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# Associations Between Sensorimotor Impairments in the Upper Limb at 1 Week and 6 Months After Stroke

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**Background and Purpose:** Longitudinal information regarding the prevalence of upper limb somatosensory deficits and the association with motor impairment and activity limitations is scarce. The aim of this prospective cohort study was to map the extent and distribution of somatosensory deficits, and to determine associations over time between somatosensory deficits and motor impairment and activity limitations.

**Methods:** We recruited 32 participants who were assessed 4 to 7 days after stroke, and reassessed at 6 months. Somatosensory measurements included the Erasmus-modified Nottingham sensory assessment (Em-NSA), perceptual threshold of touch, thumb finding test, 2-point discrimination, and stereognosis subscale of the NSA. Evaluation of motor impairment comprised the Fugl-Meyer assessment, Motricity Index, and Action Research Arm Test. In addition, at 6 months, activity limitation was determined using the adult assisting hand assessment stroke, the ABILHAND, and hand subscale of the Stroke Impact Scale.

**Results:** Somatosensory impairments were common, with 41% to 63% experiencing a deficit in one of the modalities within the first week and 3% to 50% at 6 months. In the acute phase, there were only very low associations between somatosensory and motor impairments ($r = 0.03$-$0.20$), whereas at 6 months, low to moderate associations ($r = 0.32$-$0.69$) were found for perceptual threshold of touch, thumb finding test, and stereognosis with motor impairment and activity limitations. Low associations ($r = 0.01$-$0.29$) were found between somatosensory impairments in the acute phase and motor impairments and activity limitations at 6 months.

**Discussion and Conclusions** : This study showed that somatosensory impairments are common and suggests that the association with upper limb motor and functional performance increases with time after stroke.

**Video Abstract available** for more insights from the authors (see Supplemental Digital Content 1, http://links.lww.com/JNPT/A138).

**Key words:** *longitudinal study, motor deficit, somatosensory impairment, stroke, upper extremity*

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## INTRODUCTION

Stroke is a leading cause of long-term disability.[1] In particular, 2 out of 3 stroke survivors experience upper limb sensorimotor impairments resulting in limitations in functional arm use during daily activities.[2-4] An intact sensorimotor network has shown to be a prerequisite for purposeful arm use[5]; optimal interaction between the somatosensory and motor systems is needed to perform functional arm and hand activities.

Somatosensation is defined as sensation arising from the skin, muscles, and joints, and in clinical application is divided into primary and secondary somatosensation.[6,7] For primary somatosensation, the somatosensory receptors in the body provide the primary input to the primary somatosensory cortices[8,9] where tactile, haptic, and nociceptive information is processed. Primary somatosensation includes exteroception and proprioception. Exteroception refers to tactile sensation such as touch, pressure, pain, and temperature that originate in peripheral receptors located in the skin. Proprioception arises from the deeper tissues of the body, predominantly from the muscles, ligaments, tendons, and joints and refers to position or movement sense of a body part. Secondary somatosensation, also called cortical somatosensation, includes 2-point discrimination (2PD), stereognosis, graphesthesia, and tactile localization. Cortical somatosensation involves discrimination of sensory stimuli and requires the primary sensory areas of the cortex to perceive the stimulus and the sensory association areas in the parietal lobe to interpret the meaning of the stimulus.[6,7]

Somatosensory deficits in the upper limb are common after stroke.[10-18] Reported prevalence rates range from 23% to 55% for exteroceptive impairments,[10-16] from 19% to 64% for proprioceptive impairments,[10,12,14-17] and up to 89% for

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cortical somatosensory deficits.[12,16,18] The variability of findings related to poststroke somatosensory deficits is attributable to differences in study populations, time after stroke, somatosensory modality tested, and assessment method used.[19] In more recent studies, robotic-based measurements have been used to quantify different aspects of proprioceptive acuity after stroke.[20-22] Although robotic-based measurements provide reliable quantitative results, this approach is rarely available in clinical practice.

Studies investigating somatosensory deficits mostly assessed patients in the subacute to chronic phase after stroke. Only 3 studies[15,17,18] reported on the extent of somatosensory deficits assessed clinically within the first week after stroke. Studies combining different measures to map exteroceptive, proprioceptive, and cortical somatosensory deficits in the acute phase after stroke are missing. In addition, reports of longitudinal follow-up of deficits in somatosensory function are scarce. Connell et al[12] investigated somatosensory recovery in 70 stroke survivors from admission to a rehabilitation unit up to 6 months after stroke. The somatosensory recovery showed a similar pattern to that widely acknowledged for motor recovery, with the greatest proportion of recovery occurring in the first weeks after stroke, and the recovery slope reaching a plateau between 3 and 6 months.[23] However, their study started from a variable point on admission to the rehabilitation center and did not relate the recovery of somatosensory function to the recovery of motor function.[12]

Loss of somatosensory functioning after stroke has been related to decreased independence during activities of daily living,[10] and impacts on performance and perceived well-being during daily activities.[11] Cross-sectional studies reported a significant association between somatosensory deficits and upper limb motor performance,[13,24] pinch grip deficits,[25] and impaired bimanual coordination.[26] To date, only one study[15] reported on the change over time in associations between somatosensory functions and fine motor hand use in the first week, and at 3 and 18 months after stroke. A significant moderate association between fine motor hand use and both light touch and proprioception was reported at all 3 measurement points. In a number of recent systematic reviews,[27,28] somatosensory loss has been suggested as an independent predictor of upper limb recovery. Despite these results, the reviews highlight the need for high-quality cohort studies that combine reliable and valid somatosensory measures of different modalities to determine the relationship with motor and functional performance. These insights are crucial for guiding and delineating treatment interventions for upper limb sensorimotor deficits after stroke.

