Improving Spatiotemporal Gait Asymmetry Has Limited Functional Benefit for Individuals Poststroke

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Background and Purpose: Prior literature suggests a relationship between spatiotemporal gait asymmetry and metabolic cost of walking, balance, endurance, quality of life, and physical activity in people with chronic stroke. Our purpose was to determine whether targeting spatiotemporal gait symmetry would concomitantly improve these measures.

Methods: This study represents secondary outcome measures from a trial in which 48 participants with chronic stroke were randomized to groups that all targeted spatiotemporal gait asymmetry. Measures of balance, daily step count, endurance (6-minute walk test [6MWT), metabolic cost of walking, quality of life (Stroke Impact Scale [SIS]), and overground spatiotemporal asymmetries were collected 1 week prior to and following training. Separate analyses were performed for those who trained for spatial versus temporal asymmetry. The effect of time (pre/post) was examined for all measures and correlational analyses evaluated the potential relationships between changes in spatiotemporal asymmetry and all other measures.

Results: Individuals who trained to target step length asymmetry improved balance, 6MWT distance, metabolic cost of walking, and SIS-Mobility. Individuals who trained to target stance time asymmetry improved balance, 6MWT distance, SIS-Mobility, and SIS-Global recovery scores. However, step length asymmetry improvements were only related to improved 6MWT distance ($P = 0.025$; $r = -0.49$). Stance time asymmetry improvements were only related to improved metabolic cost of walking ($P = 0.031$; $r = 0.558$).

Discussion and Conclusions: Despite a targeted training approach and noted improvements in most measures, these changes did not appear to arise from improved spatiotemporal gait asymmetry. Furthermore, improvements in gait function observed in the laboratory setting did not appear to translate to increased community mobility.

Video Abstract available for more insights from the authors (see the Video, Supplemental Digital Content 1, available at: http://links.lww.com/JNPT/A316).

Key words: *community mobility, human movement system, physical activity, stance time, step length*

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INTRODUCTION

Individuals recovering from stroke often experience challenges in relearning to walk that yield gait speeds that do not represent full recovery.[1] Gait speed, however, is just one metric associated with mobility poststroke, and may actually represent compensation, rather than recovery.[2] Given the profound hemiparesis and unilateral altered motor control that persists poststroke, the presence of spatiotemporal gait asymmetry is ubiquitous in this population.[3,4] Consequentially, spatiotemporal gait asymmetry has served as a target of treatment for individuals after stroke.[5,6] Although some have argued that gait asymmetry should be a natural consequence of an asymmetric motor system,[7] others have noted that symmetric movements remain possible and should be encouraged.[8] Our recent work showed that improvements in spatiotemporal gait asymmetry through targeted training were related to improvements in gait speed,[5] suggesting that step length asymmetry is a suitable target for also improving gait speed.

Despite the attention given to gait speed in the literature,[1,9,10] other measures across the International Classification of Functioning, Disability and Health (ICF) spectrum should be considered. For example, an increase in gait speed may not mean as much if daily walking activity and perceptions of quality of life do not improve. This is particularly important given the already decreased daily walking, at home and in the community, performed by individuals poststroke compared to age-matched peers.[11,12] It is possible that individuals poststroke perform less daily walking due to diminished endurance from a higher metabolic cost of walking.[13] Additionally, individuals recovering from stroke may self-limit daily walking to contend with the increased risk of falls during walking,[14,15] due, in part, to deficits in dynamic balance,[16,17] and a fear of falling due to a lack of confidence in their paretic limb.[18] Overall, many of these gait-related deficits may influence stroke-related quality-of-life measures, which are diminished for individuals recovering from stroke.[19-21] Consequently, these myriad issues need to be addressed with an appropriate therapeutic target.

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Importantly, cross-sectional studies have related spatiotemporal gait asymmetry to deficits in dynamic balance,[22,23] metabolic cost of walking,[24,25] stroke severity,[26] and endurance.[27] The presence of these relationships across a cohort suggests that improving spatiotemporal asymmetry for an individual may yield improvements in these associated factors. Furthermore, several authors have speculated that improving spatiotemporal gait asymmetry might also lead to improvements in participation/physical activity and quality-of-life measures.[28,29] It is currently unknown, however, whether decreasing spatiotemporal gait asymmetry will lead to concomitant improvements in balance, metabolic cost of walking, endurance, community mobility, and perceived quality of life.

