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The Association between Spatiotemporal Gait Asymmetry and Walking Balance in People Post Stroke

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ABSTRACT

Background: Falls are a common complication post-stroke and often induce due to poor balance. Given that falls often occur during walking, it is possible that gait patterns influence balance during walking. Walking post-stroke is frequently spatiotemporally asymmetric, which may reduce walking balance. The aim of this study was to determine the relationship between gait asymmetry and walking balance in persons with chronic stroke.

Methods: Fifty-four persons with chronic stroke (34 men and 20 women) with the mean age of 57.28 participated in this cross-sectional study. Participants walked at their self-selected speed to calculate gait asymmetry ratios for stance time, swing time, and step length. The data were collected using a conventional camera with a sampling frequency of 60 Hz. Reflective markers were attached to the heel and toe regions. Participants also performed walking balance tests including Functional Gait Assessment (FGA) and Mini Balance Evaluation System Test (Mini-BESTest). Pearson correlation test was used to determine the relationships between gait asymmetry and walking balance.

Results: The mean±standard deviation values of stance, swing and step asymmetry ratios and FGA and Mini-BESTest were 1.2±0.11, 1.43±0.24, 1.25±0.15, 24.11±2.93 and 22.87±2.29, respectively. Increased FGA and Mini-BESTest scores were related to decreased swing (r=-0.64, P≤0.001 and, r=-0.71, P≤0.0001, respectively) and step asymmetry (r=-0.41, P≤0.002 and, r=-0.51, P≤0.001, respectively). No significant relationship was identified between FGA, and Mini-BESTest and stance asymmetry (r=-0.25, P≤0.06 and r=-0.23, P≤0.08 respectively).

Conclusion: According to the current results spatiotemporal gait asymmetry may be related to decreased balance during walking in individuals with chronic stroke suggesting that rehabilitation interventions should focus specifically on ameliorating spatiotemporal gait asymmetry.

Introduction

Falling is a common medical complication during all stages post-stroke [1, 2]. Even at chronic stage post-stroke, the risk of falling is higher than in similarly aged healthy adults [2]. Consequences of falls may include minor or serious injuries, reduced mobility and functional limitations [2, 3]. Although several factors may contribute to falls post-stroke, balance deficits which are common in this population, are considered as the largest contributing factors to falls in individuals who had experienced strokes [1, 2].

Walking balance can be determined as the ability to control the center of mass within the base of support during walking-related tasks. Maintenance of balance during walking needs the complex integration of

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somatosensory, vestibular and visual inputs to direct the motor responses against perturbations [4]. Impaired walking balance is also common in persons with strokes indicating the reduced ability of this population to adjust walking to task and environmental demands [4, 5].

Temporal and spatial asymmetries (greater stance time, swing time and step length of one leg relative to contralateral leg) are two common abnormal gait characteristics which were exhibited by 55.5% and 33.3% of persons with chronic stroke, respectively [6]. Restoration of gait symmetry is commonly addressed by therapists since it may be associated with a number of negative impacts including cumulative musculoskeletal injury to the non-affected lower limb, gait inefficiencies and impaired balance control [6-8]. Although it has been purported that gait asymmetry is related to impaired balance post-stroke, however, it is currently unknown whether spatiotemporal gait asymmetry is, in fact, associated with impairments in balance control during walking. Only one study by Lewek et al. investigated the association between asymmetric gait pattern and balance post-stroke [9]. However, in this study the balance function was evaluated using the Berg Balance Scale and weight bearing asymmetry during standing that do not evaluate balance during walking. The items of Berg Balance Scale mainly evaluate balance function in various standing-related tasks which do not provide a sufficient insight into the maintenance of balance during various walking-related tasks. For this purpose, functional tests which directly evaluate a broad range of walking balance tasks may be needed to better understand the link between asymmetric gait pattern and balance during walking. These functional tests mainly evaluate balance during change in walking speed, walking with head turns, backward walking, walking with eyes closed, stepping over obstacles and stair climbing. Walking balance is important given that falls in stroke survivors occur most often during walking and walking is also the most frequently reported activity (39%-90%) at the time of a fall [10-12]. Investigation of the relationship between gait asymmetry and walking balance may have significant clinical implications for the large number of stroke survivors who have asymmetric gait pattern.

