, & Tallis, 2006; Tyson, Hanley, Chillala, Selley, & Tallis, 2008; Ubeda, Azorin, Chavarriaga, & Millan, 2017; Ugurlu et al., 2015; Unsworth et al., 2012; Urban et al., 2010; Uswatte & Taub, 2005; Vakanski, Ferguson, & Lee, 2016; van Bloemendaal, Kokkeler, & van de Port, 2012; van der Lee, 2003; van der Lee et al., 1999; H. J. R. van Duijnhoven et al., 2016; van Kuijk, Hendricks, Pasman, Kremer, & Geurts, 2007; van Nes, Geurts, Hendricks, & Duysens, 2004; I. J. W. van Nes et al., 2006; van Vliet, Lincoln, & Foxall, 2005; Vandana et al., 2016; Vannucchi, Corsani, Gianfriddo, Pedata, & Faussone-Pellegrini, 2005; Veltmeijer, Pluim, Thijssen, Hopman, & Eijsvogels, 2014; Veronelli, Ginex, Dinacci, Cappa, & Corbo, 2014; Vestergaard, Andersen, Gottrup, Kristensen, & Jensen, 2001; Vieira, Coelho, & Teixeira, 2014; Virley et al., 2004; Visudharom et al., 2003; K. R. H. von Wild, 2005; Wagner, Lang, Sahrmann, Edwards, & Dromerick, 2007; Wain et al., 1999; Wali, Ishrat, Won, Stein, & Sayeed, 2014; M. L. Walker et al., 2010; R. W. Walker et al., 2012; R. W. Walker, M. Rolfe, P. J. Kelly, M. O. George, & O. F. W. James, 2003; Wall, Isaacs, Copland, & Cumming, 2015; R. Y. Wang, Chan, & Tsai, 2000; R. Y. Wang, Tsai, & Chan, 1998; Y. H. Wang, Meng, Zhang, Xu, & Yue, 2016; Wang, Yang, Pan, & Wang, 2014; Ward, 2008; Watts, Zheng, Garling, Frohlich, & Lechleiter, 2015; Welfringer, Leifert-Fiebach, Babinsky, & Brandt, 2011; Wells et al., 2005; Welmer, von Arbin, Murray, Holmqvist, & Sommerfeld, 2007; Whitson et al., 2006; Williamson & Colbourne, 2017; Wilson et al., 2016; Winter, Crome, Sim, & Hunter, 2013; Wirtz & Voigt-Radloff, 2008; Wissel, Manack, & Brainin, 2013; Wittenberg, Lovelace, Foster, & Maldjian, 2014; Wolf et al., 2011; Wongphaet, Butrach, Sangkrai, & Jitpraphai, 2003; Wonsetler & Bowden, 2017; Worms et al., 2006; C. W. Wu, Seo, & Cohen, 2006; P. Wu et al., 2015; Yaghi & Elkind, 2015; T. Yamamoto, Katayama, Hirayama, & Tsubokawa, 1997; Y. Yamamoto, Nishiyama, Katsura, Yamazaki, & Katayama, 2011; Yavuzer, Oken, Atay, & Stam, 2007; Yawson et al., 2014a; Yawson et al., 2014b; Yazici et al., 2015; Yelnik et al., 2008; Yoo et al., 2008; You & Lee, 2013; J. Young, Bogle, & Forster, 2001; W. B. Young, Richardson, & Shukla, 2005; Yousuf, Atif, Sayeed, Tang, & Stein, 2014; Yousuf et al., 2015; Yozbatiran, Donmez, Kayak, & Bozan, 2006; H. B. Yu et al., 2013; N. B. Yu, Estevez, Hepp-Reymond, Kollias, & Riener, 2011; Z. Yu, 2014; Yuan, Zi, & Huang, 2008; Zaghi, Acar, Hultgren, Boggio, & Fregni, 2010; Zahn et al., 2004; Zahn et al., 2002; Zhang, Lu, & Zee, 2011; S. X. Zhang & T. H. Murphy, 2007; Ziccardi, Hullett, & Gomes, 2009; Zult, Howatson, Kadar, Farthing, & Hortobagyi, 2014)

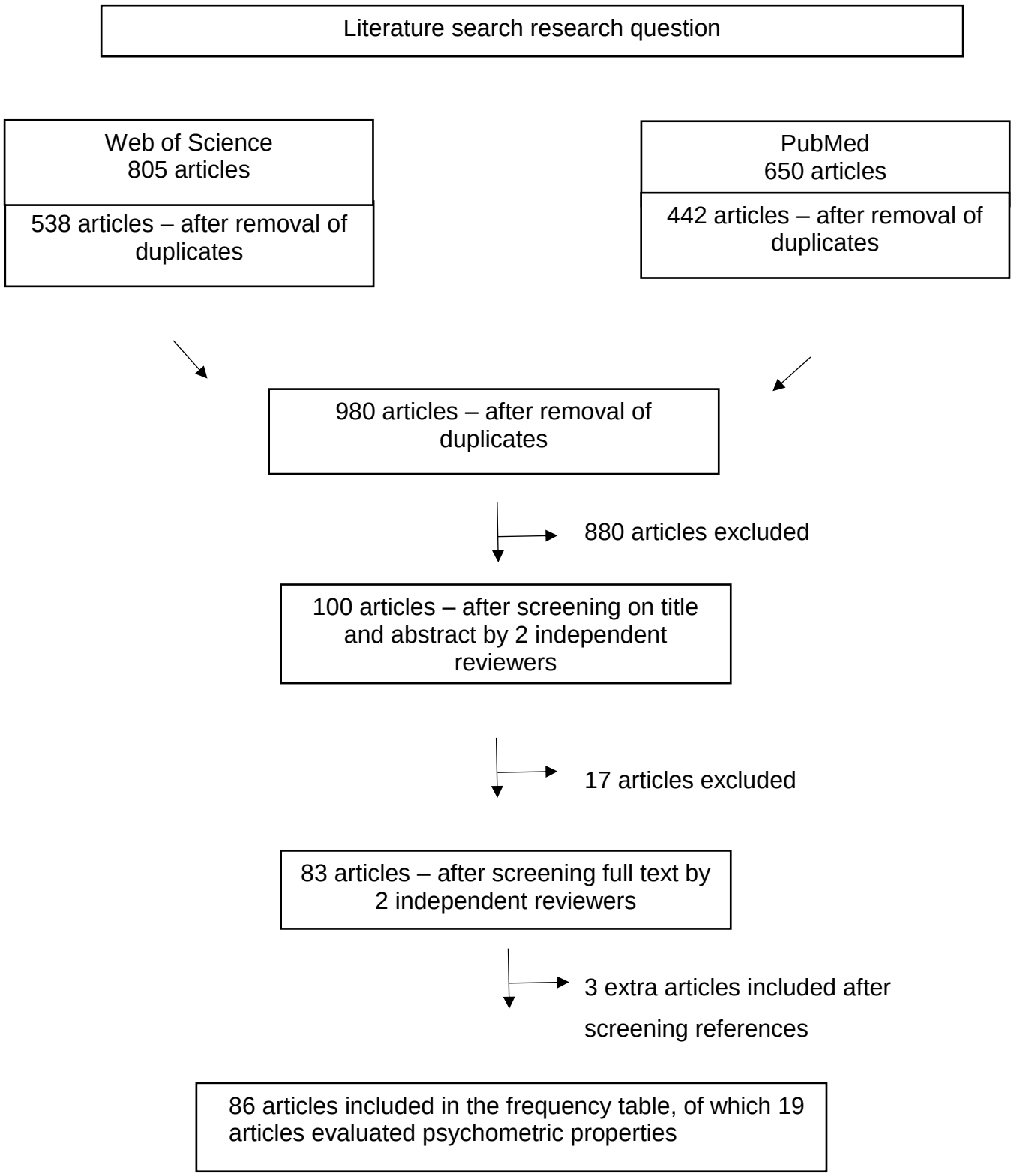


Fig. 1: Flow chart in- and excluded articles Web of Science and PubMed search

Table 3: Frequency table

Extracted Outcome Measures	Number of studies investigating psychometric	Responsiveness	Inter-rater reliability	Intra-rater reliability	Internal consistency	Correlation	NPP
Proprioception/ position sense							
Ayres Southern California Sensory Integration Test	0						1
Sensory Integration and Praxis Test (SIPT)	0						2
Sensory organization test (SOT)	0						2
The Brief Kinesthesia test (BKT)	1					[6]	0
Thumb finding test	1					[68]	2
Up or down Test	0						1
Wrist Position Sense Test (WPST)	0						9
Temperature							
Hot-cold discrimination Test	0						1
TSA-II Neurosensory Analyzer system	0						1
Testing more than 1 modality							
Cumulative Somatosensory Impairment index (CSII)	1					[29]	0
Erasmus MC modifications of the Nottingham Sensory Assessment (EmNSA)	2		[36]			[68]	2
Revised Nottingham Sensory Assessment (rNSA)	4	[102]	[90], [61]	[90]	[23]	[23], [102]	13
Rivermead Assessment of Somatosensory Performance (RASP)	2		[98]	[98]	[11]	[98]	9
Sensory scale of the Fugl-Meyer Assessment (FMA-s)	2	[59]	[59], [82]	[82]		[59]	15

Extracted Outcome Measures	Number of studies investigating psychometric	Responsiveness	Inter-rater reliability	Intra-rater reliability	Internal consistency	Correlation	NPP
Touch (discrimination)							
Fabric Matching Test (FMT)	0						1
Grating Orientation Test	0						1
Two-point discrimination Test (TDT)	2			[19]		[68]	17
Sustained Touch- Pressure (STP)	1		[25]	[25]		[25]	0
Touch (threshold)							
AsTex	1	[70]		[70]			0
Light touch-pressure sensation	1					[68]	0
Moving Touch-Pressure (MTP)	1		[25]	[25]		[25]	0
Semmes- Weinstein Enhanced Sensory Test (SWM)	0						7
Von Frey Monofilaments	0						8
Vibration sense							
Quantitative sensory tests (QST)	0						5
Combined modalities							
Hand Active Sensation Test (HASTe)	2	[95]		[5], [95]	[95]	[95]	2
Stereognosis							
Byl-Cheney-Boczai Test (BCB)	0						2
Grid Matching Test (GMT)	0						1
Haptic Object Recognition Test (HORT)	0						2
Shape sorter drum task (SSDT)	0						1
Shape/Texture Identification test (STI test™)	1		[34]				0

Abbreviations: NPP; no psychometric properties

Table 4: Quality Assessment

Study	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
Borstad et al. 2015	Y	Y	NR	N	N	Y	Y	NR	NR	Y
Borstad et al. 2016	Y	Y	Y	N	N	Y	Y	Y	NR	Y
Busse et al. 2009	Y	Y	Y	N	Y	Y	Y	Y	NR	Y
Carey et al. 1997	Y	Y	Y	Y	Y	Y	Y	Y	NR	Y
Connell et al. 2008	N	Y	Y	Y	Y	Y	Y	Y	NR	Y
Dannenbaum et al. 2002	Y	Y	U	Y	Y	Y	Y	Y	NR	Y
Deshpande et al. 2010	Y	Y	Y	N	Y	Y	Y	Y	NR	Y
Ekstrand et al. 2015	Y	Y	Y	N	Y	Y	Y	Y	NR	Y
Gaubert et al. 2000	Y	Y	Y	N	N	Y	Y	Y	Y	N
Lin et al. 2004	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Lincoln et al. 1991	Y	Y	Y	Y	Y	Y	Y	Y	NR	Y
Lincoln et al. 1998	Y	Y	Y	U	Y	Y	Y	Y	NR	Y
Meyer et al. 2016	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Miller et al. 2009	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Sanford et al. 1993	Y	Y	Y	Y	N	Y	Y	Y	NR	Y
Stolk-Hornsveld et al. 2006	Y	Y	Y	N	N	Y	Y	Y	Y	Y
Williams et al. 2006	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Winward et al. 2002	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Wu et al. 2016	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

Abbreviations: Q1, Is investigating the psychometric properties of an outcome measure the primary objective of the study?; Q2, Is the study design appropriate to answer the research question(s)?; Q3, Is the recruitment strategy appropriate?; Q4, Is the study sample representative for the population?; Q5, Is the sample size large enough?; Q6, Are all outcome measures clearly described?; Q7, Are the outcome measures used in the study the most relevant ones for answering the research question(s)?; Q8, Are the statistical analyses appropriate to answer the research question(s)?; Q9, Are there any efforts made to address potential sources of bias?; Q10, Are the results adequately described?; Y= yes; N= No; U= Unclear; NR= Not reported.