Therefore, the aims of this study were firstly to map the prevalence and distribution of upper limb exteroceptive, proprioceptive and cortical somatosensory impairments within the first week and at 6 months. On the basis of previous findings, we hypothesized that somatosensory impairments would be common both within the first week and at 6 months, with the highest prevalence for cortical somatosensory deficits. We further hypothesized that the prevalence of different deficits would decrease over time during the course of spontaneous neurological recovery. Second, we wanted to determine the association between somatosensory deficits and motor impairment within the first week, and between somatosensory deficits and motor impairment and activity limitations at 6 months. A final objective was to define the association between somatosensory impairments within the first week and motor impairments and activity limitations at 6 months. We hypothesized, based on findings of Welmer et al,[15] that somatosensory impairments are significantly related to motor impairment and activity limitations, both within the first week as at 6 months.

## METHODS

### Subjects and Setting

Participants for this prospective cohort study were recruited consecutively from the acute stroke unit of 2 university hospitals in Belgium: University Hospitals Leuven and UCL Saint-Luc Brussels. Adults who had an acute (<1 week) first-ever stroke (as defined by the World Health Organization[29]), who experienced a motor and/or somatosensory impairment in the upper limb, and who showed sufficient cooperation to perform the assessment, were included in the study. Cooperation was evaluated clinically on the basis of whether it was feasible for the participant to conduct the study protocol during a 1-hour session, in a sitting position. Individuals were excluded if they had a prestroke Barthel index[30] score of less than 95 out of 100; other neurological conditions with permanent damage; a subdural hematoma, tumor, encephalitis or trauma that led to similar symptoms as a stroke; or serious communication, cognitive or language deficits, which could hamper the assessment. Communication deficits and cognitive functioning were evaluated clinically to assess whether these deficits were too severe for the participant to understand and participate in the study protocol. Participants signed a written informed consent form before inclusion. Ethical approval was obtained from the Ethics Committee of the University Hospitals Leuven and Brussels.

### Measures

Participants were assessed within the first week (4-7 days after stroke), and again at 6 months. One trained researcher performed all data collection. Participant characteristics were obtained, including age at stroke onset, gender, comorbidities (Cumulative Illness Rating Scale[31]), hand dominance (writing), time after stroke, stroke severity (National Institute of Health Stroke Scale[32]), type of stroke (ischemic or hemorrhagic), stroke lesion location according to affected vascular territory (anterior cerebral artery, middle cerebral artery, posterior cerebral artery, or basilar artery), side of impairment, and the presence of visuospatial neglect (star cancellation test[33]). Assessment of somatosensory and motor impairment was performed within the first week and again at 6 months after stroke. In addition, at 6 months after stroke, upper limb activity limitation was assessed.

### Somatosensory Impairment

#### Exteroceptive Impairments

The Erasmus MC modification of the (revised) Nottingham sensory assessment (Em-NSA)[34] was used to assess light touch (cotton wool), pressure (index finger), and pinprick (toothpick) impairment at predefined points of contact in the affected upper limb. Scores for each modality range from 0 (loss of function) to 8 (intact function). A cut-off score of less than 7 indicates the presence of exteroceptive impairment. The Em-NSA has good to excellent intrarater and interrater reliability.[34]

The perceptual threshold of touch (PTT)[35] is the minimal detectable stimulus level of touch. Therefore, a transcutaneous electric nerve stimulation was applied with a portable device: A CEFAR Primo Pro (Cefar Medical AB, Sweden). Round electrodes (diameter 3 cm) were applied to the index finger and bulb of the thumb of the affected upper limb. A high-frequency constant current of 40 Hz with single square pulses of 80-$\mu$s pulse duration was applied. The amplitude was gradually increased from 0 mA with increments of 0.5 mA, until a tingling sensation is being perceived at the index finger. Good psychometric properties are established for the PTT, including excellent interrater and test-retest reliability.[35] To evaluate the PTT impairment, individual scores were compared with age- and gender-matched cut-off norm values. PTT values for healthy participants range from 2.50 to 7.25 mA, determined by age, gender, and side of assessment.[36]

### Proprioceptive Impairments

The Em-NSA[34] was used to assess proprioception (movement sense) impairment at predefined joints of the affected upper limb. Scores range from 0 (loss of function) to 8 (intact function). A cut-off score of less than 7 indicates the presence of proprioceptive impairment. The Em-NSA has good to excellent intrarater and interrater reliability.[34] Position sense was examined using the thumb finding test (TFT).[37] The scoring ranges from 0 (no difficulty) to 3 (severe difficulty). A cut-off score of more than 0 indicates the presence of impaired proprioception (position sense). Psychometric properties of the TFT are not reported in literature and therefore, we performed a separate reliability study (unpublished data). For that study, a total of 43 participants with stroke were assessed within the first 6 months after stroke and the assessment of the TFT was videotaped. To determine the intrarater reliability, videos were scored 2 times, after a minimum of 1 month in between the scoring. The intrarater reliability was almost perfect, with a weighted $\kappa$ (95% confidence interval) of 0.95 (0.89-1.00) and percentage of agreement of 95%.

