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Changes in Gait Symmetry and Velocity After Stroke: A Cross-Sectional Study From Weeks to Years After Stroke

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Abstract

Background. There is little information about the quality of gait in the years following stroke. Long-term changes in mobility, using global indices of function, suggest a decline well after initial rehabilitation. However, global indices of mobility do not reveal more specific changes in walking competency or underlying gait-specific impairment. *Objectives.* The authors used a cross-sectional design with gait-specific measures (velocity and symmetry) to investigate whether deterioration in gait occurs over the long term poststroke. *Methods.* Data were abstracted from a standardized database containing clinical assessments and spatiotemporal gait analyses for 171 individuals with stroke. Velocity and 3 expressions of symmetry ratios (swing time, stance time, and step length) were calculated for each individual; they were then assigned to 1 of the 5 following groups: 0 to 3, 3 to 12, 12 to 24, 24 to 48, and >48 months poststroke. *Results.* Swing time, stance time, and step length symmetry demonstrated a systematic linear trend toward greater asymmetry in groups in the later stages poststroke, whereas velocity, neurological deficit, and lower-extremity (LE) motor impairment did not. *Conclusions.* The quality of gait, as measured by spatial and temporal symmetry, appears to worsen in later years. These results suggest a dissociation between quantitative measures of gait, such as velocity versus symmetry, and that these parameters may measure independent features. A longitudinal study is needed to confirm the presence and to interpret the clinical meaning of a long-term decline in specific parameters of poststroke gait.

Keywords

stroke rehabilitation, gait, symmetry, velocity

Introduction

Walking dysfunction is the most commonly reported limitation after stroke[1] and can profoundly affect independence, quality of life, and participation.[2] The conventional view is that gait improves over the first 3 to 6 months poststroke and then plateaus.[3-7] Some rehabilitation interventions for chronic stroke patients (>1 year duration) have produced gains in the level of independence, walking velocity, and distance walked.[8-11] However, these gains are sometimes lost at follow-up 3 to 9 months later.[8,11] This inability to maintain gains after the period of active rehabilitation may be attributed to several factors. Continuation of the benefits of rehabilitation may depend on continued skilled use of the paretic limb. In addition, persisting limitations for walking after stroke (eg, increased energy cost,[12] control of balance,[13] and musculoskeletal injury to the nonparetic lower extremity [LE][13]) may cause patients to restrict their activity (in spite of a capacity for independent walking), leading to the decline in mobility poststroke described by Wade and colleagues.[8]

There is little information specific to long-term changes in poststroke gait. Previous studies have relied on global indices of mobility such as the Motor Assessment Scale (MAS) and the Rivermead Mobility Index (RMI). These ordinal measures contain a few test items (1 and 5, respectively) that directly address walking at the functional level but do not

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reveal more specific poststroke changes in walking competency (eg, capacity for forward progression, symmetry of the gait pattern). Nevertheless, studies using these measures provide some evidence of decline poststroke after rehabilitation. Langhammer and Stanghelle[14] found a decline in MAS scores at 1 year poststroke and a further decline at 4 years poststroke.[14] In contrast, 2 studies using the RMI found no change in mobility status over the first and second years poststroke.[15,16] However, although RMI did not change over time when averaged across the entire group, a subset of individuals did exhibit a decline in mobility (12.2% and 42.6% of the 2 study groups, respectively).[15,16]

Although mobility measures such as the MAS and RMI are useful to indicate an individual's level of function, they are unlikely to be sensitive to persisting gait-specific challenges associated with stroke. Although improved function is the overall aim of rehabilitation, the interventions are targeted at the level of gait-related impairments, and therefore, these should be measured directly.

Two gait-specific parameters relevant to the stroke population are velocity and symmetry. Velocity is a widely used measure of gait performance and can differentiate levels of disability in the stroke population.[7] In contrast, symmetry provides a measure of the parallels between the 2 lower extremities; specifically, interlimb ratios of step length, swing time, and stance time provide some insight into the underlying control of gait.[17,18] It is important to include both these measures because there are likely times when the 2 classes of measures are not strongly associated (eg, individuals exhibiting very low walking speed but normal symmetry).[13,19,20] What is important is that measures such as gait velocity and symmetry are responsive to a variety of rehabilitation interventions in the short term,[21-25] but little is known about how these parameters might change in the long term, once rehabilitation is complete. A small study (n = 8) previously revealed that the poststroke asymmetrical pattern was accentuated over 10 years, whereas no differences in velocity were found.[26] Our study used a cross-sectional design to extend these earlier observations and to investigate the potential for significant deterioration in gait in the years after a stroke. The hypothesis was that there would be a progressive, linear decline. This would be evident by a decrease in gait velocity and an increase in gait asymmetry, including step length, swing time, and stance time symmetry ratios.