Quality Assessment Checklist

Rater:
Author:
Year:
Title:

Scoring: Yes/No/Unclear/Not reported/Not applicable

1. Is investigating the psychometric properties of an outcome measure the primary objective of the study?
2. Is the study design appropriate to answer the research question(s)?
3. Is the recruitment strategy appropriate?
4. Is the study sample representative for the population?
5. Is the sample size large enough? (sample size justification or statistical power)
6. Are all outcome measures clearly described?
7. Are the outcome measures used in the study the most relevant ones for answering the research question(s)?
8. Are the statistical analyses appropriate to answer the research question(s)?
9. Are there any efforts made to address potential sources of bias?
10. Are the results adequately described?

Table 5: Patient characteristics and aims of the studies investigating psychometric properties of outcome measures.

Study	n	Sample Characteristics	Study aim	Outcome measures	Psychometric properties
Borstad et al.2015	12	Poststroke: 64,3y Control group: 63,9y Disease duration: 12,3m 5 right hemiparesis Incusion: - Able to grasp lift and release 3.81cm diameter cylinder, weighting 224g. [95] Exclusion: - Past or current diagnosis peripheral nervous system, central nervous system, skin, medical, or orthopaedic condition that could alter sensation. [95]	Design, fabrication and administration of HASTe.	HASTe	Reliability Internal consistency Sensitivity and specificity
Borstad et al.2016	12	64y Disease duration: 25m 5 right hemiparesis Inclusion: - > 3m - > 10° active extension in the contralesional fingers and wrist - > 45° active elbow and shoulder flexion - communication in English	To determine the feasibility of administering BKT.	BKT HASTe Touch-test Wolf MAL BBT	Sensitivity and specificity Validity

Study	n	Sample Characteristics	Study aim	Outcome measures	Psychometric properties
		Exclusion: - < 24 MMSE - severe spatial neglect on Albert's test - Apraxia - Another neurologic or sensory disorder			
Busse et al.2009	102	70,7y (12.6 SD) Disease duration: 21 (5SD) 37 right hemiparesis Inclusion: - First-time anterior circulation stroke causing a unilateral weaknesses Exclusion: - Feeling unwell to participate - Another condition affecting balance or mobility - Discharged within two weeks of their stroke	To identify how many body locations need to be tested to establish whether sensation is intact, impaired or absent and to asses validity of that classification.	RASP BBA MI RMI BI	Redundancy Validity
Carey et al.1997	35 100	Experiment 1: 54y (13SD) 14 right hemiparesis Experiment 2: 52y (12.6SD) Inclusion: - Medical stable - Adequate comprehension of instructions for assessment Exclusion: - Unilateral spatial neglect - Peripheral neuropathy	To discriminate differences in tactile stimuli, such as textures, is commonly and characteristically impaired after stroke.	TDT	Reliability

Study	n	Sample Characteristics	Study aim	Outcome measures	Psychometric properties
Conell et al.2008	70	71y (10.00 SD) Duration of disease: 15d 34 right hemiparesis Inclusion: - First-time stroke - Lived within 50km of the stroke units - 40-85 years - within 6 weeks of stroke Exclusion: - Other neurological impairments - <10 BI	To investigate the frequency of somatosensory impairment in stroke patients within different somatosensory modalities and different body areas, and their recovery.	RMA NIHSS BI NSA NEADL	Validity Responsiveness
Dannenbaum et al. 2002	28	69y (12,5 SD) Disease duration: 23.5m (3.1SD) 15 right hemiparesis Inclusion: - hemiparesis - complete two of three tasks outlined for each level without assistance to obtain a grade from 1 to 7 - to determine the motor impairment level of their hand using the Chedoke Mcmaster Stroke Assessment scale - discharged from acute care facilities.	To establish validity and reliability of MTP and STP and their relationship to hand function for patients with stroke.	MTP STP BBT TEMPA-8 Modified-Moberg SWM	Inter/intra-rater reliability Concurrent validity Construct validity
Deshpande et al.2010	960 31	All patients 64y Inclusion: - >/= 24 MMSE	To establish validity and reliability of two new sensory tests evaluating	CSII FISCIT	Validity

Study	n	Sample Characteristics	Study aim	Outcome measures	Psychometric properties
		exclusion: - Diabetes PAD	MTP and STP and their relationship to hand function for patients with stroke.		
Ekstrand et al. 2015	45	65y (7 SD) Disease duration: 44m (28SD) 25 right hemiparesis Inclusion: - >6m stroke - Mild to moderate paresis in their more affected arm and hand Exclusion: - Inability to understand test instructions due to impaired cognition and/ or communication - Other diseases that could affect somatosensory function	To evaluate the test-retest reliability of the STI-test in persons with chronic stroke.	STI-test ™	Reliability
CS Gaubert et al. 2000	20	70y (13,05 SD) Disease duration: 3.85w (2,78SD) 9 right hemiparesis 4 bilateral stroke Inclusion: - First- time stroke Exclusion: - Neglect - Cognitive deficits - MSEE < 24/30	To investigate the inter-rater reliability of stereognosis assessment in stroke patients, as measured by the NSA.	rNSA: Stereognosis	Inter-rater reliability

Study	n	Sample Characteristics	Study aim	Outcome measures	Psychometric properties
Lin et al.2003	176	67,9y (10,9 SD) 14,30,90 and 180 days poststroke 101 right hemiparesis Inclusion: - First-time stroke Exclusion: - Communication deficits	To examine the psychometric properties of the sensory scale of the FMA-S in stroke patients with a broad range of neurological and functional impairment at times from 14 to 18 days after stroke.	FMA-s FMA-m Barthel-index	Inter-rater reliability Internal consistency Validity (convergent and predictive) Responsiveness
Lincoln et al. 1991	89	55-83y 38 intra-rater reliability 15 right hemiparesis 1 bilateral stroke 47-81y 51 inter-rater reliability 11 right hemiparesis Inclusion: - >1y stroke	To investigate the inter-rater reliability of the NSA.	NSA	Inter/intra-rater reliability Responsiveness
Lincoln et al. 1998	27	No data ages 26 hemiparesis 1 bilateral stroke Exclusion: - Cognitive deficits	To revise of the rNSA and to determine the inter-rater reliability of the rNSA.	rNSA	Inter-rater reliability

Study	n	Sample Characteristics	Study aim	Outcome measures	Psychometric properties
Meyer et al. 2015	122	67y (58.8 to 76.1) Disease duration: 82d (57 to 132.8) 48 right hemiparesis Inclusion: - First-time stroke - <6m after stroke - Motor and/or somatosensory impairment in the upper limb using outcome measures as described in the last colon. - >18y - substantial cooperation to perform the assessment. Exclusion: - Neurological impairments - Subdural hematoma, tumor, encephalitis, or trauma that led to similar to that of a stroke - Serious communication, cognitive, or language deficits	To investigate the distribution of upper-limb somatosensory impairments and the association with unimanual and bimanual motor outcomes and visuospatial neglect.	Em-NSA PTT TFT Two- point discrimination FMA-UE MI ARAT Ad-AHA	Validity
Miller et al.2009	46	22 chronic, 65.2y (9.5 SD) Disease duration: 46m (29,3 SD) 24 subacute stroke, 59.7 y (17.1 SD) Disease duration: 29,4d (8,3 SD) All hemiparesis Inclusion: - 18- 85y	To investigate the clinimetric properties and clinical utility of the AsTex.	The AsTex Chedoke Mc-master MAS	Reliability Validity (Clinical utility) Responsiveness

Study	n	Sample Characteristics	Study aim	Outcome measures	Psychometric properties
		Exclusion: - History of neurological impairment - Serious upper quadrant injury - Numbness or paraesthesia in arms or hands - Diabetes mellitus - Peripheral vascular disease Raynaud's phenomena or scleroderma.			
Stanford et al.1993	12	66y (11,47 SD) Disease duration: 56d (30 SD) 8 right hemiparesis Inclusion: - <80y - <6m post-stroke	To establish the inter-rater reliability of assessments made with the Fugl-Meyer evaluation of physical performance in a rehabilitation setting.	FMA	Inter-rater reliability Intra-rater reliability
Stolk-Hornsveld et al.2006	18	57,7y (20-84) Disease duration: 14,9d (4-92) Intracranial disorders 6 right and 4 left hemiparesis, 2 bilateral stroke, 2 Cerebral Tumour, 2 Hydrocephalus and 1 Traumatic brain injury Inclusion: - Neurological or neurosurgical disorders Exclusion: - MMSE < 15	To investigate the intra-rater and inter-rater reliability of the EmNSA.	EmNSA	Intra/inter-rater reliability

Study	n	Sample Characteristics	Study aim	Outcome measures	Psychometric properties
Williams et al.2006	28	60.18y (14,46 SD) 14 right hemiparesis Disease duration: 17m (21 SD) Inclusion: - Able to grasp lift and release 3.81cm diameter cylinder, weighting 224g. Exclusion: - Past or current diagnosis peripheral nervous system, central nervous system, skin, medical, or orthopaedic condition that could alter sensation.	To develop and establish the reliability and validity of the HASTe.	HASTe WPST 2-point-discrimination APHQ	Reliability Validity Sensitivity and specificity
Winward et al.2002	100	50 right hemiparesis → (64.2y, SD = 15,6) Disease duration: 4.7w (5,4 SD) 50 left hemiparesis → (64,0y, SD = 15,4) Disease duration: 6,1w (8.6 SD) Inclusion: - First-time stroke Exclusion: - Bilateral signs - Unable or unwilling to participate - Visual or hearing impairments - Cognitive impairments - Another neurological condition.	To develop a standardized, clinically relevant, quantitative assessment of somatosensory performance in patients with stroke.	RASP RMI RMA BI	Intra-rater reliability Inter-rater reliability Validity

Study	n	Sample Characteristics	Study aim	Outcome measures	Psychometric properties
Wu et al. 2016	147	53y (10,56 SD) 72 right hemiparesis Disease duration: 21,79m (18,27 SD) Inclusion: - First-time unilateral stroke Exclusion: - >2 MAS - >24 MMSE - another neurological, muscular or orthopaedic condition.	To establish the concurrent validity, predictive validity, and responsiveness of the rNSA during rehabilitation for people with stroke.	rNSA FMA-s FMA-m NEADL	Validity Responsiveness

Ad-AHA; Adult Assisting Hand Assessment Stroke, APHQ; Annett Hand Preference Questionnaire, ARAT; Action Research Arm Test, The AsTex, BBA, BBT; Box and Blocks Test, BI; Barthel Index, BKT; The Brief Kinesthesia test, CSII; Cumulative Somatosensory Impairment Index, FISCIT; The Frailty and Injuries: Cooperative Studies of Intervention Techniques, FMA-m; Fugl-Meyer Assessment of motor recovery, FMA-s; Fugl-Meyer Assessment of sensory recovery, FMA-UE; FMA-Upper extremity, HASTe; Hand Active Sensation Test, MAL; Motor Activity Log, MAS; Motor Assessment Scale, MI; Motricity Index,, MMSE; Mini-mental state examination, MTP; Moving Touch-pressure, NEADL; Nottingham Extended Activities of Daily Living Index, NIHSS; National Institutes of Health Stroke Scale, NSA; Nottingham Sensory Assessment, Em-NSA; Erasmus Modification of Nottingham Sensory Assessment, rNSA; revised Nottingham Sensory Assessment, PTT; Threshold of Touch, RASP; Rivermead Assessment of Somatosensory Performance, RMA; Rivermead Motor Assessment, RMI; Rivermead Mobility Index, STP; Sustained Touch-pressure, SWM; Semmes- Weinstein Monofilament, TDT, TEMPA-8; Upper Extremity Performance Test for the Elderly, TFT; Thumb Finding Test, Touch-test, Two- point discrimination, Wolf; Wolf Motor Function Test, WPST; Wrist Position Sense Test.