### Cortical Somatosensory Impairments

The Em-NSA[34] was used to assess sharp-dull discrimination (toothpick/index finger) impairment at predefined points of contact in the affected upper limb. Scores range from 0 (loss of function) to 8 (intact function). A cut-off score of less than 7 indicates the presence of cortical somatosensory impairment. The Em-NSA has good to excellent intrarater and interrater reliability.[34]

Stereognosis assessment was based on the original NSA,[38] in which participants were asked to identify 11 common objects by touch and manipulation in the affected hand. When needed, assistance to the manipulation of objects in the hand was given by the assessor. Total scores range from 0 to 22. A cut-off score of less than 19 indicates the presence of stereognosis impairment. The stereognosis section of the NSA shows a moderate to good test-retest reliability in persons with stroke.[39]

2PD[40] was assessed at the fingertip of the affected index finger. Distance between the points was gradually reduced from 15 mm until the participant incorrectly felt only one point. The last correct answer was recorded as the result. The 2PD threshold in healthy controls has a mean of 3.5 mm (standard deviation, 1.7).[18] Participants with a 2PD threshold higher than 5 mm were classified as having impaired 2PD. Good reliability has been found for the 2PD assessment.[40]

Overall, exteroceptive somatosensation comprised the measures of light touch, pressure, and pinprick (of the Em-NSA) and the PTT. Proprioceptive somatosensation was evaluated using the TFT and the proprioception subscale of the Em-NSA. Finally, cortical somatosensation was assessed by sharp-dull discrimination, stereognosis, and 2PD.

### Motor Impairment

The Fugl-Meyer assessment upper extremity (FMA-UE)[41] measures overall motor impairment, with a total score between 0 (loss of motor function) and 66 (intact motor function). A cut-off score of less than 60 indicates the presence of motor impairment.[42] The FMA-UE is considered valid and reliable.[41] The arm section of the Motricity Index (MI)[43] is a reliable measure of muscle strength during pinch grip, flexion of the elbow, and abduction of the shoulder. Total scores vary between 0 and 100, with higher scores corresponding to better muscle strength. A cut-off score of less than 90 indicates impaired arm muscle strength. The action research arm test (ARAT)[44] assesses motor performance in 4 different subscales: grasp, grip, pinch, and gross movement. The maximum score is 57, reflecting good motor performance. A cut-off score of less than 50 indicates the presence of fine motor impairment.[42] Reliability[45] and validity[46] are established.

### Upper Limb Activity Limitation

The adult assisting hand assessment stroke[47] is a Rasch-based performance scale that measures how effectively the affected hand is spontaneously used during performance of a bimanual functional task. Nineteen test items, describing different object-related hand actions, result in total scores varying between 1 (no bimanual ability) and 100 (high bimanual ability). The ABILHAND questionnaire[48] is a Rasch-based inventory of 23 uni- and bimanual activities that the participant was asked to judge as 0 (impossible), 1 (difficult), and 2 (easy), irrespective of the limb(s) actually used to do the activity. The raw scores were then converted to logit-scores, and minimal clinical detectible change have been established.[49,50] Using the hand subscale of the Rasch-based Stroke Impact Scale, version 3,[51] the participant needed to indicate the difficulty of 5 manual activities using the most affected hand such as carrying heavy objects, picking up a dime, or turning the doorknob. The total score ranges from 0 to 100, with higher scores indicating better perceived hand function.

### Statistical Analysis

Clinical and demographic characteristics of participants, both within the first week and at 6 months after stroke, were displayed as frequencies with percentage, mean with standard deviation, and median with interquartile range, as appropriate. A paired-sample Wilcoxon signed rank test was performed to assess changes over time for each of the somatosensory and motor impairment measures. The prevalence of deficits in different somatosensory modalities and in motor performance was calculated both within the first week and at 6 months, using frequencies with percentages. The distribution pattern of somatosensory impairments both within the first week and at 6 months was examined according to the presence or absence of exteroceptive, proprioceptive, or cortical somatosensory problems.

For the distribution pattern, 8 somatosensory categories were created on the basis of the somatosensory impairment measures: (1) no somatosensory impairment, (2) exteroceptive impairment, (3) proprioceptive impairment, (4) cortical somatosensory impairment, (5) mixed exteroceptive and proprioceptive impairment, (6) mixed exteroceptive and cortical somatosensory impairment, (7) mixed proprioceptive and cortical somatosensory impairment, and (8) mixed exteroceptive, proprioceptive, and cortical somatosensory impairment. The prevalence of each of these categories was plotted in pie charts. Spearman rank correlation coefficients were used to assess (1) the association between somatosensory impairments and motor impairment within the first week, (2) the association between somatosensory impairments and motor impairment as well as upper limb activity limitations at 6 months, and (3) the association between somatosensory impairments measured within the first week and motor impairment as well as upper limb activity limitations at 6 months. Strength of the relation was interpreted according to Munro's correlation descriptors[52]: very low ($r = 0.01$-$0.24$), low ($r = 0.25$-$0.49$), moderate ($r = 0.50$-$0.69$), high ($r = 0.70$-$0.89$), and very high ($r = 0.90$-$1.00$). $P$ values were considered statistically significant at the 0.05 level. All statistical analyses were performed using SPSS, version 22.

## RESULTS

Forty participants were enrolled in the study, of whom 32 completed the study procedures and 8 participants dropped out before the 6-month assessment (5 deceased, 2 were medically unstable, and 1 declined to participate). Characteristics of participants who dropped out were not significantly different from participants who were assessed at 6 months, except for a significantly higher age in the dropout group (Mann-Whitney $U$ test, $P < 0.05$). Thus, 32 participants were assessed at 2 time points—within the first week (4-7 days after stroke) and at 6 months—and were included in the analysis. Median age at stroke onset was 68 years and 53% were males. The majority (84%) suffered from ischemic stroke and 72% showed left-sided hemiparesis.

Participant characteristics are given in Table 1. Stroke severity was mild to severe with a median score on the National Institute of Health Stroke Scale of 8. Visuospatial neglect was present in 5 participants. Overall, participants had poor upper limb motor function within the first week, with a median score of 15.5 out of 66 on the FMA-UE, of 41 out of 100 on the MI, and of 3 out of 57 on the ARAT. Motor function improved significantly ($P < 0.001$) at 6 months after stroke, with median scores of 57, 79.5, and 53 on the FMA-UE, MI, and ARAT, respectively. A similar pattern is seen for the somatosensory function, with poor upper limb somatosensory function within the first week, and with significant improvement at 6 months after stroke on all somatosensory outcome measures.

