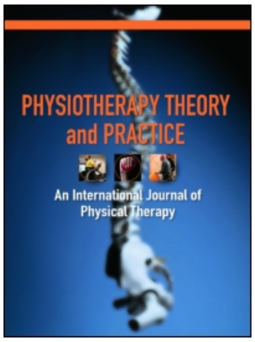

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Associations between changes in gait parameters, balance, and walking capacity during the first 3 months after stroke: a prospective observational study

Ole Petter Norvang MSc, PT, Torunn Askim PhD, PT, Thorlene Egerton PhD, PT, Anne Eitrem Dahl MSc, PT, and Pernille Thingstad PhD, PT

Department of Neuromedicine and Movement Science, NTNU-Norwegian University of Science and Technology, Trondheim, Norway; Department of Physiotherapy, St Olavs Hospital, Clinical Services, Trondheim, Norway; Department of Physiotherapy, Centre for Health Exercise and Sports Medicine, University of Melbourne, Melbourne, Australia

ABSTRACT

Background: Independent ambulation is a common rehabilitation goal after stroke, requiring adequate balance and efficiency of gait. Spatiotemporal gait parameters are expected to improve in the first 3 months and their association with balance and efficiency of gait may provide useful insights into the recovery of safe and independent mobility.
Objective: Examine the associations between changes in spatiotemporal gait parameters, balance, and walking capacity during the first 3 months after stroke.
Methods: This prospective observational study included participants diagnosed with stroke. Within the first 2 weeks after stroke onset and again 3 months (±2 weeks) later, gait was assessed using a GAITRite mat at self-selected gait speed, balance using the Berg Balance Scale (BBS), and walking capacity using the 6-minute walk test (6 MWT). Changes in gait parameters, balance, and walking capacity were assessed using paired sample t-tests, and linear regression analyses were used to assess associations between changes in spatiotemporal gait parameters, BBS, and 6MWT.
Results: Seventy-nine participants (mean (SD) age 75.4 (8.5) years; 44 men) were included. Gait parameters, balance, and walking capacity all improved during follow-up. The bivariate regression analyses showed associations between improvements in all gait parameters, except walk ratio, with improvement in balance, and in all gait parameters with improvement in walking capacity. Only gait speed was associated with balance (13.8 points, 95% CI 0.5, 27.8, $p = .0042$) and walking capacity (256 m, 95% CI 173,340, $p < .001$) in the multivariate analyses.
Conclusion: Improved spatiotemporal gait parameters were associated with improved balance and walking capacity within the first 3 months after stroke.

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Gait; balance; walking ~~capacity~~; stroke; rehabilitation

Introduction

For older people, the ability to walk without the fear of falling is strongly associated with health-related quality of life (Stenhagen, Ekstrom, Nordell, and Elmstahl, 2014). With most spontaneous recovery taking place the first months after stroke (Jorgensen et al., 1995), an early and adjusted rehabilitation is important to regain independence. Following stroke, independent ambulation is reported to be the most frequent self-stated rehabilitation goal (Bohannon, Andrews, and Smith, 1988; Duncan et al., 2007). Walking with adequate postural stability to be safe and avoid falls and a level of gait efficiency that enables a functional level of walking capacity should be a focus in post-stroke rehabilitation (van Ooijen et al., 2015).

Gait speed is well documented as a marker for health and function and is one of the most common and recommended overall measures of gait for older adults (Cummings, Studenski, and Ferrucci, 2014). Following a stroke, most people improve their gait speed during the first 3 months (Fulk, He, Boyne, and Dunning, 2017; Wonsetler and Bowden, 2017), and this improvement is associated with improved community ambulation (Lord et al., 2004; van de Port, Kwakkel, and Lindeman, 2008). However, improved community ambulation also relies on adequate balance and walking capacity (van de Port, Kwakkel, and Lindeman, 2008).