Table 6: Reliability of outcome measures in stroke

Outcome Measures	Inter-rater Reliability	Intra-rater Reliability	Internal consistency
AsTex **Affected hand** **Unaffected hand**		[70] ICC = 0.86 (0.68 to 0,94) ICC = 0.86 (0,66 to 0,94)	
FMA-s	κ = 0.30 to 0.90 [59] ICC = 0.93 (0.85 to 0.96) [59] ICC= 0.85 (0.67 to 0.94) [82] SEM = 2.9 [82]	ICC= 0.85 (0.67 to 0.94) [82] SEM = 2.9 [82]	
HASTe		ICC = 0.77, r= 0.78 [5] [95] SEM = 1.70 to 1.96 [95]	α= 0.82 [3] [95]⊗
MTP **STP**	ICC =0.92 (0.66 to 0.94) [25] ICC = 0.66 (0.40 to 0.82) [25]	ICC = 0.92 (0.62 to 0.82) [25] ICC= 0.62 (0.34 to 0.80) [25]	
Em-NSA **Light touch** **Pressure** **Pinprick** **Sharp/ blunt discrimination** **Proprioception** **Two- point discrimination**	[90] κ = 0.71 to 1.00 κ = 0.83 to 1.00 κ = 0.76 to 1.00 κ = 0.53 to 1.00 κ = 0.46 to 1.00 κ = -0.63 to 0.66	[90] κ = 0.62 to 1.00 κ = 0.63 to 1.00 κ = 0.79 to 1.00 κ = 0.58 to 1.00 κ = 0.63 to 1.00 κ = 0.11 to 0.63	
rNSA **Light touch** **Pressure** **Pinprick** **Temperature** **Tactile localization** **Bilateral simultaneous touch** **Kinesthetic (detection of movement)** **Stereognosis** **Affected side** **Unaffected side**	[61] κ = 0.16 to 0.77 κ = 0.29 to 0.65 κ = 0.26 to 0.52 κ = 0.04 to 0.53 κ = 0.36 to 0.58 κ = 0.36 to 0.59 κ = 0.31 to 0.53 κ = 0.40 to 0.80 [36] κ = 0.63 to 1.00 [36]		κ = -0.1 to 0.54 [23] ⊗ κ = 0.42 to 0.96 [23] ∅ κ = 0.07 to 0.77 [23] ∅

Outcome Measures	Inter-rater Reliability	Intra-rater Reliability	Internal consistency
RASP	r = 0.92 [98]	[98]	[11]
Detection of movement		r = 0.83	κ = 0.72 to 0.93** ϴ
Direction of movement		r = 0.50	κ = 0.88 to 0.94** ϴ
Detection of touch		r = 0.90	κ = 0.89 to 0.97** ϴ
Location of touch		r = 0.96	κ = 0.92 to 0.95** ϴ
Sharp/ dull discrimination		r = 0.84	
Temperature		r = 0.84	
STI-test™		[34]	
Affected side			
Subtest shapes		PA = 0.96	
Subtest textures		PA = 0. 82	
Unaffected side			
Subtest shapes		PA = 0.62	
Subtest textures		PA = 0.91	
TDT		r = 0.92 [19] SEM = 9.08 to 3.80 [19]	

NOTE. ICCs are presented with (95% confidence interval). ICC and κ and r and PA: > 0.75 = good reliability, 0.50-0.75= average, < 0.50 poor; $p < 0.05$* $p < 0.01$**

ICC= intraclass correlation coefficient, κ= kappa value, r= Pearson correlation coefficient, SEM= Standard error of measurement, PA = percentage agreement, α = Cronbach alfa, ⊗= internal consistency between different items or modalities, ∅= internal consistency between body areas, ϴ = consistency between the total limb score and the individual anatomical site

FMA-s; Fugl-Meyer Assessment of sensory recovery, HASTe; Hand Active Sensation Test, MTP/STP; Moving and Sustained Touch-pressure, EmNSA; Erasmus Modification of Nottingham Sensory Assessment rNSA; revised Nottingham Sensory Assessment, RASP; Rivermead Assessment of Somatosensory Performance, , STI-test™; shape and texture identification, TDT; Tactile Discrimination Test.

Table 7: Correlation coefficients sensory and other sensory measures

Outcome	FMA-S	HASTe	Modified Moberg	SWM	Two- point discrimination	WPST
BKT		r = 0.355 [6]		r = 0.095 [6]		
HASTe					r = - 0.571 to – 0.643** [95]	r =-0.609** [95]
MTP			r = 0.49*[25]	r = -0.83** [25]		
rNSA	r = 0.59 to 0.69** [102] R^2= 0.80-0.83 [102]					
STP			r = 0.21 to 0.71 [25]	r = -0.39 to 0.80** [25]		

NOTE. Values are the ranges of Pearson correlation coefficients (r) found between outcome measures reported in different articles.

P < 0,001**, P < 0,05*

r or R^2: < 0.30= weak, < 0.50= moderate, < 70= high, 1 = excellent.

BKT; The Brief Kinesthesia test, CSII; Cumulative Somatosensory Impairment Index, FMA-s; Fugl-Meyer Assessment of sensory recovery, HASTe; Hand Active Sensation Test, MTP; Moving Touch-pressure, STP; Sustained Touch-pressure, WPST; Wrist Position Sense Test

Table 8: correlation coefficients of sensory and other outcome measures

Outcome	Ad-AHA Stroke	ARAT	BBT	BI	FISCIT	FMA-M	FMA- UE	MAL
BKT			r = -0.77* [6]					r = 0.84* [6] r = 0.76* [6]
CSII					β = -1.380*, SD= 0.441 [29]			
FMA-s				r = 0.38 to 0.53**[59]		r = 0.31 - 0.44 **[59]		
MTP			r = 0.25 [25]					
Em-NSA								
Light touch	ρ = 0.372*[68]	ρ = 0.386*[68]					ρ = 0.309*[68]	
Pressure	ρ = 0.371*[68]	ρ = 0.382*[68]					ρ = 0.329* [68]	
Pinprick	ρ = 0.367*[68]	ρ = 0.377*[68]					ρ = 0.337*[68]	
Kinesthesia	ρ = 0.422*[68]	ρ = 0.444*[68]					ρ = 0.412*[68]	
SD/DD	ρ = 0.282*[68]	ρ = 0.312*[68]					ρ = 0.223*[68]	
rNSA				R^2 = 0.464*[25]		r =0.22 to 0.37 *[102] R^2 = 0.12		
PTT	ρ = -0.608**[68]	ρ = -0.611**[68]					ρ = -0.580**[68]	
RASP				r = 0.09 to 0.41** [95]				
STP			r =0.17 to 0.49 [23]					
TFT	ρ = -0.389*[68]	ρ = -0.365 [68]					ρ = -0.360* [68]	
TDT	ρ = -0. 360*[68]	ρ = - 0.403*[68]					ρ = -0.316* [68]	

NOTE. Values are the ranges of Spearman correlation coefficients (ρ) or Pearson correlation coefficients (r) found between outcome measures reported in different articles. ρ, r or R^2 are graded very high (<0.90), high (0.70-0.89), moderate (0.50-0.69), and low (<0.49). P < 0,001**, P < 0,05*

Ad-AHA; Adult Assisting Hand Assessment Stroke, ARAT; Action Research Arm Test, BBT; Box and Blocks Test, BKT; The Brief Kinesthesia test, BI; Barthel Index, FISCIT; The Frailty and Injuries: Cooperative Studies of Intervention Techniques, FMA-m; Fugl-Meyer Assessment of motor recovery, FMA-s; Fugl-Meyer Assessment of sensory recovery, FMA-UE; FMA-Upper extremity, MAL; Motor Activity Log, MTP; Moving Touch-pressure, EmNSA; Erasmus Modification of Nottingham Sensory Assessment, rNSA; revised Nottingham Sensory Assessment, PTT; Threshold of Touch, RASP; Rivermead Assessment of Somatosensory Performance, STP; Sustained Touch-pressure, SD/DD; sharp/ dull discrimination, TDT; Two point discrimination test, TFT; Thumb Finding Test

Outcome	MI	Modified Moberg	NEADL	NIHSS	RMA	Tempa-8	WOLF
BKT							r = 0.69* [6]
MTP		r = 0.49*[25]				r = -0.34 [25]	
Em-NSA Light touch Pressure Pinprick Kinesthesia Sharp/ dull discrim.	 ρ = 0.318* [68] ρ = 0.337* [68] ρ = 0.348* [68] ρ = 0.394* [68] ρ = 0.220 [68]						
rNSA			r = 0.21 to 0.33 *[102] R^2= 0.15	R^2 = 0.212-0.406*[23]			
PTT light touch	ρ = -0.564**[68]						
RASP	r = 0.08 to 0.36**[98]				r = 0.05 to 0.32**[98]		
STP		r = 0.21 to 0.71 [25]				r = 0.35 to 0.53 [25]	
TFT	ρ = -0.354*[68]						
TDT	ρ = -0.316*[68]						

NOTE. Values are the ranges of Spearman correlation coefficients (ρ) or Pearson correlation coefficients (r) found between outcome measures reported in different articles. P < 0,001**, P < 0,05*

BKT; The Brief Kinesthesia test, MI; Motricity Index, MTP; Moving Touch-pressure, NEADL; Nottingham Extended Activities of Daily Living Index, NIHSS; National Institutes of Health Stroke Scale, EmNSA; Erasmus Modification of Nottingham Sensory Assessment, rNSA; revised Nottingham Sensory Assessment, PTT; Threshold of Touch, RASP; Rivermead Assessment of Somatosensory, Performance, RMA; Rivermead Motor Assessment, STP; Sustained Touch-pressure, TDT; Two point discrimination, Tempa-8; Upper Extremity Performance Test for the Elderly, TFT; Thumb Finding Test, WOLF; Wolf Motor Function Test

Table 9: Responsiveness values of outcome measures

Outcome	SRM	MDC	Floor/Ceiling effect
AsTex	SRM = 0.57 [70]	MDC = 0.38 mm* [70]	Floor effect: 0.125 ⊗[70] Ceiling effect: 0.083 ⊗[70] 0.045 ∅[70]
FMA-s	SRM = 0.27 – 0.67* [59]		
rNSA	[102]		
Tactile Sensation	SRM= 0.83		
Proprioception	SRM= 0.51		
Stereognosis	SRM= 0.55		

SRM= Standard response mean, p < 0,05*, MDC= Minimal detectable change
FMA-s; Fugl-Meyer Assessment of sensory recovery, rNSA; revised Nottingham Sensory Assessment
⊗ = subacute stroke population ∅ = chronic stroke population
Cohen's criteria: SRM <0.5 = small, 0.50 to 0.80 = moderate, >0.80 = large.

Table 10: Strengths and weaknesses of the included studies

Authors	Limitations	Strengths
Borstad et al.2015	- Small sample size - The subjects comprised only stroke survivors with somatosensory impairments→ results cannot be generalised to all stroke patients. - HASTe is not appropriate for individuals with severe upper extremity motor impairments, only moderate to mild.	- Can be used in both research and clinical settings. - Inexpensive, common materials and relatively easy to construct - Example objects were provided to the participants to get familiar with the objects, which resulted in lower variability scores. - A 18-point scale provides more information about haptic performance than dichotomous descriptions (intact, impaired).
Borstad et al.2016	- There is a small sample size and only chronic stroke patients are included. Therefore interpretation should be done with caution and results should not be generalized to the whole stroke population. - It is possible that a participant's ability to generate motor output affects the BKT-scores. - Poor reaching accuracy may be due to limited motor output and not to kinaesthetic sense.	- A continue scoring scale (distance from target) - Normative data available - No ceiling effect in stroke patients - Simple instructions may limit the potential for confounding by cognitive impairments
Busse et al.2009	- Redundancy was not tested in other modalities such as perception of temperature, deep pressure a two-point discrimination. - Specific testing materials are needed - Only acute stroke patients included	- First study that assess redundancy - Minimizing the number of tests performed should help patients to maintain their concentration and engagement with testing: a problem using the full RASP.
Carey et al.1997	- The unaffected hand was tested first→ learning effect - The preferred finger was only tested	- Step by step instruction and demonstration of the test minimalize the influence of cognitive impairment. - Objective guidelines for interpretation of scores were provided.
Conell et al.2008	- The sample was limited to those admitted to a stroke rehabilitation unit - Patients with only sensory loss have been excluded.	- One of the larger studies on somatosensory impairment after stroke

Authors	Limitations	Strengths
Dannenbaum et al. 2002	- Responsiveness is not investigated - Not all the therapists performed the test in the same way. - Variability in the size of the skin surface stimulated by the brush and the amount of pressure applied to each brush and the speed of stimulus application. - Variability in intensity and duration of the stimulus. - Testing period was too short to measure the full extent of fading for the STP.	- /
Deshpande et al.2010	- Patients with other neurological conditions were included - No data available of the reliability of the CSII - CSII is not compared with other sensory scales	- CSII is compared with elaborated motor tests, balance and functional tests in this study - 3 year follow-up
Ekstrand et al. 2015	- This study included only persons with mild to moderate impairments in the arm and hand post stroke - More men than women agreed to participate - They only investigated reliability.	- The test situation was standardized and the test protocol was thoroughly described.
CS Gaubert et al. 2000	- Small sample size - Answers have been interpreted differently by the examiners. - Only patients < 3 m post stroke	- The ordering of assessors was randomized and the second assessor was unaware of the results obtained by the first to eliminate bias - Examiners underwent a short training program to ensure standardization of the method - Subjects were blindfolded. - The affected side was tested first, this would decrease the learning effect.
Lin et al.2003	- /	- This study followed subjects at four specific time points after stroke for a period up to 180 days to evaluate the clinical use of the FMA-s at different recovery stages. - The protocol is clearly described.

