PTJ: Physical Therapy & Rehabilitation Journal | *Physical Therapy*, 2021;101:1–6
DOI: 10.1093/ptj/pzab060
Advance access publication date February 12, 2021
Original Research

Paretic and Nonparetic Step Tests Are Noninterchangeable in Stroke: A Prospective Cohort Study

Shamala Thilarajah, PhD[1], Kelly J. Bower, PhD[2], Gavin Williams, PhD[2,3], Ross A. Clark, PhD[4], Dawn Tan, DClinPT[1], Yong-Hao Pua, PhD[1]

[1]Department of Physiotherapy, Singapore General Hospital, Singapore
[2]Department of Physiotherapy, The University of Melbourne, Melbourne, Victoria, Australia
[3]Epworth HealthCare, Richmond, Melbourne, Victoria, Australia
[4]School of Health and Exercise Science, The University of the Sunshine Coast, Queensland, Australia
*Address all correspondence to Dr Thilarajah at: shamala.thilarajah@sgh.com.sg, @sthilarajah

Abstract

Objective. The step test (ST) is a common clinical assessment of dynamic balance among survivors of stroke. The ST assesses a person's ability to place their paretic (paretic ST) or nonparetic (nonparetic ST) foot rapidly and repeatedly on and off a standardized block while standing. No study has formally explored if the 2 tests are interchangeable. Our study aimed to: (1) differentiate the correlates of paretic and nonparetic ST, and (2) compare their associations with physical function and falls.

Methods. Eighty-one survivors of stroke were consecutively recruited from inpatient rehabilitation units (n = 4) and were assessed within 1 week prior to discharge. In addition to the ST, a handheld dynamometer and computerized posturography were used to measure lower limb muscle strength and standing balance, respectively. Self-selected gait speed and Timed Up and Go test were also assessed as measures of physical function. Falls data were monitored for 12 months post discharge using monthly calendars. Multivariable regression analyses were used to differentiate (1) the correlates of paretic and nonparetic STs, and (2) their associations with physical function and falls.

Results. The median score for the paretic and nonparetic STs were 8 and 9 steps, respectively. Paretic ankle plantar-flexor and dorsiflexor strength were the strongest correlates of nonparetic ST, whereas both paretic ankle and knee extensor strength were the strongest correlates of paretic ST. In multivariable analyses adjusting for each other, both STs were independently associated with gait speed and Timed Up and Go scores. Paretic ST (odds ratio = 0.37; 95% CI = 0.22 to 0.62) was a stronger predictor than nonparetic ST (odds ratio = 0.51; 95% CI = 0.34 to 0.78) in predicting future falls.

Conclusion. This study confirmed that the paretic and nonparetic STs are noninterchangeable. ST scores should be assessed separately to achieve a more complete interpretation.

Impact. To our knowledge, this study is the first to objectively evaluate the similarities and differences between paretic and nonparetic STs. This information may refine the use and interpretation of the 2 STs for survivors of stroke.

Keywords: Balance, Outcome Measurement, Rehabilitation, Step Test, Stroke

Received: May 15, 2020. **Revised:** November 20, 2020. **Accepted:** December 31, 2020

Introduction

Balance deficits can contribute to activity limitations and disability after stroke and are commonly assessed to guide treatment and predict outcomes.[1] There is a wide range of clinical balance assessments, and thus, it is important to understand the components of balance evaluated and the underlying impairments in order to interpret the results for targeted interventions.[2,3]

A common clinical balance assessment of dynamic stability is the step test (ST). The test assesses a person's ability to rapidly and repeatedly place their nonparetic (nonparetic ST) or paretic (paretic ST) foot on and off a standardized block (7.5 cm) for 15 seconds while in single-leg stance.[4] The test is inexpensive and quick and has demonstrated good intrarater reliability.[5] Research has found large responsiveness to change in the subacute phase post stroke.[6] The ST has also shown good correlations to lower limb strength, the Berg Balance Scale, and gait speed.[5] Furthermore, this test is predictive of falls following stroke.[7,8]

Clinically, the nonparetic and paretic ST appear to measure different aspects of balance among survivors of stroke, as their scores may differ on the 2 tests. No study to our knowledge has formally examined if paretic or nonparetic ST are interchangeable. Therefore, an understanding of the redundancy between the paretic and nonparetic ST is needed for a more focused interpretation of ST scores and effective intervention during stroke rehabilitation. To bridge this knowledge gap, our study aims are to: (1) differentiate the clinical correlates of paretic and nonparetic ST, and (2) compare their associations with gait speed, Timed Up and Go (TUG) scores, and falls.