Gait speed is a nonspecific measure and tells us little about gait quality and strategies. Although gait speed is closely associated with other gait parameters, such as cadence, step length, time in single support and asymmetry (Brandstater, de Bruin, Gowland, and Clark, 1983; Roth et al., 1997; Wonsetler and Bowden, 2017), increased speed may not always be the result of improved quality of gait as faster walking may be achieved through developing compensatory strategies

CONTACT Ole Petter Norvang ole.p.norvang@ntnu.no Department of Neuromedicine and Movement Science, Norwegian University of Science and Technology, Trondheim 7491, Norway

(Nadeau, Betschart, and Bethoux, 2013). Compensatory strategies may lead to lower safety or efficiency when walking (Olney and Richards, 1996; Weerdesteyn, de Niet, van Duijnhoven, and Geurts, 2008) and lead to reduced overall capacity and increased risk of falling. Exploring the relationship between other gait parameters and both balance and walking capacity may improve understanding of the importance of quality of gait (Thingstad et al., 2015), and guide rehabilitation following stroke.

Balance is a complex system, involving both motor, sensory, and cognitive components, interacting with each other and with surroundings. A deficiency in any of these systems following a stroke can lead to balance impairments (Zou et al., 2018), and may be related to gait impairments. Previous studies have reported decreased step length and time in single support on the affected side early after stroke (Cruz, Lewek, and Dhaher, 2009; Mizuike, Ohgi, and Morita, 2009; von Schroeder et al., 1995). This spatiotemporal gait asymmetry indicates decreased ability to shift body weight onto the affected side (Patterson et al., 2010; van Dijk et al., 2017). During walking, this reduced ability to shift body weight onto the affected side may be related to the same deficits in motor and/or sensory control systems involved in maintaining balance. Reduced balance control has previously been shown to be associated with gait asymmetry (Hendrickson et al., 2014). However, while most spatiotemporal gait parameters improve early after stroke, gait symmetry may require more targeted rehabilitation for many stroke patients (Patterson et al., 2015; Rozanski et al., 2019).

Gait efficiency is related to energy cost of walking. Following a stroke, compensatory strategies resulting from persistent gait impairments may increase energy expenditure (Awad et al., 2015; Bae et al., 2018; Farris, Hampton, Lewek, and Sawicki, 2015), leading to fatigue (Michael, Allen, and Macko, 2006), and affect walking capacity. For example, improved step length on the affected side may lead to less asymmetry and improve efficiency (Awad et al., 2015). Walk ratio, the ratio of step length to cadence, may be related to gait efficiency as there appears to be an optimal stride length–cadence relationship (Egerton, Danoudis, Huxham, and Iansek, 2011). For stroke patients, an improvement in walk ratio toward that reported for healthy adults (Sekiya and Nagasaki, 1998), would indicate that step length has increased relative to cadence, which may imply improvements in gait efficiency.

Several studies have investigated changes in spatiotemporal gait parameters after stroke (Forrester et al., 2014; Lee, 2015; Verma, Arya, Garg, and Singh, 2011). Spatiotemporal gait parameters have also been associated with both balance (Dobkin et al., 2014; Rose et al., 2018) and walking capacity (Awad et al., 2015; Farris, Hampton, Lewek, and Sawicki, 2015) in cross-sectional and longitudinal studies.

However, investigating how changes in spatiotemporal gait parameters are associated with changes in balance and walking capacity will add further to this enquiry and could provide useful insights into the recovery of safe and efficient gait following a stroke. The aim of this study was therefore to examine the associations between changes in primary and calculated spatiotemporal gait parameters with changes in balance and walking capacity during the subacute phase post stroke. We hypothesize that changes in gait speed, step length, time in single support, and single support asymmetry would be most highly associated with changes in balance, as improvements in these spatiotemporal gait parameters would suggest an improved ability to shift body weight from side to side. In addition, we hypothesize that gait speed, step length, cadence, step length asymmetry, and walk ratio would be most highly associated with walking capacity, as improvements in these spatiotemporal gait parameters would suggest a more efficient gait with less energy expenditure.

Methods

Design

This study used a prospective observation design, with an initial assessment within 14 days and a follow-up assessment 3 months (±2 weeks) post stroke. The study was approved by the Central Regional Committee for Medical and Health Research Ethics (REC number 2011/2517). Informed and written consent was obtained from all participants. As this was an observational study in a comprehensive stroke unit, health and safety were obtained in accordance with standard procedures in the 2010 Norwegian guidelines for the management of stroke (Norwegian Directorate of Health, 2017).