Given the observational cross-sectional analyses, which suggest a significant relationship between spatiotemporal gait asymmetry and gait economy, balance, and endurance in people with chronic stroke, our purpose here was to determine whether targeting spatiotemporal gait symmetry would concomitantly alter these outcome measures. We hypothesize that individuals with a greater reduction in spatiotemporal gait asymmetry will have greater improvements across all secondary outcome measures.

METHODS

Setting and Participants

The study was a secondary analysis of a randomized controlled trial[5] in which we recruited 48 individuals with chronic hemiparesis who were at least 6 months poststroke (Table 1). The intent of that study was to determine which motor learning strategy (error augmentation or error minimization) best improves overground spatial and temporal gait symmetry in individuals with chronic hemiparesis poststroke. Because our intent here was not to examine the effect of specific interventions, we collapsed participants in the error augmentation, error minimization, and control group into one group for analysis of secondary outcome measures. Participants were included if they had an overground comfortable gait speed less than 1.0 m/s (using assistive devices and bracing below the knee as needed) and exhibited a step length asymmetry of more than 0.537 or stance time asymmetry of more than 0.524. These thresholds represent a doubling of the minimal detectable change (MDC)[30] so as to exceed the cutoffs to establish asymmetry.[3] Asymmetry measures were defined as: max(paretic, nonparetic)/(paretic+nonparetic). Participants were excluded for cerebellar lesions, uncontrolled cardiorespiratory/metabolic disease, other neurologic disorders, or orthopedic injury that may affect gait, botulinum toxin to the lower limb in the past 6 months, or concurrent physical therapy. All subjects received medical clearance to participate in training and signed an informed consent approved by the University of North Carolina-Chapel Hill Institutional Review Board. The trial was listed on Clinicaltrials.gov (NCT01598675).

Table 1. Subject Demographics

	Step Length Asymmetry Intervention Group (n = 21)	Stance Time Asymmetry Intervention Group (n = 16)
Sex	13 M, 8 F	9 M, 7 F
Paretic limb	9 R, 12 L	7 R, 9 L
Assistive device	16	9
Baseline gait speed, m/s	0.36 ± 0.25	0.48 ± 0.20
Age, y	58.96 ± 13.08	59.61 ± 11.43
Time since stroke, y	3.79 ± 4.06	3.08 ± 2.06

Abbreviations: F, female; L, left; M, male; R, right.

Intervention

Thirty-seven participants completed all 18 gait training sessions over 6 to 9 weeks. During each training session, participants walked for up to 20 minutes on a treadmill (FIT, Bertec Corp, Worthington, Ohio) followed by up to 15 minutes of practicing overground walking. Details of training are presented elsewhere.[5] Briefly, the ratio of treadmill belt speeds was based on real-time, step-by-step performance of gait asymmetry, and was adjusted to either augment, minimize, or not modify asymmetry based on group assignment. Verbal feedback from the treating therapist was provided to all participants to improve symmetry, regardless of group assignment.

Testing and Outcome Measures

We collected all primary and secondary outcome measures during a pretraining session (completed 1 week before training began) and during a posttest session (1 week following the last training session). The primary outcome measures of the original study included overground gait speed and spatiotemporal gait asymmetry captured using an instrumented gait mat (GAITRite; CIR Systems, Franklin, New Jersey), which have been reported previously.[5] In addition, we assessed daily physical activity, quality of life, balance, gait endurance, and metabolic cost of walking. Daily physical activity was measured using an activity monitor (Stepwatch Activity Monitor [SAM]; modus health, Edmonds, WA) placed around the nonparetic ankle during waking hours for 5 to 7 consecutive days. Participants wore the SAM prior to the first training session (pretest) and after the final training session (posttest). We assessed stroke-specific quality of life (QoL) using the Stroke Impact Scale (SIS), which has been shown to have excellent psychometric properties in individuals poststroke.[31] We assessed gait endurance using the 6-minute walk test (6MWT), which has excellent test-retest reliability in individuals with chronic stroke.[32]