Authors	Limitations	Strengths
Lincoln et al. 1991	- A categorical scale (5 levels) - The assessment could last up to an hour and results in inconsistencies - No resting periods were added to avoid disorientation and fatigue - No clear description of methods - Patients characteristics were not described	- Blinding of the third assessor/ doctor - First demonstrating the test to the patient before testing.
Lincoln et al. 1998	- No data about the age of the participants - Judging whether a limb has been touched is very subjective and producing discrepancies between the two assessors	- The researchers were able to simplify the NSA without missing important information. - The sample size was adequate for research purposes. - Experienced physiotherapists - Assessors each saw half the patients first, which would reduce any systematic bias.
Meyer et al. 2015	- Only patients with an anterior circulation stroke were included - Differences in assessment methods - Recruitment of the patients was not performed consecutively. - No flowchart, because there is no data available - The specific content and frequency of the treatment were not documented and therefore not possible to control.	- A clearly inclusion and exclusion criteria - Assistance to manipulate the objects in the hand is given by the assessor - Clear methodology
Miller et al.2009	- Differences in attention between trials may have influence the measures.	- The assessor support the participants when the active movement is limited.
Sanford et al.1993	- Indirect observation - A small sample size	- /
Stolk-Hornsveld et al.2006	- A small sample size - Patients with other neurological conditions also included (Traumatic brain injury etc.)	- A clearly inclusion and exclusion criteria - The two physiotherapists has a clinical caseload throughout the period of the study and minimize the recall of the results of inter-rater reliability. - Each examiner was blinded and tested all patients on two occasions. - To minimize recall bias, an interval of at least 24 hours was induced between the initial and repeat test occasions.

Authors	Limitations	Strengths
Williams et al.2006	- No example objects were provided to the participants, which may have resulted in greater variability in healthy participant scores. - A small and varied sample size group	- No learning effect was seen in the interval of one hour.
Winward et al.2002	- Most of the data was collected by one individual. - The study does not whether some subtests are redundant.	- Clear description of the subtests - Big sample size - Patients whose performance might be considered affected by 'suggestibility,' fatigue and mental confusion.
Wu et al. 2016	- Many participants achieved maximum scores at pre-treatment, therefore the responsiveness of proprioception have been overestimated. - Only acute and chronic stroke patients were included. (No subacute patients)	- A clearly inclusion and exclusion criteria - Participants were randomly assigned to the two groups. - Participants were evaluated immediately after the intervention - The six evaluators were blinded to the group assignments.

PART 2: RESEARCH PROTOCOL

1. Introduction

Patients with stroke often suffer from motor impairments, cognitive deficits and somatosensory impairments. Somatosensory impairments occur in around 70% of patients after stroke (Carey & Matyas, 2011). Evidence shows that somatosensory impairment leads to a poor prognosis for functional recovery after stroke in patients with more severe impairments (Feys et al., 2000; Han et al., 2002; Abela et al., 2012).

Sensory information about our body and environment is registered by receptors and send to the somatosensory cortex for processing and interpretation. These sensory receptors can be classified in three types: superficial, deep and combined cortical sensations (O'Sullivan, Schmitz, & Fulk, 2014). Proprioceptors provides information of deep sensations and can be divided into limb or joint position sense and kinaesthesia (the sense of movement) (O'Sullivan, 2014; Gilman, 2002).

Somatosensory impairments can be present in different somatosensory modalities such as light touch, pain, proprioception, and somatosensory discrimination sense (DeJong, 1979). Proprioception and stereognosis are most frequently impaired, followed by tactile sensations (Connell, Lincoln, & Radford, 2008). To be able to generate and correct movements, especially for fine motor function of the upper limb such as aiming, reaching and grasping, proprioception is critical (Hasan, 1992; Sober and Sabes, 2003; Butler et al., 2004; Konczak et al., 2009). It's well known among clinicians that proprioception is an important predictor for recovery of sensorimotor function (Winward, Halligan, & Wade, 1999). To better understand this influence of somatosensory impairments on motor function and recovery, it is important to assess adequately sensory function (Mrotek, Bengtson, Stoeckmann, & Botzer, 2017).

However, there are a few clinically accepted and used tests for proprioception, such as the Brief Kinaesthesia Test (Borstad, & Nichols-Larsen, 2016), Thumb finding test (Smith, Akhtar, & Garraway, 1983), Up or down Test (Lincoln et al., 1991), the Wrist Position Sense Test (Carey, Oke, & Matyas, 1996) and the proprioception subtest of the Nottingham Sensory Assessment, Fugl-Meyer Assessment and Rivermead assessment of somatosensory performance. Although these tests are simple and quick to administer, they are largely subjective, lack standardized protocols and show poor interrater agreement (Lincoln et al., 1991, 1998; Winward et al., 1999, Borstad, et al, 2016). Because their dichotomous or ordinal scales, the measurements can only be used for screening proprioception impairments and not to detect small functional improvements. (Hillier, Immink, & Thewlis, 2015). Furthermore previous research has shown that, for example the thumb finding test showed limited agreement with robotic assessment technique (Dukelow, Herter, Moore, & Demers, 2010). Therefore the methods of assessing proprioception should be improved.

Recently, more quantitative assessment methods to investigate proprioception in the upper limb have been developed, of which many make use of robotics. Advantages of robotic approaches are high resolution, high reliability and good control over extern stimuli (Scott & Dukelow, 2011). However, their use in clinical practice is limited because of expensiveness of the devices or the length of the experimental protocols (Hillier et al., 2015). Furthermore, psychometric properties such as reliability, validity, precision, feasibility and clinical utility, are often either poorly evaluated and reported or not reported at all in a stroke population (Hillier et al., 2015).

The primary aim of this study is to evaluate and report the test-retest, clinical utility and validity of a robotic assessment of finger proprioception using a passive gauge position matching task in stroke subjects.

2. Aim of the study

The main aim of the study is to investigate the test-retest, clinical utility and validity of a robotic assessment of finger proprioception using a passive gauge position.

2.1 Research questions related to the master thesis

RQ1: What is the test-retest reliability of the ReFlex, a one degree-of-freedom robotic wrist or finger interface, in stoke subjects? Reliability is the degree of consistency between repeated measurements.

RQ2: Is the ReFlex clinical utility and quick to administer in stroke patients? This can be measured by the System Usability Scale (SUS), a reliable tool for measuring the usability of this robot.

RQ3: What is the convergent validity of the ReFlex compared to clinical assessments of somatosensory impairment such as the Erasmus modification Nottingham Sensory Assessment (EmNSA) and the stereognosis subtest of the revised Nottingham Sensory Assessment (rNSA) and Up or Down test? Convergent validity tests if measurements that are supposed to be related, are actually correlated.

RQ4: What is the correlation of the finger proprioception measured by the ReFlex and fine and gross motor function, respectively measured by the Nine Hole Peg Test and The Frenchay Arm Test?

2.2. Hypotheses

Hypothesis 1: The ReFlex shows higher test-retest reliability compared to clinical assessment because of a higher resolution, because of a more standardized method and the exclusion of subjectivity of clinical examination.

Hypothesis 2: The ReFlex is a feasible and quick tool to measure proprioception of fingers in patients with stroke.

Hypothesis 3: The ReFlex shows high correlations with the subtest proprioception of the Em-NSA and moderate correlations with the subtests light touch, pressure pinprick and sharp-blunt discrimination (Stolk-Hornsveld, Crow, Hendriks, & van der Baan, 2006). A moderate to high correlation is shown with the subtest stereognosis (biro, scissors, comb and cup) of the rNSA (Gaubert & Mockett, 2000).

Hypothesis 4: Fine motor function, that is required to complete the NHPT, might not be correlated with the clinical robotic assessment of somatosensory function in the finger. This is because patients (especially chronic stroke patients) have learnt compensations for their loss of somatosensory function, like for example the use of vision and increased grip forces. It is also likely that proximal motor control and health related quality of life will not be correlated with loss of somatosensory function.

3. Methods

3.1. Research design and procedure

The robot that will be used in this cross-sectional study is the ReFlex, a one degree-of- freedom robotic wrist or finger interface (Rinderknecht, Popp, Lambercy, & Gassert, 2016). Data collection will take place in the MS center in Overpelt and the Herk-de-stad hospital. To assess the test-retest reliability of the ReFlex in stroke, each examiner will test all 30 patients on two occasions.

To minimize the learning effect, there will be an interval of 24-48 hours between the baseline and repeat test. Two examiners will assess each patient on the same day, with an interval of at least one hour. Throughout the study, the examiners will be blinded to each other's results. Two physiotherapist students will act as examiners for this study. Before the start of the study the examiners will undergo a short program to get familiar with the robot and to ensure all measurements will be done standardized.

3.2. Participants

3.2.1 Inclusion criteria

Patients that participate in the study should meet the following criteria:

- First time stroke
- Both acute (< 3m) and chronic stroke patients
- > 18 years
- Unilateral stroke
- Having signed the informed consent documents
- Normal or corrected-to-normal vision

3.2.2 Exclusion criteria

- ≤ 18 years
- Having other medical conditions such as diabetes, Parkinson, orthopaedic or rheumatoid impairment of the hand, etc.
- Severe spatial neglect on Albert's test

- Mini Mental Scale Examination > 24
- Difficulty in understanding or complying with the instructions given by the researchers
- Unable to detect passive movements in the hand and fingers.
- The kind of medication or the dosing is altered substantially during the course of the study
- Marked or severe increase in tone (Ashworth spasticity score ≥ 4 at the elbow, wrist or MCP)
- Marked or severe intention tremor (Fahn's tremor rating scale > 3)

3.2.3 Patient recruitment

The aim is to recruit a minimum of 30 patients for the study. Information about the study will be announced on several locations: The Rehabilitation and MS center in Overpelt and the JESSA Hospital Jessa campus Sint-Ursula Herk-de-Stad. Patients will be divided in an acute and chronic stroke group in the data-analysis but not during the testing.

3.3. Medical ethics

The request for this experimental study will be submitted the 22 of August.

3.4 Outcome measures

3.4.1 Descriptive measures

At baseline the following measures are conducted to describe the population.
Demographic and descriptive data collected stroke patients

- Sex
- Age
- Type of stroke
- Time after stroke
- Hand Dominance evaluated with Edinburgh Handedness Inventory
- Spasticity evaluated with modified Ashworth scale (Bohannon & Smith, 1987)
- Nine Hole Peg test (Parker et al, 1986; Heller et al. 1987)
- The Frenchay Arm Test (Parker et al, 1986; Heller et al. 1987)
- Medication use

3.4.2 Primary outcome measures

Apparatus:

This robot will be lent by the Rehabilitation Engineering Laboratory ETH of Zurich (Rinderknecht, Popp, Lambercy, & Gassert, 2016).

The assessments will be executed with an adapted ergonomic interface for the meta carpophalangeal (MCP) joint using the ReFlex robotic device (Figure 1a and 1b). It is a portable version of the ReFlex robot especially designed for proprioceptive assessments of both left and right hands. The ReFlex is capable of providing well-controlled and reproducible passive flexion extension movements of the index finger. The portable version of the ReFlex is a similar 1-DOF device, based on the design of the ReFlex. Compared to the ReFlex, it features a less powerful motor and does not require a brake system. The encoder is also mount directly on the motor axis. The force sensor located directly at the finger/MCP joint interface. Identically to the ReFlex, the portable version is controlled by a LabVIEW RealTime system. The exchangeable ergonomic interface allows the assessment of both left and right hands. The LabVIEW program will run the tasks automatically without intervention of the experimenter and prompt the participant after each trial to provide feedback by using buttons. Data from the robot and participant feedback will be recorded and saved for subsequent offline data analysis conducted with MATLAB and SPSS.