The aim of the current study was to determine the presence of a relationship between spatiotemporal gait asymmetry measures and functional tests which evaluate balance during various walking tasks in persons with chronic stroke. These functional tests may provide helpful information regarding specific walking balance deficits [4]. Given the similar mechanisms underlying gait asymmetry and impaired walking balance (sensory and motor dysfunction) [4, 8], it was hypothesized that spatiotemporal gait asymmetry would be associated with walking balance measures.

Methods

Participants

The study design was cross-sectional. A convenience sample of 54 persons with chronic stroke (34 male / 20 female; age: 57.28±9.32 years; height: 167±5.67cm; weight: 69.5±8.33kg) was recruited from rehabilitation clinics. The chronicity range of the participants was between 12 to 27 months. Participants were screened by a physician based on inclusion and exclusion criteria. The diagnosis of stroke was determined using the World Health Organization (WHO) definition [13]. The inclusion criteria for the study were a history of first-ever stroke more than 1 year ago, the stroke chronicity range between 12 to 36 months, a Mini-Mental State Examination (MMSE) score above 24 [14], a Fugl-Meyer Assessment (FMA) score above 18 [15, 16], and a Modified Ashworth Scale (MAS) between 0 to 2. Participants were excluded if they had any concurrent neurologic, orthopedic or rheumatologic condition that could affect walking pattern, uncorrected visual problems, any deformity of the lower limbs that could affect walking patterns, spinal surgeries, and inability to understand instructions due to severe aphasia or cognitive impairments.

Cognitive impairment was evaluated using the Mini-Mental State Examination test [14]. This test is a 30-point questionnaire which includes tests of orientation, attention, memory, language and visual-spatial skills. Any score greater than or equal to 24 points (out of 30) demonstrates a normal cognition [14]. The level of sensory and motor impairments of the affected lower limb was assessed with the Fugl-Meyer Assessment (FMA) [15, 16]. This assessment has been reported to be valid and reliable in individuals with stroke [15-17]. The FMA comprises a cumulative numeric scoring system, with 6 sensory and 17 motor items for assessing the lower limb, each scored from 0 to 2. The maximum possible score for motor and sensory components is 34 and 12, respectively. A score of 0 represents complete loss of sensory function or inability to complete a motor item; a score of 2 represents normal sensory function or ability to complete a motor item to the full range. The spasticity in the ankle plantar flexors of the affected lower limb was assessed with the Modified Ashworth Scale (MAS) [18]. The grades of this test range from 0 to 5, with 0 indicating no increase in muscle tone and 5 indicating that joint is fixed in extension or flexion.

All participants were informed about the study procedure and signed informed consent. The study protocol was approved by the local university.

Spatiotemporal Gait Measures

Gait asymmetry measures were determined using a simple video-based portable tool for gait analysis. The validity and reliability of this system were demonstrated by previous studies [19, 20]. The test-retest reliability of stance, swing, and step asymmetry measures was excellent (ICC between 0.88 and 0.95) in 25 participants in our laboratory. The system used a single conventional camera (Sony model HDR-XR350E) with a sampling frequency of 60 Hz to record gait and computer programs that analyzed video footage and calculated spatiotemporal parameters. The camera was located on a tripod perpendicular to, and 4 m from, the walkway. Participants walked at their self-selected speeds across a level of 10 m walkway. The field of view of the camera was the central 2 m of the walkway. The participants began and stopped walking 5–6 steps before and after reaching the field of view of the camera so as to ensure steady-state gait throughout the test. Adhesive reflective markers were attached to the heel and toe regions (Figure 1).

Figure 1: A participant with markers in the laboratory field

Walking trials were performed until 12 steps were collected (2-3 steps in each trial). A software program written in MATLAB R2006a (Natick, MA) calculated the values (averaged over 4-6 walking trials) for right and left stance, swing time and step length. A gait cycle was determined (from heel strike to heel strike) as is the transition from stance to swing phase, at toe-off. Heel strike was determined as occurring when the toe marker was within 1 cm of its height as measured during standing, and toe off was also determined as occurring when the heel marker exceeded 1 cm of its height as measured during standing [19, 20]. To determine the step lengths for each limb, the software obtained 2D coordinates of heel markers in the foot strike frame of each foot in one gait cycle then calculated the distance between the markers.

