2019-09-25

The prevalence, distribution, and functional importance of lower limb somatosensory impairments in chronic stroke survivors: a cross sectional observational study

Gorst, T

10.1080/09638288.2018.1468932
Disability and Rehabilitation
Taylor & Francis

Disability and Rehabilitation

ISSN: 0963-8288 (Print) 1464-5165 (Online) Journal homepage: http://www.tandfonline.com/loi/idre20

The prevalence, distribution, and functional importance of lower limb somatosensory impairments in chronic stroke survivors: a cross sectional observational study

Terry Gorst, Alison Rogers, Stewart C. Morrison, Mary Cramp, Joanne Paton, Jenny Freeman & Jon Marsden

To cite this article: Terry Gorst, Alison Rogers, Stewart C. Morrison, Mary Cramp, Joanne Paton, Jenny Freeman & Jon Marsden (2018): The prevalence, distribution, and functional importance of lower limb somatosensory impairments in chronic stroke survivors: a cross sectional observational study , Disability and Rehabilitation, DOI: 10.1080/09638288.2018.1468932

To link to this article: https://doi.org/10.1080/09638288.2018.1468932

Published online: 04 May 2018.

Taylor & Francis
Taylor & Francis Group

Check for updates

ORIGINAL ARTICLE

The prevalence, distribution, and functional importance of lower limb somatosensory impairments in chronic stroke survivors: a cross sectional observational study

Terry Gorst[a], Alison Rogers[b], Stewart C. Morrison[c], Mary Cramp[d], Joanne Paton[a], Jenny Freeman[a] and Jon Marsden[a]

[a]School of Health Professions, University of Plymouth, Plymouth, UK; [b]Faculty of Medicine and Health Sciences, Keele University, Keele, UK; [c]School of Health Sciences, University of Brighton, Brighton, UK; [d]Department of Allied Health Professions, University of the West of England, Bristol, UK

ABSTRACT

Purpose: To investigate the prevalence and distribution of lower limb somatosensory impairments in community dwelling chronic stroke survivors and examine the association between somatosensory impairments and walking, balance, and falls.

Methods: Using a cross sectional observational design, measures of somatosensation (Erasmus MC modifications to the (revised) Nottingham Sensory Assessment), walking ability (10 m walk test, Walking Impact Scale, Timed "Get up and go"), balance (Functional Reach Test and Centre of Force velocity), and falls (reported incidence and Falls Efficacy Scale-International), were obtained.

Results: Complete somatosensory data was obtained for 163 ambulatory chronic stroke survivors with a mean (SD) age 67(12) years and mean (SD) time since stroke 29 (46) months. Overall, 56% ($n = 92/163$) were impaired in the most affected lower limb in one or more sensory modality; 18% ($n = 30/163$) had impairment of exteroceptive sensation (light touch, pressure, and pin-prick), 55% ($n = 90/163$) had impairment of sharp-blunt discrimination, and 19% ($n = 31/163$) proprioceptive impairment. Distal regions of toes and foot were more frequently impaired than proximal regions (shin and thigh). Distal proprioception was significantly correlated with falls incidence ($r = 0.25$; $p < 0.01$), and centre of force velocity ($r = 0.22$, $p < 0.01$). The Walking Impact Scale was the only variable that significantly contributed to a predictive model of falls accounting for 15–20% of the variance.

Conclusion: Lower limb somatosensory impairments are present in the majority of chronic stroke survivors and differ widely across modalities. Deficits of foot and ankle proprioception are most strongly associated with, but not predictive, of reported falls. The relative contribution of lower limb somatosensory impairments to mobility in chronic stroke survivors appears limited. Further investigation, particularly with regard to community mobility and falls, is warranted.

ARTICLE HISTORY
Received 1 December 2017
Revised 19 April 2018
Accepted 20 April 2018

KEYWORDS
Stroke; somatosensation; lower-limb; mobility; falls

➤ **IMPLICATIONS FOR REHABILITATION**

- Somatosensory impairments in the lower limb were present in approximately half of this cohort of chronic stroke survivors.
- Tactile discrimination is commonly impaired; clinicians should include an assessment of discriminative ability.
- Deficits of foot and ankle proprioception are most strongly associated with reported falls.
- Understanding post-stroke lower limb somatosensory impairments may help inform therapeutic strategies that aim to maximise long-term participation, minimise disability, and reduce falls.

Introduction

With improved acute stroke services and consequent survival rates, more people are enduring the long-term consequences of stroke [1]. With this shift, stroke is moving away from being a major cause of mortality, to becoming a disabling, long-term chronic condition [2]. Whilst the majority of stroke survivors gain "independent walking" [3], up to 50% of chronic stroke survivors regularly request a companion when walking outdoors [4]. Mobility issues such as reduced balance [5], walking speed and endurance [6,7], and falls [8] have been demonstrated in people several years after stroke. The effect on individuals, health care systems, and society suggest a greater need to focus attention on the long-term consequences, management, and rehabilitation of people with stroke to reduce the global stroke burden is thus needed [2].

Recent qualitative work [9] highlighted that in community dwelling people with chronic stroke, limitations to outdoor walking ability, balance reactions, step clearance and falls, were profoundly influenced by reduced awareness of foot-ground interactions and foot position sense. Such difficulties suggest

CONTACT Terry Gorst terry.gorst@plymouth.ac.uk School of Health Professions, Faculty of Health and Human Sciences, University of Plymouth, Peninsula Allied Health Centre, Derriford Road, Plymouth, UK PL6 8BH

impairment to the somatosensory system, which provides sense of touch (exteroception) and body position/movement sense (proprioception). To successfully adapt to altered walking terrains, avoid obstacles and manage slopes for example, somatosensory information such as changes in foot plantar pressures, lower limb positions, and limb/foot loading must be detected, relayed, and integrated by the Central Nervous System (CNS) [10]. Laboratory studies have shown that altered somatosensation in the lower limb, independent of motor weakness, impacts postural regulation [11], foot placement [12], and obstacle avoidance performance error [13]. Thus, clinical interventions acknowledge the importance of accurate somatosensory feedback in the rehabilitation of movement post stroke [14] and case studies of those with tactile and proprioceptive deficits and intact motor pathways, due to central [15] or peripheral [16,17] neurological deficits, report substantially impaired motor function, gait, and spatial orientation. However, few studies have investigated the functional impact of lower limb somatosensory impairments in community-dwelling, chronic stroke survivors.

