Research Report

How Do Somatosensory Deficits in the Arm and Hand Relate to Upper Limb Impairment, Activity, and Participation Problems After Stroke? A Systematic Review

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Background. The association between somatosensory impairments and outcome after stroke remains unclear.

Purpose. The aim of this study was to systematically review the available literature on the relationship between somatosensory impairments in the upper limb and outcome after stroke.

Data Sources. The electronic databases PubMed, CINAHL, EMBASE, Cochrane Library, PsycINFO, and Web of Science were systematically searched from inception until July 2013.

Study Selection. Studies were included if adult patients with stroke (minimum n=10) were examined with reliable and valid measures of somatosensation in the upper limb to investigate the relationship with upper limb impairment, activity, and participation measures. Exclusion criteria included measures of somatosensation involving an overall score for upper and lower limb outcome and articles including only lower limb outcomes.

Data Extraction. Eligibility assessment, data extraction, and quality evaluation were completed by 2 independent reviewers. A cutoff score of ≥65% of the maximal quality score was used for further inclusion in this review.

Data Synthesis. Six articles met all inclusion criteria. Two-point discrimination was shown to be predictive for upper limb dexterity, and somatosensory evoked potentials were shown to have predictive value in upper limb motor recovery. Proprioception was significantly correlated with perceived level of physical activity and social isolation and had some predictive value in functional movements of the upper limb. Finally, the combination of light touch and proprioception impairment was shown to be significantly related to upper limb motor recovery as well as handicap situations during activities of daily living.

Limitations. Heterogeneity of the included studies warrants caution when interpreting results.

Conclusions. Large variation in results was found due to heterogeneity of the studies. However, somatosensory deficits were shown to have an important role in upper limb motor and functional performance after stroke.

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Stroke is a major health burden and the leading cause of serious long-term disability around the world.[1,2] One of the most cumbersome deficits after unilateral stroke is impairment in the contralateral upper limb, typically seen in approximately 70% of the stroke population.[3,4] Despite studies reporting on motor and functional recovery of the upper limb,[5,6] information on the contribution of somatosensory deficits toward motor and functional outcome is scant.

The term *somatosensation* refers to a sensation arising from the skin, muscles, or joints. Somatosensation is distinct from interoceptive or visceral sensation and special senses such as sight, hearing, smell, and taste. Within the somatosensory system, different modalities such as light touch, proprioception, and stereognosis are identified.[7] Somatosensory deficits of these modalities appear to be common after stroke, with prevalence rates ranging from 11% to 85%.[8] Variability is thought to be related to differences in definition, somatosensory modalities tested, and assessment method used.[8] Most health care professionals consider somatosensory testing an essential part of the clinical assessment process and a valuable method of obtaining information for diagnosis and prognosis of functional ability.[9] Somatosensory impairment also is often a concern of the patient, emphasizing the need to accurately monitor somatosensory impairments with reliable assessment methods to gain further insight into the extent of these deficits after stroke.

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- **eTable:** Characteristics of Included Studies

An extensive body of animal literature suggests that the projection from the somatosensory cortex to the motor cortex is important in the acquisition of new motor skills.[10,11] Activation of the sensory cortex has been linked to excitation of the motor human cortex as well.[12] The work of Vidoni and Boyd[13] showed that stroke-related somatosensory deficits are associated with disrupted motor learning. They demonstrated that proprioceptive integrity was strongly related to the magnitude of behavioral change associated with learning a repeated tracking task. Furthermore, repetitive peripheral nerve sensory stimulation has been shown to facilitate motor performance.[14]

Several studies investigated the impact of somatosensory deficits on outcome after stroke. Impaired somatosensory function has been related to a longer hospital length of stay and dependency in activities of daily living (ADLs).[15,16] Previous studies[17,18] showed that patients with well-preserved somatosensation achieve a greater improvement in upper limb motor function and are more likely to reach independence in self-care function compared with patients with somatosensory deficiencies. Also, in 2 systematic reviews,[19,20] some of the included studies suggested somatosensory loss to contribute as an independent predictor of upper limb motor and functional recovery. However, these reviews were conducted to summarize potential predictors of upper limb recovery after stroke. Therefore, the focus of these reviews was not on the predictive value of somatosensory impairments, as the clinical somatosensory variables were studied only as co-factors. Also, only longitudinal recovery studies were included in these reviews, and the psychometric properties of the predictor variables and outcome measures were not considered. So far, there is a range of diverse studies with different study designs, all using different measures of somatosensation, both clinical and neurophysiological measures, to determine the impact on various outcome measures after stroke. This variability makes it difficult to draw rigorous conclusions. There is need for a better understanding of the role of different modalities of somatosensation in outcome after stroke.

To our knowledge, there has been no systematic overview of the association between somatosensory impairments in the upper limb and outcome after stroke. This information would be useful to identify appropriate interventions because treatment of somatosensory impairment may positively influence motor output.[8] Therefore, the aim of this study was to systematically review the current, available literature regarding the association of somatosensory impairments in the upper limb with outcome after stroke.