Testing was performed in a hallway, as participants walked back and forth around tape marks placed 100 ft apart. Participants were instructed to walk at a quick, but comfortable, pace so that they could cover as much ground as possible during the test without having to stop. The distance travelled during each minute was recorded, as was the total distance travelled in the 6-minute timeframe. During the 6MWT, we measured O_2 cost using a portable metabolic cart (K4b2, Cosmed, Chicago, Illinois). Volumes of inspired and expired air were sampled on a breath-by-breath basis during quiet sitting for 5 minutes prior to testing as well as continuously during the 6MWT. The net volume of oxygen (ie, walking – sitting) was divided by body mass and distance walked to quantify the metabolic cost of walking (volume of oxygen in mL/kg/m walked).[33,34] To assess balance, we used the Berg Balance Scale (BBS), which is used extensively in individuals poststroke but may have significant floor and ceiling effects.[35] For this reason, we used the BBS in conjunction with the Four Square Step Test (4SST). The 4SST is a feasible and valid test of dynamic standing balance sensitive to change in stroke rehab.[36]

Statistical Methods and Data Analysis

We performed data analyses with SPSS (ver 26, IBM, Armonk, New York). We lost posttraining metabolic data from 2 participants due to user error; for another participant we did not acquire pretraining daily step activity due to participant adherence. For all other participants and all other outcome measures (6MWT, metabolic cost, daily stepping, BBS, 4SST, and SIS), we first assessed the effect of training (ie, pre vs post) on each of the outcome measures using paired-samples *t* tests. Effect sizes were calculated based on Cohen's *d*. We then computed the change in each outcome measure (post vs pre) and assessed the potential relationship between the change in spatiotemporal asymmetry and the change in each outcome measure using Pearson or Spearman rank correlation analyses, as appropriate. To aid in the interpretation of changes, we counted the number of participants who exceeded established MDC (or minimally clinically important difference [MCID], where available) values.

RESULTS

As individuals who trained to improve step length symmetry exhibited improvements in step length symmetry ($P = 0.004$; $d = 0.71$),[5] they also demonstrated improvements in additional measures after the 6 weeks of training (Table 2). Participants significantly improved their balance, as demonstrated by scores on the BBS ($P = 0.002$; $d = 0.76$) and the 4SST ($P = 0.048$; $d = 0.46$). Despite a significant improvement for the group as a whole, only 7 (out of 21) participants exceeded the MDC for the BBS.[37] During the 6MWT, participants improved the distance walked ($P < 0.001$; $d = 1.14$) and metabolic cost of walking ($P = 0.032$; $d = 0.52$). Here, 7 (out of 21) participants exceeded the MDC for distance,[38] and 11 (out of 21) participants exceeded the MDC for the metabolic cost of walking.[39] Despite these functional changes in the laboratory, participants did not take more steps/day at home after training ($P = 0.085$; $d = 0.41$). They did, however, perceive an improvement in the Mobility subscale of the SIS ($P = 0.019$; $d = 0.56$), but not in the Participation ($P = 0.670$; $d = 0.09$) or Activity ($P = 0.068$; $d = 0.42$) subscales of the SIS. For the Mobility subscale, 15 (out of 21) participants exceeded the MCID.[40] Finally, they did not perceive substantial improvements in their overall recovery (SIS-Global Recovery: $P = 0.127$; $d = 0.35$).

Individuals who trained to improve stance time symmetry did not demonstrate improvements in stance time asymmetry ($P = 0.233$; $d = 0.31$),[5] but did exhibit many comparable changes to the individuals who trained to improve step length asymmetry (Table 3). In particular, those who trained to improve stance time asymmetry also improved on the BBS ($P = 0.001$; $d = 0.97$) and the 4SST ($P = 0.047$; $d = 0.54$). Here, 6 (out of 16) participants exceeded the MDC for the BBS.[37] Although the distance walked during the 6MWT improved ($P = 0.001$; $d = 1.03$), the metabolic cost of walking did not change ($P = 0.161$; $d = 0.38$). Likewise, these participants did not increase their daily step count ($P = 0.309$; $d = 0.26$), or the scores on Participation ($P = 0.052$; $d = 0.53$) or Activity ($P = 0.634$; $d = 0.12$) subscales of the SIS. Nevertheless, the participants who trained to improve stance time asymmetry reported greater overall Recovery ($P = 0.008$; $d = 0.76$) and Mobility subscales ($P = 0.009$; $d = 0.76$) on the SIS. Here, 10 (out of 16) individuals exceeded the MCID for the Mobility subscale of the SIS.[40]