Evidence from studies of acute/sub-acute stroke suggest lower limb somatosensation influences activities of daily living, but not mobility or balance, when weakness is included as a factor [18]. At six months post stroke however, those with somatosensory and motor impairments have less favourable walking outcomes, lower independence in activities of daily living and lower self-reported health status than those with motor impairments alone [19]. Evidence detailing the relationship between lower limb somatosensation and functional outcomes in chronic stroke is variable; some have found significant associations with gait speed [20] whilst others have found that lower limb somatosensation is not significantly associated with community ambulation [4], gait speed [7], or falls [21]. The functional importance of lower limb somatosensory impairments into the chronic phase of stroke is yet to be established and warrants further investigation.

Similarly, the prevalence of lower limb somatosensory impairments in chronic stroke are also yet to be established. Most studies investigating this have done so in hospitalised stroke patients in the acute/sub-acute phase (i.e., within 2–4 weeks post stroke). Recovery of sensation is, however, variable and unpredictable with somatosensory ability at 15 days accounting for just 46–51% of the variance in lower limb tactile and proprioceptive ability at six months [22]. A recent survey of 145 people (mean 45 months post stroke) found 43% reported reduced sensation in the feet; the second most common foot problem after weakness [23]. Prevalence rates of somatosensory deficits range from 7–70% [21,24] of chronic stroke survivors, with such variability partly attributable to the somatosensory modality tested and the use of different often non-standardised assessments. Therefore, an understanding of the prevalence and distribution of lower limb deficits in different somatosensory modalities in the chronic phase post-stroke is lacking.

The aim of this study was to investigate lower limb somatosensory impairment in chronic, community dwelling, and ambulatory stroke survivors. The objectives were to (1) map the prevalence, type, and distribution of lower limb somatosensory impairments; (2) explore the association between somatosensory impairments and walking, balance, and falls; and (3) investigate differences between fallers and non-fallers and the extent to which lower limb somatosensory function is predictive of falls, when other potentially confounding variables are accounted for.

Methods

Ethical approval was obtained from the NHS Health Research Authority NRES Committee (13/SW/0302). The somatosensory data informing this study was collected alongside several clinical measures of foot and ankle impairments as part of a multi-centre cross sectional observational study: the "Foot and Ankle iMpairment in Stroke study (FAiMiS)." "Strengthening the Reporting of Observational studies in Epidemiology" [25] was used as a framework for this study.

Study participants

Participants were recruited from a convenience sample identified through NHS community services and stroke support groups across East London and Devon, UK. Recruitment was conducted at the two centres on predefined assessment days. Eligibility criteria were: aged 18 and above, stroke diagnosis confirmed via CT scan and clinical presentation, >3 months post-stroke, able to independently stand, and walk at least 10 m indoors. Potential participants were excluded if they had additional neurological disease or co-morbidities/injuries that would affect mobility and/or foot somatosensory function.

Procedures and measures

Participants attended a single assessment session. The assessments were conducted at sites local to the participant; Either university premises or local community hospital. Two neurological physiotherapists with 10–12 years post-graduate experience conducted the assessments.

After informed consent, demographic data including age, gender, medical history, and current mobility level was recorded along with details of stroke (location, hemisphere, and time since stroke) to describe the study population. The following assessment measures were chosen based on their published validity and reliability, clinical feasibility, and appropriateness in a chronic stroke population.

Lower limb somatosensation

The Erasmus MC modified version of the (revised) Nottingham Sensory Assessment (EmNSA) [26] measured somatosensory performance in the lower limb contralateral to stroke lesion. It is considered psychometrically robust and clinically feasible [27] and assesses modalities of exteroceptive sensation (light touch, pressure touch, and pin-prick), higher cortical discriminatory sensation (sharp-blunt), and proprioception (movement detection and discrimination). Scores for each body part for the five modalities range from 0 (total loss of somatosensory function) to 8 (wholly intact). A cut-off score of ≤6/8 in a modality was used to indicate the presence of somatosensory impairment in line with a recent upper limb study in stroke [28]. In those with bilateral stroke, the subjectively "most affected" limb was assessed.

Walking speed

The 10 m Walk Test (10 mWT) [29] assesses walking speed, calculated in metres per second over the middle 6 m of the walkway. The psychometric properties of the 10 mWT have been extensively reviewed [30]; excellent reliability has been demonstrated in chronic stroke survivors [31] and it is strongly associated with activities of daily living [32] and community ambulation [7].

Walking balance

The Timed "Get up and Go" (TUG) [33] assesses walking balance. It has demonstrated to be a reliable measure in chronic stroke survivors [31] and has shown to be strongly associated with the

Berg Balance Scale and the Community Balance and Mobility measure [34].

Self- reported walking ability

The Walking Impact Scale (WIS) [35] is a standardised and validated patient based self- report scale of mobility. It has demonstrated good responsiveness, validity, and clinical feasibility in people with a range of neurological conditions, including stroke [35].

Dynamic Balance

The Forward Functional Reach Test (FRT) [36] is a standardised, validated measure of dynamic balance. It has demonstrated excellent reliability and validity in stroke survivors [37]. A score <15 cm is indicative of increased falls risk in stroke [38].