The magnitude of stance, swing time and step length asymmetry was defined as the ratio of right and left values, with the larger value in the numerator regardless of the affected side so that results were not skewed by values <1.0 [21]. The value of 1.0 indicates perfect symmetry. The direction of asymmetry was determined with respect to the lower extremity that represented the larger stance, swing time and step length value; affected or non-affected. It should be noted that only the magnitude of the asymmetry was considered for statistical analyses.

Walking Balance Measures

Two outcome measures were selected for measuring walking balance [4]. FGA was used to evaluate balance during various walking tasks. The FGA is a 10-item walking test that was developed to evaluate postural stability during various walking tasks including walking with a narrow support base, walking with head turns, stepping over obstacles, ambulating backwards, walking with eyes closed, change in gait speed and stair climbing [22]. The performance on the items of the FGA was determined on a four-point ordinal scale (0-3), with a maximum possible score of 30 points. The higher scores indicate better performance. The FGA is considered a valid and reliable tool for evaluating walking balance in individuals with stroke [22].

The Mini-BESTest is a clinical balance assessment measure that consists of 14 items that evaluates anticipatory postural adjustment, reactive postural control, sensory orientation and dynamic gait. Each task is scored on a three-point scale with the total score of 28. Better balance performance is demonstrated with higher scores. The Mini-BESTest includes many aspects of walking balance identified in physical therapy practice. This test has been found to be reliable and valid in individuals with hemiparesis [23].

Statistical Analysis

Descriptive statistics were used to describe the study population. Shapiro-Wilk test was used to evaluate the normal distribution of outcome measures. The relationships between each gait asymmetry measure (stance time, swing time, and step length) and each walking balance measure (FGA, and Mini-BESTest) were determined using Pearson correlation coefficient and 95% confidence intervals (CI) were calculated for each r value. Six correlations were performed between gait asymmetry and walking balance measures (Bonferroni corrected P level=0.008). Statistical analyses were performed using SPSS statistics software (Version 19 for Windows).

Results

Stroke characteristics of participants are shown in Table 1.

Forty of the participants (74%) exceeded the threshold of 1.08 that determines asymmetry in step length, forty-six of the participants (85%) exceeded the threshold of 1.05 that determines asymmetry in stance time, and forty-seven participants (87%) exceeded a threshold of 1.06 to determine swing time asymmetry [21]. Gait measures of subjects are represented in Table 2.

Correlational analyses revealed that FGA was related to swing and step asymmetry ratios. Increased FGA scores was associated with decreased swing time asymmetry (r=-0.64, P≤0.001, CI: -0.75 to -0.5) and step length asymmetry (r=-0.41, P≤0.002, CI: -0.6 to -0.36) (Figure 2). No significant association was identified between FGA and the stance asymmetry ratio (r=-0.25, P≤0.06, CI: -0.47 to 0.01). Mini-BES Test was also related to swing and step asymmetry ratios. Increased Mini-BESTest scores was associated with decreased swing time asymmetry (r=-0.71, P≤0.0001, CI: -0.83 to -0.55) and step length asymmetry (r=-0.51, P≤0.001, CI: 0.7 to 0.41) (Figure 3). No significant association was identified between Mini-BESTest and the stance asymmetry ratio (r=-0.23, P≤0.08, CI: -0.5 to 0.06).

Table 1: Stroke characteristics of participants

Variable		Participants (n=54)
Time since stroke (months)		17.64±3.8
Paretic side (right/left)		30/24
Dominant side (right/left)		32/22
Type of stroke (ischemic/hemorrhagic)		44/10
Motor impairment (score)		27.67±3.84
Sensory impairment (score)		8.66±1.87
Modified Ashworth Scale Ankle, maximum 4 (grade range)		0-2
Fall history	Faller*	31
	Non-faller	23

Values are mean±SD from time since stroke, motor and sensory impairment. Values are a number for paretic side, dominant side and type of stroke. Modified Ashworth Scale is presented according to grade range. *Fallers were determined by the occurrence of at least one fall during the last year

Table 2: Gait measures of participants (n=54)