Methods

Data were abstracted from an ongoing database that includes individuals with stroke recruited at 2 institutions: the Toronto Rehabilitation Institute and the Sunnybrook site of the Heart and Stroke Foundation Centre for Stroke Recovery. All the original studies were approved by the Research Ethics Boards at these institutions. All participants provided written informed consent.

Participants were selected from this database if they had sustained first occurrence of a unilateral stroke (hemorrhagic or ischemic) and had completed an overground, preferred-pace walking task without assistance or a gait aid. Note that this measurement of walking was simply added on to an individual's routine clinical assessment (follow-up) by a neurologist or therapist. Some participants had more than 1 visit recorded in the database. In these cases, a single visit was randomly selected for each individual. We included 171 participants in the analysis.

Measurements

The database included clinical and laboratory gait assessments.

Clinical assessment. The clinical assessment consisted of 2 stroke-specific measures: the National Institutes of Health Stroke Scale (NIHSS) and the Chedoke McMaster Stroke Assessment (CMSA). The NIHSS is a measure of stroke-related neurological deficit, and the reliability and validity of this measure have been established.[27] The leg and foot dimensions of the CMSA (each measured with a 7-point scale) were used as a measure of motor impairment. Lower scores indicate greater motor impairment. The CMSA has good intrarater and interrater reliability as well as good concurrent validity with the Fugl-Meyer assessment.[28,29]

Spatiotemporal gait measures. Spatiotemporal parameters of gait were measured using a pressure-sensitive mat (GAITRite, CIR Systems, Clifton, NJ). The GAITRite mat is 366 cm in length and 81 cm in width and contains a grid of 48 × 288 sensors (total of 13 824 sensors) arranged 1.27 cm on the center. The system records footfalls by the location of activated sensors and also the time of activation/deactivation. Data were sampled at 30 Hz and stored in a personal computer that calculated spatial and temporal parameters using application software. Participants walked across a level walkway over the pressure-sensitive mat at their preferred, comfortable speed. The participants began and stopped walking at least 150 cm before and after the mat so as to ensure steady-state gait throughout the test. A total of 3 walking trials were recorded and stored for offline analysis.

Data and Statistical Analysis

Gait symmetry calculations. The output from the GAITRite application software was exported as a text file and opened in a spreadsheet using Microsoft Office Excel 2003 for further calculations. All spatiotemporal values were averaged over the 3 walking trials; 3 gait symmetry measures (2 temporal and 1 spatial) were calculated as ratios of the spatiotemporal values from the left and right limbs that were averaged over the 3 walking trials (time was reported in seconds and length was reported in centimeters).

Temporal symmetry includes the following:

Swing time symmetry = Larger swing time/smaller swing time.

Stance time symmetry = Larger stance time/smaller stance time.

Spatial symmetry includes the following:

Step length symmetry = Larger step length/smaller step length.

A sign convention, as previously recommended, was used to indicate the direction of asymmetry.[17] A negative symmetry ratio indicates that the nonparetic value (ie, swing time, stance time, or step length) was larger, and a positive symmetry ratio indicates that the paretic value was larger.

Time poststroke groups. To examine group differences in gait characteristics and motor impairment, participants were grouped according to months poststroke at the time of the visit recorded in the database. Participants were assigned to 1 of the 5 following stages poststroke: 0 to 3, 3 to 12, 12 to 24, 24 to 48, and >48 months poststroke.