Study setting

All participants were being managed in an evidence-based comprehensive stroke unit that emphasized a multidisciplinary approach and early rehabilitation, with a special focus on early mobilization and independence in daily life. Those in need of rehabilitation after discharge were transferred to a rehabilitation program in accordance with standard procedures in the 2010 Norwegian guidelines for the management of stroke (Norwegian Directorate of Health, 2017). According to the guidelines, patients discharged directly at home received further rehabilitation according to their individual needs. This typically consists of 45 minutes of physiotherapy per week in the patient's home or at an outpatient clinic.

Study population

Between March 2012 and October 2014, people admitted to the stroke unit at Trondheim University Hospital, Norway, were screened for eligibility. Those living in the municipality of Trondheim, diagnosed with first ever or recurrent acute ischemic or hemorrhagic stroke were eligible for inclusion if, within 14 days post stroke, their modified Rankin Scale (mRS) score was 0–3 points (able to walk without personal assistance), they were capable of walking with or without walking aid and without support from another person for 10 m, scored 4–6 points on the item "orientation" on Scandinavian Stroke Scale (SSS) (correct on two out of three on time, place, and situation), suffered from stroke impairments scoring from 0 to 57 points on SSS (max score 58 points), and were capable of providing informed consent. Having a life expectancy of fewer than 6 months, serious impairments prior to the stroke that could have a significant impact on functional outcome or unstable medical condition after acute stroke were exclusion criteria.

Measurements

An experienced physiotherapist (MSc) with more than 9 years of experience from assessment and treatment of patients in an acute stroke unit conducted all assessments. The severity of stroke was scored using the SSS (Askim, Bernhardt, Churilov, and Indredavik, 2016). Activities of daily living (ADL) score were measured with the Barthel Index (Mahoney and Barthel, 1965) and degree of independence with the modified Rankin Scale (mRS) (van Swieten et al., 1988), in order to describe the functional level of the sample and make it possible to be comparable to the general stroke population and other study samples.

Gait was assessed using either a 6.10 m or a 5.49 m GAITRite® mat (CIR systems Inc. Franklin, NJ, USA). To measure gait asymmetry, the ratio between left and right foot was calculated for both step length and single support time. Walk ratio was calculated as the ratio between step length/cadence. Participants were instructed to walk back and forth at a self-selected gait speed, along the walkway which included 1 m at either end for acceleration/deceleration. Walking aids, such as a cane or a walker, were permitted only when necessary for safety reasons. The GAITRite mat has previously shown to be both valid (Bilney, Morris, and Webster, 2003) and reliable (Menz et al., 2004; Webster, Wittwer, and Feller, 2005) for assessing gait.

Berg Balance Scale (BBS) was applied in accordance with the tests manual guide (Berg, Wood-Dauphinee, Williams, and Gayton, 1989) to assess balance. The scale ranges from zero (worst) to 56 (normal balance) points and has been shown to be a reliable and valid measure of balance after stroke (Berg, Wood-Dauphinee, Williams, and Maki, 1992). A change of six points on the BBS is considered the minimal important change (MIC) early after stroke (Saso, Moe-Nilssen, Gunnes, and Askim, 2016).

The 6-minute walk test (6MWT) was used to assess walking capacity using a 20 m track following a standard protocol (Guyatt et al., 1985) where participants were instructed to walk as far as they could in 6 minutes. They were permitted to take a break during the test but informed that the timer would still be running. After each minute, participants were informed of the time remaining. The need for walking aid during testing was a joint decision between participant and physiotherapist and was only for safety. The 6MWT is a widely accepted method for measuring walking capacity (Butland et al., 1982), with a minimal clinically important change between 14.0 m and 30.5 m for adults with pathology (Bohannon and Crouch, 2017).