Static balance

Centre of force (COF) measurements are commonly used to quantify postural sway, with $COF_{velocity}$ suggested as a sensitive measure for detecting change in balance ability [39]. Quiet standing in barefoot under eyes open (EO) and closed (EC) conditions was recorded using a HR Matscan pressure platform (Tekscan, Biosense Medical, Essex UK). In each condition, participants stood for as long as possible up to a maximum of 30 s. $COF_{velocity}$ (mm/s) was calculated by dividing the COF excursion (mm) by time (seconds) standing, for each condition (EO and EC), and then subtracting EO $COF_{velocity}$ from EC $COF_{velocity}$. A larger value indicates a greater difference between EO/EC conditions and larger postural sway.

Falls incidence

Falls data was collected through participant retrospective recall, which has shown excellent agreement with diarised falls in people with stroke [40] and used a well-accepted definition of falls [41]. Participants were categorised as fallers if they reported at least one fall in the previous three months, in line with other falls studies in stroke [23,42].

Fear of falling

Fear of falling was measured using the Falls Efficacy Scale – International (FES-I) [43], a 16-item self-report tool, which measures an individual's level of concern about falling during social and physical activities inside and outside the home. Higher scores indicate greater fear of falling, which has shown to lead to activity restriction, psychological, and physical deterioration [44]. The FES-I has demonstrated excellent reliability in a chronic stroke population [45] and validity in the elderly [46].

Statistical analyses

Participant clinical and demographic characteristics were summarised using descriptive statistics, as was their performance across each somatosensory modality. Data distribution was assessed for normality using Shapiro-Wilks tests and assumed normally distributed when $p > 0.05$. Missing data was handled using pairwise deletion. Associations between lower limb somatosensation and measures of mobility, balance, and falls were analysed using either Pearson's product-moment correlation or Spearman's rank order correlation; assumptions to determine appropriate use were observed [47]. Differences between non-faller and faller outcomes were analysed using Mann Whitney U tests for variables with non-normally distributed data and/or ordinal measurement scales; Independent samples t-tests were used where continuous data was normally distributed. Bonferroni adjustments were made to account for multiple comparisons and statistical significance amended and highlighted in results. Binary logistic regression analysis with forced entry was performed to assess the impact of a number of factors on the likelihood that participants reported one or more falls. Odds ratio (OR), was used to provide the estimated change in reported falls due to a single unit change in predictor variable. Assumptions of logistic regression were observed with data assessed for multicollinearity and outliers [48]. All data were analysed with SPSS version 22.0 for Windows statistical programme (SPSS, Chicago, IL).

Results

One hundred and eighty stroke participants were recruited of which complete somatosensory data was obtained for 163 participants and complete somatosensory and functional data were obtained for 157 participants. Demographic, clinical, and functional outcomes are presented in Table 1. Mean age (standard deviation (SD)) was 67 (12) years and mean (SD) time from stroke onset to assessment was 29 (46) months.

Objective 1: Map the prevalence, type, and distribution of lower limb somatosensory impairments

Impairment to light touch, pressure, pin prick (exteroceptive sensation), sharp-blunt discrimination, and proprioception, was present if scored ≤6/8. The majority of participants ($n = 92/163$) were impaired in at least one modality in the limb contralateral to

Table 1. Demographic, clinical, and functional characteristics of stroke participants.

Characteristics	Stroke ($n = 163$)
Age, years, mean (SD)	67 (12)
Gender, *n* (%)	
Male	95 (58)
Female	68 (42)
Type of stroke, *n* (%)	*n* (%)
Ischaemic	115 (70)
Haemorrhagic	37 (23)
Unknown/missing data	11 (7)
Time since stroke, months	
Mean (SD)	29 (46)
Stroke hemisphere, *n* (%)	
Left	75 (46)
Right	77 (47)
Bilateral	10 (6)
Unknown/missing data	1 (1)
Stroke location, *n* (%)	
Cortical	129 (79)
Subcortical:	26 (16)
Unknown/missing data	8 (5)
Function	
Walking ability	
Walking speed, m/s, mean (SD)	1.1 (0.6)
WIS, median (IQR, range)	37 (23,48)
TUG, seconds, mean (SD)	17 (11)
Balance	
FRT cm, mean (SD)	25 (10.0)
$COF_{velocity}$ mm/s mean (SD)	9 (16)
Falls	
Number of falls reported, *n* (%)	
0	108 (60)
1	39 (22)
2	13 (7)
3	10 (5.5)
≥4	10 (5.5)
FES-I score median, (IQR, range)	33 (21,48)

SD: standard deviation; m/s: metres per second; mm/s: millimetres per second; cm: centimetres; TUG: Timed up and Go; WIS: Walking Impact Scale; FRT: Functional Reach Test; COF: Centre of Force; FES-I: Falls Efficacy Scale – International.

stroke lesion site (Table 2). The greatest proportion of participants experiencing a single modality deficit was in that of sharp-blunt discrimination with 30% ($n = 49/163$) scoring ≤6/8 on that modality. Forty-one participants (25% overall) had a mixed picture exhibiting a combination of two or more somatosensory impairments, with 18 participants (11% overall) impaired in all three, suggesting profound somatosensory impairment.

The anatomical distribution of somatosensory impairments by modality is presented in Table 3. Overall, somatosensation was more frequently absent or impaired in distal regions of the most affected lower limb (toes and foot) across all modalities. The ability to discriminate between a sharp and blunt stimulus was most frequently impaired.