The prevalence of somatosensory impairments at the first week and 6-month time points is illustrated in Figure 1. Within the first week, exteroceptive impairments were present in 41% to 50% of the participants, whereas at 6 months only 3% to 22% of the participants had exteroceptive deficits. At the 6-month time point, PTT revealed the highest frequency of exteroceptive dysfunction. Second, proprioceptive impairment was diagnosed in 44% of participants when using the Em-NSA within the first week, and 63% of participants showed proprioceptive impairment using the TFT at the first week time point. At 6 months after stroke, the prevalence dropped to 3% when using the Em-NSA, whereas still 50% of participants had a position sense deficit assessed by the TFT. Finally, deficits in cortical somatosensation were present in 50% to 63% of participants early after stroke and decreased to 22% to 28% at 6 months.

The distribution of somatosensory impairments also changed over time (Figure 2). Within the first week, only 22% of participants had no somatosensory impairment, which increased to 31% at 6 months (Figure 2, indicated in red). Furthermore, 66% of participants had mixed somatosensory impairments within the first week, whereas only 28% had mixed somatosensory impairments at 6 months (Figure 2, indicated in different types of green). At 6 months, more unique exteroceptive, proprioceptive, or cortical impairments were present. At 6 months, there were less mixed forms of somatosensory impairments (Figure 2, indicated in different types of blue), especially proprioceptive impairments were present without other somatosensory impairments in 25% of the participants at 6 months compared with none of the participants within the first week.

Prevalence of motor impairments at the first week and 6-month time points is shown in Figure 3. Within the first week, 30 participants (93.8%) have impaired motor function on all 3 motor outcome measures, whereas at 6 months after stroke, prevalence of impairments drops to 43.8% on the ARAT, 53.1% on the FMA-UE, and 62.5% has still motor impairments identified by the MI.

The cross-sectional correlation analysis between somatosensory and motor impairments at both time points is shown in Table 2. Within the first week, only very low and nonsignificant associations ($r = 0.03$-$0.20$) between somatosensory and motor impairment were found. At 6 months, low to moderate correlations were found for the association between motor impairments and different exteroceptive, proprioceptive, and cortical somatosensory impairments. Poor performance on the somatosensory assessments was associated with poor performance on the motor assessments. For exteroceptive impairments, PTT showed moderate correlations with all motor impairment measures ($r = -0.60$ to $-0.66$), and proprioceptive impairments measured with both the TFT and the movement sense scale of the Em-NSA showed low correlations ($r = 0.26$-$0.39$) with motor impairments. Finally, for the

**Table 1. Participant Characteristics (n = 32)**

| | Within 1 wk | At 6 mo | $P^a$ |
|---|---|---|---|
| Age at stroke onset, median ($Q_1$-$Q_3$) | 68.3 (61.3-80.1) | | |
| Gender, n (%) | | | |
| Male | 17 (53.1) | | |
| Female | 15 (46.9) | | |
| Center, n (%) | | | |
| UZ Leuven | 19 (59.4) | | |
| UCL Brussels | 13 (40.6) | | |
| NIHSS, median ($Q_1$-$Q_3$) | 8 (5-13) | | |
| Lateralization, n (%) | | | |
| Right hemiparesis | 9 (28.1) | | |
| Left hemiparesis | 23 (71.9) | | |
| Type of stroke, n (%) | | | |
| Ischemia | 27 (84.4) | | |
| Hemorrhage | 5 (15.6) | | |
| Vascular territory of stroke lesion, n (%) | | | |
| ACA | 1 (3) | | |
| MCA | 26 (81) | | |
| PCA | 2 (6) | | |
| Basilar artery | 3 (10) | | |
| Hand dominance, n (%) | | | |
| Left | 2 (6.3) | | |
| Right | 29 (90.6) | | |
| Both | 1 (3.1) | | |
| CIRS, median ($Q_1$-$Q_3$) | 5.5 (4-8) | | |
| Visuospatial neglect, n (%) | 5 (16.1) | | |
| Days after stroke, median ($Q_1$-$Q_3$) | 6 (5-7) | 183 (181-185) | |
| Exteroceptive somatosensation, median ($Q_1$-$Q_3$) | | | |
| Em-NSA—light touch | 6.5 (1.5-8) | 8 (8-8) | <0.001 |
| Em-NSA—pressure | 8 (3-8) | 8 (8-8) | 0.001 |
| Em-NSA—pinprick | 8 (3-8) | 8 (8-8) | 0.001 |
| PTT—light touch | 5 (4-11) | 3.5 (3-4.5) | <0.001 |
| Proprioceptive somatosensation, median ($Q_1$-$Q_3$) | | | |
| Em-NSA—movement sense | 7.5 (4-8) | 8 (8-8) | <0.001 |
| TFT—position sense | 1 (0-2) | 1 (0-1) | 0.011 |
| Cortical somatosensation, median ($Q_1$-$Q_3$) | | | |
| Em-NSA-—sharp/dull discrimination | 6 (0-8) | 8 (7-8) | <0.001 |
| NSA—stereognosis | 6.5 (0-19.8) | 21 (18.3-22) | <0.001 |
| Two-point discrimination | 7 (4-16) | 4.5 (3.3-6) | 0.001 |
| FMA-UE, median ($Q_1$-$Q_3$) | 15.5 (2.3-54.8) | 57 (10.3-63.8) | <0.001 |
| MI, median ($Q_1$-$Q_3$) | 40.5 (0-76) | 79.5 (23.5-100) | <0.001 |
| ARAT, median ($Q_1$-$Q_3$) | 3 (0-31) | 53 (3-57) | <0.001 |
| ABILHAND logit score, median ($Q_1$-$Q_3$) | | 1.4 (-0.4-3.8) | |
| Ad-AHA stroke, median ($Q_1$-$Q_3$) | | 75 (28-100) | |
| SIS hand function, median ($Q_1$-$Q_3$) | | 47.9 (16.7-95.8) | |