Methods

Participants

Stroke survivors were consecutively recruited from 4 inpatient rehabilitation facilities in Australia (n = 30) and Singapore (n = 66). Eligibility criteria were: (1) a medical diagnosis of stroke; (2) ability to walk 10 m with at most minimal assistance; (3) adequate cognition and language to provide consent and participate in testing (as per assessment by the treating team, eg, occupational therapist or speech pathologist); (4) medically stable; and (5) no other condition that could affect assessment. The study received ethical approval from the relevant institutions at each site.

Procedures

A total of 96 individuals were recruited, with 81 (Australia: n = 25, Singapore: n = 56) completing baseline testing and 12-month prospective falls follow-up. The reasons for loss of follow-up were voluntary withdrawal (n = 7), unable to contact or moved overseas (n = 5), and death or further serious medical event (n = 3). All variables (except falls) were assessed within 1 week prior to discharge from inpatient rehabilitation. Participants were assessed by an experienced physiotherapist or exercise physiologist. Baseline data collected included demographic details, stroke characteristics, and self-reported falls history in the 12 months prior to stroke. Falls were defined as "an unexpected event in which the participants come to rest on the ground, floor, or lower level."[9] This study analyzed secondary outcomes from the primary study that investigated the factors associated with falls.[8]

Step Test

For the ST, participants were asked to place 1 foot onto a 7.5-cm step and then back down to the floor repeatedly as fast as possible for 15 seconds without physical support or compromising safety.[4] Participants completed several taps on each leg to provide familiarization. They first completed the test with the paretic foot tapping (paretic ST) and then with the nonparetic foot tapping (nonparetic ST). Participants were not allowed to use an assistive device during testing. If they were unable to perform the test without support, then the number of steps was recorded as zero. If the participant lost balance during the test, the test was stopped and the complete number of steps recorded. The number of steps completed in 15 seconds for each leg was used for the analysis.

Independent Variables

Isometric muscle strength of the paretic and nonparetic knee extensors, ankle dorsiflexors, and plantar flexors were measured using peak force with a hand-held dynamometer (Lafayette Model-01165, Lafayette Instrument, Lafayette, IN, USA) using the standardized instructions and testing positions in the Supplemental Appendix 1.[10] Knee extensors were chosen as the proxy muscle group for proximal strength as it is easy to standardize the measurement in clinic and it has been shown to be correlated to the hip flexors.[11]

Static standing balance was assessed with a Wii Balance Board (WBB) (Nintendo, Kyoto, Japan). The participant was asked to stand "as still as possible" on the WBB with feet positioned on footprints pasted on the board (heel 17 cm apart and toe-out angle 14 degrees—running between 1st and 2nd toes). The test was conducted with bare feet and no aids, with both eyes open (looking at a target 1.5 m in front) and eyes closed. A chair was placed on the unaffected side of participant. The assessor stood on the affected side and behind the patient in case steadying was required. The average of 2 successful trials was used for analysis. This device has demonstrated excellent concurrent validity for static balance assessment in healthy and clinical populations compared with other force platforms and high test–retest reliability in people following stroke.[12] Outcome variables included total and mediolateral and anteroposterior center of pressure velocity. The results were determined using the analysis techniques contained in SeeSway, an online calculator incorporating Matlab and LabVIEW software.[13] The WBBs were connected to a laptop running custom-written software created by one of the authors (R.A.C.; LabVIEW, National Instruments, Austin, TX, USA). The WBBs were calibrated prior to data collection using techniques described previously.[14] In addition to the physical assessments, participants were also asked to rate the Falls Efficacy Scale (short), which is a 7-item questionnaire that examines their concerns about falling when performing daily activities.[15] A higher score indicates a greater concern of falling.