Statistical analyses. All statistical analyses were performed using SAS 9.1 (SAS Institute Inc, Cary, NC). One-way analyses of variance (ANOVAs) were used to compare the 5 poststroke groups on age, gender, and hemiparetic side. Two-way ANOVAs (poststroke group with 5 levels, direction of asymmetry with 2 levels) were computed on swing, stance, and step length symmetry ratios. Finally, 1-way ANOVAs were computed on velocity, NIHSS, and CMSA leg and foot scores. To test the study hypothesis that gait asymmetry and gait velocity are worse in later stages poststroke, contrast analyses were computed on the 3 symmetry measures and velocity across the 5 groups to look for significant linear trends in the data. This analysis was also carried out for NIHSS and CMSA foot and leg scores to check for recruitment bias (ie, increased likelihood of recruiting individuals with greater impairment at later stages poststroke). Rank transformations were performed prior to analysis on data that were not normally distributed as well as on ordinal data (ie, NIHSS, CMSA). Post hoc analysis (Tukey) was conducted to assess the specifics of group differences revealed by the ANOVA that were not consistent with the prior hypothesized linear trends.

Results

Participants

The database contained data from 194 individuals. The number of individuals excluded and the reasons for exclusion were as follows: 8 because of a second stroke, 2 because gait analysis was completed with a cane, 6 because the exact date of stroke was missing, 6 because they did not have a confirmed diagnosis of stroke, and 1 because too few steps were recorded by the pressure-sensitive mat. Of the remaining 171 individuals, 39 had more than 1 visit recorded in the database. A single visit was randomly selected for each of these 39 individuals. In total, 171 visits (from 171 unique participants) were used in the analysis. The mean (standard deviation) age of the group was 63.2 (13.3) years, and the mean time poststroke was 23.3 (31.1) months. A total of 60 participants (35%) were women, and 82 (48%) exhibited right hemiparesis. The mean values of gait measures for the entire group were as follows: velocity 73.07 (32.92) cm/s, swing time symmetry 1.24 (0.33), stance time symmetry 1.09 (0.10), and step length symmetry 1.13 (0.25). The mean NIHSS for the entire group was 2.6 (2.3), and mean CMSA leg and foot scores were 5.1 (1.4) and 4.8 (1.5), respectively. The 5 poststroke groups were not significantly different in mean age, proportions of men and women, or proportions of individuals with left and right hemiparesis. A summary of demographic variables, direction of asymmetries, and clinical measures for the entire group and each of the 5 poststroke groups is included in Table 1.

Differences in Gait Symmetry

The mean swing time, stance time, and step length symmetry values for each poststroke group are included in Figure 1. Two-way ANOVAs computed on swing time symmetry and stance time symmetry revealed a significant main effect for stage poststroke (swing: $F = 3.92$, $P < .01$; stance: $F = 2.83$, $P = .03$) but no main effect for direction of asymmetry (swing: $F = 2.10$, $P = .15$; stance: $F = 0.45$, $P = .50$) and no significant interaction (swing: $F = 0.79$, $P = .53$; stance: $F = 1.54$, $P = .19$). A 2-way ANOVA computed on step length symmetry revealed a significant main effect for stage poststroke ($F = 3.56$, $P < .01$) but no main effect for direction of asymmetry ($F = 0.34$, $P = .56$). In contrast to swing and stance time asymmetry, there was a significant interaction between stage poststroke and direction of step length asymmetry ($F = 4.33$, $P < .01$). Contrast analysis revealed a linear trend in swing time ($F = 13.71$, $P < .01$), stance time ($F = 10.34$, $P < .01$), and step length ($F = 7.27$, $P < .01$) symmetry values over the 5 poststroke groups (Figure 1).

Differences in Gait Velocity

The mean gait velocity for each poststroke group is included in Figure 2. Note that the average velocity for the entire group, 73.07 (32.92) cm/s, is considerably lower compared with reported values for healthy adults aged 60 to 69 years (139.5 [20.9] cm/s for men and 129.6 [21.3] cm/s for women).[30] In contrast to symmetry, the 1-way ANOVA revealed no significant main effect of stage poststroke ($F = 1.36$; $P = .25$), and contrast analysis revealed no significant linear trend in gait velocity ($F = 1.27$; $P = .36$). This difference in the group trends between velocity and symmetry

Table 1. Study Group Demographics and Clinical Measures[a]