Abbreviations: ABILHAND, ABILHAND questionnaire; ACA, anterior cerebral artery; Ad-AHA stroke, adult-assisting hand assessment stoke; ARAT, action research arm test; CIRS, Cumulative Illness Rating Scale; Em-NSA, Erasmus MC modification of the (revised) Nottingham sensory assessment; FMA-UE, Fugl-Meyer motor assessment upper extremity; MCA, middle cerebral artery; MI, Motricity Index; NIHSS, National Institute of Health Stroke Scale; NSA, Nottingham sensory assessment; PCA, posterior cerebral artery; PTT, perceptual threshold of touch; SIS, Stroke Impact Scale; TFT, thumb finding test.

[a] *P* value of paired-sample Wilcoxon signed rank test.

cortical somatosensory impairments, low to moderate correlations ($r = 0.37$-$0.56$) were found for the link between motor function and stereognosis. A similar pattern was found for the association between somatosensory impairment and activity limitations at 6 months. Low to moderate correlations ($r = 0.32$-$0.69$) were found for the association with PTT, TFT, and stereognosis, again indicating that a worse performance on somatosensory assessments was associated with more limited upper limb activities.

Finally, the correlation analysis between somatosensory impairments measured within the first week and motor impairments and activity limitations at 6 months after stroke showed very low to low ($r = 0.01$-$0.29$) associations.

## DISCUSSION

This study showed that somatosensory impairments are common in the acute phase after stroke, with prevalence rates of 41% to 63% for the different outcome measures of exteroceptive, proprioceptive, and cortical somatosensory impairments. At 6 months after stroke, the prevalence of the different deficits decreases substantially. Overall, the distribution pattern showed that 78% of the participants experiences one or more somatosensory impairment within the first week, with mostly mixed exteroceptive, proprioceptive, and cortical somatosensory deficits. Although many of the participants recover from different somatosensory impairments, more than half of the participants have a remaining deficit

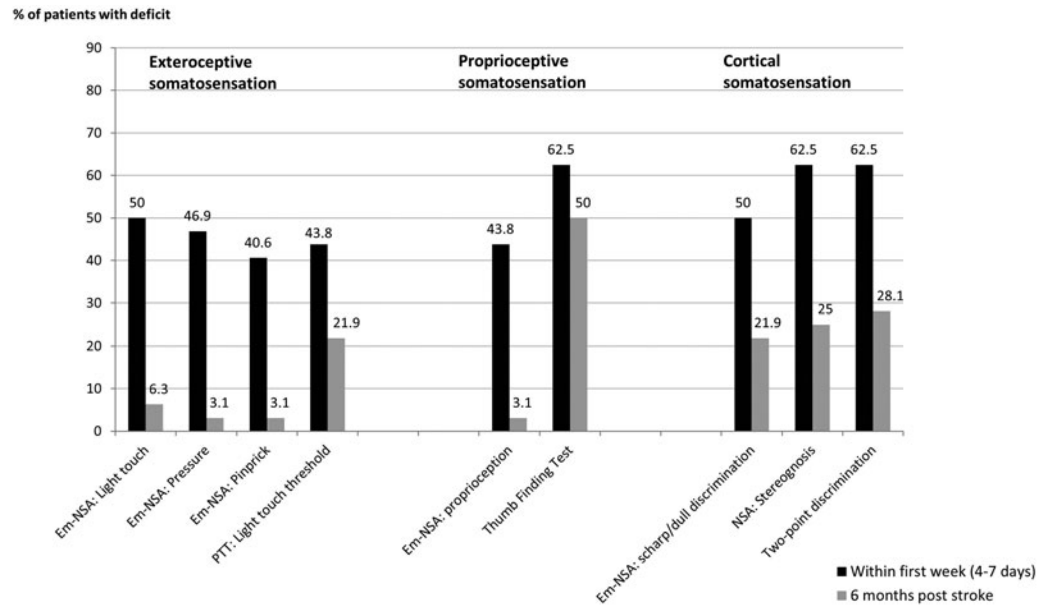


**Figure 1.** Percentage of patients with different somatosensory impairments in the upper limb. Black bars show impairments within the first week after stroke, whereas gray bars show impairments at 6 months after stroke. Abbreviations: Em-NSA, Erasmus MC modification of the (revised) Nottingham sensory assessment; NSA, Nottingham sensory assessment; PTT, perceptual threshold of touch.

at 6 months. Furthermore, we found that within the first week, there is a very low association between somatosensory and motor impairment. On the other hand, at 6 months low to moderate associations exist between different exteroceptive, proprioceptive, and cortical somatosensory impairments and motor impairments and upper limb activity limitations. Finally, only very low associations were found for the association between somatosensory impairments within the first week and motor impairments and activity limitations at 6 months.