Covariates

Five potential confounders associated with physical function were selected for the analysis[16,17]: age, sex, height, weight, and time since stroke. Data were extracted from the electronic medical records where possible or obtained from the participant during the assessment. Time since stroke was calculated as number of days from the date of stroke onset to date of

Table 1. Demographics and Clinical Characteristics of Participants (n = 81)[a]

Characteristics	Mean (SD) (25th, 50th, 75th Percentile)[b]
Country (Singapore), n (%)	56 (69.1%)
Age, y	63.0 ± 13.2 (53.5, 63.0, 73.0)
Sex (male), n (%)	43 (53.1%)
Height, cm	163.9 ± 10.0 (157, 164, 171)
Weight, kg	68.2 ± 15.8 (57.9, 64.4, 77.4)
Time since stroke, d	27.8 ± 12.0 (20, 24, 34.5)
Side of stroke lesion (right), n (%)	39 (48.1%)
Type of stroke (infarct), n (%)	64 (79.0%)
Comfortable gait speed, m/s	0.7 ± 0.4 (0.4, 0.8, 1.0)
TUG, s	19.6 ± 15.6 (11.3, 15.0, 22.6)
Paretic ST, n	7.8 ± 5 (5, 8, 10)
Nonparetic ST, n	9.1 ± 5 (6, 9, 13)
Strength variables	
Nonparetic knee extensor, Nm/kg	20.3 ± 7.2 (15.1, 20.9, 23.8)
Paretic knee extensor, Nm/kg	16.6 ± 7.2 (11.6, 16.6, 20.8)
Nonparetic ankle dorsiflexor, Nm/kg	11.7 ± 4.1 (9.8, 11.6, 14.4)
Paretic ankle dorsiflexor, Nm/kg	9.7 ± 5.0 (6.4, 9.7, 12.9)
Nonparetic ankle plantar flexor, Nm/kg	14.7 ± 5.2 (11.9, 14.9, 17.8)
Paretic ankle plantar flexor, Nm/kg	13.4 ± 5.2 (10.0, 13.4, 16.9)
Balance variables	
COP vel EC total, cm/s	2.3 ± 1.2 (1.5, 1.9, 2.9)
COP vel EO total, cm/s	1.6 ± 0.8 (1.1, 1.4, 1.9)
Short Falls Efficacy Scale-International (7–28)	12.4 ± 5.7 (8, 10, 15)
≥1 fall in 12 mo preceding stroke (yes)	19 (23.5%)
≥1 fall in 12 mo after discharge (yes)	22 (28.4%)

[a]COP = center of pressure; EC = eyes closed; EO = eyes open; ST = step test; TUG = Timed Up and Go test; vel = velocity. [b]Values are mean (SD) (25th, 50th, 75th percentile) unless otherwise indicated. If the median and mean are similar and the outer quartiles are symmetrical with respect to the median, the variable may be interpreted as being normally distributed.

first assessment. Additionally, for falls regression analysis, the number of falls in the 12 months prior to stroke was included as a covariate.

Dependent Variables

Gait speed was measured over a 10-m walkway at a comfortable speed.[18] The middle 6 m was timed using a stopwatch. If participants required assistance or a gait aid, this was provided and recorded. Two trials were performed and the average used for the analysis. The outcome variable was self-selected gait speed in meters per second. The TUG test was assessed using a stopwatch.[19] The total time that the participant required to stand from a chair, walk 3 m at a comfortable pace, and turn and return to sitting was recorded. Two trials were conducted and the faster trial used for the analysis.

Participants prospectively recorded any falls over 12 months following discharge using a monthly calendar returned via post. Telephone interviews were used to rectify missing data and confirm details of falls.

Statistical Analysis

Sample size was calculated according to the main outcome (number of falls) in the primary study.[8] The sample size of 81 participants recruited for the primary study was sufficient to reliably fit a multivariable model based on the guideline of at least 10 patients per degree of freedom for the present analysis.[20] Pearson correlation was used to analyze the association between paretic and nonparetic ST values. To identify the correlates of paretic and nonparetic ST, we included, in separate multivariable ordinary least-squares models, the various strength, balance, and falls efficacy variables as predictors, and we adjusted all models for 5 covariates. To evaluate the relative contribution of each correlate, we computed its squared semi-partial correlation coefficient.