Objective 2: Explore the association between somatosensory impairments and walking, balance, and falls

Spearman's correlations between exteroceptive, sharp-blunt discrimination, proprioception and walking, balance, and falls are presented in Table 4. Distal (first metatarsophalangeal joint (MTPJ) and ankle) proprioception showed significant, negative correlations with falls incidence ($r = -0.25$; $p < 0.01$) and centre of force measurements ($r = -0.22$, $p < 0.01$), with poorer distal proprioception associated with increased falls and increased postural sway. Lower distal proprioception scores were also significantly correlated with increased scores on the walking impact scale (WIS) ($r = -0.20$, $p < 0.01$), indicating those with poorer proprioception felt their stroke has a greater impact on walking ability. Proximal (knee and hip) proprioception was significantly correlated with falls incidence ($r = -0.17$; $p < 0.05$) and WIS ($r = -0.18$, $p < 0.05$) but not COF ($r = -0.08$; $p > 0.05$). Distal and proximal exteroceptive sensation was also significantly correlated with falls incidence ($r = 0.17–0.19$, $p < 0.05$). Measures of walking speed, walking balance, and dynamic balance, were not significantly correlated with any aspect of somatosensation.

Table 2. Somatosensory profile of stroke patient ($n = 163$) showing prevalence of unique and combined lower limb somatosensory impairments.

Modality	*n*	%
No somatosensory impairments	71	44
Impaired exteroceptive sensation only	1	0.5
Impaired proprioception only	1	0.5
Impaired sharp-blunt discrimination only	49	30
Impaired exteroceptive sensation and sharp-blunt discrimination	11	7
Impaired proprioception and sharp-blunt discrimination	12	7
Impaired exteroception, sharp-blunt discrimination, and proprioception	18	11
Total	163	100

Objective 3: Investigate differences between fallers and non-fallers and the extent to which lower limb somatosensory function predicts falls when other potentially confounding variables are accounted for

Lower limb somatosensation, categorised into distal and proximal anatomical segments and functional outcomes of non-fallers and fallers are presented in Table 5. Statistically significant differences between the groups, were identified in distal and proximal exteroceptive sensation ($p = 0.003$) and distal and proximal proprioception ($p = 0.001$ and 0.005, respectively). The WIS and FRT were also significantly different between the two groups ($p = 0.003$ and $p < 0.001$). Gait speed, the Timed Up and Go, Falls Efficacy Scale-International, and COF measurement when accounting for

Table 3. Prevalence of somatosensory performance by modality and body region in stroke participants ($n = 163$).

		Light touch		Pressure		Pin prick		Sharp/blunt		Proprioception	
Limb Area/joint	Classification	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
Thigh/hip	Absent	6	3	3	2	3	2	11	7	0	0
	Impaired	14	8	14	8	14	8	42	25	6	3
	Normal	154	89	157	90	156	90	114	68	168	97
Shin/knee	Absent	7	4	3	2	3	2	13	8	0	0
	Impaired	17	10	18	10	14	8	56	33	8	5
	Normal	154	86	157	88	160	90	101	59	165	95
Foot/Ankle	Absent	8	4	5	4	5	4	17	10	2	1
	Impaired	30	17	22	12	18	10	79	46	34	20
	Normal	141	79	152	84	155	86	75	44	140	79
Toes/first MTPJ	Absent	15	9	10	5	8	4	21	12	5	3
	Impaired	29	16	19	12	18	11	101	59	48	27
	Normal	135	75	150	83	152	85	49	29	124	70

Table 4. Spearman's correlation coefficients for association between distal/proximal somatosensation and measures of walking/mobility, falls, and balance in stroke participants ($n = 157$).

	Walking/mobility			Falls		Balance	
Somatosensory characteristic	Gait speed	WIS	TUG	Incidence	FES-I	FRT	COFv
Exteroceptive sensation							
Distal	0.08	−0.18*	−0.14	−0.19*	−0.23**	0.07	−0.05
Proximal	0.01	−0.11	−0.09	−0.17*	−0.14	0.07	−0.04
Sharp-blunt discrimination							
Distal	0.07	−0.15	−0.14	−0.16	−0.14	0.08	−0.09
Proximal	0.09	−0.1	−0.12	−0.12	−0.06	0.14	−0.09
Proprioception							
Distal	0.08	−0.20**	−0.12	−0.25**	−0.09	0.07	−0.22**
Proximal	0.05	−0.18*	−0.07	−0.17*	−0.11	0.04	−0.08

*$p < 0.05$.
**$p < 0.01$.
WIS: Walking Impact Scale; TUG: Timed up and Go; FES-I: Falls Efficacy Scale – International; FRT: Functional Reach Test; COFv: Centre of Force velocity.

Bonferroni correction (0.05/6 = 0.0083), were not significantly different between fallers and non-fallers.

Direct logistic regression analysis was performed to assess the impact of a number of factors on the likelihood that stroke participants reported one or more fall. Distal and proximal exteroceptive sensation were strongly correlated ($r = 0.70$, $p < 0.01$) so did not meet the assumption of multicollinearity and were included as a single predictor variable. Case wise diagnostics found three cases with standardised residual values greater than ±3.3 indicative of outliers. Evaluation of these outliers using Cook's distance [48], indicated they had no undue influence on the regression model overall. Binary logistic regression analysis included five predictor variables identified as significantly different between non-fallers and fallers (distal and proximal proprioception, exteroceptive sensation, FRT, and WIS) and two predictor variables identified in the literature as factors in falls (age and time since stroke - TSS; Table 6). Self-reported falls incidence was the dependent variable. The full model containing all seven predictors was statistically significant X^2 (7, $n = 161$) = 25.46, $p < 0.001$, indicating that the model was able to distinguish between participants reporting one or more fall and those reporting no falls. The model as a whole explained between 15 (Cox and Snell R squared) and 20.1% (Nagelkerke R squared) of the variance in falls status, and correctly classified 66.9% of cases. As shown in Table 6 the only independent variable which made a unique statistically significant contribution to the model was the WIS. The strongest predictor of falls reporting was thus the WIS with an odds ratio of 1.04 (95%confidence interval (CI) 1.01–1.07). This indicated that for each point increase on this scale (indicating greater perceived impact on walking), participants were more likely to report one or more fall by a factor of 1.04 (4%), when all factors are controlled for. Neither exteroceptive nor proprioceptive sensation significantly contributed to the model.