	Whole Group (N = 171)	0-3 Months (n = 62)	3-12 Months (n = 27)	12-24 Months (n = 26)	24-48 Months (n = 27)	>48 Months (n = 29)
Age (years)	63.2 (13.3)	65.2 (13.2)	63.4 (10.6)	66.4 (11.5)	61.2 (16.1)	57.5 (13.1)
Percentage of women	35	34	37	39	22	45
Time poststroke (months)	23.3 (31.1)	1.2 (0.7)	7.1 (3.0)	17.4 (3.1)	32.5 (7.4)	82.7 (26.7)
Percentage with right hemiparesis	48	39	52	54	48	59
Percentage ± swing time symmetry ratio	36/64	27/73	30/70	58/42	48/52	31/69
Percentage ± stance time symmetry ratio	65/35	71/29	70/30	46/54	52/48	76/24
Percentage ± step length symmetry ratio	49/51	56/44	41/59	42/58	48/52	48/52
NIHSS (0-42)	2.6 (2.3) [1.0-4.0]	3.5 (2.4) [2.00-5.0]	1.6 (2.2) [0-2.0]	2.6 (2.6) [1.0-4.0]	2.0 (1.7) [1.0-3.0]	2.0 (1.9) [1.0-3.0]
CMSA leg (1-7)	5.1 (1.4) [4.0-6.0]	5.0 (1.1) [4.0-6.0]	5.6 (1.5) [5.0-7.0]	5.3 (1.3) [5.0-6.0]	4.7 (1.5) [3.0-6.0]	4.7 (1.8) [3.0-6.0]
CMSA foot (1-7)	4.8 (1.5) [4.0-6.0]	4.8 (1.1) [4.0-6.0]	5.5 (1.8) [3.0-7.0]	4.9 (1.7) [3.0-6.0]	4.2 (1.7) [3.0-6.0]	4.6 (1.7) [3.0-6.0]
Percentage of whole group (N = 171)	—	36	16	15	16	17

Abbreviations: NIHSS, National Institutes of Health Stroke Scale; CMSA, Chedoke McMaster Stroke Assessment.

[a]Summary of mean (standard deviation) values for demographic variables and clinical measures for the entire study group as well as each of the 5 poststroke groups. The first and third quartile values are included in square brackets. Finally, the distribution of the direction of asymmetry for each of the 3 symmetry ratios (−, larger nonparetic value; +, larger paretic value) is indicated (as a percentage of the group) for the whole group and each poststroke group.