Data and statistical analysis

Data from the GAITRite mat were processed in the PKMAS® (version 5.07c2) (Egerton, Thingstad, and Helbostad, 2014) and transferred to Microsoft Excel 2016 and IBM SPSS Statistics version 25 for analysis. Demographic data were reported as mean values and standard deviation (SD) for all participants unless otherwise stated. Residuals were visually inspected for normal distribution by Q–Q plots and variables transformed if residuals were not normally distributed. Asymmetry was calculated as the percentage of the logarithm (LN) between the left (L)/right (R) leg ($100x(|LN(L/R))|)$) providing a measure of percentage of asymmetry (Yogev et al., 2007). An average of the spatiotemporal gait parameters from the two walks was calculated. Paired sample t-tests were applied to investigate changes over 3 months in spatiotemporal gait parameters, walking capacity, and balance. Those showing a statistically significant change were applied in bivariate and multiple regression analyses for associations between changes in spatiotemporal gait parameters and changes in either of 6MWT and BBS. Because spatiotemporal gait parameters may influence each other, we set cutoff values for correlations between the parameters at below 0.9 and variance inflation factors

(VIF) >10 for inclusion in the multivariate analysis to avoid collinearity. Therefore, only gait speed, percentage of time in single support, walk ratio, and asymmetry measures were included in the multivariate analysis.

Results

A total of 98 people met the inclusion criteria and were recruited for the study. By 3 months, ten had declined further participation, eight were re-hospitalized and not available, and one participant was lost to follow-up due to technical error. Seventy-nine people (44 men, 55.7%) were therefore included in the final analysis. Table 1 shows demographic and functional data at baseline. Participants were discharged either to a rehabilitation center (n = 24, 30.4%) or home (n = 55, 69.6%) in accordance with their physical and cognitive level. At baseline, fourteen participants used a walker, six participants used a cane or a unilateral crutch, and one participant used bilateral crutches (Table 1). After 3 months, only three participants were still in need of a walker, four participants used a stick or unilateral crutch, and one participant used bilateral crutches.

Table 2 shows changes in the spatiotemporal gait parameters, balance, and walking capacity from the acute phase to 3 months later at self-selected gait speed. Participants increased their gait speed by 18% (0.2 $m\ s^{-1}$, $p < .001$), with 11% longer steps (6.6 cm, $p < .001$), spent 1.2% longer time in single support ($p < .001$), and increased their cadence by 7% (7.7 steps/min, $p < .001$). Walk ratio improved by 3% from 0.58 to 0.60 ($p = .010$). Both asymmetry measures indicated a decreased asymmetry after 3 months, but only step length asymmetry showed a statistically significant decrease (2.5%, $p = .004$). There was a statistically and clinically significant improvement in both balance (10.3 points, $p < .001$) and walking capacity (61 m, $p < .001$).

Table 3 shows the associations between changes in spatiotemporal gait parameters and changes in balance from the acute phase to 3 months later. The bivariate analyses showed a statically significant association, with an increased BBS score of 1.8 points for every 0.1 $m\ s^{-1}$ improvement in gait speed. We found small, but statistically significant associations between increased step length, increased cadence and decreased step length asymmetry with improved balance. For percentage of time in single support, a 1% improvement was associated with an increased BBS score of 1.3 points. Controlling for all included spatiotemporal gait parameters in the multivariate analysis, a significant independent association was only found between increased gait speed and improved balance: 1.4 points increase on BBS per 0.1 $m\ s^{-1}$ increased gait speed (95% CI 0.05 to 27.79, $p = .042$). The multivariate regression analysis had an R^2 value of 0.17 and changes in gait speed explained about a third of the variation in BBS change.

Table 4 shows the bivariate and the multivariate analysis of association for changes in spatiotemporal gait parameters and changes in walking capacity from the acute phase to 3 months later. In the bivariate analysis, for every 0.1 $m\ s^{-1}$ increase in walking speed from baseline, there was a 26.5 m improvement in walking distance as

Table 1. Demographic and functional data at baseline (n = 79). Mean (SD) unless otherwise state.

	Mean (SD)
Age (years)	75.4 (8.48)
Days hospitalized	6.5 (3.3)
Male gender, N (%)	44 (55.7)
Types of stroke	
Embolic stroke, N (%)	75 (94.9)
Hemorrhagic stroke, N (%)	4 (5.1)
Modified Rankin Scale (0–6)	2.7 (1.0)
Barthel index (0–100)	85.7 (14.8)
Scandinavian Stroke Scale (0–58)	51.8 (4.6)
Bergs Balance Scale (0–56)	37.7 (15.5)
6-minute walk test (meters)	400.9 (177.8)
Walking aid at baseline tests	58 (73.4)
None, N (%)	7 (8.9)
Cane, N (%)	14 (17.7)
Walker, N (%)	

SD: Standard Deviation

Table 2. Changes in spatiotemporal gait parameters, balance, and walking capacity from the acute phase to 3 months later at self-selected gait speed.