Discussion

This study investigated the prevalence and distribution of lower limb somatosensory impairments in ambulatory chronic stroke survivors and the association between these impairments and measures of walking, balance, and falls. To our knowledge, it is the first study to provide a detailed evaluation of lower limb somatosensory impairments in chronic stroke survivors. It demonstrated that somatosensory deficits were present in 56% of this study sample, indicating that lower limb somatosensory deficits are common in people with chronic stroke. It also found that, despite their prevalence, lower limb somatosensory deficits are not strongly associated with, or predictive of walking, balance, or falls.

The prevalence figures reported in this study are higher than previous studies of chronic stroke populations in which lower limb somatosensory function has been evaluated. Schmid et al. [21] reported just 7% of 160 chronic stroke survivors had somatosensory deficits in the foot, as determined by pin-prick sensitivity

Table 5. Comparison of measure performance between non-fallers and fallers.

Characteristic	Non-fallers ($n = 93$)	Fallers ($n = 64$)	p Value	Odds ratio (95% CI)
EmNSA score, median (IQR, range)				
Exteroceptive sensations				
Distal	12 (0,9)	12 (2,12)	0.003[a]*	1.17 (1.05–1.33)[c]
Proximal	12 (0,6)	12 (0,12)	0.003[a]*	1.25 (1.06–1.44[c]
Sharp-blunt discrimination				
Distal	2 (2,4)	2 (1.75,4)	0.02[a]	1.45 (1.11–1.89)[c]
Proximal	4 (2,3)	4 (2,4)	0.03[a]	1.45 (1.09–1.88)[c]
Proprioception				
Distal	4 (0,3)	4 (1.75,2)	0.001[a]*	1.69 (1.19–2.38)[c]
Proximal	4 (0,1)	4 (0,2)	0.005[a]*	5.88 (1.11–33.3)[c]
Functional outcomes				
Gait speed (m/s), mean (SD)	1.2 (0.5)	1.0 (0.6)	0.02[b]	1.85 (1.07–3.12)[c]
WIS, score /60, median (IQR, range)	33 (23,48)	44 (19,47)	0.003[a]*	1.05 (1.02–1.07)
TUG (seconds), mean (SD)	16 (10)	20 (13)	0.01[b]	1.02 (1.00–1.05)
FES-I score /64, median (IQR, range)	28 (23,48)	34 (19,39)	0.02[a]	1.03 (1.01–1.06)
COF velocity (mm/s), mean (SD)	8 (17)	13 (21)	0.15[a]	1.01 (0.99–1.02)
FRT (cm), mean (SD)	26 (9)	22 (11)	0.003[b]*	1.05 (1.02–1.08)[c]

SD: Standard deviation; EmNSA: Erasmus modified Nottingham Sensory Assessment; WIS: Walking Impact Scale; TUG: Timed up and go; FES-I: Falls Efficacy Scale-International; FRT: Functional Reach Test; mm/s: millimetres per second; cm: centimetres; COF: Centre of force.
*Statistically significant at adjusted level of 0.0083 accounting for Bonferroni correction (0.05/6 = 0.0083).
[a]Mann-Whitney U test.
[b]Independent t-test.
[c]Odds ratios and 95% CI inverted.

Table 6. Binary logistic regression of factors predicting likelihood of reporting one or more falls in stroke participants.

Variable	B	S.E.	Wald	df	p Value	Odds ratio	95% CI for Odds ratio Lower	95% CI for Odds ratio Upper
Age	0.017	0.023	0.221	1	0.639	0.99	0.95	1.03
TSS	−0.002	0.004	0.14	1	0.706	0.99	0.99	1.01
Distal proprioception	−0.081	0.247	0.107	1	0.743	0.92	0.57	1.5
Proximal proprioception	−1.139	0.869	1.716	1	0.19	0.32	0.06	1.76
Exteroception	−0.059	0.051	1.335	1	0.25	0.94	0.85	1.04
FRT	−0.011	0.024	0.221	1	0.64	0.99	0.95	1.03
WIS	0.041	0.015	7.392	1	0.007	1.04	1.01	1.07
Constant	3.356	3.75	0.801	1	0.37	28.67		

TSS: Time since stroke; FRT: Functional Reach Test; WIS: Walking Impact Scale; CI: Confidence interval.

of the great toe. Robinson et al. [4], found 13% of 30 ambulatory, community dwelling chronic stroke survivors had abnormal proprioception, as measured by manual testing of movement detection at the first metatarsal joint. The higher rates in this study may be explained by the more comprehensive, multi-modal assessment of sensation employed.

The EmNSA used in this study includes an assessment of sharp-blunt discrimination, which accounted for a large proportion of somatosensory deficits in this study. Fifty-five percent of our sample were impaired in this modality: much higher than the prevalence rates of exteroceptive deficits (18%) and proprioceptive deficits (19%). Notably, impairment in the individual modalities of pin-prick and pressure detection, which constitute the sharp-blunt discrimination test, were much lower (12 and 13%, respectively). Success in a test of discrimination, by its very nature, requires intact detection, so impairment rates in tests of discrimination are, at least, likely to be higher. Findings from this study are in line with others in stroke, in which discriminative ability is more commonly affected after stroke than stimuli detection [22,28,49,50]. The neurophysiology of somatosensory processing is not fully understood, although imaging studies highlight that multiple cortical and sub cortical brain structures are active during tests of texture discrimination [51,52]. It is further proposed in the assessment of somatosensation, that a "somatosensory hierarchy," could be applied. In this model, stimulus detection is considered the lowest "level" of somatosensory processing and discriminating between two or more stimuli, considered "higher level" processing [53]. With 70% of physiotherapists and occupational therapists not using a standardised assessment of sensation, favouring the assessment of light touch detection and proprioception [54], a substantial proportion of tactile impairments in clinical practice may go undetected. The findings from this study support that a thorough assessment of somatosensory ability in stroke should include an assessment of tactile discriminative ability. Our findings further indicate that recovery of lower limb sensation is not complete in the majority of chronic stroke survivors. Further, one in 10 chronic stroke survivors experience profound somatosensory impairment.