Gait measures	Mean±standard deviation	Minimum-maximum
Step asymmetry magnitude (ratio)	1.25±0.15	1.02-1.56
Step asymmetry direction (affected/non-affected)	35/19	-
Stance asymmetry magnitude (ratio)	1.2±0.11	1.01-1.42
Stance asymmetry direction (affected/non-affected)	0/54	-
Swing asymmetry magnitude (ratio)	1.43±0.24	1.03-1.9
Swing asymmetry direction (affected/non-affected)	54/0	-
FGA	24.11±2.93	19-30
Mini-BESTest	22.87±2.29	19-28

FGA: Functional Gait Assessment; Mini-BESTest: Mini Balance Evaluation System Test

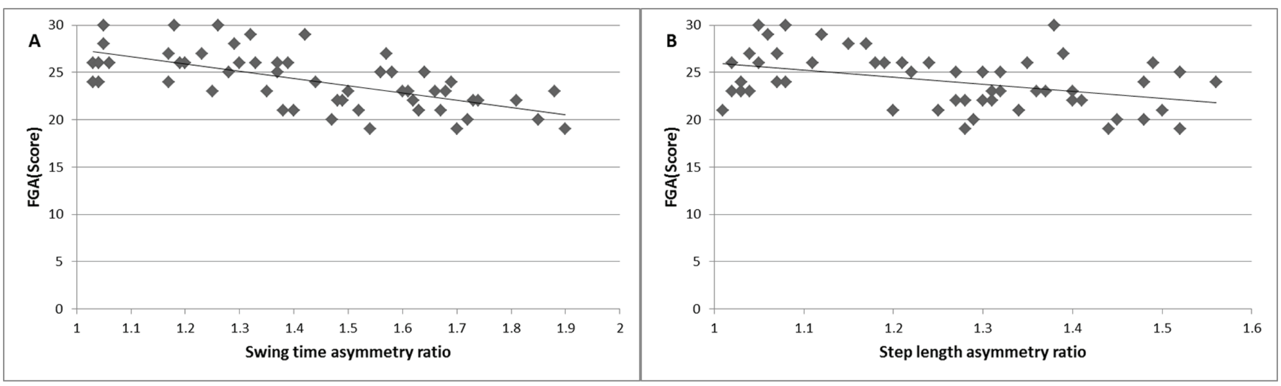

Figure 2: The relationship between FGA and (A) swing time asymmetry ratio and (B) step length asymmetry ratio (n=54). FGA: Functional Gait Assessment

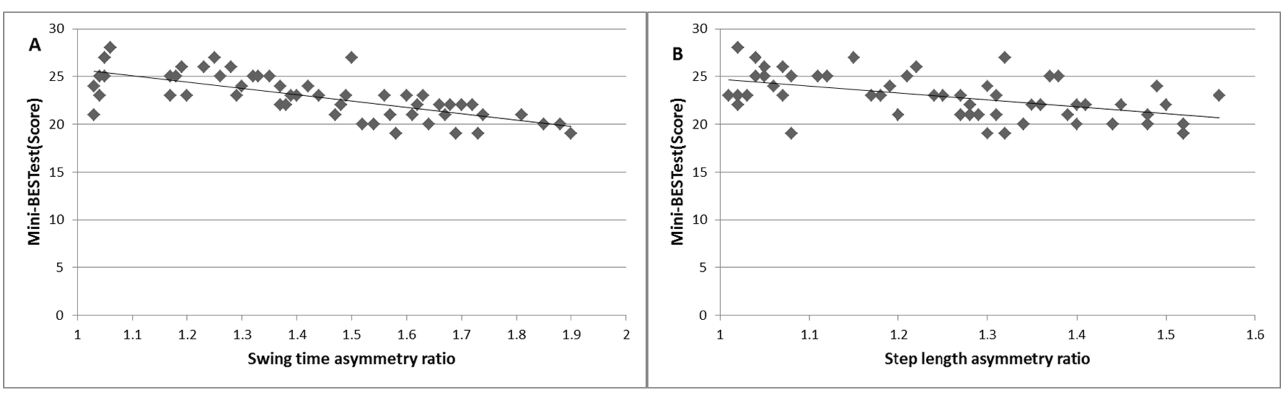

Figure 3: The relationship between Mini-BESTest and (A) swing time asymmetry ratio and (B) step length asymmetry ratio (n=54). Mini-BESTest: Mini Balance Evaluation System Test

Discussion

This study supported our hypothesis that spatiotemporal gait asymmetry measurements would be related to impairments in walking balance in persons with chronic stroke. Swing time and step length asymmetry ratios were negatively correlated with FGA and Mini-BESTest scores. In all relationships greater spatiotemporal asymmetry was related to greater impairments in walking balance suggesting that gait asymmetry may increase the difficulty of balance control during various walking postures.