Testing protocol:

The patient will be seated in front of a screen and the ReFlex will be adjusted to the patient. The robotic device will be able to passively flex and extend the fingers, expressed in angular position (number of degrees in flexion or extension). Each trial of the matching task consists of the presentation of one passive MCP-flexion (between 10-30° flexion). The patient is asked to indicate the perceived angular position on a needle display on the screen. After providing feedback, the MCP will be passively moved back to the resting position (0° flexion/extension). No visual feedback will be provided.

To test the alertness of the patients, randomly embedded into the measurement procedure, proprioceptive alertness tests will be given. In these proprioceptive alertness trials the ReFlex will present a small and short finger-flexion or -extension movement (< 5° and shorter than 1 second). The patient is requested to react as quickly as possible to this stimulus by pressing on a button.

During the whole measurement patients will receive white noise played over headphones to avoid auditory cues.

The touchscreen is mounted horizontally above the tested finger, such that the perceived finger position can be indicated by the subject by aligning a displayed angular gauge indicator with the perceived orientation of the hand. This touchscreen allows at the same time to prevent the subject from seeing the tested finger, hand and part of the forearm. The finger was attached to the handle by two Velcro straps. To reduce visual parallax errors when aligning the gauge to the finger position, a

nonadjustable head support frame was mounted on top of the touch screen ensuring reproducible head positions across subjects and sessions.

Primary outcome measures, that will be analysed in the master thesis are:

- Robotic measurements:
    - Average constant error (CE = average error)
    - Absolute error (AE = average absolute error)
    - Variable error (VE = standard deviation of errors
    - Total variability (E = root mean square of errors)
    - Administration time

The error is calculated as reported angle by the subject minus presented angle. Following this convention, a positive CE represents an overestimation of the finger flexion angle, whereas a negative CE represents an underestimation. While the implementations of CE, AE, and E follow the standard definitions, the VE was implemented as the standard deviation of errors across all the presented angles, as each angle was presented only once and the classical definition would result in a non-zero VE for zero error.

3.4.3 Secondary outcomes measures: clinical measures

- Erasmus modification of the Nottingham Sensory Assessment (Em-NSA)

  The EmNSA is chosen to clinically evaluate somatosensory impairments. The EmNSA has good inter-rater agreement (κ = 0.71) and excellent intra-rater (κ = 0.84-1) agreement for the subtest proprioception in fingers. In addition, the proprioception subtest was further standardized in comparison to the revised Nottingham Sensory Assessment (rNSA). Appendix one shows the protocol of the EmNSA. No special expensive equipment is required for the administration of the EmNSA. It is therefore a widespread used clinical assessment method for screening stroke population. The EmNSA only uses three categorical scales (absent, impaired and normal). A limitation is that the reliability is only investigated in a small amount of stroke patients (Stolk-Hornsveld et al., 2006). The responsiveness is not investigated. Appendix 1 shows the full explanation and scoring of the Em-NSA (Stolk-Hornsveld et al, 2006).

- Revised Nottingham Sensory Assessment (rNSA)

  Only the subtest stereognosis of the rNSA will be used. In this study, the only object who will be used are the biro, scissor, comb and cup. These objects show average to high reliability (κ= 0.75-0.80) (Gaubert et al., 2000). Appendix 2 shows the instruction of the stereognosis subtest of the rNSA.

- Up or Down test

  The patient is asked to close his eyes while the researcher is moving the distal limb segment of the finger up and down for several times. The researcher must take care to avoid proximal pressure and gravitational cues related to the movement. When the researcher stops moving the joint, the patient must say the joint orientation. It will be repeated different times at each joint. The proprioception will be indicated as intact if the answers are fast and accurate. It's defined as impaired if the patient is doubting and makes one mistake. The absent score will be given if the patient is unable to determine position reliably (2 or more errors) (Mrotek, et al., 2017).

- The Nine Hole Peg Test (NHPT)

  The NHPT is used to measure fine motor function and finger dexterity. It shows good to excellent inter- and intra-rater reliability in stoke patients (Parker, Wade, & Hewer, 1986; Heller, Wade, Wood, & Sunderland et al. 1987) Additionally, the NHPT is an inexpensive test and can be administered quickly. Appendix 3 shows the instruction of the NHPT (Mathiowetz, Weber, Kashman et al, 1985).

- The Frenchay Arm Test (FAT)

  The Frenchay Arm Test (FAT) evaluates the proximal motor control and dexterity of the paretic arm during daily living activities. Psychometric properties of the FAT such as reliability and validity show good to excellent values. (Parker et al, 1986; Heller et al. 1987)
  Appendix 4 shows the instruction of the FAT (Parker et al, 1986).

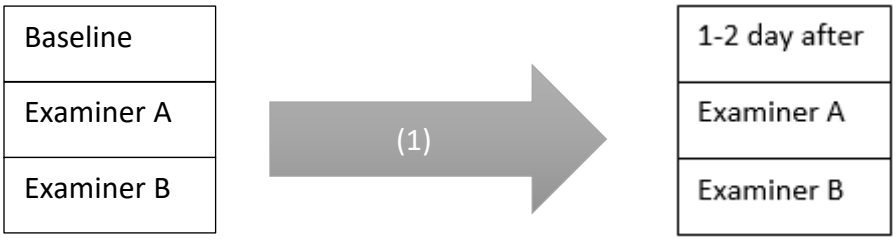
3.4.4 Secondary outcomes measures: clinical utility

- The System Usability Scale (SUS)

  The last measure that will be used is the System Usability Scale (SUS), a scale that determine the usability of a measure. Participants are asked to score 10 items with one of five responses that rage from 'strongly agree' to 'strongly disagree' (Brooke, 1996). Appendix 5 shows the instruction of the SUS (Brooke, 1996).

3.5 Data analysis

The following statistical tests will be performed:



(1) Test retest-reliability is going to be analysed by comparing different measures of examiners at baseline and one or two days later. The test-retest reliability was calculated based on the ICC (Shrout &Fleiss, 1979). Its 95% confidence interval (CI), the standard error of measurement (SEM) and the smallest real difference (SRD) will be calculated according to Lexell and Downham (2005).

In addition, the mean and standard deviation (SD) of absolute differences will be calculated to estimate the variation of measurement errors around the 'true score' of the participants between testing occasions. (Stratford & Goldsmith, 1997)

Paired t-tests for normally distributed data will be used to analyse the learning effects between testing occasions. Wilcoxon signed ranks test will be used for not normally distributed data. Significance levels were set to $\alpha = 0.05$. Probability values $p < 0.05$ and $p < 0.01$.

The Pearson and Spearman correlation coefficient will be used to examine the association between the ReFlex and the other outcome measures: EmNSA, the stereognosis subtest of the rNSA, NIHPT, FAT and the Up or Down test. The following criteria will be used to interpret the correlation: ρ or $r <$ 0.25 is low; 0.25-0.50, fair; 0.50-0.75, moderate to good; > 0.75, excellent (Portney & Watkins, 2009)

4. Time planning

	Protocol	preparation EC	Final EC	Preliminary tests	Data collection stroke	Data collection PwMS	Data analysis	Publication
July '17								
Aug '17								
Sept '17								
Oct '17								
Nov' 17								
Dec' 17								
Jan '18								
Feb '18								
Mar '18								
Apr '18								
May '18								

September 2017- March 2018: patient's recruitment and data collection. Data collection will take place in Jessa hospital Hasselt from September 2017 – December 2017. From January until March 2018 patients will be tested in Rehabilitation and Multiple Sclerosis center Overpelt.

5. List of references

Abela, E., Missimer, J., Wiest, R., Federspiel, A., Hess, C., Sturzenegger, M., & Weder, B. (2012). Lesions to primary sensory and posterior parietal cortices impair recovery from hand paresis after stroke. *PLoS One, 7*(2), e31275. doi:10.1371/journal.pone.0031275

Bohannon, R. W., & Smith, M. B. (1987). Interrater reliability of a modified Ashworth scale of muscle spasticity. *Phys Ther, 67*(2), 206-207.

Brooke, J. (1996). SUS: A "quick and dirty" usability scale. In P. W. Jordan, B. Thomas, B. A. Weerdmeester, & A. L. McClelland (Eds.), Usability Evaluation in Industry. London: Taylor and Francis.

Borstad, A., & Nichols-Larsen, D. S. (2016). The Brief Kinesthesia test is feasible and sensitive: a study in stroke. *Braz J Phys Ther, 20*(1), 81-86. doi:10.1590/bjpt-rbf.2014.0132

Butler, A. J., Fink, G. R., Dohle, C., Wunderlich, G., Tellmann, L., Seitz, R. J., et al. (2004). Neural mechanisms underlying reaching for remembered targets cued kinesthetically or visually in left or right hemispace. Hum. Brain Mapp. 21, 165–177. doi: 10.1002/hbm.20001

Carey, L. M., & Matyas, T. A. (2011). Frequency of discriminative sensory loss in the hand after stroke in a rehabilitation setting. *J Rehabil Med, 43*(3), 257-263. doi:10.2340/16501977-0662

Carey, L. M., Oke, L. E., & Matyas, T. A. (1996). Impaired limb position sense after stroke: a quantitative test for clinical use. *Arch Phys Med Rehabil, 77*(12), 1271-1278.

Connell, L. A., Lincoln, N. B., & Radford, K. A. (2008). Somatosensory impairment after stroke: frequency of different deficits and their recovery. *Clin Rehabil, 22*(8), 758-767. doi:10.1177/0269215508090674

DeJong R. Philadelphia. Harper & Row; 1979. The neurologic examination

Dukelow, S. P., Herter, T. M., Moore, K. D., Demers, M. J., Glasgow, J. I., Bagg, S. D., . . . Scott, S. H. (2010). Quantitative assessment of limb position sense following stroke. *Neurorehabil Neural Repair, 24*(2), 178-187. doi:10.1177/1545968309345267

Feys, H., De Weerdt, W., Nuyens, G., van de Winckel, A., Selz, B., & Kiekens, C. (2000). Predicting motor recovery of the upper limb after stroke rehabilitation: value of a clinical examination. *Physiother Res Int, 5*(1), 1-18.

Gaubert, C. S., & Mockett, S. P. (2000). Inter-rater reliability of the Nottingham method of stereognosis assessment. *Clin Rehabil, 14*(2), 153-159. doi:10.1191/026921500677422368

Gilman, S. (2002). Joint position sense and vibration sense: anatomical organisation and assessment. *J Neurol Neurosurg Psychiatry, 73*(5), 473-477.

Han, L., Law-Gibson, D., & Reding, M. (2002). Key neurological impairments influence function-related group outcomes after stroke. *Stroke, 33*(7), 1920-1924.

Hasan, Z. (1992). Role of proprioceptors in neural control. *Curr Opin Neurobiol, 2*(6), 824-829.

Heller, A., Wade, D. T., Wood, V. A., Sunderland, A., Hewer, R. L., & Ward, E. (1987). Arm function after stroke: measurement and recovery over the first three months. *J Neurol Neurosurg Psychiatry, 50*(6), 714-719.

Hillier, S., Immink, M., & Thewlis, D. (2015). Assessing Proprioception: A Systematic Review of Possibilities. *Neurorehabil Neural Repair, 29*(10), 933-949. doi:10.1177/1545968315573055

Konczak, J., Corcos, D. M., Horak, F., Poizner, H., Shapiro, M., Tuite, P., . . . Maschke, M. (2009). Proprioception and motor control in Parkinson's disease. *J Mot Behav, 41*(6), 543-552. doi:10.3200/35-09-002

Lexell, J. E., & Downham, D. Y. (2005). How to assess the reliability of measurements in rehabilitation. *Am J Phys Med Rehabil, 84*(9), 719-723.

Lincoln, N. B., Crow, J. L., Jackson, J. M., Waters, G. R., Adams, S. A., & Hodgson, P. (1991). The unreliability of sensory assessments. *Clin Rehabil, 5*(4), 273-282. doi:10.1177/026921559100500403

Lincoln, N. B., Jackson, J. M., & Adams, S. A. (1998). Reliability and Revision of the Nottingham Sensory Assessment for Stroke Patients. *Physiotherapy, 84*(8), 358-365. doi:http://dx.doi.org/10.1016/S0031-9406(05)61454-X

Mathiowetz, V., Weber, K., Kashman, N., & Volland, G. (1985). Adult Norms for the Nine Hole Peg Test of Finger Dexterity. *The Occupational Therapy Journal of Research, 5*(1), 24-38. doi:10.1177/153944928500500102

Mrotek, L. A., Bengtson, M., Stoeckmann, T., Botzer, L., Ghez, C. P., McGuire, J., & Scheidt, R. A. (2017). The Arm Movement Detection (AMD) test: a fast robotic test of proprioceptive acuity in the arm. *J Neuroeng Rehabil, 14*(1), 64. doi:10.1186/s12984-017-0269-3

O'Sullivan, Susan B., Schmitz, Thomas J.Fulk, George D. (©2014) Physical rehabilitation /Philadelphia : F.A. Davis Co.