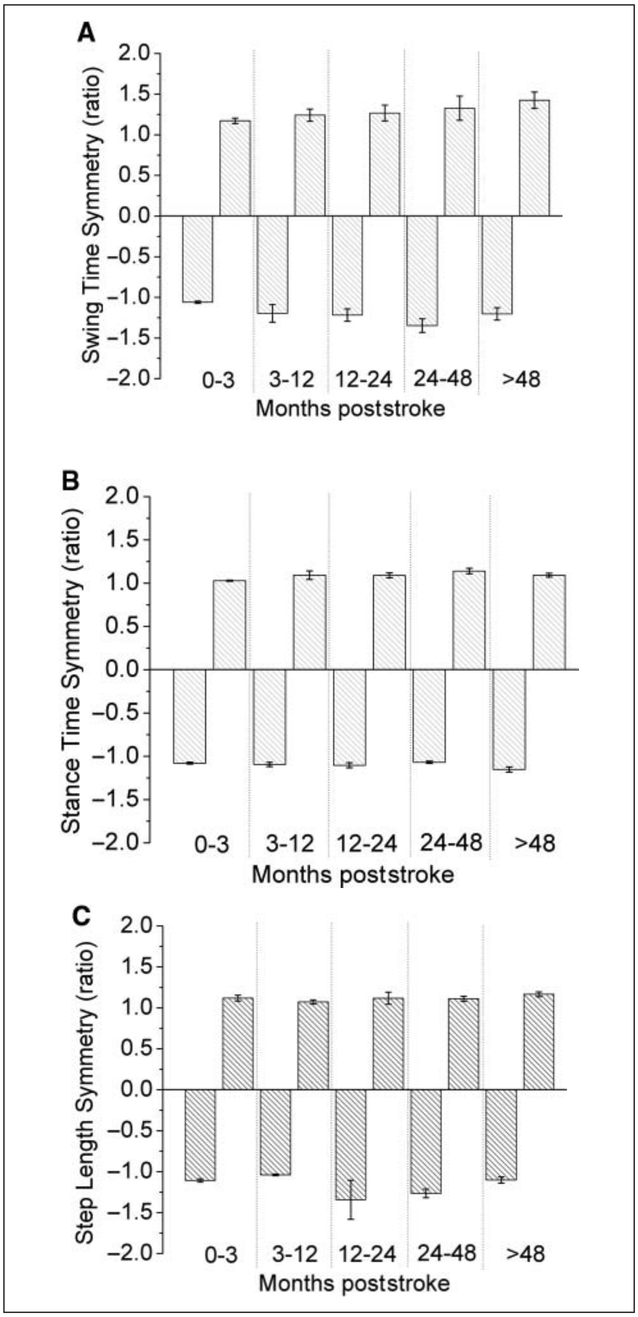

Figure 1. Temporal and spatial symmetry: (A) Swing time symmetry (F = 13.71; P < .01). (B) Stance time symmetry (F = 10.34; P < .01). (C) Step length symmetry (F = 7.27; P < .01)[a]
[a]Mean symmetry values for each poststroke group demonstrating a significant linear trend across the groups for temporal asymmetry and spatial asymmetry. Negative values indicate asymmetry in the direction of the nonparetic lower limb (ie, larger nonparetic value), and positive values indicate asymmetry in the direction of the paretic lower limb.

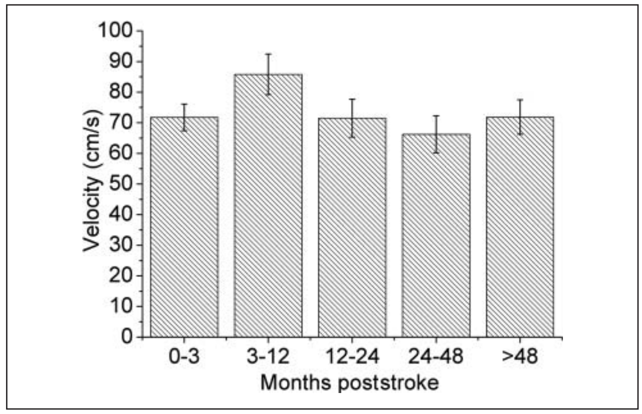

Figure 2. Gait velocity: mean gait velocity values for each time group demonstrating no main effect for stage poststroke (F = 1.36; P = .25) and no significant linear trend (F = 1.27; P = .36)

reveals a potentially important dissociation in behavior (ie, no linear trend vs linear trend) across the poststroke groups. Interestingly, this dissociation does not conflict with the more global association between symmetry and velocity because Pearson correlations, using the entire study group (N = 171), revealed a significant negative relationship between velocity and all 3 symmetry measures (swing: r = –0.54; stance: r = –0.48; step: r = –0.46; all P < .01) as has been reported in previous studies.[13,20,31,32]

Differences in Neurological Deficit and Motor Impairment

The mean NIHSS scores for each poststroke group are included in Figure 3. One-way ANOVA revealed a main effect for stage poststroke (F = 4.38; P < .01); however, no significant linear trend was found with contrast analysis (F = 2.48; P = .12). A post hoc Tukey analysis revealed a significant difference in NIHSS scores between the 0- to 3-month and 3- to 12-month poststroke groups. The mean NIHSS score was lower in the 3- to 12-month group (also noted in Figure 3).

The mean CMSA leg and foot scores for each poststroke group are included in Figure 4. There was no significant main effect of stage poststroke (F = 2.02; P = .09), and contrast analysis revealed no significant linear trend in CMSA leg scores across the 5 poststroke groups (F = 2.58; P = .11). In contrast, 1-way ANOVA computed on CMSA foot scores revealed a significant main effect for stage poststroke (F = 2.45; P = .05). However, no significant linear trend was found with contrast analysis (F = 3.20; P = .08). A post hoc Tukey analysis revealed a significant difference in CMSA foot scores between the 3- to 12-month and 24- to 48-month poststroke groups. The mean CMSA foot score was lower in the 24- to 48-month group (also noted in Figure 4). As mentioned for velocity above, our results are consistent with the more global association between symmetry and motor impairment, as reported in previous studies.[13,31,33,34] Pearson correlations (using the entire study group, N = 171) revealed a significant negative relationship between CMSA leg scores and all 3 symmetry measures (swing: r = –0.58; stance: r = –0.52; step: r = 0.41;

