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Spatial asymmetry of post-stroke hemiparetic gait: assessment and recommendations for physical rehabilitation

YURY ZVEREV
Lobachevsky State University of Nizhni Novgorod, Nizhni Novgorod, Russian Federation
Previously: Department of Physiology, College of Medicine, University of Malawi, Blantyre, Malawi
Correspondence E-mail: yzverev@yahoo.com

Abstract

Background: Asymmetry of various bilateral gait parameters is an important characteristic of quality of post-stroke hemiparetic gait. Persistent gait asymmetry has a negative impact on energy cost of locomotion, balance control, muscular-skeletal health and activity level of hemiparetic patients and, therefore, it needs to be addressed during rehabilitation post-stroke. Despite potential benefits, quantitative analysis of gait asymmetry is still not routinely used in many hospitals and rehabilitation institutions in developing countries due to the high cost involved in setting a gait laboratory. The objective of this study was to evaluate the potential of the footprint and Symmetry Index (SI) methods for the assessment of gait asymmetry in hemiparetic post-stroke patients with the goal of achieving recommendations regarding physical rehabilitation.

Methods: The study was conducted at the Queen Elizabeth Central Hospital, Blantyre, Malawi. A total of 36 post-stroke patients who had survived six months or more after a unilateral stroke participated in the study. The non-disabled control group was matched with the hemiparetic group by age, sex and anthropometric characteristics. Step length and foot rotation angle of the participants were recorded using the footprint method.

Results: Results showed that steps on the paretic side were significantly longer and foot rotation angle was wider than those on the non-paretic side ($p<0.005$ and $p<0.01$, respectively). Compare to the controls, patients had significantly shorter steps on both sides ($p<0.05$ and $p<0.001$, respectively) while the values of foot rotation angle were only higher on the affected side ($p<0.001$). The mean values of step length and foot rotation angle SI in the patients were significantly higher than in the controls ($p<0.001$). Based on the magnitude of the SI, most of post-stroke patients were classified as asymmetric.

Conclusion: Overall, the study demonstrated asymmetry of step length and foot rotation angle during walking of post-stroke hemiparetic individuals and highlighted the potential of the footprint and SI methods as objective and easy to apply tools suitable for the assessment of symmetry of spatial gait parameters in clinical and rehabilitation settings. The results also emphasized the need for rehabilitation interventions designed specifically to improve the spatial symmetry of post-stroke hemiparetic gait.

Key words: hemiparesis, stroke, gait, spatial parameters, symmetry

Introduction

Stroke is one of the important causes of morbidity, mortality and disability of adults not only in the industrialized countries but also in developing regions of the world, such as sub-Saharan Africa. According to the World Health Organization estimates, 8% of all strokes occur in Africa and 5% of stroke survivors worldwide live in Africa (WHO, 2004). A study conducted in Tanzania demonstrated that stroke incidence rates in a rural area were similar to those observed in developed countries while the rates in Dar es Salaam were even higher (Walker *et al.,* 2010).

Long-term disability is the most important physical impact of brain damage on stroke survivors. Post-stroke patients exhibit varying neurological deficits and impairments. Many of them have hemiparesis, which significantly limits mobility and decreases functional independence and health-related quality of life. Therefore, independent ambulation is a primary goal of treatment and rehabilitation programmes for stokes survivors (Jorgenson *et al*., 1995; Vats, 2013).

Multiple gait aspects are impaired post-stroke. According to numerous studies, hemiparetic gait is typically characterized by asymmetry of bilateral kinetic, kinematic and spatiotemporal parameters, increased step width, decreased cadence, prolonged double limb support phase and slow speed (Balasubramanian *et al*., 2007; Patterson *et al*., 2008, 2010a).

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Symmetry is an important characteristic of quality of human gait not only from aesthetical point of view, but also from biochemical, physiological and clinical prospective. Asymmetric gait is not efficient as it increases oxygen consumption and energy cost of locomotion (Cunha-Filho *et al.*, 2003; Patterson *et al.*, 2008). Persistent gait asymmetry may lead to loss of bone mass density and osteoporosis of the affected leg (Jorgensen *et al.*, 2000), higher dynamic loading on the contralateral limb and joints with increased risk of osteoarthritis and musculoskeletal injury (Block & Shakoor, 2010). Difficulties in balance control associated with gait asymmetry increase risk of falls and related injuries of patients (Weerdesteyn *et al*., 2008).