	Baseline	3 months	Mean change	
	Mean (SD)	Mean (SD)	Mean (95% CI)	p-value
Gait speed ($m\ s^{-1}$)	0.9 (0.3)	1.1 (0.3)	**0.2 (0.1, 0.2)**	**<0.001**
Step length (cm)	55.7 (12.9)	62.3 (13.1)	**6.6 (4.5, 8.6)**	**<0.001**
Stride width (cm)	8.1 (3.1)	7.6 (3.5)	−0.5 (−1.2, 0.2)	0.129
Single support (%)	33.9 (3.6)	35.1 (3.0)	**1.2 (0.5, 1.8)**	**<0.001**
Cadence (steps/min)	96.5 (16.7)	104.2 (12.0)	**7.7 (5.0, 10.4)**	**<0.001**
Walk ratio (step length/cadence)	0.58 (0.11)	0.60 (0.11)	**0.02 (0.01, 0.03)**	**0.010**
Asymmetry step length (%)	7.4 (9.3)	4.9 (4.1)	**−2.5 (−4.1, −0.8)**	**0.004**
Asymmetry single support (%)	5.9 (6.5)	4.8 (4.7)	−1.1 (2.4, −0.2)	0.098
Bergs Balance Scale (range 0–56)	37.7 (15.8)	48.0 (10.0)	**10.3 (7.9, 12.6)**	**<0.001**
6MWT (m)	380 (133)	441 (143)	**61 (41, 79)**	**<0.001**

SD: Standard Deviation, CI: Confidence Interval, 6MWT: 6-Minute Walk Trial; *p*-value <0.05.

Table 3. Bivariate and multivariate associations between changes in spatiotemporal gait parameters and changes in balance from acute phase to 3 months later.

	Bivariate analysis			Multivariate analysis		
	Coefficient (95% CI)	Standardized coefficient	p-value	Coefficient (95% CI)	Standardized coefficient	p-value
Step length (cm)	**0.5 (0.3, 0.8)**	**0.4**	**<0.001**			
Cadence (steps/min)	**0.3 (0.2, 0.5)**	**0.4**	**0.001**			
Gait speed (m s^{-1})	**18.1 (8.3, 27.8)**	**0.4**	**<0.001**	**13.8 (0.5, 27.8)**	**0.3**	**0.042**
Single support (%)	**1.3 (0.5, 2.1)**	**0.3**	**0.003**	0.3 (−1.0, 1.5)	0.1	0.684
Walk ratio (step length/cadence)	22.4 (−17.6, 62.3)	0.1	0.268	11.1 (−27.8, 50.0)	0.1	0.572
Asymmetry step length (%)	**−0.3 (−0.7, −0.1)**	**−0.2**	**0.036**	−0.2 (−0.6, 0.2)	−0.1	0.354

CI: Confidence Interval; *p*-value <0.05.

Table 4. Bivariate and multivariate associations between changes in spatiotemporal gait parameters change in walking capacity from acute phase to 3 months later.

	Bivariate analysis			Multivariate analysis		
	Coefficient (95% CI)	Standardized coefficient	p-value	Coefficient (95% CI)	Standardized coefficient	p-value
Step length (cm)	**6.8 (5.2, 8.3)**	**0.7**	**<0.001**			
Cadence (steps/min)	**5.1 (3.7, 6.5)**	**0.7**	**<0.001**			
Gait speed (m s^{-1})	**265 (209, 322)**	**0.7**	**<0.001**	**256 (173, 340)**	**0.7**	**<0.001**
Single support (%)	**17.4 (11.1, 23.7)**	**0.6**	**<0.001**	1.0 (−6.8, 8.8)	<0.1	0.792
Walk ratio (step length/cadence)	**349.8 (1.6, 698.1)**	**0.2**	**0.049**	−49.9 (−311.5, 211.6)	<-0.1	0.705
Asymmetry step length (%)	**−5.1 (−8.9, −1.4)**	**−0.3**	**0.008**	−0.8 (−3.9, 2.4)	<-0.1	0.619