To evaluate the associations of ST with physical function and falls, we used multivariable least-squares regression for the gait speed outcome and proportional-odds ordinal regression for TUG and falls outcomes adjusting for age, sex, height, weight, time since stroke, and number of falls prior to stroke onset. We used ordinal regression because it can handle both ordinal and clumped continuous outcomes.[21] To compare the explanatory value of paretic and nonparetic ST, we used the partial *F*-test (gait speed model) and the likelihood ratio chi-square test (TUG and falls outcomes) to assess whether paretic ST added incremental explanatory value to a model that included both nonparetic ST and covariates, and vice versa. Missing values in the covariates (9%) were singly imputed using the regression technique.[20,22] All analyses were conducted using SPSS software, version 26 (IBM, Armonk, New York, NY, USA).

Role of the Funding Source

The funders played no role in the design, conduct, or reporting of this study.

Results

In total, 81 of the 96 individuals who were recruited completed baseline testing and falls follow-up for 12-months after discharge (the study profile is reported elsewhere).[8] Table 1 shows the characteristics of the sample. All variables except TUG scores and number of falls were normally distributed. Mean paretic and nonparetic ST scores were 7.8 and 9.1, respectively, and the common variance shared by both tests was 0.71 (Pearson $r = 0.84$, $P \leq .001$). Over a 12-month

Table 2. Relative Contribution of Balance, Muscle Strength, and Falls Efficacy Variables to Nonparetic and Paretic Step Tests[a,b]

Correlates	Percentile		Nonparetic ST				Paretic ST			
	25th	75th	Difference (95% CI)[c]	P	Partial Effects Analysis[d]		Difference (95% CI)[c]	P	Partial Effects Analysis[d]	
					Partial R^2	Rank			Partial R^2	Rank
Paretic ankle dorsiflexor, Nm	6.4	12.9	3.7 (2.3 to 5.1)	<.01	0.39	1	3.1 (1.7 to 4.4)	<.01	0.30	2
Paretic ankle plantar flexor, Nm	10.0	16.9	3.0 (1.5 to 4.5)	<.01	0.35	2	2.6 (1.2 to 4.0)	<.01	0.29	3
Paretic knee extensor, Nm	11.6	20.8	3.1 (1.7 to 4.5)	<.01	0.30	3	2.7 (1.4 to 4.1)	<.01	0.31	1
COP vel EC total, cm/s	1.5	2.9	−2.4 (−3.7 to −1.2)	<.01	0.21	4	−1.2 (−2.5 to 0.1)	0.10	0.04	7
COP vel EO total, cm/s	1.1	1.9	−2.0 (−3.0 to −1.1)	<.01	0.17	5	−1.3 (−2.3 to −0.3)	0.01	0.08	6
Short FES-I	8.0	15.0	−3.0 (−4.7 to −1.3)	<.01	0.12	6	−2.6 (−4.2 to −0.9)	<.01	0.10	5
Nonparetic knee extensor, Nm	15.1	23.8	2.5 (0.8 to 4.1)	<.01	0.10	7	2.6 (1.1 to 4.1)	<.01	0.13	4
Nonparetic ankle dorsiflexor, Nm	9.8	14.4	0.9 (−0.6 to 2.4)	.2	0.02	8	1.0 (−0.4 to 2.4)	0.2	0.02	8
Nonparetic ankle plantar flexor, Nm	11.9	17.8	0.8 (−0.5 to 2.2)	.2	0.02	9	0.3 (−1.1 to 1.6)	0.7	0.00	9

[a]COP = center of pressure; EC = eyes closed; EO = eyes open; FES-I = Falls Efficacy Scale-International; vel = velocity. [b]All multivariable linear regression analyses were adjusted for age, sex, height, weight, and time since stroke. [c]Adjusted differences in ST performance reflect a comparison between the 75th and 25th percentile values of each balance or muscle strength measure. For example, other variables being equal, patients with paretic knee extensor strength of 21 Nm (75th percentile) achieved, on average, 3 more steps on the nonparetic ST (95% CI = 1.7 to 4.5) relative to patients with knee extensor strength of 12 Nm (25th percentile). [d]To examine the relative contribution of variables in the adjusted models, the partial R^2 was calculated for each variable and variables were ranked by this value.