Parker, V. M., Wade, D. T., & Langton Hewer, R. (1986). Loss of arm function after stroke: measurement, frequency, and recovery. Int Rehabil Med, 8(2), 69-73.

Portney, L. G., & Watkins, M. P. (2009). Foundations of clinical research: Applications to practice. Upper Saddle River, N.J: Pearson/Prentice Hall.

Rinderknecht, M. D., Popp, W. L., Lambercy, O., & Gassert, R. (2016). Reliable and Rapid Robotic Assessment of Wrist Proprioception Using a Gauge Position Matching Paradigm. Front Hum Neurosci, 10. doi:10.3389/fnhum.2016.00316

Scott, S. H., & Dukelow, S. P. (2011). Potential of robots as next-generation technology for clinical assessment of neurological disorders and upper-limb therapy. *J Rehabil Res Dev, 48*(4), 335-353.

Shrout, P. E., & Fleiss, J. L. (1979). Intraclass correlations: uses in assessing rater reliability. *Psychol Bull, 86*(2), 420-428.

Smith, D. L., Akhtar, A. J., & Garraway, W. M. (1983). Proprioception and spatial neglect after stroke. *Age Ageing, 12*(1), 63-69.

Sober, S. J., & Sabes, P. N. (2003). Multisensory integration during motor planning. *J Neurosci, 23*(18), 6982-6992.

Stolk-Hornsveld, F., Crow, J. L., Hendriks, E. P., van der Baan, R., & Harmeling-van der Wel, B. C. (2006). The Erasmus MC modifications to the (revised) Nottingham Sensory Assessment: a reliable somatosensory assessment measure for patients with intracranial disorders. *Clin Rehabil, 20*(2), 160-172. doi:10.1191/0269215506cr932oa

Stratford, P. W., & Goldsmith, C. H. (1997). Use of the standard error as a reliability index of interest: an applied example using elbow flexor strength data. *Phys Ther, 77*(7), 745-750.

Williams, L. S., Weinberger, M., Harris, L. E., Clark, D. O., & Biller, J. (1999). Development of a stroke-specific quality of life scale. *Stroke, 30*(7), 1362-1369.

Winward, C. E., Halligan, P. W., & Wade, D. T. (1999). Current practice and clinical relevance of somatosensory assessment after stroke. *Clin Rehabil, 13*(1), 48-55. doi:10.1177/026921559901300107

6. Appendices part 2 – research protocol

Figure 1: The ReFlex

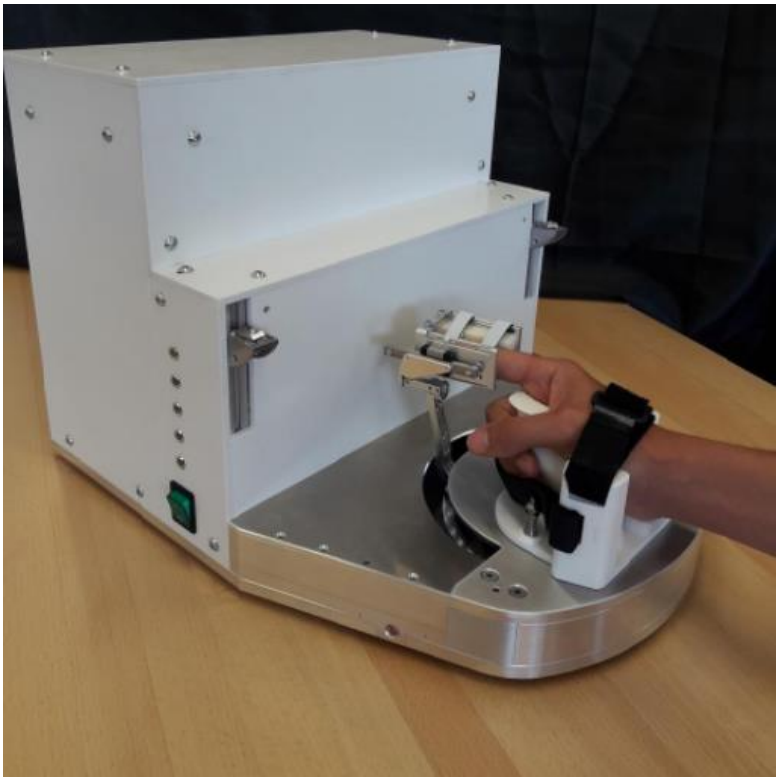
Appendix 1: Test instructions for the Em-NSA

Appendix 2: Test instructions for the subtest stereognosis rNSA

Appendix 3: Instructions for the Nine Hole Peg Test

Appendix 4: Instructions for the Frenchay Arm Test

Appendix 5: Instructions for the System Usability Scale



(a)

(b)

Figure 1

Appendix 1.

Erasmus modification of the Nottingham Sensory Assessment

De Erasmus MC Modificatie van de (revised) Nottingham Sensory Assessment (EmNSA)[1] is een meetinstrument om bij patiënten met intracraniële aandoeningen de tastzin, de scherp-dof discriminatie en de propriocepsis te testen. Aanvankelijk maakte ook de tweepuntsdiscriminatie deel uit van dit meetinstrument. In verband met een slechte betrouwbaarheid is dit onderdeel echter komen te vervallen.

Testbenodigdheden

- Wattenbolletje.
- Cocktailprikker.
- Eventueel blinddoek.

Algemene uitgangspunten

- De patiënt ligt, voor zover nodig ontkleed, in rugligging op bed met de armen in supinatie.
- Elk testitem wordt aan de patiënt uitgelegd en gedemonstreerd (bij een eenzijdige aandoening aan de niet-aangedane zijde).
- Tijdens het testen heeft de patiënt de ogen gesloten. Indien dit niet mogelijk blijkt kan gebruik gemaakt worden van een blinddoek.
- De bovenste extremiteit is opgesplitst in vier delen c.q. gewrichten.
  Voor de tastzin en scherp-dof discriminatie: 1. vingers; 2. hand; 3. onderarm; 4. bovenarm.
  Voor de propriocepsis: 1. vingers; 2. pols; 3. elleboog; 4. schouder.
- De onderste extremiteit is opgesplitst in vier delen c.q. gewrichten.
  Voor de tastzin en scherp-dof discriminatie: 1. tenen; 2. voet; 3. onderbeen; 4. bovenbeen.
  Voor de propriocepsis: 1. tenen; 2. enkel; 3. knie; 4. heup.
- Er wordt distaal gestart met testen (vingers c.q. tenen).
- In geval van een eenzijdige aandoening kan volstaan worden met het testen van de aangedane zijde. Indien het onduidelijk is of de patiënt de opdracht goed heeft begrepen wordt dit beoordeeld d.m.v. het testen van de niet-aangedane zijde.
- Indien de patiënt aangeeft een aanraking te voelen, terwijl hij op dat moment niet wordt aangeraakt, wordt dat deel van de test opnieuw uitgevoerd. Aan de patiënt wordt gevraagd zich goed te concentreren en alleen aan te geven wanneer hij daadwerkelijk een aanraking voelt. Als de patiënt toch weer aangeeft een aanraking te voelen, terwijl hij op dat moment niet wordt aangeraakt, wordt het testitem gescoord als 'niet te testen' (ntt).
  Ditzelfde geldt indien bij het testen van de propriocepsis de patiënt aangeeft een beweging te voelen zonder dat er bewogen wordt.

Tastzin

Het onderzoek naar de tastzin bevat aanrakingen van drie verschillende modaliteiten, oplopend in intensiteit, nl. lichte aanraking, druk en scherpe aanraking.
Per testonderdeel (lichte aanraking, druk, scherpe aanraking) wordt de patiënt ter hoogte van ieder lichaamsdeel op drie gedefinieerde punten ad random aangeraakt.
Deze aanrakingspunten zijn in bijlage 1 beschreven en op het scoreformulier in een figuur aangegeven.
De tijd tussen de aanrakingen varieert van twee tot vijf seconden.
De patiënt geeft, op verbale of op non-verbale wijze, aan of hij wordt aangeraakt.*

Testonderdelen

-	Lichte aanraking	Raak de huid licht aan met een wattenbolletje.
-	Druk	Oefen met de wijsvinger net voldoende druk uit op de huid om een lichte vervorming van de huidcontour te bewerkstelligen.
-	Scherpe aanraking	Oefen met de punt van een cocktailprikker net voldoende druk uit op de huid om een lichte vervorming van de huidcontour te bewerkstelligen.

Score

0	Afwezig	Patiënt voelt géén van de drie aanrakingen.
1	Gestoord	Patiënt voelt de aanraking een- of tweemaal.
2	Normaal	Patiënt voelt alle drie de aanrakingen.

Gestart wordt met het testen van de lichte aanraking. Vervolgens worden de druk en de scherpe aanraking getest en gescoord.

In navolging van de al bestaande (revised) Nottingham Sensory Assessment[2] geldt voor alle testonderdelen:
- bij een score van 2 punten voor zowel vingers als hand wordt ook aan onderarm en bovenarm een score van 2 punten toegekend;
- bij een score van 2 punten voor zowel tenen als voet wordt ook aan onderbeen en bovenbeen een score van 2 punten toegekend.

Op basis van de data, verzameld tijdens het betrouwbaarheidsonderzoek van de EmNSA, lijkt de volgende handelswijze legitiem:
- indien in de gehele extremiteit voor de lichte aanraking de maximale score van 2 punten wordt behaald, kan automatisch ook aan de onderdelen druk en scherpe aanraking de maximale score van 2 punten toegekend worden.

Ter onderbouwing hiervan is nog wel verder onderzoek noodzakelijk.

Scherp-dof discriminatie

De scherp-dof discriminatie wordt niet getest wanneer bij de tastzin een 0 of 1 wordt gescoord.

Ter hoogte van ieder lichaamsdeel wordt de patiënt zes keer ad random aangeraakt op de drie in bijlage 1 gedefinieerde aanrakingspunten (zie ook figuur op scoreformulier); drie keer met een cocktailprikker en drie keer met de wijsvinger. De patiënt wordt gevraagd, verbaal of non-verbaal, aan te geven of de aanraking scherp of dof aanvoelt.*

Score

0	Afwezig	Patiënt geeft bij geen van de zes aanrakingen de juiste sensatie aan.
1	Gestoord	Patiënt geeft een of meerdere malen de juiste sensatie aan, echter niet bij alle zes de aanrakingen.
2	Normaal	Patiënt geeft de juiste sensatie aan bij alle zes de aanrakingen.

Propriocepsis

De propriocepsis wordt beoordeeld door middel van passieve bewegingen.
De gestandaardiseerde uitvoering is beschreven in bijlage 2.

De patiënt wordt geïnstrueerd om de te onderzoeken extremiteit zoveel mogelijk te ontspannen. Het te testen gewricht wordt drie keer bewogen.
De patiënt wordt gevraagd om, op verbale of non-verbale wijze, de *bewegingsrichting* aan te geven.* Indien de patiënt de bewegingsrichting niet voelt wordt hem gevraagd om (verbaal of non-verbaal) aan te geven wanneer er een *beweging* plaatsvindt.*

Score

0	Afwezig	Patiënt voelt geen beweging.
1	Waarneming van beweging	Patiënt voelt driemaal dat er beweging plaatsvindt, echter kan niet driemaal de juiste bewegingsrichting aangeven.
2	Normale bewegingszin	Patiënt voelt driemaal de juiste bewegingsrichting.

---

* Fysiotherapeut en patiënt maken daarbij een afspraak over de voor die patiënt meest praktische wijze om dit aan te geven.

Gedefinieerde aanrakingspunten

Voor het testen van de tastzin (lichte aanraking, druk en scherpe aanraking) en de scherp-dof discriminatie zijn onderstaande aanrakingspunten gedefinieerd. Deze aanrakingspunten zijn grafisch weergegeven in een figuur op het scoreformulier.