CI: Confidence Interval; *p*-value <0.05.

measured by the 6MWT. The analysis showed a statistically significant association between increased walking distance and step length (i.e. 6.8 m increase for every extra centimeter of step length). This was also the case for cadence, where an increase in 5.1 m in 6MWT for an increase in cadence of one step/minute. For percentage of time in single support, a 1% improvement was associated with an increased walking capacity of 17.4 m. There was an increase in walking capacity with decreasing spatial and temporal asymmetry, with associations being statistically significant. Controlling for changes in all included spatiotemporal gait parameters, the multivariate analysis showed an increase in walking distance of 25.6 m for every 0.1 m s^{-1} increase in gait speed (95% CI 17.3 to 34.0, $p < .001$). The increase in gait speed accounted for 72% of the variation in change of walking capacity and the multivariate analysis had an R^2 of 0.56.

Discussion

Our results support clinically meaningful improvements in gait, balance, and walking capacity during the first 3 months after stroke. Improvements in step length, cadence, gait speed, percentage of time in single support, and step length asymmetry were all associated with the improvement in balance. Improvements in step length, cadence, gait speed, percentage of time in single support, walk ratio, and step length asymmetry measures were associated with the improvement in walking capacity. However, in the multivariate analysis, only change in gait speed was significantly associated with the changes in balance or walking capacity.

Improvements in many of the spatiotemporal gait parameters are thought to enable safer and more efficient gait. The improved gait speed of 0.2 m s^{-1} is considered clinically significant early after stroke (Fulk et al., 2011; Perera, Mody, Woodman, and Studenski, 2006; Tilson et al., 2010) and a gait speed above 0.8–1.0 m s^{-1} is considered safe in community ambulation. (Studenski et al., 2003). The increased step length and percent of time in single support are suggestive of an improvement in motor control with less time needed in double support (Kollen et al., 2005; Kwakkel, Kollen, and Twisk, 2006). Our results showing decreased step length asymmetry are in accordance with our hypothesis as we expected that early motor recovery would decrease asymmetry. However, single support asymmetry did not change significantly, possibly because it is slower to improve (Rozanski et al., 2019). The increased walk ratio in our study may suggest a more efficient gait, with the ratio moving toward the level of healthy adults (Sekiya and Nagasaki, 1998). The lack of improvement in single support asymmetry and the sustaining associations in multivariate analyses between gait speed and balance and walking capacity raises a question whether our findings are due to compensatory strategies. However, most of the other spatiotemporal gait parameters improve and are associated with both improved balance and walking capacity. Gait speed may be considered as the sum of spatiotemporal gait parameters and may have affected associations between other spatiotemporal gait parameters and balance and walking capacity. We would, therefore, argue that the results found here represent an improvement toward a safer and more efficient gait. It is possible that some participants improve because of compensatory strategies whereas others improvement is due to an improved gait. This aspect could be interesting to study in future studies.

The bivariate analysis shows several associations between changes in spatiotemporal gait parameters and changes in balance. A higher percentage of time in single support on the affected side allows for a longer swing phase of the unaffected leg and would help achieve longer steps. These improvements are also likely to be reflected in the spatial (step length) asymmetry measure (Lewek, Bradley, Wutzke, and Zinder, 2014). There was an association between decreased step length asymmetry and improved balance, suggesting that balance improves as step length asymmetry decreases. When including all gait parameters in the multivariate analysis, most associations disappeared apart from the association between gait speed and balance. Gait speed may therefore effectively be the "sum" of all the other gait parameters (Brandstater, de Bruin, Gowland, and Clark, 1983; Roth et al., 1997; Wonsetler and Bowden, 2017). We hypothesized improved step length would be associated with improved balance. However, because our model breached limits of collinearity, step length was excluded from the multiple analysis. The low R^2 value of 0.17 in the multiple regression model suggests that there are other factors explaining more of the changes in balance. Gait and balance are both complex tasks that rely on the functioning of multiple systems, such as improved vestibular function (Tramontano et al., 2018); improved postural stability (Puckree and Naidoo, 2014); and improved muscle strength (Lund et al., 2018), and it is likely that these systems also can be associated with changes in balance.