Table 3. Associations of Nonparetic and Paretic STs with Physical Function and Falls[a,b]

	Gait Speed			TUG			Falls		
	Difference (95% CI)[c]	P	P[d]	OR (95% CI)[e]	P	P[d]	OR (95% CI)[e]	P	P[d]
Nonparetic ST	0.33 (0.25 to 0.40)	<01	.01	0.17 (0.11 to 0.26)	<01	<01	0.51 (0.34 to 0.78)	<01	.64
Paretic ST	0.30 (0.23 to 3.63)	<01	<01	0.19 (0.12 to 0.30)	<01	<01	0.37 (0.22 to 0.62)	<01	.01

[a]OR = odds ratio; ST = step test; TUG = Timed Up and Go test. [b]Results shown are from linear regression models (gait speed) or proportional odds regression models (TUG and falls). All analyses were adjusted for age, sex, height, weight, time since stroke, and prior falls. [c]Adjusted differences in gait speed per 3-step increment in ST performance. For example, other variables being equal, increasing the nonparetic ST performance by 3 steps is associated with 0.33 m/s (95% CI = 0.25 to 0.40) faster gait speed. [d]P value from a partial F-test (gait speed) or likelihood ratio chi-square test (TUG and falls) for nested models evaluating the incremental value of nonparetic ST over paretic ST, adjusting for covariates, and vice versa. [e]ORs estimate the odds of slower TUG and more falls per 3-step increment in ST performance. For example, other variables being equal, patients with a nonparetic ST performance of 8 steps had, on average, 0.5 times (95% CI = 0.3 to 0.8) the odds of having more falls relative to patients with a nonparetic ST performance of 5 steps.

follow-up, 22 (28%) participants fell at least once. Table 2 shows the variables associated with ST scores. Ranked by the partial R^2 statistic, both paretic ankle dorsiflexor and plantar-flexor strength were the strongest correlates of nonparetic ST. The strongest correlates of paretic ST were both paretic ankle dorsiflexor and plantar-flexor strength and knee extensor strength. Additionally, standing balance, indexed by center of pressure velocity with eyes open and closed, was associated more closely with nonparetic ST than with paretic ST.

Table 3 shows that in multivariable analyses adjusted for covariates, paretic and nonparetic ST were significantly associated with all outcomes, with better ST performance associated with better physical function and fewer falls. In gait speed and TUG models that included paretic and nonparetic STs, both tests provided incremental explanatory value over each other. For falls outcomes, paretic ST added statistically significant explanatory value to the model that included nonparetic ST and covariates ($P < .01$).

Discussion

Our principal findings are as follows: (1) the paretic limb strength tests had the strongest associations with both paretic and nonparetic ST; (2) standing balance was more closely associated with nonparetic ST than with paretic ST; (3) both STs were associated with physical function and were independent of each other; and (4) both STs were associated with future falls, with paretic ST the stronger predictor. Together, these findings suggest that paretic and nonparetic STs are similar but not interchangeable in survivors of stroke.

Our study improves on prior work by evaluating and ranking the relative contributions of physical and psychological variables to paretic and nonparetic ST.[4,5,23] We observed that the strength of paretic ankle dorsiflexors and plantar flexors were the strongest correlates of nonparetic ST, while paretic ankle plantar flexor, paretic ankle dorsiflexor, and knee extensor strength were the strongest correlates of paretic ST. This finding could reflect the critical influence of the paretic ankle strength on both ST performance in stance (1) to maintain balance during fast lateral weight shifting and (2) to ensure that the ankle is maintained in dorsiflexion when swinging the limb forward during stepping. Given these findings, 1 potential implication is that the nonparetic ST may also be more sensitive to changes (improvement and deterioration) in paretic ankle dorsiflexor strength, whereas improved paretic ST performance may be achieved not only by having sufficient ankle strength but also by using compensatory strategies involving the hip and knee.