Method

Data Sources and Searches

We carried out a systematic review on the association between somatosensory impairments in the arm and hand and upper limb impairment, activity, and participation measures after stroke. Guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement for reporting systematic reviews[21] were followed. Articles were identified by searching the following electronic databases: PubMed (from 1966 to July 2013), CINAHL (from 1982 to July 2013), EMBASE (from 1980 to July 2013), Cochrane Library (from 1993 to July 2013), PsycINFO (from 1806 to July 2013), and Web of Science (from 1955 to July 2013). The search strategy was built following consultation with an experienced librarian. Key words for the search strategy relating to the terms *stroke, upper extremity*, *sensation*, *prognosis*, *correla-*

tion, and *prediction*, as well as their synonyms and plurals, were included. The Appendix shows the search strategy used for EMBASE, which was adapted for the other electronic databases. In addition, reference lists from the included articles were hand searched to detect further relevant articles.

Study Selection

The inclusion and exclusion criteria for article selection were as follows. Adult participants with a diagnosis of stroke were considered. We included patients with both hemorrhagic and ischemic stroke. Articles were selected for inclusion if the study included at least 10 participants, as determination of clinical prediction rules requires a minimum of 10 participants per prognostic variable investigated.[22] As proposed by Connell and Tyson,[23] independent variables of interest were reliable and valid clinical measures of somatosensory function in the upper limb, such as measures of touch, position sense, stereognosis, and so on. Studies using neurophysiological measures of somatosensation (ie, somatosensory evoked potentials [SSEPs]) also were included. Following the *International Classification of Functioning, Disability and Health* (ICF) model,[24] outcomes of primary interest comprised standardized measures of impairment, activity, and participation of the upper limb. Only those studies with a correlational analysis or integration of the measure of somatosensation in a predictive regression model were included. Articles needed to be written in English, Dutch, Finnish, or Swedish. We excluded articles that had mixed etiology groups if data for participants with stroke could not be extracted. Studies using measures of somatosensation involving an overall score for both upper limb and lower limb outcome, as well as those including only lower limb outcome measures, also were excluded.

Data Extraction and Quality Assessment

After removal of duplicates, eligibility assessment was performed by 2 independent reviewers (S.M. and A.H.K.) by screening titles and abstracts. This assessment was subsequently followed by the assessment of the full text of articles. In case of disagreement, consensus was reached through discussion. A specifically developed data extraction sheet was used during the full-text screening. Information was collected about study design (cross-sectional or longitudinal), study setting, time points of follow-up assessments, participant details, inclusion and exclusion criteria, independent variables, outcome variables, statistical analysis, and results on the association between the measure of somatosensation and the outcome. When crucial information was missing, the author of the article was contacted.

The selected studies in the review were subjected to a methodological quality assessment according to the validated Downs and Black quality scale,[25] which was modified to suit the observational study designs of the studies. Due to the lack of a gold standard for assessing quality of observational studies, the Downs and Black quality scale was used, as this scale was recommended in a systematic review[26] of instruments for assessing quality of observational studies (albeit with recognized limitations). Furthermore, the Cochrane Collaboration[27] recommends the same instrument for assessing quality in nonrandomized studies. Therefore, we used the Downs and Black scale. Eight questions of this quality appraisal instrument (questions 4, 8, 14, 15, 19, 23, 24, and 27), therefore, were not applicable due to the nature of the observational study designs included in this review. Additionally, 2 other items (questions 9 and 26) were not applicable for studies with a cross-sectional design. Therefore, when all remaining items were positively appraised, total scores of 20 and 18 points could be assigned to studies with a longitudinal design and a cross-sectional design, respectively. Finally, the total scores were transformed to a percentage. Although no cutoff score is available for the Downs and Black quality scale to identify high-quality studies, a previous study[28] using a similar quality scale showed that studies should have a score of at least 65% of the maximum possible score to be classified as having substantial quality. Therefore, a cutoff score of ≥65% was used for inclusion in this review. Both data extraction and quality evaluation checklists were completed by 2 independent reviewers (S.M. and A.H.K.), and, in case of disagreement, consensus was reached through discussion.

Data Synthesis and Analysis

The heterogeneity among studies with regard to the population, somatosensory, and outcome variables used precluded a pooling of results in a formal meta-analysis. Therefore, a descriptive review of the results of the included studies is reported, according to the different outcome measures within the domains of the ICF model.[24] Within each domain, results are presented according to the somatosensory modalities that were measured.

Results

Characteristics of the Included Studies

Our search identified a total of 3,440 hits. A flowchart of the selection process is shown in the Figure. The process yielded a total of 6 articles[29–34] for inclusion in this systematic review.

The main characteristics of the included articles, such as patient characteristics and the somatosensory and