Walking balance encompasses the range of various walking tasks which challenge the balance system [4]. Walking balance is fundamental for people to change body positions, respond automatically to postural adjustments, react to external perturbations and walking at different speeds [24]. The observed relationship between impaired walking balance and increased gait asymmetry in this study is likely to be related to the fact that both of these outcome measures have correlated with similar impairments. It is known that sensorimotor impairments of the paretic leg which are usually common in individuals with stroke [25], are related to impaired dynamic balance and also swing time and step length asymmetry [8].

Previous studies also investigated the relationships between some gait parameters and functional tasks in individuals with stroke. For example, Patterson et al. indicated that both swing time and step length asymmetry were related to reduce gait speed [6]. Bonnyaud et al. demonstrated that the percentage of single support time on the paretic leg was predictive of Timed up and Go (TUG) test performance time in a person with stroke [26]. Lewek et al. also indicated a significant negative correlation between Berg Balance Scale (BBS) and swing asymmetry post stroke [12]. Although these studies investigated the relationship between some spatiotemporal gait measures and some functional tasks post stroke, however, the functional tasks that were measured in these studies such as gait speed and BBS provide limited inferences on walking balance requirements [4, 27]. The current study may provide more important information regarding the association between gait asymmetry and walking performance after a stroke. FGA and Mini-BESTest are comprehensive tests that evaluate the ability of an individual to perform multiple motor tasks during walking [4, 22, 23]. Based on a previous study, the Mini-BESTest is the most accurate tool for identifying older adults with a history of falls compared with the BBS, and TUG [28]. This is an important finding given that balance deficits are significant predictor of falls and most falls often occur during walking [9, 10].

The current results demonstrated that two temporal gait asymmetry measurements including stance and swing time asymmetry were not related in the same way to walking balance measurements. In other words, although there was a significant negative relationship between swing asymmetry and walking balance, however, the relationship between stance asymmetry and walking balance was not significant. This result suggests that swing asymmetry may be a more appropriate indicator of reduced balance. A strong relationship which was identified between swing time asymmetry and Mini-BESTest in this study may also be due to the inherent challenge associated with the balance requirement during swing phase. Stance time includes two double-support times, which may provide stability, while swing time coincides with single limb stance time, which may provide a significant challenge to the paretic leg [21]. In this study, stance asymmetry was not related to walking balance possibly because two double support phases of stance time provide sufficient stability during gait. The current results are in line with a previous report. Lewek et al. reported that decreased Berg balance Scores were associated with increased swing time asymmetry and not stance time asymmetry in individuals with strokes [12].

Although significant relationships were observed between spatiotemporal gait asymmetry and clinical balance scores; however, a previous study by Mieville et al. demonstrated that the immediate decreasing of spatiotemporal asymmetry using a split-belt treadmill protocol in people post-stroke did not alter balance during walking [29]. Our explanation is that improving gait symmetry via this protocol was acute and mainly due to mechanical factors. This improvement might not be adapted by the central nerves system to be reflected in the improvements of balance control. Long-term interventions which would systematically change spatiotemporal parameters are needed to confirm these results and to better understand the link between spatiotemporal parameters and balance.

This study has some limitations that need to be addressed. Given the cross-sectional nature of the investigation, inferences about a cause and effect relationship between gait asymmetry and walking balance measurements cannot be drawn. Therefore, it is not clear if improving spatiotemporal symmetry will improve walking balance and decrease the risk of falling. To support this purport, a longitudinal study is required which documents changes in gait asymmetry and changes in walking balance and number of falls. All participants in this study had a moderate to good recovery (they were able to walk and perform all tests independently without any customary gait aid). These points might limit the ability to generalize the results of this study.

Conclusion

This study indicated a significant relationship between gait asymmetry and walking balance measurements, suggesting that increased spatiotemporal gait asymmetry may be associated with decreased walking balance after a stroke. Future study is needed to determine whether intervention that improves spatiotemporal gait asymmetry has a similar effect on walking balance.

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