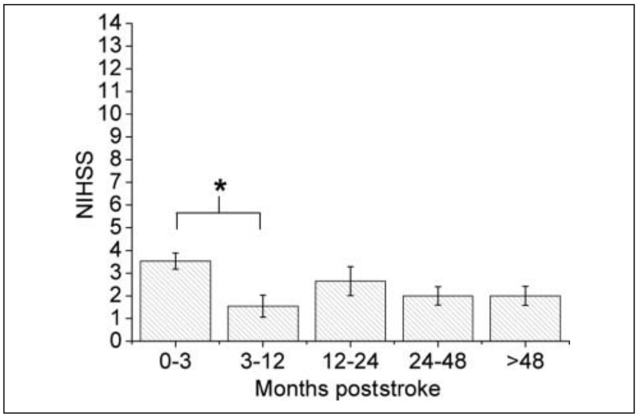

Figure 3. Neurological deficit: mean National Institutes of Health Stroke Scale (NIHSS) scores for each time group demonstrating a significant main effect for stage poststroke ($F = 4.38$; $P < .01$) but no significant linear trend ($F = 2.48$; $P = .12$).
[a]Significant differences between groups are indicated by an asterisk, and error bars represent standard error.

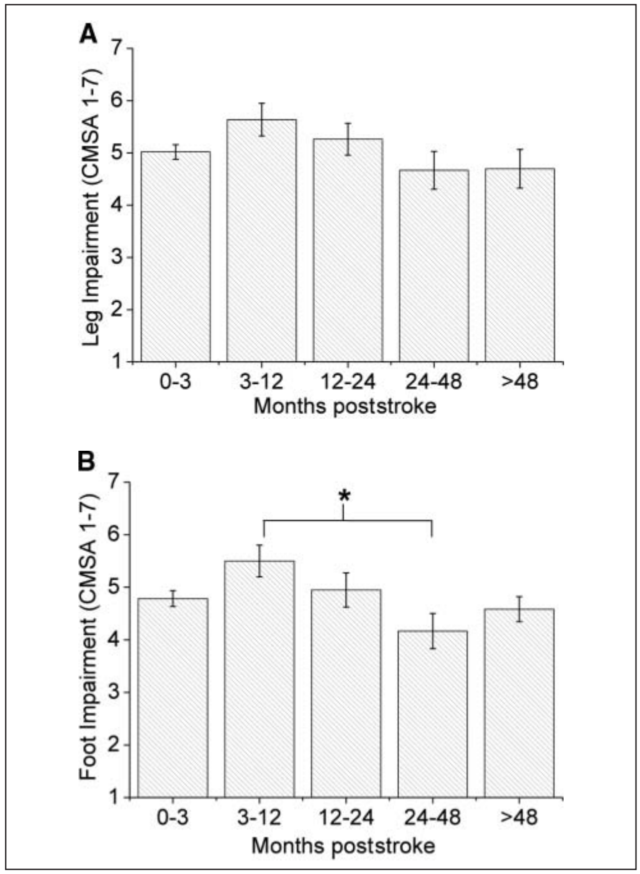

Figure 4. Lower limb motor impairment: mean Chedoke-McMaster Stroke Assessment (CMSA). (A) Leg scores for each time group. (B) Foot scores for each time group[a]
[a]Part A demonstrates that there is no significant main effect for poststroke group ($F = 2.58$; $P = .11$) and no significant linear trend ($F = 0.05$; $P = .82$). Part B demonstrates the significant main effect for poststroke group for CMSA foot scores ($F = 2.45$; $P = .05$) but no linear trend ($F = 3.20$; $P = .08$). Significant differences between groups are indicated by an asterisk, and error bars represent standard error.

all $P < .01$) as well as between CMSA foot scores and the symmetry measures (swing: $r = -0.59$; stance: $r = -0.53$; step: $r = -0.41$; all $P < .01$).

Discussion

This preliminary, cross-sectional study indicates that swing time, stance time, and step length asymmetries are worse in the later stages poststroke. In contrast, gait velocity, neurological deficit, and motor impairment did not exhibit the same systematic differences across the stages poststroke. The current finding of stable gait velocity and worsening gait asymmetry is consistent with previous work by Turnbull and Wall.[26] However, our results differ from a cross-sectional study of 49 individuals with stroke by von Schroeder and colleagues, which found an increase in velocity over the first 12 months poststroke and a constant pattern of temporal asymmetry (although actual symmetry ratios were not reported).[35] With respect to the von Schroeder et al[35] work, the current study featured a larger, more gait-impaired study group (ie, slower and more asymmetric). Therefore, the probability of revealing changes in asymmetry would be greater in the present sample.