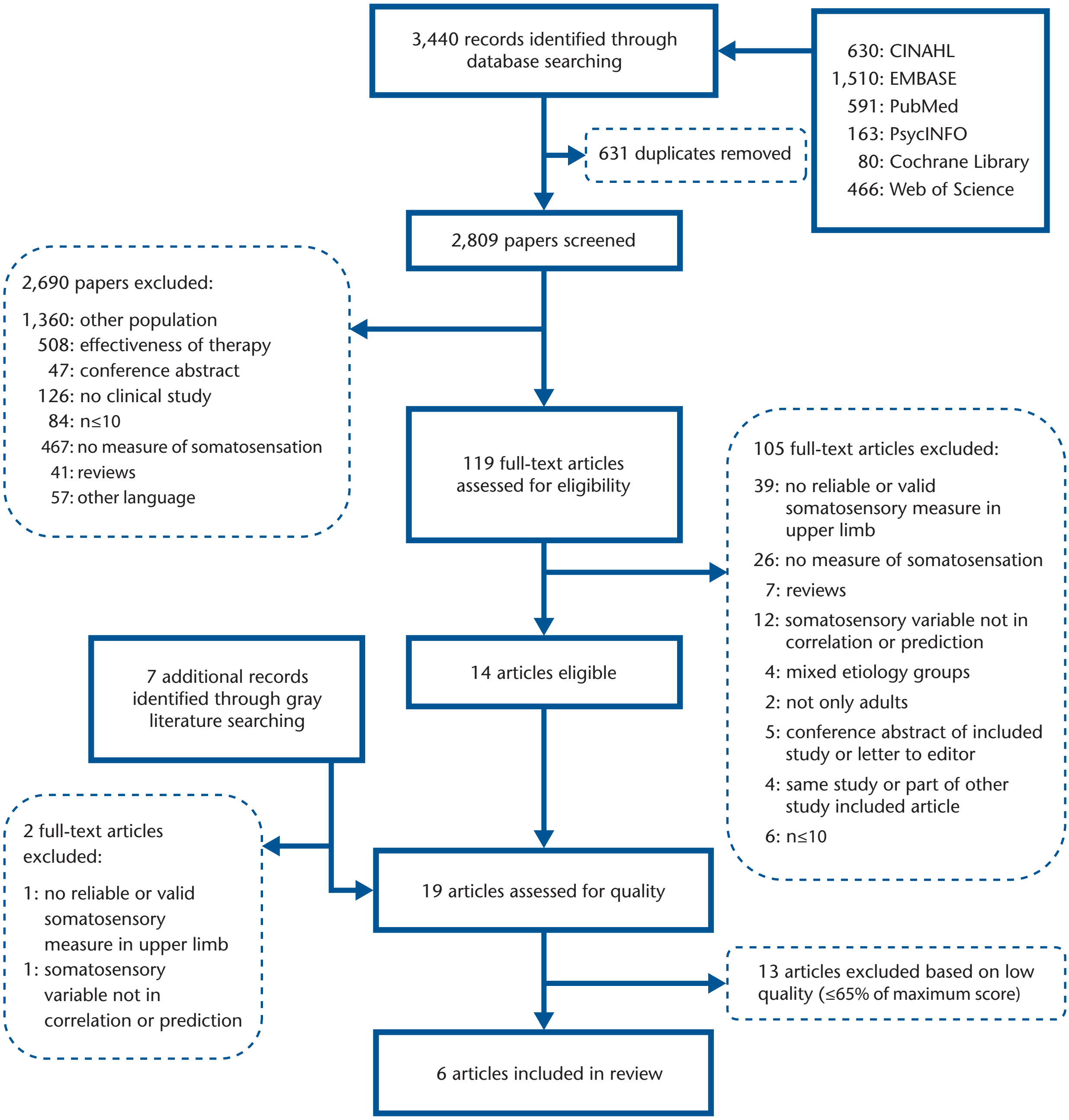

Figure.
Flowchart showing how studies were derived. Gray literature searching encompasses searching the reference lists of articles already eligible for inclusion.

outcome measures used, are shown in the eTable (available at ptjournal.apta.org). Five articles[29–31,33,34] had a longitudinal design, and 1 article[32] had a cross-sectional design. Cumulatively, these 6 articles involved 694 adult participants with stroke. The sample size reported within the included articles ranged from 64[31] to 222[34] at baseline, and half of the studies[30,33,34] had an initial sample size of more than 100 participants. Three articles[29,31,33] included patients in the early phase after stroke, ranging from the first week[29] to 1 month[31] after stroke, whereas 1 article[32] focused on patients in the chronic phase (ie, more than 6 months after stroke). With regard to the type of stroke, 58% of the patients were classified with infarction, 6% were classified with hemorrhage, and for 36% of the patients, the pathology was unavailable. In the longitudinal studies reporting loss to follow-up,[29–31,33] the percentage of participants lost to follow-up varied between 12%[33] and 23%.[30]

A wide range of somatosensory variables, including neurophysiological and clinical somatosensory measures, was reported on. The search process identified 1 study[31] that measured SSEPs over the trajectory of the median nerve at the wrist. Furthermore, the Fugl-Meyer sensory assessment of the upper limb, assessing light touch and proprioception, was used in 3 studies.[30,33,34] This valid and reliable test is used extensively in stroke studies.[35] Investigating light touch by using Semmes-Weinstein monofilaments was described in 1 study.[29] Intraclass correlation coefficients greater than .90 were reported for both interrater and intrarater reliability.[29] Two-point discrimination[29] and the revised Nottingham Sensory Assessment (NSA)[32] were similarly only tested occasionally, both being reliable assessment methods[29,36] for somatosensory functioning. None of the studies combined SSEPs and a clinical somatosensory measure to evaluate the prognostic information of both type of measures.

Six different outcome measures were identified in the included studies. Of these, according to the classification proposed by Connell and Tyson,[37] 3 outcome measures assessed upper limb impairments: the Fugl-Meyer motor assessment,[31,33] shoulder pain,[33] and the Action Research Arm Test (ARAT).[29] Only 1 measure of activity limitations was used in the included studies: the Motor Activity Log.[34] Additionally, 2 articles reported outcomes at the participation level.[30,32]

The included studies also used a wide range of follow-up periods, ranging from 1 month after discharge from the rehabilitation center[33] to approximately 2 years after stroke.[34] Most of the studies used fixed time points for measurements, such as 3 months,[29] 6 months,[29,31] or 12 months[31] after stroke. Multiple regression analysis was used in all 6 studies.