Despite their prevalence, this study did not provide strong evidence that lower limb somatosensory function is strongly associated with walking, balance, or falls; it demonstrated that impaired distal and proximal lower limb proprioception and exteroceptive sensation is significantly, but weakly associated with increased self-reported falls and increased postural sway. Overall, lower limb somatosensory impairments were only weakly associated with walking speed, self-reported walking ability, balance, and falls. Despite significant differences in lower limb proprioception and exteroceptive sensation between fallers and non-fallers, these factors did not significantly contribute to a predictive model for falls, suggesting falls may be explained by other factors. Schmid et al. [21], found neither stroke severity nor any of the individual components of the neurological examination (such as leg weakness, sensation, or ataxia) were associated with fall risk. Similarly, Hyndman et al. [55], found no significant differences in mobility or motor control, between fallers and non-fallers, yet did find different characteristics amongst repeat fallers. The multi-factorial nature of falls and the heterogeneity amongst falls groups, with factors such as cognitive impairment, depression, and psychotropic medications identified as significant risk factors alongside impaired balance and mobility [56] may explain these findings.

The results of this study are broadly in line with several other cohort studies in stroke which report mostly weak associations between lower limb somatosensory impairments and walking [20], balance [18], community ambulation, and falls [7,21]. The qualitative reports [9,57], laboratory studies [11–13] and clinical approaches [14], which emphasise the importance of accurate somatosensory information to movement, could not be fully supported.

Weak associations between lower limb somatosensation and functional outcomes may in part, be explained by the CNS reducing relative reliance on somatosensory information and increasing that of visual and vestibular inputs. For example, it is widely recognised that the relative contribution or weighting of somatosensory, visual, and vestibular sensory inputs alter in response to individual, task, and environmental factors [58]. Early after stroke visual dominance is more markedly enhanced [59], which may reflect a re-weighting of sensory information. It has been suggested that the use of visual information may be preferentially enhanced over other sensations, as there is less multi-sensory integration required to interpret visual as opposed to vestibular and somatosensory information, at least within constrained laboratory-based conditions [59,60].

It is further postulated that demand on somatosensory cortical structures increases with greater task requirements and movement accuracy. Electroencephalography (EEG) studies show increased cortical activity levels in supra-spinal areas during more challenging locomotor tasks such as narrow beam [61] and incline walking [62], compared with flat walking. The implication is that the somatosensory cortex is in a "heightened state" to monitor somatosensory feedback during more complex locomotion tasks [62]. Commonly used clinical mobility measures, such as the 10 mWT which is often used as a clinical end-point measure, may not capture the multi-faceted and somatosensory-dependent functions required during more challenging, "real life" walking [63,64]. Assessment of gait asymmetry however might provide greater insight to understanding paretic leg impairments [65]. With community dwelling chronic stroke survivors often exhibiting spatiotemporal gait asymmetries despite good motor control [66], abnormal tactile, and proprioceptive inputs might perpetuate such abnormal gait patterns. Further studies investigating the relationship between lower limb somatosensation and spatiotemporal parameters of gait are needed.

Further insight may also be provided by a detailed analysis of how lower limb somatosensation is measured. The results of this study and others [28,67,68] highlight issues regarding the validity, reliability, and appropriateness of traditional, clinical measures of somatosensory detection, particularly within the context of function. Such measures may lack the sensitivity to capture the complex somatosensory changes, which may occur following stroke. This may, in part be explained by their focus on identifying the presence or absence of impairment, not the severity, or functional impact of that impairment. These aspects are key for planning and evaluating appropriate rehabilitation interventions. The development and use of functionally oriented somatosensory measures have been suggested [30,69,70] and may help provide more meaningful somatosensory data.

Interpretation of our findings must be considered, as with any study, in light of the study limitations. The study used a convenience sampling approach, which may have led to sample bias. Assessment centres were limited to local community hospitals and the university laboratory, so these results may not be generalisable to very limited community walkers or those unable to attend outpatient clinics.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by a research grant from the Dr William M. Scholl Podiatric Research and Development Fund (FAiMiS Grant).

References

[1] Crichton S, Bray B, McKevitt C, et al. Patient outcomes up to 15 years after stroke: survival, disability, quality of life, cognition and mental health. J Neurol Neurosurg Psychiatry. 2016;87:1091–1098.

[2] Feigin V, Forouzanfar M, Krishnamurthi R, et al. Global and regional burden of stroke during 1990-2010: findings from the Global Burden of Disease Study 2010. Lancet. 2014;383:245–254.

[3] Veerbeek J, Kwakkel G, van Wegan E, et al. Early prediction of outcome of activities of daily living after stroke: a systematic review. Stroke. 2011;42:1482–1488.

[4] Robinson C, Shumway-Cook A, Matsuda P, et al. Understanding physical factors associated with participation in community ambulation following stroke. Disab Rehabil. 2011;33:1033–1042.

[5] Durcan S, Flavin E, Horgan F. Factors associated with community ambulation in chronic stroke. Disability and Rehabilitation. 2016;38:245–249.

[6] Severinsen K, Jakobsen JK, et al. Normalized muscle strength, aerobic capacity, and walking performance in chronic stroke: a population-based study on the potential for endurance and resistance training. Arch Phys Med Rehabil. 2011;92:1663–1668.