Despite the noted improvements following training, most changes were not related to changes in gait asymmetry (Table 4). However, for those who trained to improve step length asymmetry, we observed that an improvement in step length asymmetry was moderately associated with an improvement in 6MWT distance ($P = 0.025$; $r = -0.487$, Figure 1). For those training to improve stance time asymmetry, there was a moderate relationship between the change in stance time asymmetry and the change in metabolic cost of walking ($P = 0.031$; $r = 0.558$, Figure 2).

Given the relative lack of significant relationships in both groups, we chose to pursue additional unplanned analyses to combine the groups of individuals who trained to improve step length asymmetry and those who trained to improve stance time asymmetry. It is possible that a subset of participants in the step length asymmetry training group changed their stance time asymmetry and vice versa, and we believe this is useful information for determining the presence of a relationship between changes in spatiotemporal asymmetry and each of the outcomes of interest. Nevertheless, this analysis did not

Table 2. Outcome Measure Results for Group Trained to Improve Step Length Symmetry

Outcome Measures	Pretraining	Posttraining	Change	*P* Value	Effect Size
Step length asymmetry	0.636 ± 0.099	0.590 ± 0.058	0.046 ± 0.065	0.004	0.71
BBS	37.9 ± 10.1	40.5 ± 9.7	2.67 ± 3.50	0.002	0.76
4SST, s	64.3 ± 48.6	55.8 ± 42.3	8.55 ± 18.60	0.048	0.46
Cost of walking, mL O_2/kg/m	0.410 ± 0.262	0.360 ± 0.210	0.054 ± 0.105	0.032	0.51
6MWT distance, ft	509.3 ± 387.0	608.5 ± 392.5	99.1 ± 86.9	<0.001	1.14
Average steps per day	1337.9 ± 1091.4	1535.1 ± 1165.7	197.3 ± 486.3	0.085	0.41
SIS-Participation	53.3 ± 17.3	51.2 ± 19.8	2.08 ± 22.1	0.670	0.09
SIS-Recovery	49.5 ± 16.5	53.2 ± 17.1	3.71 ± 10.69	0.127	0.35
SIS-Mobility	58.1 ± 17.1	68.7 ± 17.2	10.6 ± 19.0	0.019	0.56
SIS-Activity	59.6 ± 16.0	64.4 ± 14.1	4.76 ± 11.29	0.068	0.42

Abbreviations: BBS, Berg Balance Scale; 4SST, Four Square Step Test; 6MWT, 6-minute walk test; SIS, Stroke Impact Scale.

Table 3. Outcome Measure Results for Group Trained to Improve Stance Time Asymmetry

Outcome Measures	Pretraining	Posttraining	Change	*P* Value	Effect Size
Stance time asymmetry	0.551 ± 0.018	0.548 ± 0.019	0.003 ± 0.011	0.233	0.31
BBS	44.6 ± 10.6	47.5 ± 9.3	2.875 ± 3.0	0.001	0.97
4SST, s	50.4 ± 39.2	46.0 ± 38.0	4.52 ± 8.34	0.047	0.54
Cost of walking, mL O_2/kg/m	0.346 ± 0.225	0.300 ± 0.172	0.050 ± 0.131	0.161	0.38
6MWT distance, ft	639.1 ± 310.9	793.0 ± 366.0	153.9 ± 149.8	<0.001	1.03
Average steps per day	1716.9 ± 1308.6	1863.6 ± 1155.4	146.7 ± 556.7	0.309	0.26
SIS-Participation	41.01 ± 22.03	53.91 ± 20.78	12.9 ± 24.4	0.052	0.53
SIS-Recovery	43.3 ± 16.5	54.7 ± 17.6	11.4 ± 15.0	0.008	0.76
SIS-Mobility	69.1 ± 16.0	79.5 ± 19.5	10.4 ± 13.8	0.009	0.76
SIS-Activity	63.75 ± 19.28	65.16 ± 18.90	1.41 ± 11.58	0.634	0.12

Abbreviations: BBS, Berg Balance Scale; 4SST, Four Square Step Test; 6MWT, 6-minute walk test; SIS, Stroke Impact Scale.