The nonparetic ST was better associated with the balance variables compared with the paretic ST. This finding is similar to a previous study that reported that balance, as measured by Berg Balance Scale, was significantly correlated to the nonparetic ST but not the paretic ST.[15] Possibly, movement-induced perturbations may be greater when patients balance on their paretic limb (during the nonparetic ST), which in turn may require greater balance to maintain equilibrium. Individuals may also favor their nonparetic leg in standing, so their static standing is affected when their nonparetic leg is compromised. Future studies involving motion analysis systems should examine this possibility.

Our results demonstrated that the nonparetic and paretic ST were unique predictors of gait speed and TUG scores at discharge from inpatient rehabilitation. Reviewing the literature, our finding with gait speed is supported by a previous smaller study done on survivors of stroke in the late subacute phase of stroke recovery.[23] However, this study did not discriminate between the 2 tests in their analysis of the association between ST and physical function. In the falls model, nonparetic and paretic ST had different explanatory power, as evidenced by their difference in odds ratios (adjusted odds ratios for nonparetic ST and paretic ST were 0.51 [95% CI = 0.34 to 0.78] and 0.37 [95% CI = 0.22 to 0.62], respectively). Falls studies in the stroke population have revealed that most falls happen towards the paretic side or forwards due to reduced clearance of the paretic limb while crossing obstacles.[24] Our findings suggest that although both ST sides may assess different aspects of gait and TUG performance, the paretic ST may be a better falls predictor than nonparetic ST.

Study Limitations

The separate measurement of the hip flexors and hip extensors, both of which are important muscle groups for the forward propulsion and primary compensatory strategy for plantar flexor weakness in walking, would have refined further the understanding of the associations of lower limb strength to ST scores.[25] This study recruited participants who were already able to walk 10 m with no more than minimal assistance. Thus, the study findings can only be generalized to individuals with similar characteristics. Survivors of stroke with a lower level of physical function may also not be able to complete the ST.[6] This relationship will need to be further explored among survivors of stroke who have different abilities.

Our study has shown that the paretic and nonparetic STs are noninterchangeable, in people with relatively independent mobility, in the subacute phase post stroke. Future studies should analyze paretic and nonparetic ST scores separately for accurate assessments.

Author Contributions

Concept/idea/research design: S. Thilarajah, Y.-H. Pua
Writing: S. Thilarajah, K.J. Bower, G. Williams, R.A. Clark, Y.-H. Pua
Data collection: S. Thilarajah, K.J. Bower, D. Tan
Data analysis: S. Thilarajah, Y.-H. Pua
Project management: S. Thilarajah, K.J. Bower, G. Williams, R.A. Clark
Fund procurement: D. Tan
Providing facilities/equipment: R.A. Clark
Consultation (including review of manuscript before submitting): S. Thilarajah, K.J. Bower, Y.-H. Pua, D. Tan, G. Williams, R.A. Clark

Acknowledgements

The authors thank the Physiotherapy Department and Rehabilitation Medicine Department at the Singapore General Hospital for their support.

Ethics Approval

This study was approved by the institutional ethics committee at Epworth HealthCare (Melbourne, Australia) and Singapore General Hospital (Singapore).

Funding

This study was supported by a National Health and Medical Research Council Career Development Fellowship (R.A.C.) and the Australian Government Research Training Program Scholarship (S.T.). The Singapore arm of the study was funded by the Singapore General Hospital Research Grants (SRG#04/2015 and SRG-AN#09/2016).

Disclosures

All authors completed the ICMJE Form for Disclosure of Potential Conflicts of Interest. R.A. Clark reports being paid by University of the Sunshine Coast for the review/writing of the manuscript. All other authors declared no conflicts of interest.