[7] Lee KB, Lim SH, Ko EH, et al. Factors related to community ambulation in patients with chronic stroke. Top Stroke Rehabil. 2015;22:63–71.

[8] Batchelor F, Mackintosh S, Said C, et al. Falls after stroke. Int J Stroke. 2012;7:482–490.

[9] Gorst T, Lyddon A, Marsden J, et al. Foot and ankle impairments affect mobility and balance in stroke (FAiMiS): the views of people with stroke. Disabil Rehabil. 2016;38: 589–596.

[10] Wolpert D, Pearson K, Ghez C. The Organization and planning of movement. In: Kandel E, Schwartz J, Jessell T, et al., editors. Principles of neural science. New York: McGraw Hill; 2013. p.743–767.

[11] Kavounoudias A, Roll R, Roll JP. Foot sole and ankle muscle inputs contribute jointly to human erect posture regulation. J Physiol. 2001;532:869–878.

[12] Zehr E, Nakajima T, Barss T, et al. Cutaneous stimulation of discrete regions of the sole during locomotion produces "sensory steering" of the foot. BMC Sports Sci Med Rehabil. 2014;6:33.

[13] Qaiser T, Chisholm A, Lam T. The relationship between lower limb proprioceptive sense and locomotor skill acquisition. Exp Brain Res. 2016;234:3185–3192.

[14] Raine S, Meadows L, Lynch-Ellington M. Bobath concept: theory and clinical practice in neurological rehabilitation. Chichester: Wiley-Blackwell; 2009.

[15] Kato H, Izumiyama M. Impaired motor control due to proprioceptive sensory loss in a patient with cerebral infraction localized to the postcentral gyrus. J Rehabil Med. 2015;47: 187–190.

[16] Hohne A, Ali S, Stark C, et al. Reduced plantar cutaneous sensation modifies gait dynamics, lower-limb kinematics and muscle activity during walking. Eur J Appl Physiol. 2012;112:3829–3838.

[17] Bringoux L, Scotto DiCesare C, Borel L, et al. Do visual and vestibular inputs compensate for somatosensory loss in the perception of spatial orientation? Insights from a deafferented patient. Front Hum Neurosci. 2016;10:181.

[18] Tyson S, Crow L, Connell L, et al. Sensory impairments of the lower limb after stroke; A pooled analysis of individual patient data. Top Stroke Rehabil. 2013;20:441–449.

[19] Patel A, Duncan P, Lai S, et al. The relation between impairments and functional outcomes poststroke. Arch Phys Med Rehabil. 2000;81:1357–1363.

[20] Hsu A, Tang P, Jan M. Analysis of impairments influencing gait velocity and asymmetry of hemiplegic patients after mild to moderate stroke. Arch Phys Med Rehabil. 2003;84:1185–1193.

[21] Schmid A, Yaggi K, Burrus N, et al. Circumstances and consequences of falls among people with chronic stroke. J Rehabil Res Dev. 2013;50:1277–1286.

[22] Connell L, Lincoln N, Radford K. Somatosensory impairment after stroke: frequency of different deficits and their recovery. Clin Rehabil. 2008;22:758–767.

[23] Bowen C, Ashburn A, Cole, et al. A survey exploring self-reported indoor and outdoor footwear habits, foot problems and fall status in people with stroke and Parkinson's. J Foot Ankle Res. 2016;9:39.

[24] Yalcin E, Akyuz M, Onder B, et al. Position sense of the hemiparetic and non-hemiparteic ankle after stroke: is the non-hemiparetic ankle also affected? Eur Neurol. 2012;68:294–299.

[25] von Elm E, Altman DG, Egger M, et al. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) Statement: guidelines for reporting observational studies. PLoS Med. 2007;4:e296.

[26] Stolk-Hornsveld F, Crow JL, Hendriks EP, et al. The Erasmus MC modifications to the (revised) Nottingham Sensory Assessment: a reliable somatosensory assessment measure for patients with intracranial disorders. Clin Rehabil. 2006;20:160–172.

[27] Connell L, Tyson S. Measures of sensation in neurological conditions: a systematic review. Clin Rehabil. 2012;26:68.

[28] Meyer S, De Bruyn N, Lafosse C, et al. Somatosensory impairments in the upper limb post stroke: distribution and association with motor function and visuospatial neglect. Neurorehabil Neural Repair. 2016;30:731–742.

[29] Bohannon RW, Andrews AW, Thomas MW. Walking speed: reference values and correlates for older adults. J Orthop Sports Phys Ther. 1996;24:86–90.

[30] Tyson S, Connell L. The psychometric properties and clinical utility of measures of walking and mobility in neurological conditions: a systematic review. Clin Rehabil. 2009;23: 1018–1033.

[31] Flansbjer UB, Holmback AM, et al. Reliability of gait performance tests in men and women with hemiparesis after stroke. J Rehabil Med. 2005;37:75–82.

[32] Maeda A, Yuasa T, Nakamura K, et al. Physical performance tests after stroke: reliability and validity. Am J Phys Med Rehabil. 2000;79:519–525.

[33] Podsiadlo D, Richardson S. The timed up and go. A test of basic functional mobility for frail elderly persons. J Am Geriatr Soc. 1991;39:142.

[34] Knorr S, Brouwer B, Garland J. Validity of the community balance and mobility scale in community-dwelling persons after stroke. Arch Phys Med Rehabil. 2010;91:890–896.

[35] Holland A, O'Connor RJ, Thompson AJ, et al. Talking the talk on walking the walk: a 12-item generic walking scale suitable for neurological conditions? J Neurol. 2006;253: 1594–1602.

[36] Weiner DK, Duncan PW, et al. Functional reach: a marker of physical frailty. J Am Geriatr Soc. 1992;40:203–207.

[37] Tyson S, DeSouza L. Reliability and validity of functional balance tests post stroke. Clin Rehabil. 2004;18:916–923.