Previous work has found that the timing of gait phases (eg, stance phase, double support phase) in healthy adults is consistent regardless of gender or age.[36] Therefore, it is unlikely that the trend for increasing asymmetry and thus the decline in gait control, observed in the current study, can be attributed to increasing age alone. In addition, the absence of change in velocity among the same individuals contradicts the view that increases in asymmetry are a product of a more general age-related decline in gait performance. One limitation of the current study is that the database used in the analysis does not contain information about possible contributing factors to gait decline (eg, amount of daily walking activity, orthopedic conditions, and cardiovascular conditions). This limits our ability to suggest possible mechanisms of the observed trend for increasing asymmetry.

In contrast to temporal symmetry measures, the step length asymmetry ratio exhibited a more complex pattern. Although there was a significant main effect of stage poststroke, there was also a significant interaction between stage poststroke and the direction of asymmetry. This difference across the stages poststroke, comparing temporal versus spatial symmetry, is consistent with the idea that there are important distinctions between spatial and temporal gait symmetry.[17]

As mentioned above, gait velocity did not exhibit a linear trend across the stages poststroke. Velocity is more strongly associated with gait phases of the nonparetic LE compared with the paretic LE.[20] This may reflect adaptive behaviors of the nonparetic LE that compensate for the affected LE.[20] It is possible that once behavioral compensations have been developed and refined in the subacute period, an individual may not deviate from his or her poststroke preferred walking velocity, and thus, velocity remained relatively constant in the present study. Perhaps of more interest is the apparent difference between measures of gait velocity and symmetry when examined across the stages poststroke (ie, linear trend in symmetry measures but not velocity). As noted, this dissociation is independent of the relatively strong association between velocity and symmetry (assessed across all individuals) found in the present and previous work.[13,20,31,32] The difference in the behavior of these 2 variables across the stages poststroke indicates that they may measure separate features of poststroke gait.

It could be argued that in such cross-sectional studies, there may have been selection bias: patients with more severe deficits were more likely to be recruited in the later stages poststroke than patients with less severe impairments. The individuals included in the database used in the current study were seen for routine clinical follow-up or were recruited for a variety of studies (none of which were specifically focused on gait interventions). Examples of such studies include aerobic training and bilateral upper-extremity training. Therefore, the current sample likely represents a range in stroke severity and gait function because individuals were seen either for general clinical purposes not specifically related to gait or for studies that did not have strict inclusion/exclusion criteria with respect to gait. We also think that recruitment bias is unlikely to be a significant concern because stroke severity as defined by both neurological deficit (NIHSS) and motor impairment (CMSA) did not exhibit a linear trend of worsening severity across the groups. However, similar to the dissociation between velocity and symmetry, the difference in trends between limb-specific impairment (CMSA) and gait-specific impairment (symmetry) is a potentially important observation.

There is a prevailing clinical belief that gait asymmetry is merely an individual's compensation for LE motor impairment. Indeed, motor impairment is significantly associated with gait asymmetry as demonstrated in both the present and previous studies.[13,31,33] However, it has also been shown that individuals with mild motor impairment (eg, CMSA scores of 5-7) may exhibit temporal asymmetry.[13,17] Therefore, motor impairment alone is unlikely to account for all the variation of gait asymmetry observed in the poststroke population. The current results further support this assertion. If gait asymmetry is simply a compensation for LE impairment and the two are tightly linked, then the systematic increase in symmetry values, across the poststroke groups, would not have been expected because the CMSA scores did not show the same trend. The current study reinforces the need for better understanding the link between parameters of walking. These matters remain important to resolve as they greatly affect the focus of therapy and would help guide gait rehabilitation interventions.

Implications

We believe that the asymmetrical gait pattern warrants increased attention both clinically and in research for several reasons. First, gait asymmetry may be associated with many potential negative issues (eg, challenges to balance control, increased energy expenditure, increased risk of musculoskeletal injury to the nonparetic LE, and decreased overall activity levels[13]). Second, current results support the concept that velocity and symmetry measure separate characteristics of gait. Third, the current results indicate that gait asymmetry clearly persists and may progress in the long term poststroke. A prospective, longitudinal study is warranted to further investigate this potential decline in gait. If the current results are supported, then new approaches to poststroke gait will be needed.

Authors' Note

Dr Brooks holds a Canada Research Chair in Rehabilitation (Tier 2). Dr Black holds the Brill Chair in Neurology, University of Toronto. The views expressed do not necessarily reflect those of the funding agencies.

Declaration of Conflicting Interests

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