Results regarding the association between somatosensory deficits and outcome after stroke and an overview of the methodological quality assessment of the 6 included studies are shown in the Table.

Body Function

Light touch and proprioception (Fugl-Meyer sensory assessment). In the study by Paci et al,[33] a very small proportion of the variance in motor performance in the upper limb 1 month after admission to the rehabilitation center could be explained by the ability to feel light touch and proprioception in the upper limb (measured on admission to the rehabilitation center [R^2=.01]). The somatosensory variable was not retained as a predictive factor for shoulder pain at follow-up.

Somatosensory evoked potentials. In the study by Feys et al,[31] SSEPs, measured on admission to the rehabilitation center, were shown to have predictive value in upper limb motor outcome at 6 and 12 months after stroke. The somatosensory impairment accounted for 8% in the explained variance of upper limb motor outcome.

Two-point discrimination. Au-Yeung[29] found significant odds ratios of 0.51 to 0.83 for the relationship between 2-point discrimination, measured at the first 3 weeks after stroke and an outcome of more than 35 points on the ARAT at 3 and 6 months after stroke. This finding indicates that patients who are able to discriminate between 2 points at the distal pulp of their index finger in the acute phase after stroke have a greater chance of achieving dexterity at 3 and 6 months after stroke.

Pressure perception. The level of pressure perception, as measured with monofilaments, was not retained as a predictive factor for recovery of dexterity in the study by Au-Yeung.[29]

Activity

Light touch and proprioception (Fugl-Meyer sensory assessment). In the study by Park et al,[34] a significant odds ratio of 0.2 for the relationship between proprioception measured with the Fugl-Meyer sensory assessment at 3 to 9 months after stroke and the quality of movement subscale of the Motor Activity Log 12 months later was demonstrated. A statistically nonsignificant relationship was found for the light touch subscale of the Fugl-Meyer sensory assessment.

Participation

Light touch and proprioception (Fugl-Meyer sensory assessment). Desrosiers et al[30] found a low but significant univariate correlation (r=.24) between the Fugl-Meyer sensory assessment assessing light touch and proprioception at discharge from the rehabilitation center and the handicap situations during ADLs and social roles, as assessed with the Assessment of Life Habits questionnaire 6 months later.

Tactile sensation, proprioception, and stereognosis (revised Nottingham Sensory Assessment). In a cross-sectional study in the chronic phase after stroke by Morris et al,[32] a low but significant negative correlation (r=−.17, r=−.25) was only found between proprioceptive dysfunction and the perceived physical activity subscale and social isolation subscale of the Nottingham Health Profile. The somatosensory variable could not be retained in the multiple regression analysis.

Table.
Results of Association of Somatosensory Deficits With Outcomes After Stroke[a]

Study	D&B Score (%)	Somatosensory Measure (Time Point)	Statistical Analysis	Outcome Measure (Time Point)	Results
Body Function					
Au-Yeung, 2006[29]	80	2PD; monofilaments–light touch (1 wk, 2 wk, 3 wk, 4 wk, 2 mo)	Multiple logistic regression; odds ratios	ARAT ≥35 (3 mo, 6 mo)	3 mo: 2PD 1 wk: OR=0.74[b] 2PD 2 wk: OR=0.75[b] 2PD 3 wk: OR=0.72[b] 2PD 4 wk and 2 mo: not retained in multiple regression model Light touch: not retained in multiple regression model 6 mo: 2PD 1 wk: OR=0.83[b] 2PD 2 wk: OR=0.5[b] 2PD 3 wk: OR=0.74[b] 2PD 4 wk and 2 mo: not retained in multiple regression model Light touch: not retained in multiple regression model
Feys et al, 2000[31]	65	SSEP median nerve: present vs absent (admission rehabilitation)	Multiple regression	FM motor assessment upper limb (2 mo, 6 mo, 12 mo)	2 mo: not retained in multiple regression model 6 mo: R^2=.0838[b] 12 mo: R^2=.0864[b]
Paci et al, 2007[33]	80	FM sensory assessment upper limb–light touch and proprioception (admission rehabilitation)	Multiple regression	FM motor assessment upper limb Shoulder pain (30–40 d later)	FM motor assessment upper limb R^2=.01[b] Shoulder pain not retained in multiple regression model
Activity					
Park et al, 2008[34]	80	FM sensory assessment upper limb–light touch and proprioception (3–9 mo)	Univariate logistic regression; multivariate logistic regression	MAL-quality of movement (12 mo later)	Univariate: Light touch: β=–0.538 Proprioception: β=–1.430[b] Multivariate: Proprioception: OR=0.2 (0.06–0.59)[b]
Participation					
Desrosiers et al, 2002[30]	80	FM sensory assessment upper limb–light touch and proprioception (discharge rehabilitation)	Pearson correlation coefficient; multiple regression	LIFE-H questionnaire (6 mo later)	r=.24[b] Not retained in multiple regression model
Morris et al, 2013[32]	83.3	Revised NSA–tactile sensations, proprioception, stereognosis (6 mo)	Bivariate correlations; multiple linear regression	Health-related QOL: Nottingham Health Profile: energy, sleep, social isolation, pain, emotion, physical mobility (cross-sectional: 6 mo)	NHP total: Proprioception: r=−.20 Stereognosis: r=−.09 Tactile sensation: r=−.11 NHP social isolation: Proprioception: r=−.17[b] Stereognosis: r=−.16 Tactile sensation: r=−.18 NHP physical activity: Proprioception: r=−.25[b] Stereognosis: r=.02 Tactile sensation: r=−.03 Not retained in multiple regression model Other subscales NHP: nonsignificant correlations