Vingers
1. Distale phalanx van digitus V, palmaire zijde.
2. Distale phalanx van digitus III, palmaire zijde.
3. Distale phalanx van digitus I, palmaire zijde.

Hand
1. Distale uiteinde van metacarpale V, palmaire zijde.
2. Distale uiteinde van metacarpale II, palmaire zijde.
3. Midden van de duimmuis, palmaire zijde.

Onderarm
1. Processus styloideus ulnae, ventrale zijde.
2. Midden van de onderarm, ventrale zijde.
3. Circa 2 cm distaal van de elleboogplooi, laterale zijde.

Bovenarm
1. Circa 2 cm proximaal van de elleboogplooi, mediale zijde.
2. Midden van de bovenarm, ventrale zijde.
3. Circa 2 cm distaal van het acromion, laterale zijde.

Tenen
1. Distale phalanx digitus V, plantaire zijde.
2. Distale phalanx digitus III, plantaire zijde.
3. Distale phalanx digitus I, plantaire zijde.

Voet
1. Distale uiteinde van metatarsale V, dorsale zijde.
2. Distale uiteinde van metatarsale II, dorsale zijde.
3. Midden van de voet, dorsale zijde.

Onderbeen
1. Malleolus medialis, mediale zijde.
2. Midden van het onderbeen, ventrale zijde.
3. Caput fibula, laterale zijde.

Bovenbeen
1. Epicondylus medialis femoris, mediale zijde.
2. Midden van het bovenbeen, ventrale zijde.
3. Trochantor major, laterale zijde.

Bijlage 2

Uitvoering van het onderzoek van de propriocepsis

De grote gewrichten (schouder, elleboog, heup en knie) worden over ongeveer een kwart van de totale bewegingsuitslag bewogen. De overige gewrichten (pols, vinger, enkel en teen) worden over de volledige bewegingsuitslag bewogen.

Vingers

- *Handvatting* (zie fig. 1)
  Distale (bewegende) hand: plaats de duim aan de radiaire en de wijsvinger aan de ulnaire zijde van de distale phalanx van de duim.
  Proximale (fixerende) hand: fixeer de proximale phalanx van de duim tussen duim en wijsvinger.
- *Bewegingsrichting*
  Flexie en extensie van het interphalangeale gewricht van de duim.
- *Vraag aan patiënt*
  "Wordt uw duim gebogen of gestrekt?"

Pols

De onderarm wordt door de onderzoeker zover opgetild dat de hand vrij kan worden bewogen.

- *Handvatting* (zie fig. 2)
  Distale (bewegende) hand: plaats de duim aan de radiaire en de wijsvinger aan de ulnaire zijde van de hand.
  Proximale (fixerende) hand: fixeer het distale uiteinde van radius en ulna.
- *Bewegingsrichting*
  Dorsaal- en palmairflexie van de pols.
- *Vraag aan patiënt*
  "Wordt uw hand omhoog of omlaag bewogen?"

Elleboog

De pols bevindt zich in neutraalstand, de elleboog wordt door de onderzoeker in 90° flexie gehouden.

- *Handvatting* (zie fig. 3)
  Distale (bewegende) hand: omvat het distale deel van de onderarm.
  Proximale (fixerende) hand: fixeer het distale uiteinde van de humerus.
- *Bewegingsrichting*
  Flexie en extensie van de elleboog.
- *Vraag aan patiënt*
  "Wordt uw elleboog gebogen of gestrekt?"

Schouder

De elleboog wordt door de onderzoeker in circa 90° flexie gehouden en de bovenarm wordt zover opgetild dat deze net loskomt van het bed.

- *Handvatting* (zie fig. 4)
  Distale (ondersteunende) hand: omvat het distale deel van de onderarm.
  Proximale (bewegende) hand: omvat de geflecteerde elleboog (als een kommetje).
- *Bewegingsrichting*
  Ab- en adductie van de schouder.
- *Vraag aan patiënt*
  "Wordt uw arm naar u toe of van u af bewogen?"

Tenen

- *Handvatting* (zie fig. 5)
  Distale (bewegende) hand: plaats de duim aan de laterale en de wijsvinger aan de mediale zijde van de distale phalanx van de grote teen.
  Proximale (fixerende) hand: fixeer metatarsale I, net proximaal van het metatarsophalangeale gewricht.
- *Bewegingsrichting*
  Flexie en extensie in het eerste metatarsophalangeale gewricht.
- *Vraag aan patiënt*
  "Wordt uw teen omhoog of omlaag bewogen?"

Enkel

- *Handvatting* (zie fig. 6)
  Distale (bewegende) hand: omvat de voet met de duim aan de laterale en de vingers aan de mediale zijde.
  Proximale (fixerende) hand: fixeer het distale uiteinde van het tibia en fibula.
- *Bewegingsrichting*
  Dorsaal- en plantairflexie van de enkel.
- *Vraag aan patiënt*
  "Wordt uw voet omhoog of omlaag bewogen?"

Knie

De onderzoeker houdt de heup en de knie in 90° flexie.

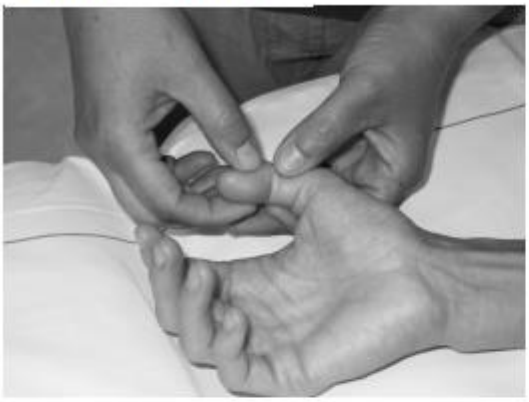
- *Handvatting* (zie fig. 7)
  Distale (bewegende) hand: omvat de hiel met de duim aan de mediale en de vingers aan de laterale zijde; ondersteun de voet met de onderarm.
  Proximale (fixerende) hand: omvat het distale uiteinde van het bovenbeen met de duim aan de laterale en de vingers aan de mediale zijde.
- *Bewegingsrichting*
  Flexie en extensie van de knie.
- *Vraag aan patiënt*
  "Wordt uw knie gebogen of gestrekt?"

Heup

De onderzoeker houdt de heup en de knie in 90° flexie.

- *Handvatting* (zie fig. 8)
  Distale (ondersteunende) hand: omvat de hiel met de duim aan de mediale en de vingers aan de laterale zijde; ondersteun de voet met de onderarm.
  Proximale (bewegende) hand: omvat het distale uiteinde van het bovenbeen met de duim aan de laterale en de vingers aan de mediale zijde; handhaaf de houding van de knie terwijl de heup wordt bewogen.
- *Bewegingsrichting*
  Flexie en extensie van de knie.
- *Vraag aan patiënt*
  "Wordt uw bovenbeen naar u toe of van u af bewogen?"

Figuur 1 **Vingers**

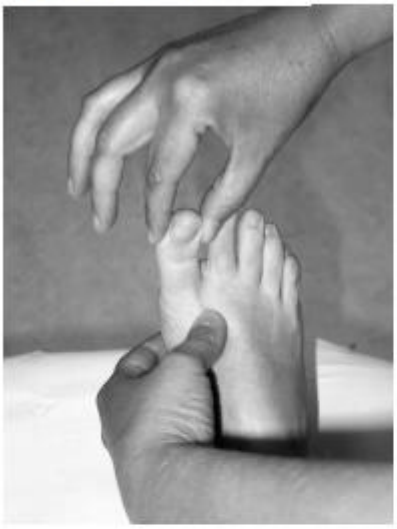


Figuur 2 **Pols**

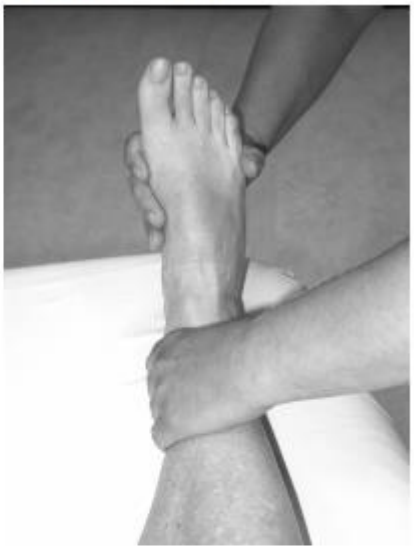
Figuur 3 **Elleboog**

Figuur 4 **Schouder**

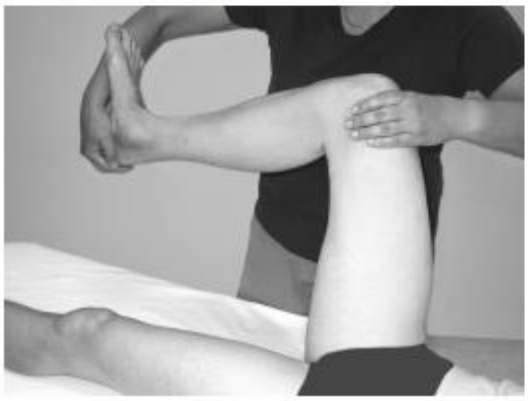
Figuur 5 Teen



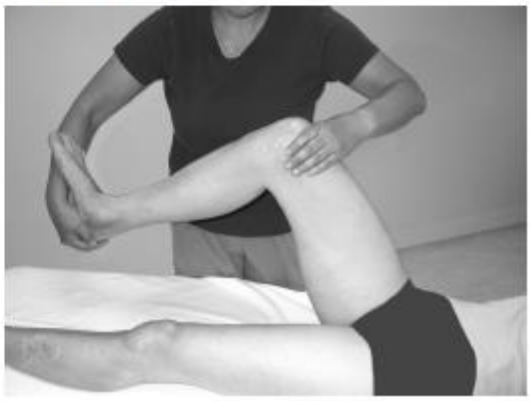
Figuur 6 Enkel



Figuur 7 Knie



Figuur 8 Heup

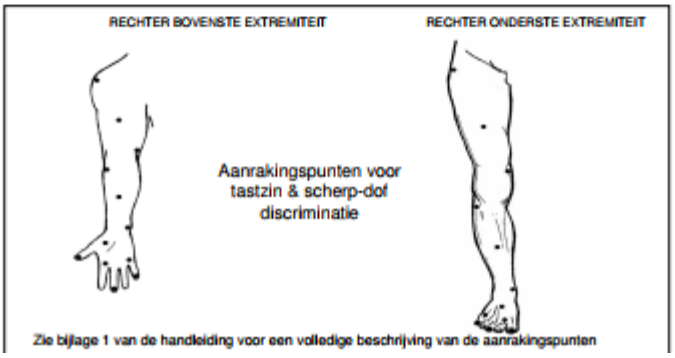


ERASMUS MC MODIFICATIE VAN DE (REVISED) NOTTINGHAM SENSORY ASSESSMENT
Scoreformulier

NAAM PATIËNT: _____ **GEBOORTEDATUM:** _____

	DATUM																
		RECHTS				**LINKS**				**RECHTS**				**LINKS**			
		L	D	S	S/D	L	D	S	S/D	L	D	S	S/D	L	D	S	S/D
TASTZIN & SCHERP-DOF DISCRIMINATIE	**BOVENARM**																
	ONDERARM																
	HAND																
	VINGERS																
	TOTALE SCORE BE																
	BOVENBEEN																
	ONDERBEEN																
	VOET																
	TENEN																
	TOTALE SCORE OE																
PROPRIOCEPSIS	**SCHOUDER**																
	ELLEBOOG																
	POLS																
	VINGERS																
	TOTALE SCORE BE																
	HEUP																
	KNIE																
	ENKEL																
	TENEN																
	TOTALE SCORE OE																

L = lichte aanraking; D = druk; S = scherpe aanraking; S/D = scherp-dof discriminatie
BE = bovenste extremiteit; OE = onderste extremiteit
0 = afwezig; 1 = verminderd; 2 = normaal



Zie bijlage 1 van de handleiding voor een volledige beschrijving van de aanrakingspunten

Appendix 2

rNSA: Instructions subtest stereognosis

Stereognosis

The object is placed in the patient's hand for a maximum of 30 seconds. Identification is by naming, description or by pair-matching with an identical set. Affected side of the body is tested first. The object may be moved around the affected hand by the examiner.