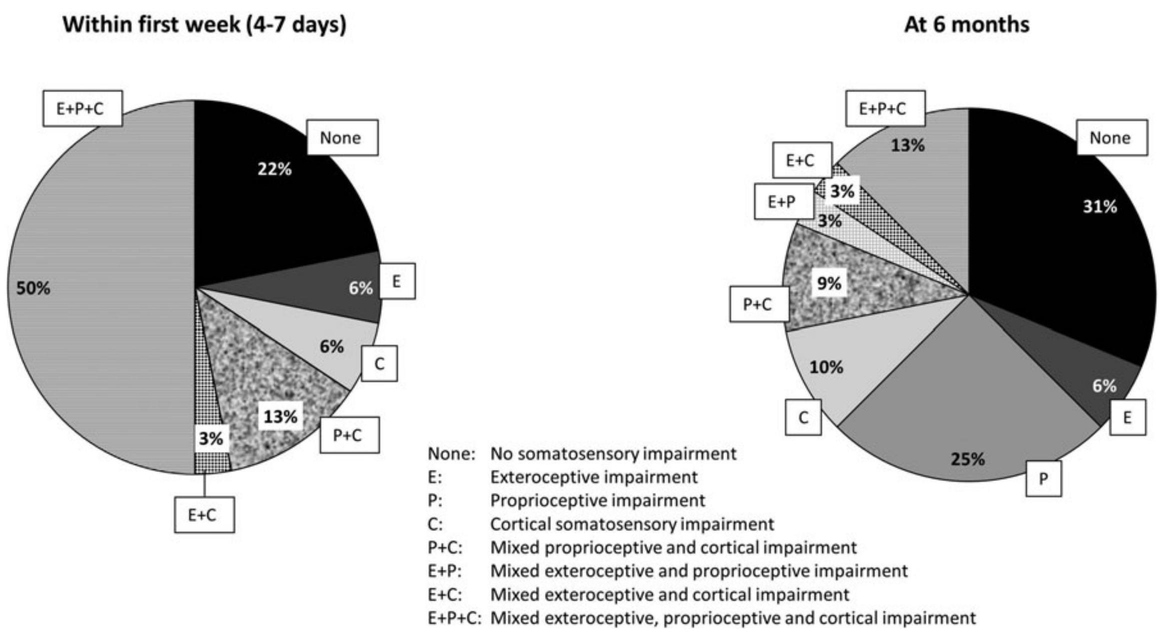


**Figure 2.** Distribution of somatosensory impairments, according to the occurrence of single exteroceptive, single proprioceptive, single cortical somatosensory impairments, or a mixture of these. Distribution pattern of somatosensory impairments within the first week after stroke (right) and 6 months after stroke (left).

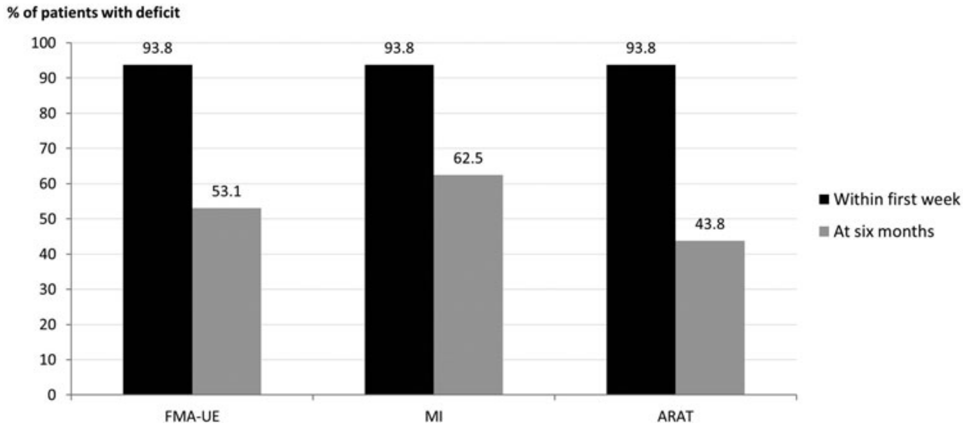


**Figure 3.** Percentage of patients with motor impairments in the upper limb. Black bars show impairments within the first week after stroke, whereas gray bars show impairments at 6 months after stroke. Abbreviations: ARAT, action research arm test; FMA-UE, Fugl-Meyer motor assessment upper extremity; MI, Motricity Index.

In the literature, information regarding the extent of somatosensory deficits in the upper limb in the acute phase is scant. Only 3 studies[15,17,18] reported on the prevalence of somatosensory deficits in the first week after stroke, but these did not assess several modalities, as our present study did. Light touch deficits were reported in 32% to 50% of the participants,[15,17] proprioceptive deficits in 41% to 50% of the participants,[15,17] and up to 85% had impaired somatosensory discrimination sense.[18] Comparable results were found in our sample, with 41% to 50% of the participants having exteroceptive dysfunction, 44% to 63% proprioceptive dysfunction, and up to 63% experiencing a cortical somatosensory impairment within the first week.

Other studies reporting on the prevalence of somatosensory deficits assessed participants generally in the subacute and chronic phases after stroke, but again not combining the assessment of several modalities.[10-16] Regarding exteroceptive impairments in the chronic phase after stroke, 2 studies[11-13] identified light touch deficits in 1 of 3 participants using the Semmes Weinstein monofilaments, whereas Welmer et al[15] reported that 19% of participants had a light touch deficit when assessed using a cotton wool. These results are again in line with our findings at 6 months. To the best of our knowledge, only one other study[53] reported on the prevalence of cortical somatosensory deficits in the chronic phase after stroke, confirming our result that still 1 of 4 participants experience somatosensory discrimination problems at 6 months. Therefore, tackling these deficits might be of added value in upper limb stroke rehabilitation.