[a] DB=Downs and Black scale, 2PD=2-point discrimination, SSEP=somatosensory evoked potentials, ARAT=Action Research Arm Test, FM=Fugl-Meyer, OR=odds ratio, NSA=Nottingham Sensory Assessment, MAL=Motor Activity Log, LIFE-H=Assessment of Life Habits questionnaire, QOL=quality of life, NHP=Nottingham Health Profile.
[b] Significant at $P<.05$.

Discussion

It was the aim of this study to systematically review and summarize the current, available literature regarding the association of somatosensory impairments in the upper limb with outcome after stroke. We identified a total of 6 high-quality studies that reported on the influence of somatosensory impairments in the upper limb on impairments in body function, activity, and participation after stroke. These studies showed that 2-point discrimination is a good predictor for upper limb dexterity and that SSEPs have predictive value in upper limb motor recovery. Additionally, proprioception was shown to be significantly correlated with the perceived level of physical activity and social isolation and had some predictive value for the quality of functional movements in the upper limb. Finally, the combination of light touch and proprioception impairment was shown to be significantly related to both upper limb motor recovery and handicap situations during ADLs and social roles. In 4 out of 6 studies, the somatosensory variable could be retained as independent predictor, but with rather low scores in explained variances.

Coupar et al[19] systematically reviewed the literature on potential predictors of upper limb motor and functional recovery after stroke. The authors also found evidence for the association between the presence of SSEPs and better upper limb recovery, but they found inconclusive evidence for an association between clinical somatosensory deficits and upper limb function. It is important to notice that our systematic review had a different emphasis. We included both cross-sectional and longitudinal studies to explore only the association of somatosensory deficits with different outcomes after stroke. Furthermore, we included only reliable and valid measures of somatosensation. This approach resulted in a clear difference in the number of studies included in both reviews. Coupar and colleagues[19] included 19 studies addressing somatosensory deficits after stroke. Our review included only 4 of these studies because of our methodologically rigorous inclusion and exclusion criteria. Additionally, we identified another 2 high-quality studies[30,32] in order to give a more focused and comprehensive review on this topic.

Critical Considerations

Some limitations regarding the studies included in our review need to be addressed. First, it is important to note that almost 40% of the full-text articles we screened for eligibility were excluded based on the absence of psychometric data of the clinical somatosensory measure in the upper limb. This finding revealed the large number of nonstandardized measures of somatosensation used for research purposes, but probably also in the clinical setting. Unfortunately, all efforts invested when conducting these studies are nullified when assessments of unknown psychometric quality are used. Given these findings, it is remarkable that the Nottingham Sensory Assessment was used in only 1 of the included studies, although it was the recommended somatosensory outcome measure in a systematic review by Connell and Tyson[23] regarding outcome measures of somatosensation in neurological conditions. Furthermore, more objective somatosensory measures may have an additional predictive value. A relatively new, promising somatosensory measure is the perceptual threshold of touch,[38] in which high-frequency transcutaneous electrical nerve stimulation is used to activate cutaneous receptors of light touch and their Aβ-fibers in order to determine the threshold of touch in an objective way. Further research is needed to determine the usefulness in clinical practice of this new technique and the predictive value on outcome after stroke. Additionally, robotic devices may help to detect proprioceptive disorders in a more standardized way. Arm position matching tasks with both arms positioned on an exoskeleton robotic device allow different variables to be tracked more accurately and provide reliable 2- or 3-dimensional quantifications of deficits in position sense.[39]

Second, we noted a low proportion of participants included in the studies with an initial diagnosis of somatosensory impairments or only mild somatosensory deficits that were present in studies examining a cohort of people after stroke. Of particular interest is the contribution of somatosensory impairments in motor and functional outcomes in a study sample in which a large proportion of patients are encompassed with somatosensory impairments or patients experience more severe somatosensory impairment. These considerations could lead to different results regarding the contribution of somatosensory impairments in the explained variances of the outcome variable. Furthermore, none of the studies explored the lesion location and volume of the stroke. This would seem to be an important factor affecting somatosensation. In 3 of the 6 included studies, magnetic resonance imaging findings were studied as 1 of the other independent variables in the regression models. Only 1 study (Au-Yeung[29]) demonstrated a significant correlation with outcome after stroke. None of the studies investigated the relationship between the location and extent of the lesion with somatosensory impairments.

Finally, we need to consider the methodological quality of the studies. Thirteen out of 19 studies eligible for inclusion had only poor to moderate quality (score <65% of the maximum score) and, therefore, were excluded from this review. This finding indicates that most of the studies (68%) in this research field are of insufficient rigor to allow meaningful conclusions; therefore, results need to be interpreted with caution. Although we acknowledge the difficult nature of carrying out this kind of study, new large, high-quality cohort studies will be needed in the future.