Scoring for each object

2	*Normal* Item is correctly named or matched.	
1	*Impaired*	Some features of object identified or attempts at descriptions of objects.
0	*Absent*	Unable to identify the object in any manner.
9	*Unable to test*	

Equipment required: Blindfold, 2p coin, 10p coin, 50p coin, biro (score 2 if labelled "pen"), pencil, comb, scissors, sponge, flannel (score 2 if labelled "cloth" or "face cloth"), cup, glass (score 2 if labelled "beaker").

Appendix 3

Nine Hole Peg Test Instructions

General Information:

- The Nine Hole Peg Test should be conducted with the dominant arm first.
- One practice trial (per arm) should be provided prior to timing the test.
- Timing should be performed with a stopwatch and recorded in seconds.
- The stop watch is started when the patient touches the first peg.
- The stop watch is stopped when the patient places the last peg in the container.

Set-up (Mathiowetz et al, 1985):

- A square board with 9 holes,
  - holes are spaced 3.2 cm (1.25 inches) apart
  - each hole is 1.3 cm (.5 inches) deep
- 9 wooden pegs should be .64 cm (.25 inches) in diameter and 3.2 cm (1.25 inches) long
- A container that is constructed from .7 cm (.25 inches) of plywood, sides are attached (13 cm x 13 cm) using nails and glue
- The peg board should have a mechanism to decrease slippage. Self-adhesive bathtub appliqués were used in the study.
- The pegboard should be placed in front of the patient, with the container holding the pegs on the side of the dominant hand.

Patient Instructions (Mathiowetz et al, 1985):

- The instructions should be provided while the activity is demonstrated.
- The patient's dominant arm is tested first.
- Instruct the patient to:
  - "Pick up the pegs one at a time, using your right (or left) hand only and put them into the holes in any order until the holes are all filled. Then remove the pegs one at a time and return them to the container. Stabilize the peg board with your left (or right) hand. This is a practice test. See how fast you can put all the pegs in and take them out again. Are you ready? Go!"
- After the patient performs the practice trial, instruct the patient:
  - "This will be the actual test. The instructions are the same. Work as quickly as you can. Are you ready? Go!" (Start the stop watch when the patient touches the first peg.)
  - While the patient is performing the test say "Faster"
  - When the patient places the last peg on the board, instruct the patient "Out again…faster."
  - Stop the stop watch when the last peg hits the container.
- Place the container on the opposite side of the pegboard and repeat the instructions with the non-dominant hand.

Appendix 4

Frenchay Arm Test Instructions

De Frenchay Arm Test (FAT) evalueert de handvaardigheid. De test geeft een indruk van de functionele mogelijkheden van de paretische arm/handfunctie. De Frenchay Arm Test is een ordinale 2-puntsschaal (0-1). In totaal zijn 5 punten te behalen (range 0-5).
Betrouwbaarheid en validiteit zijn bij patiënten met een CVA aangetoond. De Nederlandse versie van de FAI dient nog nader gevalideerd te worden.

Testprotocol Frenchay Arm Test

Benodigdheden:

1. papier;
2. meetlat;
3. pen;
4. cilinder (12 mm doorsnede; 5 cm lang);
5. glas, half gevuld met water;
6. wasknijper;
7. metalen pen (1 cm doorsnede; 15 cm lang);
8. vierkant bakje.

De patiënt zit tijdens de test in een (rol)stoel aan tafel.
De onderzoeker vraagt aan de patiënt de volgende 5 opdrachten uit te voeren:

Opdracht 1
'Kunt u de *meetlat* met de paretische arm stabiliseren en met de pen in de niet-paretische hand een rechte horizontale lijn langs de meetlat trekken?'

Opdracht 2
'Kunt u met de paretische hand de rechtopstaande *cilinder* 30 cm optillen (die ongeveer 15 cm van de tafelrand af staat) en deze vervolgens weer neerzetten zonder dat deze valt?'

Opdracht 3
'Kunt u een *glas* (half gevuld met water oppakken dat ongeveer 15 cm vanaf de tafelrand staat) en proberen enkele slokken te nemen en vervolgens het glas weer neer te zetten? Dit alles zonder te morsen.'

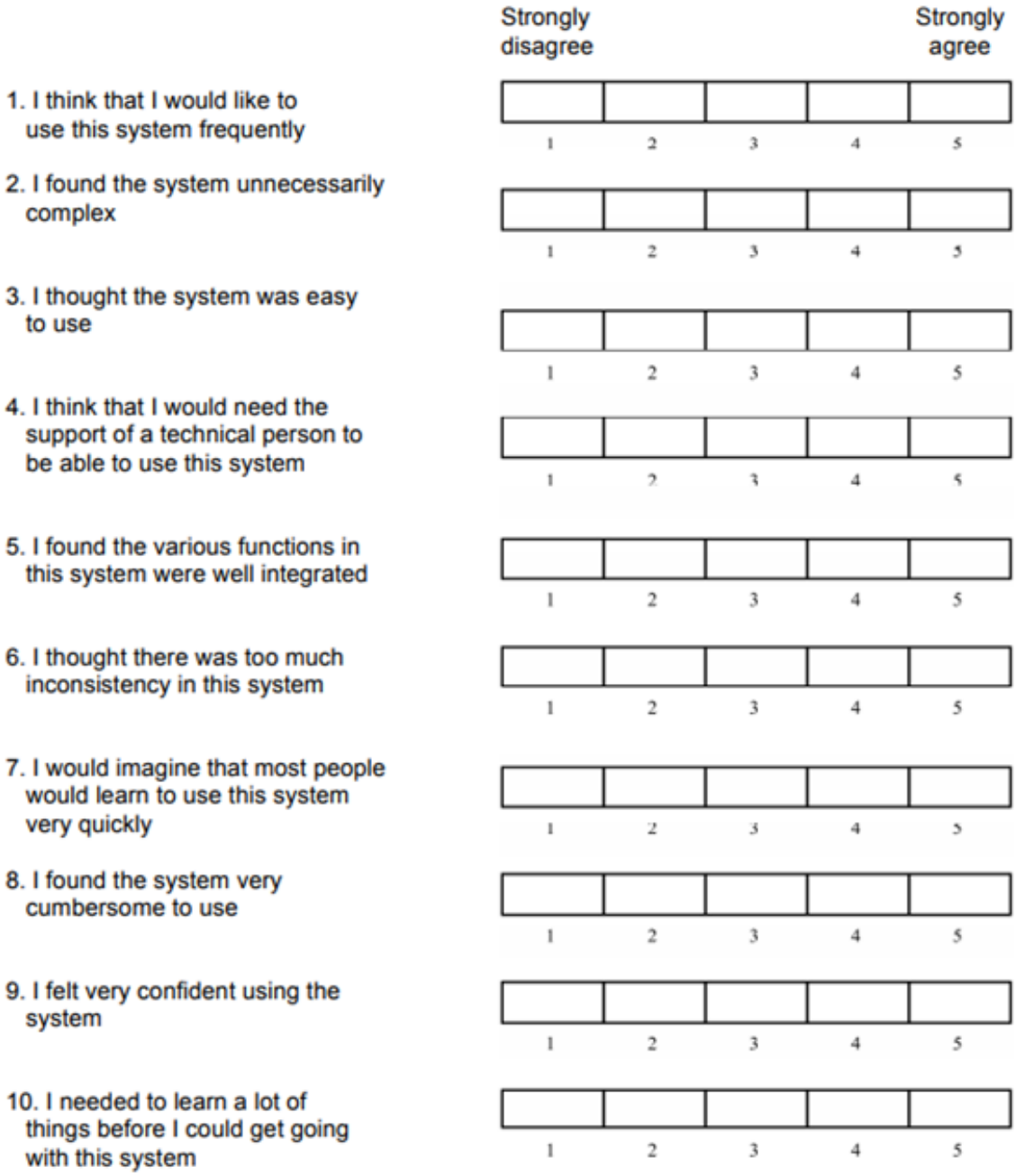
Opdracht 4
'Kunt u de *wasknijper* van de pen afhalen en deze in een vierkant bakje leggen?' (Het bakje staat 15-30 cm van de tafelrand.)

Opdracht 5
'Kunt u proberen te doen alsof u echt uw haren *kamt*. Over het hoofd, tot onderin de nek, aan beide zijden van het hoofd?'

Scoor de items die de patiënt kan uitvoeren met 1 punt. Tel de punten op en noteer de uitkomst (range 0-5 punten).

Appendix 5

System Usability Scale instructions



Appendix 6

universiteit hasselt | FACULTEIT GENEESKUNDE EN LEVENSWETENSCHAPPEN
www.uhasselt.be/glw
postadres: Universiteit Hasselt | Martelarenlaan 42 | BE-3500 Hasselt
bezoekadres: Universiteit Hasselt | Agoralaan, gebouw D | BE-3590 Diepenbeek
T +32(0)11 26 85 36 | F +32(0)11 26 85 99 | E-mail: glw@uhasselt.be

VOORTGANGSFORMULIER WETENSCHAPPELIJKE STAGE DEEL 1

DATUM	INHOUD OVERLEG	HANDTEKENINGEN
21/10/16	Ondertekenen van contract. Topic: Assessment of somatosensory disorders after stroke: a systematic review of outcome measures and their psychometric properties.	Promotor: Copromotor: Student(e): Student(e):
28/10/16	Bespreking inhoud masterproef deel 1	Promotor: Copromotor: Student(e): Student(e):
05/11/16	Bespreking zoekstrategie	Promotor: Copromotor: Student(e): Student(e):
21/11/16	Goedkeuring zoekstrategie + start schrijven van methodologie	Promotor: Copromotor: Student(e): Student(e):
05/12/16	Bespreking inclusie en exclusie van studies (data extractie)	Promotor: Copromotor: Student(e): Student(e):
15/02/17	Data extractie afgerond	Promotor: Copromotor: Student(e): Student(e):
20/02/17	Bespreking frequentietabel	Promotor: Copromotor: Student(e): Student(e):
03/04/17	Bespreking uitwerking van protocol	Promotor: Copromotor: Student(e): Student(e):
22/05/17	Uitschrijven van introductie en methode (deadline: begin juni)	Promotor: Copromotor: Student(e): Student(e):
Begin juni	Deadline protocol → gehaald op 08/08/17	Promotor: Copromotor: Student(e): Student(e):

09/07/17	Resultaten en abstract zijn afgerond	Promotor: Copromotor: Student(e): Student(e):
16/07/17	Outline en context zijn afgerond	Promotor: Copromotor: Student(e): Student(e):
03/08/17	Discussie is afgerond	Promotor: Copromotor: Student(e): Student(e):
08/08/17	Protocol is afgerond	Promotor: Copromotor: Student(e): Student(e):
10/08/17	Ondertekening van contract verdediging masterproef tweede zit + finetuning laatste versie MP.	Promotor: Copromotor: Student(e): Student(e):
		Promotor: Copromotor: Student(e): Student(e):
		Promotor: Copromotor: Student(e): Student(e):

Auteursrechtelijke overeenkomst

Ik/wij verlenen het wereldwijde auteursrecht voor de ingediende eindverhandeling:
Assessment of somatosensory disorders after stroke: a systematic review of outcome measures and their psychometric properties

Richting: **master in de revalidatiewetenschappen en de kinesitherapie-revalidatiewetenschappen en kinesitherapie bij musculoskeletale aandoeningen**
Jaar: **2017**

in alle mogelijke mediaformaten, - bestaande en in de toekomst te ontwikkelen - , aan de Universiteit Hasselt.

Niet tegenstaand deze toekenning van het auteursrecht aan de Universiteit Hasselt behoud ik als auteur het recht om de eindverhandeling, - in zijn geheel of gedeeltelijk -, vrij te reproduceren, (her)publiceren of distribueren zonder de toelating te moeten verkrijgen van de Universiteit Hasselt.

Ik bevestig dat de eindverhandeling mijn origineel werk is, en dat ik het recht heb om de rechten te verlenen die in deze overeenkomst worden beschreven. Ik verklaar tevens dat de eindverhandeling, naar mijn weten, het auteursrecht van anderen niet overtreedt.

Ik verklaar tevens dat ik voor het materiaal in de eindverhandeling dat beschermd wordt door het auteursrecht, de nodige toelatingen heb verkregen zodat ik deze ook aan de Universiteit Hasselt kan overdragen en dat dit duidelijk in de tekst en inhoud van de eindverhandeling werd genotificeerd.

Universiteit Hasselt zal mij als auteur(s) van de eindverhandeling identificeren en zal geen wijzigingen aanbrengen aan de eindverhandeling, uitgezonderd deze toegelaten door deze overeenkomst.

Voor akkoord,

Trekels, Naomi **Clement, Toon**