According to Balasubramanian *et al*. (2007), symmetry measures may characterize hemiparetic gait better than overall gait performance measures (such as gait speed). In addition, gait symmetry may serve as an overall indicator of gait quality and as a measure of effectiveness of gait control mechanisms (Dewar & Judge, 1980). Therefore, the analysis of gait symmetry is of recognized relevance in the evaluation of walking abilities of hemiparetic patients, setting goals for treatment and physical rehabilitation, designing rehabilitation programmes that address the unique deficiencies of each patient and in assessment of effects of various interventions.

Despite the potential significance of assessment of gait pattern, quantitative analysis of gait asymmetry of hemiparetic patients is still not routinely used in the clinical and rehabilitation settings. Several factors contribute to the low adoption of gait asymmetry measurement as a routine tool. First, up to now, there is no common view on the degree of asymmetry, which distinguishes normal gait from pathological. Some researches consider gait symmetry is present when no statistically significant differences of gait parameters exist between the sides of the body (Sadeghi, 2003). However, tests of significance do not provide information about the actual magnitude or the clinical importance of a difference and depend on the sample size (Norman & Streiner, 2000). Huge differences in gait symmetry may be non-significant in small samples, whereas small differences may be significant in large samples. Many researchers use an arbitrary cut-off value of 10% deviation from perfect symmetry or presence of bilateral differences in the values of gait parameters outside the limit of the 95% confidence intervals obtained in a healthy population as a criterion of asymmetric gait (Balasubramanian *et al*., 2007; Patterson *et al*., 2010a).

Second, there is no commonly accepted method to calculate gait symmetry. Numerous symmetry equations were proposed to qualify gait symmetry and differentiate pathological gait from normal. The most common statistical approaches used to quantify gait asymmetry are the Symmetry Ratio, the Symmetry Index, the Ratio Index, the Log-transformed Symmetry Ratio and the Symmetry Angle (Sadeghi, 2000; Patterson *et al*., 2010a; Błażkiewicz *et al.,* 2014,). However, many equations are reported to have limitations. For example, the Symmetry Index (SI), which is widely used for the assessment of symmetry of able-bodied and pathological gait, needs to be normalized to a reference value (Zifchock & Menz, 2008; Błażkiewicz *et al*., 2014). Therefore, lack of the reference data for most of populations in Sub-Saharan Africa may limit the use of the SI. Third, the use of different methods of gait registration and different gait parameters analysed for asymmetry make it difficult to compare across studies.

In addition, the costs involved in setting a gait laboratory and training personnel are prohibitive for many hospitals and rehabilitation institutions, especially in developing countries. This limits the opportunities for the assessment of gait pattern in many hospitals and rehabilitation centres in Sub-Saharan Africa and leads clinicians to only apply subjective observational gait analysis. Therefore, selection of inexpensive, technically simple and reliable quantitative methods of registration of gait parameters can be beneficial for gait researchers, clinicians and physical therapists. The footprint method meets these requirements. The ease of collecting footprint data allows assessment of the gait in a variety of applications without access to elaborate recording equipment. Therefore, the footprint method was used for the assessment of able-bodied and pathological gait in numerous studies (Wilkinson & Menz, 1997; Kingsnorth & Schmuckler, 2000; Zverev *et al*., 2002, Zverev, 2006).

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Despite the potential benefits of the footprint method, only a few studies have attempted to use this method to analyse the asymmetry of spatial gait parameters in hemiparetic patients (Zverev *et al*., 2002). In addition, the current focus of the research is on symmetry of step and stride length. Foot rotation angle received less attention. It may be important to assess both spatial gait parameters as they are regulated by different gait controlling mechanisms, namely gait patterning and balance control mechanisms (Sadeghi, 2000). To address these gaps in knowledge this study was designed to evaluate the potential of the footprint and SI methods for the assessment and quantification of spatial gait asymmetry in hemiparetic post-stroke patients with the goal of achieving recommendations regarding physical rehabilitation. This may help clinicians and physical therapists with an accurate and objective tool for describing and monitoring patients' gait in resource-limited settings.