Table 4. Relationship Between Change in Spatiotemporal Asymmetry and Change in Outcome Measures for Participants Separated by Training Group[a]

	Step Length Asymmetry Group (n = 21)		Stance Time Asymmetry Group (n = 16)	
Outcome Measures	Correlation	Significance (*P*)	Correlation	Significance (*P*)
ΔBBS	0.152	0.510	− 0.059	0.827
Δ4SST	0.260	0.255	− 0.123	0.649
ΔCost of walking	− 0.043	0.856	0.558	0.031
Δ6MWT distance	− 0.487	0.025	− 0.088	0.747
ΔAverage steps per day	− 0.031	0.896	0.147	0.581
ΔSIS-Participation	− 0.189	0.411	0.115	0.671
ΔSIS-Recovery	− 0.203	0.378	0.232	0.387
ΔSIS-Mobility	0.060	0.797	0.093	0.732
ΔSIS-Activity	− 0.212	0.357	− 0.262	0.327

Abbreviations: BBS, Berg Balance Scale; 4SST, Four Square Step Test; 6MWT, 6-minute walk test; SIS, Stroke Impact Scale.

[a] BBS and SIS components are Spearman's (r_S) whereas the 4SST, cost of walking, 6MWT distance, and average steps per day are Pearson's (*r*).

reveal additional significant relationships (Table 5), but rather eliminated the relationship between the change in step length asymmetry and the change in 6MWT distance observed in the individuals who trained to improve step length asymmetry.

DISCUSSION

Based on previous studies, we had hypothesized that improvements in spatiotemporal gait asymmetry would be related to improvements in balance, metabolic cost of walking,

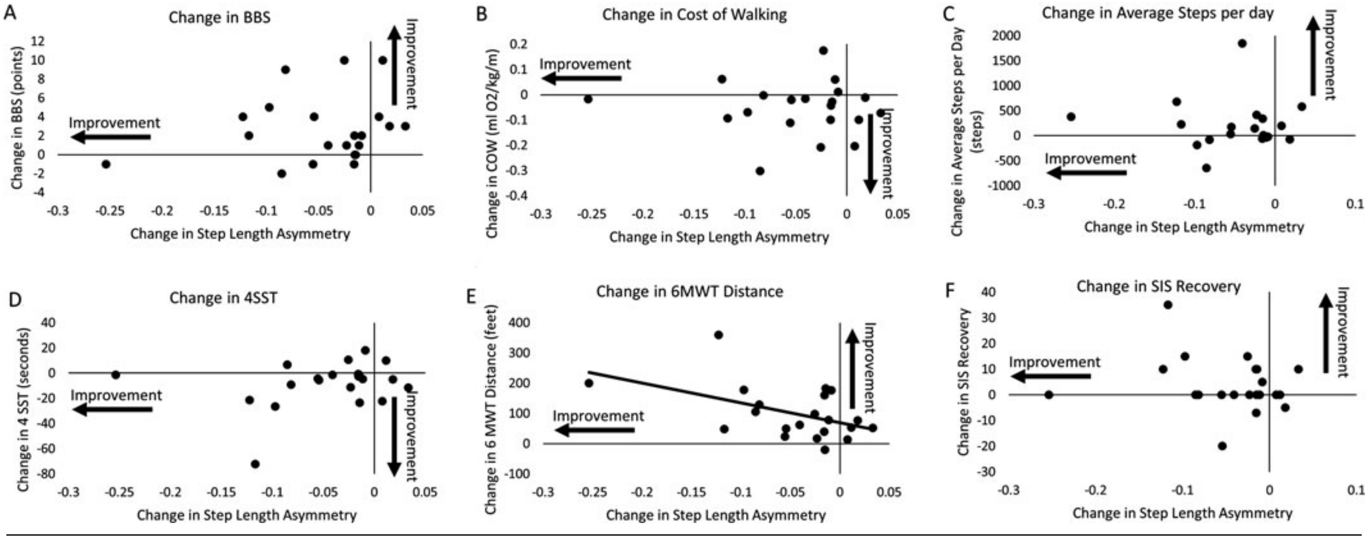

Figure 1. The relationship between the change in step length asymmetry and the change in (A) BBS scores, (B) cost of walking, (C) average steps/day, (D) Four Square Step Test times, (E) 6MWT distance, and (F) Stroke Impact Scale-Recovery subscale. The change in 6MWT distance was moderately related to the change in step length asymmetry. BBS indicates Berg Balance Scale; 6MWT, 6-minute walk test.