[38] Acar M, Karatas GK. The effect of arm sling on balance in patients with hemiplegia. Gait Posture. 2010;32:641–644.

[39] Masani A, Vette A, Abe M. Center of pressure velocity reflects body acceleration rather than body velocity during quiet standing. Gait Posture. 2014;39:946–952.

[40] Kunkel D, Pickering R, Ashburn A. Comparison of retrospective interviews and prospective diaries to facilitate fall reports among people with stroke. Age Ageing. 2011;40: 277–280.

[41] Lamb SE, Jørstad-Stein EC, Hauer K, et al. Development of a common outcome data set for fall injury prevention trials: the Prevention of Falls Network Europe consensus. J Am Geriatr Soc. 2005;53:1618–1622.

[42] Mackintosh S, Goldie P, Hill K. Falls incidence and factors associated with falling in older, community-dwelling, chronic stroke survivors 1 year after stroke and matched controls. Aging Clin Exp Res. 2005;17:74–81.

[43] Yardley L, Beyer N, Hauer K, et al. Development and initial validation of the Falls Efficacy Scale-International (FES-I). Age Ageing. 2005;34:614–619.

[44] Belgen B, Beninato M, Sullivan PE, et al. The association of balance capacity and falls self-efficacy with history of falling in community-dwelling people with chronic stroke. Arch Phys Med Rehabil. 2006;87:554–561.

[45] Hellstrom K, Lindmark B. Fear of falling in patients with stroke: a reliability study. Clin Rehabil. 1999;13:509–517.

[46] Delbaere K, Close J, Mikolaizak S, et al. The Falls Efficacy Scale International (FES-I). A comprehensive longitudinal validation study. Age Ageing. 2010;39:210–216.

[47] Cohen J. Statistical power analysis for the behavioral sciences. New York, NY: Routledge Academic; 1988.

[48] Tabachnick B, Fidell L. Using multivariate statistics. 6th ed. Boston: Pearson Education; 2012.

[49] Tyson S, 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.

[50] Carey L, Matyas T. Frequency of discriminative sensory loss in the hand after stroke in a rehabilitation setting. J Rehabil Med. 2011;43:257–263.

[51] Borstad A, Schmalbrock P, Choi S, et al. Neural correlates supporting sensory discrimination after left hemisphere stroke. Brain Res. 2012;1460:78–87.

[52] Carey LM, Abbott DF, Puce A, et al. Same intervention-different reorganisation: the impact of lesion location on training-facilitated somatosensory recovery after stroke. Neurorehabil Neural Repair. 2016;30:988–1000.

[53] Borstad A, Nichols-Larsen D. Assessing and treating higher level somatosensory impairments post stroke. Top Stroke Rehabil. 2014;21:290–295.

[54] Pumpa L, Cahill L, Carey L. Somatosensory assessment and treatment after stroke: an evidence-practice gap. Aust Occup Ther J. 2015;62:93–104.

[55] Hyndman D, Ashburn A, Stack E. Fall events among people with stroke living in the community: circumstances of falls and characteristics of fallers. Arch Phys Med Rehabil. 2002;83:165–170.

[56] Xu T, Clemson L, O'Loughlin K, et al. Risk factors for falls in community stroke survivors: a systematic review and meta-analysis. Arch Phys Med Rehab. 2017;99:563–573.

[57] Connell L, McMahon N, Adams N. Stroke survivors experiences of somatosensory impairment after stroke: an interpretative phenomenological analysis. Physiotherapy. 2014; 100:150–155.

[58] Peterka RJ. Sensorimotor integration in human postural control. J Neurophys. 2002;88:1097–1118.

[59] Bonan IV, et al. Early post-stroke period: a privileged time for sensory re-weighting? J Rehabil Med. 2015;47:516–522.

[60] Mullie Y, Duclos C. Role of proprioceptive information to control balance during gait in healthy and hemiparetic individuals. Gait Posture. 2014;40:610–615.

[61] Sipp AR, Gwin JT, Makeig S, et al. Loss of balance during balance beam walking elicits a multifocal theta band electrocortical response. J Neurophysiol. 2013;110:2050–2060.

[62] Bradford J, Lukos J, Ferris D. Electrocortical activity distinguishes between uphill and level walking in humans. J Neurophysiol. 2016;115:958–966.

[63] Lord S, McPherson K, McNaughton H, et al. Community ambulation after stroke: how important and obtainable is it and what measures appear predictive? Arch Phys Med Rehabil. 2004;85:234–239.

[64] Taylor D, Stretton C, Mudge S, et al. Does clinic-measured gait speed differ from gait speed measured in the community in people with stroke? Clin Rehabil. 2006;20:438–444.

[65] Lauzière S, Betschart M, Aissaoui R, Nadeau S. Understanding spatial and temporal gait asymmetries in individuals post stroke. Int J Phys Med Rehabil. 2014;2:201.

[66] Patterson KK, Parafianowicz I, Danells CJ, et al. Gait asymmetry in community-ambulating stroke survivors. Arch Phys Med Rehabil. 2008;89:304–310.

[67] Uszynski M, Purtill H, Coote S. Interrater reliability of four sensory measures in people with multiple sclerosis. Int J MS Care. 2016;18:86–95.

[68] Lin J, Hsueh I, Sheu C, et al. Psychometric properties of the sensory scale of the Fugl-Meyer Assessment in stroke patients. Clin Rehabil. 2004;18:391–397.

[69] Han J, Waddington G, Adams R, et al. Assessing proprioception: a critical review of methods. J Sport Health Sci. 2016;5:80–90.

[70] Elangovan N, Herrmann A, Konczak J. Assessing proprioceptive function: evaluating joint position matching methods against psychophysical thresholds. Phys Ther. 2014;94: 553–561.