An important consideration of our review relates to the heterogeneity of the included studies, which warrants caution when interpreting our results. Many different study designs, somatosensory variables, and outcome measures were used, and there was great variability in lengths of follow-up, data analysis, and presentation methods. Five of the included studies had a longitudinal design, which is crucial to assess the impact of somatosensory problems on recovery after stroke. However, based on previous literature, high-quality cross-sectional studies also may provide valuable information. The cross-sectional study included in this review allows us to gain insights into the time-independent relationship between somatosensation and health-related quality of life at 6 months after stroke.

The heterogeneity of the included studies also prevented us from pooling data and drawing more detailed conclusions about the impact of different somatosensory modalities, such as light touch or proprioception, on upper limb motor and functional outcome after stroke. Bias in setting and study participants needs consideration when indirectly comparing results across studies. Furthermore, the question of whether neurophysiological measures have a higher predictive value compared with clinical somatosensory measures in outcome after stroke could not be answered due to the small number of high-quality studies using neurophysiological measures of somatosensation and the lack of studies combining both neurophysiological and clinical somatosensory measures in predicting motor outcome after stroke. Moreover, we expected to find stronger correlations in cross-sectional studies than in longitudinal studies. Conversely, we could not find any differences in results between cross-sectional and longitudinal studies, possibly due to the high heterogeneity of the included studies and the small amount of high-quality cross-sectional studies. Another drawback is publication bias. Studies with significant results are more likely to be published. We addressed this limitation through a rigorous searching process in different databases. It is reassuring that our search identified studies similar to those in other recent reviews in this area.

Finally, it should be noted that the quality assessment criteria are also a concern with this type of review. Because of the lack of a gold standard for assessing quality of observational studies, we modified the methodological quality assessment of the Downs and Black quality scale.[25] This scale originally was designed to assess the methodological quality both of randomized and nonrandomized studies of health care interventions. Different questions of this quality appraisal instrument were not applicable due to the nature of the observational study designs included in this review. Through omitting 2 additional questions in the quality appraisal of cross-sectional studies, we can guarantee that the quality assessment was not biased toward longitudinal studies and that there was no penalization of studies with a cross-sectional design. Important to note is the fact that some of the articles included for quality appraisal were published long before the concepts brought forward in the article by Downs and Black were ever published. This may be 1 factor explaining the low scores in the quality rating.

Implications for Practice

Recommendation for practice includes the use of reliable and valid measurement instruments. The importance of somatosensory testing as an essential part of the clinical assessment process is recognized by both patients and health care personnel,[9] emphasizing the need for accurate, reliable assessment methods. As pointed out above, a huge dropout of studies was attributed to the unpublished psychometric properties of the included measures of somatosensation. The recent publication proposed by Connell and Tyson[23] offers a guideline for using reliable, valid, and clinically useful measures of somatosensation. Although the measurement of all somatosensory modalities looks impracticable and difficult to justify in the clinical setting in patients with stroke, we do recommend 1 testing of each modality of somatosensation, such as light touch, pressure, pinprick, proprioception, discrimination tasks, and stereognosis. Furthermore, it is important to assess patients from the acute phase after stroke along the rehabilitation process to accurately monitor progress. Also, up to now, results from somatosensory assessments have not been routinely used to set goals for treatment programs. Treatment of somatosensory deficits is needed because it also may positively influence motor output.[8]

A recent systematic review conducted by Doyle et al[7] examined interventions for somatosensory impairment in the upper limb after stroke and indicated insufficient evidence about the effects of treatment interventions. This finding was attributed to the large variety of interventions and the small number of included articles. Still, some of the studies included in the review of Doyle et al suggested preliminary evidence for the effects of some specific interventions, such as thermal stimulation and intermittent pneumatic compression for improving somatosensation after stroke. Another recent randomized controlled trial[40] provided evidence for improvement in functional sensory discrimination capacity after stroke when providing patients intensive sensory discrimination training based on perceptual learning for a total of 10 hours. These findings provide support for introducing interventions for somatosensory impairment in rehabilitation programs for patients with stroke.

Implications for Research

This review has highlighted the need to use reliable and valid measures of somatosensory functions in research. Additionally, more standardized somatosensory measures, such as the perceptual threshold of touch,[38] need to be investigated to determine the predictive value on outcome after stroke. Furthermore, important gaps in the current knowledge need to be addressed. First, this review showed a large range in strength of the relationship between somatosensory and motor or functional outcome after stroke. Larger, high-quality cohort studies combining neurophysiological and clinical somatosensory measures of different modalities are needed to determine this relationship with more accuracy. Second, the relationship between the lesion location and extent of the stroke with somatosensory impairments needs to be further explored, as this information will increase our insights into the neural correlates of somatosensory processing. Third, the quality assessment of observational studies needs to be standardized, and validity needs to be established. Finally, insights are lacking regarding the extent of deficits in different somatosensory modalities and the recovery patterns of the different somatosensory modalities after stroke. These insights are crucial in guiding and delineating treatment interventions for somatosensory deficits in patients with stroke.

Ms Meyer, Dr Thijs, Dr Feys, and Dr Verheyden provided concept/idea/research design. All authors provided writing. Ms Meyer provided data collection. Ms Meyer, Ms Karttunen, and Dr Feys provided data analysis. Dr Verheyden provided project management. Dr Feys and Dr Verheyden provided facilities/equipment and institutional liaisons. Ms Karttunen, Dr Thijs, Dr Feys, and Dr Verheyden provided consultation (including review of manuscript before submission).