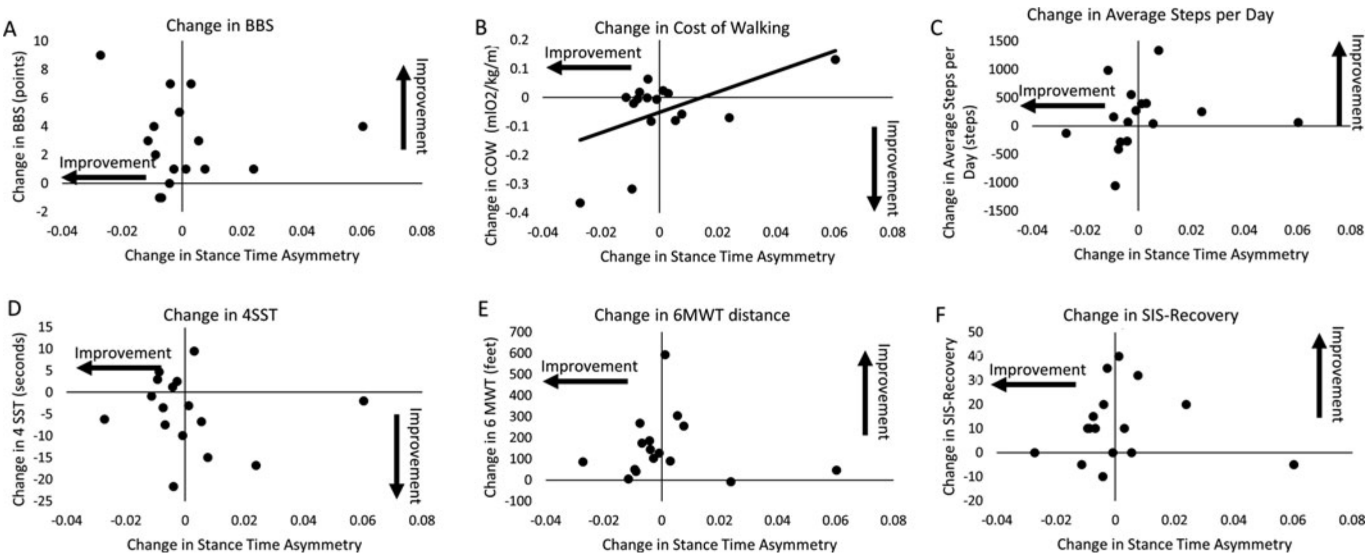

Figure 2. The relationship between the change in stance time asymmetry and the change in (A) BBS scores, (B) cost of walking, (C) average steps/day, (D) Four Square Step Test times, (E) 6MWT distance, and (F) Stroke Impact Scale-Recovery subscale. The change in the metabolic cost of walking was moderately related to the change in stance time asymmetry. BBS indicates Berg Balance Scale; 6MWT, 6-minute walk test.

endurance, quality of life, and physical activity for individuals with chronic stroke.[22,24,25,28,41] Although participants improved on many of these outcome measures, almost all improvements were unrelated to changes in spatiotemporal gait asymmetry. The exceptions were the change in 6MWT distance for the step length asymmetry group, and the metabolic cost of walking for the stance time asymmetry group. Instead, individuals appeared to improve in multiple outcome measures regardless of the gait asymmetry parameter that they trained to improve. These data create uncertainty regarding the role of spatiotemporal gait asymmetry on balance, quality of life, participation, and community mobility.