References

1. Tyson SF, Hanley M, Chillala J, Selley A, Tallis RC. Balance disability after stroke. *Phys Ther*. 2006;86:30–38.
2. Sibley KM, Beauchamp MK, Van Ooteghem K, Straus SE, Jaglal SB. Using the systems framework for postural control to analyze the components of balance evaluated in standardized balance measures: a scoping review. *Arch Phys Med Rehabil*. 2015;96:122, e129–132.
3. Sibley KM, Straus SE, Inness EL, Salbach NM, Jaglal SB. Balance assessment practices and use of standardized balance measures among Ontario physical therapists. *Phys Ther*. 2011;91: 1583–1591.
4. Hill KD, Bernhardt J, McGann AM, Maltese D, Berkovits D. A new test of dynamic standing balance for stroke patients: reliability, validity and comparison with healthy elderly. *Physiother Can*. 1996;48:257–262.
5. Hong S-J, Goh EY, Chua SY, Ng SS. Reliability and validity of step test scores in subjects with chronic stroke. *Arch Phys Med Rehabil*. 2012;93:1065–1071.
6. Bernhardt J, Ellis P, Denisenko S, Hill K. Changes in balance and locomotion measures during rehabilitation following stroke. *Physiother Res Int*. 1998;3:109–122.
7. Mackintosh SF, Hill KD, Dodd KJ, Goldie PA, Culham EG. Balance score and a history of falls in hospital predict recurrent falls in the 6 months following stroke rehabilitation. *Arch Phys Med Rehabil*. 2006;87:1583–1589.
8. Bower K, Thilarajah S, Pua Y-H, et al. Dynamic balance and instrumented gait variables are independent predictors of falls following stroke. *J Neuroeng Rehabil*. 2019;16:3.
9. Lamb SE, Jørstad-Stein EC, Hauer K, Becker C, on behalf of the Prevention of Falls Network Europe and Outcomes Consensus Group. 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.
10. Mentiplay BF, Perraton LG, Bower KJ, et al. Assessment of lower limb muscle strength and power using hand-held and fixed dynamometry: a reliability and validity study. *PLoS One*. 2015;10:e0140822.
11. Bohannon RW, Andrews AW. Relationships between impairments in strength of limb muscle actions following stroke. *Percept Mot Skills*. 1998;87:1327–1330.
12. Bower KJ, McGinley JL, Miller KJ, Clark RA. Instrumented static and dynamic balance assessment after stroke using Wii balance boards: reliability and association with clinical tests. *PLoS One*. 2014;9:e115282.
13. Clark RA, Pua Y-H. SeeSway–a free web-based system for analysing and exploring standing balance data. *Comput Methods Programs Biomed*. 2018;159:31–36.
14. Clark RA, Mentiplay BF, Pua Y-H, Bower KJ. Reliability and validity of the Wii balance board for assessment of standing balance: a systematic review. *Gait Posture*. 2018;61:40–54.
15. Kempen GI, Yardley L, van Haastregt J, et al. The short FES-I: a shortened version of the Falls Efficacy Scale-International to assess fear of falling. *Age Ageing*. 2008;37:45–50.
16. Herbert RD. Cohort studies of aetiology and prognosis: they're different. *J Physiother*. 2014;60:241–244.

17. Pua Y-H, Seah FJ-T, Clark RA, Poon CL-L, Tan JW-M, Chong H-C. Factors associated with gait speed recovery after total knee arthroplasty: a longitudinal study. *Semin. Arthritis Rheum*. 2017;46: 544–551.
18. Lam HS, Lau FW, Chan GK, Sykes K. The validity and reliability of a 6-metre timed walk for the functional assessment of patients with stroke. *Physiother Theory Pract*. 2010;26: 251–255.
19. Podsiadlo D, Richardson S. The timed "up & go": a test of basic functional mobility for frail elderly persons. *J Am Geriatr Soc*. 1991;39:142–148.
20. Harrell FE Jr. *Regression Modeling Strategies: With Applications to Linear Models, Logistic and Ordinal Regression, and Survival Analysis*. New York, NY, USA: Springer; 2015.
21. Liu Q, Shepherd BE, Li C, Harrell FE Jr. Modeling continuous response variables using ordinal regression. *Stat Med*. 2017;36: 4316–4335.
22. Janssen KJ, Donders ART, Harrell FE Jr, et al. Missing covariate data in medical research: to impute is better than to ignore. *J Clin Epidemiol*. 2010;63:721–727.
23. Mercer VS, Freburger JK, Chang S-H, Purser JL. Step test scores are related to measures of activity and participation in the first 6 months after stroke. *Phys Ther*. 2009;89:1061.
24. 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.
25. Williams G, Kahn M, Randall A. Strength training for walking in neurologic rehabilitation is not task specific: a focused review. *Am J Phys Med Rehabil*. 2014;93:511–522.