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References

1 Warlow C, Sudlow C, Dennis M, et al. Stroke. *Lancet*. 2003;362:1211–1224.

2 Roger VL, Go AS, Lloyd-Jones DM, et al. Heart disease and stroke statistics—2012 update: a report from the American Heart Association. *Circulation*. 2012;125:e2–e220.

3 Nakayama H, Jørgensen HS, Raaschou HO, et al. Recovery of upper extremity function in stroke patients: the Copenhagen Stroke Study. *Arch Phys Med Rehabil*. 1994;75:394–398.

4 Tennant A, Geddes JM, Fear J, et al. Outcome following stroke. *Disabil Rehabil*. 1997;19:278–284.

5 Kwakkel G, Meskers CG, van Wegen EE, et al. Impact of early applied upper limb stimulation: the EXPLICIT-stroke programme design. *BMC Neurol*. 2008;8:49.

6 De Wit L, Putman K, Schuback B, et al. Motor and functional recovery after stroke: a comparison of 4 European rehabilitation centers. *Stroke*. 2007;38:2101–2107.

7 Doyle S, Bennett S, Fasoli SE, McKenna KT. Interventions for sensory impairment in the upper limb after stroke. *Cochrane Database Syst Rev*. 2010;(2):CD006331.

8 Yekutiel M. *Sensory Re-Education of the Hand after Stroke*. London, United Kingdom: Whurr; 2000.

9 Winward CE, Halligan PW, Wade DT. Current practice and clinical relevance of somatosensory assessment after stroke. *Clin Rehabil*. 1999;13:48–55.

10 Bornschlegl M, Asanuma H. Importance of the projection from the sensory to the motor cortex for recovery of motor function following partial thalamic lesion in the monkey. *Brain Res*. 1987;437:121–130.

11 Nudo RJ, Friel KM, Delia SW. Role of sensory deficits in motor impairments after injury to primary motor cortex. *Neuropharmacology*. 2000;39:733–742.

12 Hamdy S, Rothwell JC, Aziz Q, et al. Long-term reorganization of human motor cortex driven by short-term sensory stimulation. *Nat Neurosci*. 1998;1:64–68.

13 Vidoni ED, Boyd LA. Preserved motor learning after stroke is related to the degree of proprioceptive deficit. *Behav Brain Funct*. 2009;5:36.

14 Conforto AB, Ferreiro KN, Tomasi C, et al. Effects of somatosensory stimulation on motor function after subacute stroke. *Neurorehabil Neural Repair*. 2010;24:263–272.

15 Tyson SF, Hanley M, Chillala J, et al. Sensory loss in hospital-admitted people with stroke: characteristics, associated factors, and relationship with function. *Neurorehabil Neural Repair*. 2008;22:166–172.

16 Sommerfeld DK, von Arbin MH. The impact of somatosensory function on activity performance and length of hospital stay in geriatric patients with stroke. *Clin Rehabil*. 2004;18:149–155.

17 Broeks JG, Lankhorst GJ, Rumping K, Prevo AJ. The long-term outcome of arm function after stroke: results of a follow-up study. *Disabil Rehabil*. 1999;21:357–364.

18 Reding MJ, Potes E. Rehabilitation outcome following initial unilateral hemispheric stroke: life table analysis approach. *Stroke*. 1988;19:1354–1358.

19 Coupar F, Pollock A, Rowe P, et al. Predictors of upper limb recovery after stroke: a systematic review and meta-analysis. *Clin Rehabil*. 2012;26:291–313.

20 Chen SY, Winstein CJ. A systematic review of voluntary arm recovery in hemiparetic stroke: critical predictors for meaningful outcomes using the *International Classification of Functioning, Disability and Health*. *J Neurol Phys Ther*. 2009;33:2–13.

21 Liberati A, Altman DG, Tetzlaff J, et al. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. *J Clin Epidemiol*. 2009;62:e1–e34.

22 Hier DB, Edelstein G. Deriving clinical prediction rules from stroke outcome research. *Stroke*. 1991;22:1431–1436.

23 Connell LA, Tyson SF. Measures of sensation in neurological conditions: a systematic review. *Clin Rehabil*. 2012;26:68–80.

24 *International Classification of Functioning, Disability and Health: ICF*. Geneva, Switzerland: World Health Organization; 2001.

25 Downs SH, Black N. The feasibility of creating a checklist for the assessment of the methodological quality both of randomised and non-randomised studies of health care interventions. *J Epidemiol Community Health*. 1998;52:377–384.

26 Deeks JJ, Dinnes J, D'Amico R, et al, Evaluating non-randomized intervention studies. *Health Technol Assess*. 2003;7:iii–x, 1–173.

27 Reeves, B, Deeks J, Higgins JP, et al. Including non-randomized studies. In: Higgins J, Green S, eds. *Cochrane Handbook for Systematic Reviews of Interventions 5.0.1*. Chichester, United Kingdom: John Wiley & Sons Ltd; 2008.

28 Weierink L, Vermeulen RJ, Boyd RN. Brain structure and executive functions in children with cerebral palsy: a systematic review. *Res Dev Disabil*. 2013;34:1678–1688.