Materials and Methods

Study setting and population

The study was conducted at the Queen Elizabeth Central Hospital (QECH), Blantyre, Southern Province of Malawi. All patients who attended a neurological clinic at the QECH and met inclusion criteria were requested to participate in the study by a purpose sampling method. Inclusion criteria were: (i) haemorrhagic or ischemic unilateral stroke with hemiparesis and with the duration post-stroke period of at least 6 months; (ii) ability to walk independently 10 m; (iii) ability to follow verbal instruction and requests; and (iv) lack of complicating history of orthopaedic, cardio-respiratory, and other disorders and conditions affecting balance and low limb functions. Patients who scored 1 to 3 on the six-point Functional Ambulation Categories (FAC) classification (Holden *et al.,* 1984) were excluded from the study.

Subjects in the control group were recruited from among patients of the hospital and visitors to the patients who lack any disease or condition, which can affect coordination, balance, muscular tone or structure and functions of the lower extremities. The controls were matched with the study group by age, gender, and anthropometric characteristics, which can affect spatial gait parameters (table 1). Gait measurements in the control group were used for intergroup comparison and also for calculation of the normalized SI and confidence intervals for the 'normal' symmetry.

Data collection

A qualified medical practitioner examined all volunteers prior to gait recordings in order to assess functional status of the participants. Anthropometric data (weight and height) were measured using standard procedures. Body mass index (BMI) of the participants was calculated with formula: BMI = weight (kg) / height $(m)^2$ (Garrow, 1987).

The gait of the participants was recorded using the footprint method (Wilkinson *et al*., 1995; Zverev *et al*., 2002).The ink and moleskin were applied to a subject's feet and footprints sequences were recorded on a white paper strip (6-meter-long, 1-meter-wide) while a subject was walking in bare feet along a strip at a self-selected comfortable and safe speed. The volunteers were asked to look directly forward during walking as observing the footprints could alter their gait pattern. At least six footprints were obtained. Two spatial gait parameters were measured: step length (the linear distance on the midline between two consecutive contralateral heel marks) and foot rotation angle (the intersection of the ipsilateral line of walking progression and the long axis of the foot). Step length was measured with a steel ruler to the nearest mm while angle of gait was measured with a standard mathematical protractor to the nearest degree. The parameters were measured and recorded separately for the two sides of the body.

Symmetry of the spatial gait parameters was assessed using the SI equation (Robinson *et al*., 1987): $SI = ((X_l - X_r) / 0.5 * (X_l + X_r)) * 100\%$, where X_l and X_r are the values on the left and right sides, respectively. The value of SI = 0 indicates full symmetry, while SI ≥ 100% indicates its

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asymmetry (Sadeghi *et al*., 2000). To define normative symmetry values, the 95% confidence interval (CI) was taken for both spatial gait measures calculated for the control group. Each patient was identified as asymmetric, if the SI value fell outside the upper boundary of the 95% CI. In order to quantify the difference between patients and controls, the SI of the patients were normalized to the mean value of SI of the controls.

Data analysis

Statistical analysis was carried out using the Statistical Package for Social Sciences (SPSS) 16.0 (SPSS Inc. Chicago, USA). Data were analysed using both descriptive and inferential statistics. The Shapiro-Wilk test was used to assess the normality of data distribution. The Student's t-test was used for inter- and intra-group comparison of the mean values of gait parameters. The level of statistical significance was fixed at $p < 0.05$.

Ethical consideration

The study received ethical approval from the University of Malawi College of Medicine Research and Ethics Committee. Permission to conduct the study was sought from the management of the QECH. The aim and methods of the study were explained to the participants and written or oral consent was obtained from each participant prior to recruitment. Patient's information obtained during this study was treated confidently and not used for other purposes.

Results

A total of 36 post-stroke patients participated (19 females and 17 males). Fourteen (38.9%) stroke survivors had left-side affectation of hemiparesis while 22 (61.1%) had the right side affected. Characteristics of the groups of patients and controls are shown in Table 1.

Table 1: Demographic, anthropometric and clinical characteristics of the two categories of participants

Groups	Age (years)	Stroke duration (months)	Height (cm)	Weight (kg)	BMI (kg/m^2)	FAC score
Patients	52.3±9.2	11.3±4.6	162.6±9.6	57.3±7.2	21.7±2.4	4.5±0.3
Controls	50.8±9.6	NA	163.2±10.2	58.1±7.8	21.8±2.8	NA

NA – not applicable, BMI – body mass index, FAC – Functional Ambulation Categories

Table 2 shows the means of the two spatial gait parameters in the group of non-disabled controls. All variables were normally distributed. The group means of step length and foot rotation angle of the right and left feet were similar. Therefore, these values were combined and used for the intergroup comparison.