Although spatiotemporal gait asymmetry has long been considered a therapeutic target,[42,43] renewed interest recently has been spurred by the expansion of literature using spatiotemporal asymmetry as a measure of motor learning.[8,29,44] Other authors have suggested that if motor learning strategies can improve spatiotemporal gait asymmetry that would then transfer to overground walking, then those changes will likely lead to clinical benefits in individuals poststroke.[45] Our data, however, raise the possibility that spatiotemporal gait asymmetry is not the optimal target for eliciting improved gait function. The fact that we elicited changes in step length asymmetry that were unrelated to changes in other outcome measures (except for 6MWT distance) suggests that step length asymmetry may not be a critical factor influencing balance, daily stepping activity, and quality-of-life measures. Furthermore, we saw group-level changes in many of these outcome measures for those who trained to improve stance time asymmetry, despite the absence of any actual change in stance time asymmetry. This raises the question of the potential overestimation of therapeutic benefit of improving spatiotemporal gait symmetry.

Although Awad et al[24] have suggested that improvements in step length asymmetry yield a reduction in metabolic

Table 5. Relationship Between Change in Spatiotemporal Asymmetry and Change in Outcome Measures for All Participants[a]

	ΔStep Length Asymmetry (n = 37)		ΔStance Time Asymmetry (n = 37)	
Outcome Measures	**Correlation**	**Significance (*P*)**	**Correlation**	**Significance (*P*)**
ΔBBS	0.189	0.262	0.159	0.347
Δ4SST	0.289	0.083	0.111	0.512
ΔCost of walking	− 0.049	0.778	0.491	0.003
Δ6MWT distance	− 0.164	0.331	− 0.075	0.659
ΔAverage steps per day	− 0.042	0.807	0.043	0.804
ΔSIS-Participation	− 0.039	0.821	− 0.115	0.498
ΔSIS-Recovery	− 0.055	0.748	− 0.073	0.666
ΔSIS-Mobility	0.020	0.908	0.107	0.530
ΔSIS-Activity	− 0.142	0.401	− 0.231	0.169

Abbreviations: BBS, Berg Balance Scale; 4SST, Four Square Step Test; 6MWT, 6-minute walk test; SIS, Stroke Impact Scale.

[a] BBS and SIS components are Spearman's (r_S) whereas the 4SST, cost of walking, 6MWT distance, and average steps per day are Pearson's (r).

cost of walking, our data do not support this association, despite a decrease in metabolic cost of walking in the step length asymmetry group. Of note, those authors targeted changes in propulsive forces during gait,[24] which is known to influence metabolic cost of walking.[13] It is possible, therefore, that targeting asymmetry in propulsive force may elicit a concomitant change in metabolic cost of walking better than targeting step length asymmetry. Additionally, metabolic cost of walking was the only measure associated with changes in stance time asymmetry. Despite being related to the change in stance time asymmetry, the metabolic cost of walking did not significantly decrease from pretraining to posttraining in those who trained to improve stance time asymmetry. Therefore, the only significant measure supporting temporal gait asymmetry as a therapeutic target did not actually improve in this study. In short, spatiotemporal gait asymmetry may not represent the optimal target if the goal is to enhance walking-related outcomes, aside from gait speed.[5]

It is also possible that individual changes in spatiotemporal gait asymmetries were not sufficiently large enough to elicit a concomitant change in other measures. As noted previously,[5] only 9 (of 21) participants experienced a change in step length asymmetry greater than the MDC and no participants (of 16) changed stance time asymmetry greater than the MDC.[5] Alternatively, it is possible that the relationship between spatiotemporal gait asymmetry and these secondary measures is nonlinear and that a threshold must be exceeded before noticeable, measurable associated changes can occur. In this case, the associated changes we observed may be due to another aspect of our intervention (eg, cardiovascular training and repeated task practice) rather than the change in spatiotemporal gait asymmetry. Perhaps if greater changes in spatiotemporal gait asymmetry were achieved, allowing us to exceed a yet-undefined threshold, then we would observe an even greater change in the associated measures. Specifically, the relationship between the change in stance time asymmetry and the change in metabolic cost of walking indicates that *if* you could alter stance time asymmetry, then you would also improve the metabolic cost of walking. On the other hand, we need to consider the possibility that there is a limit to the potential to modify spatiotemporal gait asymmetry to the extent required to elicit any associated changes. Some have even suggested that gait asymmetry is a natural consequence of the resulting hemiparesis poststroke,[7] although there is growing evidence suggesting that various gait asymmetries can be modified.[5,6,46,47]