Two studies examined proprioceptive impairments in the chronic phase after stroke, with reported prevalence rates of 16% to 19%.[14,15] The proprioceptive assessment in our study showed impairment at 6 months in 3% when assessing movement sense with the Em-NSA, whereas a surprising 50% still

**Table 2. Spearman $\rho$ Correlation Coefficients for Cross-Sectional Associations Between Somatosensory and Motor Impairments Within the First Week and Between Somatosensory and Motor Impairments and Activity Limitations at 6 Months Poststroke[a]**

| | Within 1 wk Motor Function | | | At 6 mo Motor Function | | | Activity Limitations | | |
|---|---|---|---|---|---|---|---|---|---|
| | FMA-UE | MI | ARAT | FMA-UE | MI | ARAT | Ad-AHA Stroke | ABILHAND | SIS Hand Function |
| Exteroceptive somatosensation | | | | | | | | | |
| Em-NSA—light touch | −0.05 | −0.05 | −0.06 | 0.02 | 0.05 | 0.20 | 0.23 | 0.20 | 0.18 |
| Em-NSA—pressure | −0.14 | −0.16 | −0.16 | 0.02 | 0.05 | 0.20 | 0.23 | 0.20 | 0.18 |
| Em-NSA—pinprick | −0.07 | −0.10 | −0.13 | 0.02 | 0.05 | 0.20 | 0.23 | 0.20 | 0.18 |
| PTT—light touch | −0.03 | −0.04 | −0.05 | −0.64[b] | −0.60[b] | −0.66[b] | −0.67[b] | −0.67[b] | −0.69[b] |
| Proprioceptive somatosensation | | | | | | | | | |
| Em-NSA—movement sense | −0.03 | 0.04 | 0.04 | 0.27[c] | 0.27[c] | 0.26[c] | 0.31[c] | 0.24 | 0.23 |
| TFT—position sense | −0.08 | −0.15 | −0.04 | −0.48[c] | −0.39[c] | −0.37[c] | −0.36[c] | −0.35[c] | −0.32[c] |
| Cortical somatosensation | | | | | | | | | |
| Em-NSA—sharp/dull discrimination | −0.20 | −0.18 | −0.13 | −0.02 | −0.03 | 0.13 | 0.13 | 0.03 | 0.09 |
| NSA—stereognosis | 0.06 | 0.18 | 0.08 | 0.41[c] | 0.37[c] | 0.56[c] | 0.47[c] | 0.46[c] | 0.45[c] |
| Two-point discrimination | 0.14 | 0.10 | 0.12 | −0.07 | −0.03 | −0.19 | −0.13 | −0.19 | −0.27[c] |

Abbreviations: ABILHAND, ABILHAND questionnaire; Ad-AHA stroke, adult-assisting hand assessment stoke; ARAT, action research arm test; Em-NSA, Erasmus MC modification of the (revised) Nottingham sensory assessment; FMA-UE, Fugl-Meyer motor assessment upper extremity; MI, Motricity Index; NSA, Nottingham sensory assessment; PTT, perceptual threshold of touch; SIS, Stroke Impact scale; TFT, thumb finding test.

[a]Strength of the relation was indicated according to Munro[52]: very low: no indication; [b]low; [c]moderate.

had proprioceptive impairment when assessed with the TFT. This latter result might be explained by the assessment method of the TFT. Position sense of the whole upper limb is assessed in the TFT, which might be more difficult compared with selective assessment of movement sense in separate joints in the Em-NSA. Another study of Hirayama et al[54] confirmed these results, as in their sample of 221 participants, 38% of the participants were identified with a proprioceptive deficit using the TFT, and only 13% when assessing movement sense in single joints. Goble[55] further discussed several factors affecting proprioceptive acuity, which might also explain the difference in prevalence of proprioceptive deficits detected by both scales. During the TFT, the participant is asked to grasp his thumb with the contralateral hand, which might be compared with a contralateral position matching task (mirroring). Because of the involvement of both arms, it is difficult to ascertain whether the impairment arises from the hemiplegic arm, the nonhemiplegic arm, or both. In addition, it was shown that contralateral matching requires interhemispheric communication through the transcallosal pathways of the corpus callosum.[55] This interhemispheric brain activation is less crucial during the execution of the Em-NSA measurement, as no contralateral arm movements are required. In addition, normative values for the TFT of the healthy elderly need to be determined to assess the influence of age-related changes on the performance of this test.

Our study adds to current knowledge information from a cohort in which different somatosensory modalities, motor impairments, and activity limitations were assessed within the first week and again at 6 months. The most striking result of this study is that somatosensory and motor impairments were not associated within the first week after stroke. This was in contrast to our hypothesis. Our hypothesis was driven by results of Welmer et al,[15] reporting moderate correlations ($r = 0.56$-$0.59$) between fine motor hand use, assessed with the 9-hole peg test, and light touch and proprioception in the first week after stroke. These contradictory findings might be explained by differences in study population. In the study of Welmer et al,[15] 25 out of 66 participants (38%) showed severe motor impairment as indicated by the inability to pick up a peg. Furthermore, only 1 of 3 participants had impaired somatosensory function. This is different from our study sample, in which up to 60% of the participants showed no distal arm function on the ARAT scale, thus showing overall a more severely affected group of stroke survivors. In addition, within the first week, 80% of our participants had a somatosensory deficit. As most of our participants had both very poor motor and somatosensory function in the acute phase, probably due to the cerebral shock phase, this might contribute to the very low association between somatosensory and motor function. Another possible explanation for the contradictory results is the difference in measurement of somatosensory impairments. In the study of Welmer et al,[15] no standardized and reliable assessment method was used, and participants were only classified as having normal or impaired light touch and proprioceptive function. Furthermore, the authors computed Spearman rank correlations to assess the association between the continuous outcome on the 9-hole peg test and the dichotomized outcome for somatosensory functioning. However, this could be questioned, as the calculation of point-biserial correlation coefficients should be considered when addressing this relationship.[56]