29 Au-Yeung SSY. *Treatment of Upper Extremity Paresis Using Transcutaneous Electrical Stimulation During Acute Stroke* [dissertation]. Hong Kong: Hong Kong Polytechnic University (People's Republic of China); 2006.

30 Desrosiers J, Noreau L, Rochette A, et al. Predictors of handicap situations following post-stroke rehabilitation. *Disabil Rehabil*. 2002;24:774–785.

31 Feys H, Van Hees J, Bruyninckx F, et al. Value of somatosensory and motor evoked potentials in predicting arm recovery after a stroke. *J Neurol Neurosurg Psychiatry*. 2000;68:323–331.

32 Morris JH, van Wijck F, Joice S, et al. Predicting health related quality of life 6 months after stroke: the role of anxiety and upper limb dysfunction. *Disabil Rehabil*. 2013;35:291–299.

33 Paci M, Nannetti L, Taiti P, et al. Shoulder subluxation after stroke: relationships with pain and motor recovery. *Physiother Res Int*. 2007;12:95–104.

34 Park S, Wolf SL, Blanton S, et al. The EXCITE Trial: predicting a clinically meaningful motor activity log outcome. *Neurorehabil Neural Repair*. 2008;22:486–493.

35 Lin JH, Hsueh IP, Sheu CF, Hsieh CL. Psychometric properties of the sensory scale of the Fugl-Meyer Assessment in stroke patients. *Clin Rehabil*. 2004;18:391–397.

36 Lincoln NB, Jackson JM, Adams SA. Reliability and revision of the Nottingham Sensory Assessment for Stroke Patients. *Physiother*. 1998;84:358–365.

37 Connell LA, Tyson SF. Clinical reality of measuring upper-limb ability in neurologic conditions: a systematic review. *Arch Phys Med Rehabil*. 2012;93:221–228.

38 Eek E, Engardt M. Assessment of the perceptual threshold of touch (PTT) with high-frequency transcutaneous electric nerve stimulation (Hf/TENS) in elderly patients with stroke: a reliability study. *Clin Rehabil*. 2003;17:825–834.

39 Dukelow SP, Herter TM, Bagg SD, et al. The independence of deficits in position sense and visually guided reaching following stroke. *J Neuroeng Rehabil*. 2012;9:72.

40 Carey L, Macdonell R, Matyas TA. SENSe: Study of the Effectiveness of Neurorehabilitation on Sensation: a randomized controlled trial. *Neurorehabil Neural Repair*. 2011;25:304–313.

Appendix.

Search Strategy Used for EMBASE and Adapted for the Other Databases

No. of Searches		Results
1	exp cohort analysis/	117,266
2	incidence.sh.	163,175
3	exp mortality/	402,196
4	follow up/	518,734
5	prognos$.tw.	300,513
6	predict$.tw.	759,488
7	course$.tw.	317,689
8	predictor$.tw.	194,676
9	exp statistical model/	83,263
10	1 or 2 or 3 or 4 or 5 or 6 or 7 or 8 or 9	2,149,121
11	exp cerebrovascular disease/	278,019
12	exp basal ganglion/	63,154
13	exp brain ischemia/	64,190
14	exp carotid artery disease/	28,970
15	exp cerebrovascular accident/	35,741
16	exp brain infarction/	33,297
17	exp brain ischemia/	64,190
18	intracranial hypertension/ or intracranial aneurysm/ or intracranial pressure/ or intracranial hypotension/	22,270
19	exp brain hemorrhage/	50,388
20	exp brain embolism/	3,845
21	exp brain arteriovenous malformation/	3,887
22	exp brain vasospasm/	3,683
23	artery dissection/	4,643
24	stroke.tw.	132,327
25	poststroke.tw.	2,446
26	post-stroke.tw.	4,267
27	cerebrovasc$.tw.	28,724
28	brain vasc$.tw.	652
29	cerebral vasc$.tw.	4,308
30	cva$.tw.	2,818
31	apoplex$.tw.	1,153
32	SAH.tw.	6,179
33	exp hemiplegia/	6,373
34	exp paresis/	3,898
35	hemipleg$.tw.	5,736
36	hemipar$.tw.	7,980
37	paresis.tw.	5,451
38	paretic.tw.	1,526
39	11 or 12 or 13 or 14 or 15 or 16 or 17 or 19 or 20 or 21 or 22 or 23 or 24 or 25 or 26 or 27 or 28 or 29 or 31 or 32 or 33 or 34 or 35 or 36 or 37 or 38	389,644
40	10 AND 39	108,798

(Continued)

Appendix.
Continued

No. of Searches		Results
41	exp arm/	76,240
42	(upper adj3 (limb$ or extremity)).tw.	23,134
43	arm.tw.	74,444
44	shoulder.tw.	29,863
45	elbow.tw.	15,038
46	forearm.tw.	19,668
47	hand.tw.	196,447
48	wrist.tw.	16,971
49	finger.tw.	35,216
50	fingers.tw.	12,217
51	41 or 42 or 43 or 44 or 45 or 46 or 47 or 48 or 49 or 50	381,951
52	40 AND 51	4,262
53	exp sensation/	10,789
54	sensory dysfunction/	9,078
55	motor performance/	29,998
56	convalescence/	28,267
57	functional assessment/	37,419
58	53 or 54 or 55 or 56 or 57	110,746
59	52 AND 58	699