Table 2: Means and standard errors of means of spatial gait parameters in the group of non-disabled controls

Parameter	Side			Symmetry index	
	Right	Left	Combined	Mean	95% CI Upper boundary
Step length, cm	52.1±1.60	51.4±1.63	51.3±1.54	1.3±0.11	2.7
Foot rotation angle, degrees	9.7±0.63	10.1±0.58	9.9±0.43	4.0±0.39	8.7

CI =confidence interval

The mean values of the spatial gait parameters for the group of post-stroke hemiparetic patients are shown in Table 3. Steps on the paretic side were significantly longer and foot rotation angle

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was wider than those on the non-paretic side (df = 70, t=3.077, p<0.005 and t=2.828, p<0.01, respectively), which indicated the presence of a bilateral asymmetry in these parameters.

Compare to the group of controls, the patients had significantly shorter steps on both paretic and non-paretic sides (df = 70, t=2.093, p<0.05 and t=4.413, p<0.001). At the same time, the values of foot rotation angle were only higher on the affected side (df = 70, t=4.413, p<0.001).

The mean values of the step length and foot rotation angle SI in the patients were significantly higher than in the controls (df = 70, t=11.518, p<0.001 and t=8.441, p<0.001, respectively). The normalized SI values also indicated the presence of asymmetry in the spatial gait parameters in the post-stroke hemiparetic patients. Based on the SI magnitude of both parameters, most of the patients were classified as asymmetric (Table 3).

Table 3: Means and standard errors of means of spatial gait parameters in the group of post-stroke hemiparetic patients

Parameter	Side		Symmetry index	Normalized symmetry index	Number (%) of asymmetric persons
	Paretic	Non-paretic			
Step length (cm)	46.9±1.90	38.3±2.05	20.2±1.87	14.9±1.42	29 (80.1%)
Foot rotation angle (degrees)	13.6±0.63	11.4±0.62	16.8±2.8	4.9±1.39	28 (77.8%)

Discussion

Using a quantitative approach, characteristic features of gait pattern of post-stroke hemiparetic patients were identified in the present study. Gait of the patients in relation to the controls was characterized by a decreased step length on both sides and an increased foot rotation angle on the paretic side. Based on the SI values of step length and foot rotation angle, gait of the controls had a high degree of symmetry while gait of the hemiparetic patients was asymmetric. It was also found that most of the patients in the study sample exhibited asymmetric walking pattern. In general, these findings are in agreement with previous studies (Burdett *et al*., 1988; Chen *et al*., 2005; Balasubramanian *et al.*, 2007; Kahn & Hornbym, 2009; Obembe *et al*., 2012).

Some findings of this investigation differ from other publications. For example, the present study indicated that gait asymmetry is prevalent in the post-stroke hemiparetic patients with 80.1% of stroke survivors exhibited asymmetry in step length and 77.8% - in foot rotation angle. These figures are higher than those reported by Patterson *et al*. (2008) and Patterson (2010b). The values of the step length SI of the hemiparetic patients in the present investigation were lower than those in studies published by Chen *et al*. (2005) and Obembe *et al*. (2012), but they were higher than those reported by Burdett *et al*. (1988), Patterson *et al*. (2008) and Vats (2013). The values of foot rotation angle SI in this study group were higher than those reported by Burdett *et al*. (1988) but similar to a study in Nigeria (Obembe *et al.,* 2012). Such discrepancy may be explained by the differences between study populations in the duration of post-stroke period, application of different methods of gait asymmetry quantification as well as by the differences in post-stroke rehabilitation strategies. In addition, in many studies the actual values of the SI were not given, which decreases the validity of data comparison.

In the sample of Malawian hemiparetic patients, steps on the affected side were longer than those on the other side, which is in agreement with the findings of Dettman *et al*. (1987) and Hsu *et al.* (2003). However, some other studies reported that, after a stroke, patients may walk with either relatively longer paretic steps or longer non-paretic steps (Kim & Eng, 2003, Hsu *et al.*, 2003). It was proposed that the variability in patterns of step length asymmetry may be due to

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compensatory strategies that increase or decrease the step length of either paretic or non-paretic leg (Kim & Eng, 2003).