At 6 months, we found low to moderate correlations for exteroceptive, proprioceptive, and cortical somatosensory impairments with motor impairment and activity limitations. Overall, we found slightly stronger correlations compared with the literature. Prior studies have concentrated mainly on outcomes at impairment level,[13,15,24,25] whereas our study adds to the body of knowledge information regarding the association between somatosensory impairments and activity limitations, using the adult assisting hand assessment stroke and perceived functional hand use after stroke, using the ABILHAND questionnaire and the hand subscale of the Stroke Impact Scale. Finally, the correlation analysis between somatosensory impairments measured within the first week and motor impairments and activity limitations at 6 months after stroke showed only low associations. This is in contrast to a study by Au-Yeung and Hui-Chan,[53] in which 2PD ability at 1 week has shown to be predictive for achieving dexterous hand function at 3 and 6 months after stroke, as defined by more than 35 points on the ARAT scale. This contrast might be explained by study population. In the previous study, only 32% of the subjects reached dexterity at 6 months, with a median score on the ARAT of 13.5 out of 57, whereas in our study, up to 63% of the participants reached dexterity, with a median score of 53 out of 57.

The high prevalence of different somatosensory impairments, both in the acute and chronic phases after stroke, and the important association at 6 months of several measures of exteroceptive, proprioceptive, and cortical somatosensory impairments with both motor impairments and activity limitations in our study also points to the importance of measuring somatosensory deficits in the clinical setting with standardized, reliable, and valid measures of somatosensory function, to accurately assess different somatosensory deficits. Knowledge of the extent and modality affected is the cornerstone for further developing realistic treatment goals and intervention strategies for the individual with stroke. The large change in modalities affected in the acute phase and at 6 months points to the necessity of future longitudinal studies with regular time points within the first 6 months to map the recovery of different somatosensory modalities over time. This would further increase our understanding of the evolution of somatosensory function in persons with stroke and provide a foundation for sensory intervention strategies. Furthermore, sensorimotor treatment strategies should be developed and evaluated as the treatment of somatosensory deficits might also positively influence motor recovery.[19] A Cochrane review[57] on interventions for sensory impairment in the upper limb after stroke showed that multiple interventions for upper limb sensory impairment after stroke are described, but up to now, there is insufficient evidence to support or refute their effectiveness in improving sensory or motor impairment or functional hand use.

On the basis of our findings, we propose the use of a set of 3 screening outcome measures, one for each of the following somatosensory categories: exteroceptive (PTT), proprioceptive (TFT), and cortical somatosensory functioning (stereognosis). The reason for the selection of these 3 outcome measures is 2-fold. First, these outcome measures revealed the highest frequency of deficits, suggesting that these measurements have high sensitivity and are therefore more suitable for screening for small somatosensory deficits. However, important to notice is the fact that the TFT is only a coarse measure for somatosensory functioning (4-level ordinal scale),[37] and further research is warranted to examine the specificity of these outcome measures. Although a first attempt was made to establish intrarater reliability of the TFT, the psychometric properties need to be further studied, including intrarater, interrater, and test-retest reliability, as well as different aspects of validity. Second, these outcome measures showed the strongest association with motor function and upper limb activity measures.

The novel aspect of this study relates to mapping the extent of different exteroceptive, proprioceptive, and cortical somatosensory impairments in one cohort of participants, both within the first week and at 6 months after stroke, using reliable and valid somatosensory clinical outcome measures. Furthermore, in addition to the clinical assessment methods, we used more objective measures to assess exteroceptive function, namely the PTT, by using high-frequency transcutaneous electric nerve stimulation.[35] Finally, a full overview of the association between different somatosensory impairments and motor impairment as well as activity limitations is provided. Concentrating on the association between somatosensory function and these functional upper limb activity measures is new in this field of research.

## LIMITATIONS

Some limitations need to be considered when interpreting our results. First, participants were recruited in 2 different settings. We were not able to control for treatment provided. Furthermore, a flowchart of participant selection cannot be provided as there are no data available on participants who were ineligible for participation in the study. Second, this study had a restricted sample size, and therefore a multivariate prediction analysis was not conducted. It is therefore recommended to investigate the predictive value of different somatosensory deficits in the acute phase. In addition, it would be valuable to consider other factors such as mood, fatigue, motivation, leisure, or employment status, on outcome at 6 months after stroke in a larger cohort study. Third, although we used the FMA-UE as the measure of overall upper extremity impairment, it is possible that the wrist and hand items of the Fugl-Meyer may have stronger relationship with somatosensory deficits.[58] Fourth, we were not able to investigate the influence of neglect on sensorimotor recovery because of the small number of participants with neglect ($n = 5$) in this study. Finally, we included both persons with ischemic stroke and persons with hemorrhagic stroke. Nevertheless, only 5 participants had hemorrhagic stroke; exploratory statistical analysis performed only with data from participants with ischemic stroke led to similar results (not presented in the results). Furthermore, participants presented with a large variety of stroke lesion locations, although most in the middle cerebral artery territory. Future research is needed, including a larger number of participants with specific stroke topographic lesions to further examine the influence of lesion location on different sensorimotor impairments.

## CONCLUSIONS

Somatosensory impairments are common in persons with acute stroke, with mostly mixed exteroceptive, proprioceptive, and cortical somatosensory deficits. Although many of the participants recover from different somatosensory impairments, 2 of 3 participants have remaining deficits at 6 months. In the acute phase, there is a very low association with motor impairment, whereas at 6 months, different somatosensory impairments are related to motor impairments and upper extremity activity limitations. Although no conclusions can be drawn on causality, our results suggest that the impact of somatosensory deficits on upper limb motor and functional performance increases with time after stroke. Therefore, recommendation for practice includes the assessment of somatosensory deficits with standardized, reliable, and valid measures of somatosensory function, to accurately assess different somatosensory deficits as it will help guide and delineate realistic treatment goals and sensorimotor intervention strategies for persons with stroke.

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