Despite the apparent improvements in many of our secondary outcome measures, the noted improvements may not have been clinically significant. Both groups, for example, demonstrated an improvement in BBS score from pre- to postintervention with large effect sizes. In both groups, however, these changes were unrelated to changes in spatiotemporal gait asymmetry. Furthermore, the average change on the BBS was less than 3 points, with fewer than 50% of individuals in each group exceeding the MDC.[37] Although there is currently not an established MCID for individuals in the chronic phase poststroke, there is a suggested cutoff score for falls risk (46/56).[48] Unfortunately, only 3 of our participants crossed this threshold after training (although 15 participants started at or above a 46). It is important to consider that the BBS has been reported to have a ceiling effect and lower responsiveness than other measures of balance that emphasize dynamic balance, such as the mini-BESTest.[49] Furthermore, the BBS does not contain measures of dynamic balance that participants will encounter in their daily life. Therefore, it is possible that changes in spatiotemporal gait asymmetry did lead to changes in dynamic balance associated with walking that were not captured in the BBS.

The 6MWT was the only measure significantly correlated with step length asymmetry. While an improvement in the 6MWT is a desired clinical outcome, the group-level changes observed for the 6MWT may not be large enough to elicit a substantial clinical impact. The MCID (112.86 ft) for the 6MWT distance [50] was exceeded for only 7/21 (33.3%) individuals in the step length asymmetry group and 8/16 (50%) for individuals in the stance time asymmetry group. Additional evidence regarding the clinical utility of the increased 6MWT distance is that it did not translate to increased participation in walking outside of the laboratory. In fact, the average steps per day did not appear to change much. Across all subjects, the average increase per day was 175 (512) steps. The average adult in the United States takes more than 6540 steps per day,[51] with a step count of fewer than 5000 steps per day considered a sedentary lifestyle associated with several increased health risks.[52] In contrast, individuals with chronic stroke have been shown to average approximately 1500 to 5200 steps per day.[12,33,53] Our results were consistent with this, as the preintervention steps per day averaged 1506.32 (1190.33) for all of our participants. The small change of 175 steps per day, although a statistical improvement, did not move these individuals close to the recommended or average steps per day in the general population. Targeting spatiotemporal gait asymmetry appears to be considerably less effective for daily step activity than other available interventions. For example, an intense gait training program elicited a 25% increase in steps per day compared with "usual" physical therapy alone.[33] Similarly, a study using a step activity monitor program and fast walking improved daily stepping by 1715 (1584) steps from pre- to postintervention.[54]

This important finding highlights the need to interpret results from a clinical perspective. Unfortunately, our findings are not unique. Doman et al[55] recently demonstrated that improvements in upper extremity function seen in the clinic for patients after a stroke did not translate to increased use of the paretic upper extremity in the community. Coupled with our work in gait, these works stress the need to find interventions that translate improvements in impairments and laboratory functioning to the real world. Thus, it is critically important to continue to obtain a measure of functioning outside of the clinic/laboratory in addition to functional measures in the clinic, to avoid inappropriate clinical interpretations.

CONCLUSIONS

In summary, our hypothesis that secondary gait-related measures including balance (Berg and 4SST), daily step count, and perceived quality of life (SIS) in individuals with chronic stroke would improve concomitantly with improvements in spatiotemporal gait asymmetry was not supported by the data. Gait training yielded significant improvements across many important outcome measures, but these changes did not appear to arise from changes in spatiotemporal gait asymmetry. Only one measure was significantly related to the changes in step length asymmetry (6MWT), but the changes elicited were only clinically meaningful in a third of individuals in the step length asymmetry group. Additionally, none of our participants changed their stance time asymmetry from pre- to postintervention. However, the presence of a moderate relationship with the change in metabolic cost of walking suggests that if such a change in stance time were possible, then it might have a positive impact of metabolic cost of walking. Although it is possible that greater improvements in spatiotemporal gait asymmetry would lead to greater changes in gait-related outcome measures, it is more likely that the focus of the intervention (spatiotemporal gait asymmetry) did not contribute to most of the observed changes. We can speculate that alternative targets would be more effective at improving these secondary outcome measures in individuals with chronic stroke. Critically, the improvements in gait function observed in the laboratory setting did not appear to translate to increased community mobility (daily step counts), raising the important question of how much change needs to occur in the clinic to affect the lives of patients.

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