There are several reasons for asymmetrical stepping in post-stroke hemiparetic patients. In general, it results from sensory, motor and coordination deficits post-stroke (Olney & Richards, 1996). Kahn & Hornbym (2009) proposed that spatial gait asymmetry may be caused by decreased propulsive forces of the paretic limb and increased spastic plantar-flexor activity.

The present study has several important practical implications. It demonstrated that the footprint method can be successfully used for registration of spatial gait parameters in hemiparetic post-stroke patients in clinical and rehabilitation settings and the SI – for quantitative assessment of gait asymmetry. The inclusion of non-disabled controls in the study allowed calculation of the normalized SI and confidence intervals for 'normal' symmetry. Further studies are needed to verify the potential of these methods in various populations and settings.

The assessment of gait post-stroke using the footprint and SI methods may improve rehabilitation of this category of patients by providing the quantitative measures of gait asymmetry to guide and monitor effectiveness of rehabilitation. In addition, gait symmetry indexes can serve as a complementary measure of gait control mechanisms and post-stroke recovery (Patterson, K.K., 2008). Hopefully the present research will attract attention to this important area and stimulate more studies.

The results of the present study raised an important question on the presence of gait asymmetry in chronic post-stroke hemiparetic patients. The mean duration of post-stroke period in the present study was 11.3±4.6 months. However, most of the patients exhibited asymmetry of spatial gait parameters. This finding concurs with the previous studies, which demonstrated that gait asymmetry clearly persists and can even progress in the later stages post-stroke (Patterson K. *et al*., 2008, Patterson, K.K. 2010b). Given the high prevalence and degree and also numerous negative consequences on gait efficiency, balance control, musculoskeletal health and activity level of hemiparetic patients, reduction of asymmetry in post-stroke gait should be an important goal of physical rehabilitation (Patterson, 2010b).

Resistance of gait asymmetry post-stroke to change may be attributable to the lack of specificity in rehabilitation approaches (Patterson, *2010*b). Gait velocity as an index of gait capacity and symmetry as a measure of gait quality and control are independent features of post-stroke gait that need to be addressed with separate rehabilitation interventions (Kim & Eng, 2003, Patterson K. *et al*., 2008). This study reinforces the importance of targeting gait asymmetry in post-stroke rehabilitation. One of the proposed rehabilitation approaches to improve gait symmetry is to encourage the use of the paretic leg and thereby to stimulate neuroplastic changes that may improve gait control (Kahn & Hornby, 2009, Luft *et. al*., 2009, Patterson, 2010b). Training of strength of ankle dorsiflexors and paretic leg propulsive force production can also promote spatial gait symmetry (Balasubramanian *et al*., 2007; Kim *et al*., 2013). Future work may extend the findings of the present study to develop physical rehabilitation interventions that improve gait control and symmetry in post-stroke hemiparetic patients.

The present study has some potential limitations. In this investigation, the assessment of gait symmetry was limited to the measures of the two bilateral spatial gait parameters – step length and foot rotation angle. These parameters were selected because they are regulated by different gait controlling mechanisms, namely gait patterning and balance control mechanisms, and they provide an overall impression of the gait and indicate the final effect of the movement (Sadeghi, 2000). The results suggested that both control mechanisms are affected post-stroke. Therefore, it is likely that other gait variables, which are controlled by the same mechanisms would be also affected. In addition, the focus on the selected spatial gait parameters may be appropriate since they are most likely to be adopted in the clinical and rehabilitation settings due to the ease and low cost of registration.

In the present study, gait parameters of the patients were measured once, at least six months post-stroke. The conventional view is that in hemiparetic patients gait improves over the

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first three to six months post-stroke and then plateaus (Jorgensen *et al*., 1995). The present study was not designed to examine the dynamics of spatial gait asymmetry post-stroke or to assess the effects of specific rehabilitation interventions on gait symmetry. Future studies are required to address these issues.

In conclusion, the present study demonstrated the asymmetry of step length and foot rotation angle during walking of post-stroke hemiparetic individuals and highlighted the potential of the footprint and SI methods as objective and easy to apply tools suitable for the assessment of symmetry of spatial gait parameters in clinical and rehabilitation settings. The results also emphasized the need for rehabilitation interventions designed specifically to improve the spatial symmetry of post-stroke hemiparetic gait.

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