The bivariate analysis showed that improvements in several spatiotemporal gait parameters were associated with improved walking capacity. The improvements in spatiotemporal gait parameters are likely to lead to a more efficient gait, with a decreased energy expenditure during walking (Awad et al., 2015; Bae et al., 2018; Farris, Hampton, Lewek, and Sawicki, 2015). It has also previously been shown that walking distance achieved during prolonged walks, such as the 6MWT, is strongly associated with gait speed (Awad et al., 2015). Results from our multivariate analysis show that only changes in gait speed sustained associated with increased walking capacity when including all the variables. This suggests that they were not independently associated with 6MWT when gait speed is also included in the model. The multivariate analyses excluded step length and cadence because of collinearity. However, without breaking the limits, there seems to be collinearity between speed and the other measures that were included in the model. The model had an R^2 of 0.56, showing that improvements in speed over a short 10 m walkway are reflected in improvements in speed over longer distances.

There are some methodological limitations to consider in this study. Our inclusion criteria of being able to walk 10 m without personal assistance will have excluded participants with severe physical impairments from the stroke. The baseline mRS of 2.7, the relatively high BI of 85.7, and a gait speed at baseline close to 1.0 m s^{-1} all suggest that participants were only mildly to moderately affected by the stroke. However, the relatively large standard deviations for both spatiotemporal gait parameters, balance, and walking capacity suggest a heterogeneous group of participants within this mobile cohort. Our results are also in line with data from the Norwegian Stroke Registry from 2017, showing comparable results for stroke severity, functional impairment, and independence in ADL (Norwegian Directorate of Health, 2017).

Participants were permitted to use a walking aid, if necessary, for safety, when walking unassisted on the GAITRite mat and during the 6MWT. The need for a walking aid could be expected to change from the acute phase to 3 months later for several participants. It is likely that the use of a walking aid could influence both gait speed, asymmetry, and efficiency and could question the reliability of the walking tests. The first 3 months after stroke is the period with most spontaneous recovery takes place and it is therefore likely that the need for a walking aid changed. Because we wanted to include a representative group of participants, we chose to include participants in need of a walking aid in the acute phase. This could, however, represent a possibly measurement bias of our results. Therefore, we tested the bivariate and multivariate analysis when excluding those in need of a walking aid at baseline (n = 58). In both analyses, all coefficients pointed in the same direction between improved spatiotemporal gait parameters and improved balance, but improved gait speed was no longer associated with improved balance in the multivariate analysis. This was also the case between improved gait speed and improved walking capacity, with a borderline significance level ($p = .060$) in the multivariate analysis. The lack of associations is possibly caused by the smaller sample size. However, single support asymmetry changed from a non-significant association to a significant association of −5.60 m (−10.25 to 0.94, $p = .020$) with changes in walking capacity. A possible explanation for this change of direction for the coefficient is that the walking aid helped maintain postural stability and therefore masked associations. The post hoc analyses were conducted to control whether the results were affected using walking aids. However, excluding participants in need of walking aids did not change our results.

The BBS is a common, reliable, and valid measure of balance after stroke (Berg, Wood-Dauphinee, Williams, and Maki, 1992). However, most tasks in the BBS are of standing balance. With balance control during gait requiring the ability to adjust relative to the surroundings (Zou et al., 2018) there is a question whether BBS is task-specific enough to capture balance during walking. A measure of balance during walking might have shown different results.

The change of GAITRite mats was done because of an error with the first mat. The only difference between the mats was their length. Although the length of the mat could lead to more steps, we do not expect the change of GAITRite mats to threaten the overall reliability of the study.

Clinical implications

Results from this study show that changes in spatiotemporal gait parameters are associated with changes in both balance and walking capacity over the first 3 months after stroke. Changes in gait speed may be considered as a "sum" of the changes across several gait parameters and is an easy and low-cost parameter to measure. Therefore, assessing gait speed may be helpful when monitoring the safety and efficiency of gait after stroke.

Conclusion

The observed spatiotemporal gait parameters improved from the acute phase to 3 months later. Most were associated with improved balance and walking capacity. The associations suggest that improvements in spatiotemporal gait parameters can reveal the safety and efficiency of gait. The analysis shows that improved spatiotemporal gait parameters do explain improved walking capacity better than improved balance.

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Disclosure statement

The authors report no conflict of interest.

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