Original Article

J. Phys. Ther. Sci.
27: 905–909, 2015

The characteristics of multi-directional step distance and the association between stepping laterality and walking ability of patients with stroke

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Abstract. [Purpose] The purpose of this study was to determine the effect of stepping limb and step direction on step distance and the association of step distance and stepping laterality in step difference with walking ability and motor dysfunction. [Subjects and Methods] The subjects were thirty-nine patients with chronic hemiparesis as a result of stroke, who performed the MSL (Maximum Step Length) test along with tests of motor impairment, gait speed and Functional Ambulation Category. The MSL test is a clinical test of stepping distance in which participants step to the front, side, and back. The subjects were classified into three groups according to the stepping laterality in front step distance. [Results] Step distance did not differ across stepping limbs but did differ across step directions. Front step distance was significantly longer than side and back step distance. Participants with forward paretic step length shorter than forward non-paretic step length had significantly higher walking ability than participants with symmetric forward step length or forward paretic step length longer than forward non-paretic step length [Conclusion] Patients with stroke have characteristic step distances in each direction. Adequate weight shift toward the paretic limb when stepping with the non-paretic limb is associated with walking ability.
Key words: Maximum step length, Stepping laterality, Stroke

(This article was submitted Oct. 6, 2014, and was accepted Nov. 7, 2014)

INTRODUCTION

Multi-directional steps are essential for activities of daily living. Non-straight steps that change the direction of movement account for 35–50% of all steps when walking indoors[1)]. Patients with stroke fall not only during walking but also during standing turn or transfer between bed and wheelchair[2, 3)]. Therefore, the ability to take multidirectional steps is important for patients with stroke.

There are many clinical tests that evaluate the temporal aspects of stepping[4–7)], but there are few that evaluate the spatial aspects. The Maximum Step Length (MSL) test is a clinical test of stepping distance in which participants step to the front, side, and back as far as possible with one leg, before returning to the starting position[8, 9)]. MSL values correlate significantly with clinical measures of balance in community-dwelling older adults[8)]. In addition, community-dwelling older adults showed no significant differences in step distance between the front, side, and back directions[8)]. However, differences in step distance in the three directions have not been investigated in patients with stroke. In addition, the reliability of the MSL test has been investigated only in the front direction and has not been investigated in the side and back directions[10)]. Stroke causes motor dysfunction, loss of coordination, and weakness of the muscles, which affect standing balance and walking[11)]. These features would also affect step distance, and step distance would be expected to vary between limbs (paretic vs. non-paretic) and the direction of stepping (front, side, and back). Step training in various directions improves balance and gait[12–14)], and it is important for the step training to evaluate the characteristics of stepping according to step direction and stepping limb.

The purposes of this study were to determine the reliability of the MSL test for the side and back directions, the effect of the stepping limb and step direction on step distance, and the associations of step distance and stepping laterality in step distance with walking ability and motor dysfunction. We hypothesized that step distance would vary across step directions and stepping limbs, and that the stepping laterality in step distance would be associated with motor dysfunction and walking ability.

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SUBJECTS AND METHODS

Thirty-nine patients with chronic hemiparesis as a result of stroke sustained at least 6 months previously were recruited from an outpatient rehabilitation center to participate in this study. Inclusion criteria were the ability to walk at least 10 m with or without a walking aid or ankle-foot orthosis and the ability to follow commands. Individuals were excluded if they had disturbed consciousness, dementia, or musculoskeletal conditions that affect the performance of walking. The Institutional Review Board of the Geriatrics Research Institute and Hospital approved this study and all the subjects provided their written informed consent to participation.

Step distances were measured for the paretic and the non-paretic limbs using the MSL test[8, 9]. The subjects stepped out maximally with one leg, maintaining the stance leg in the initial position, and then returned to their initial stance position in one step. Participants were instructed to step out with the paretic leg and the non-paretic leg in each direction, and therefore performed six stepping actions: to the front with the paretic limb, to the side with the paretic limb, to the back with the paretic limb, to the front with the non-paretic limb, to the side with the non-paretic limb, and to the back with the non-paretic limb. After several practices, measurements were taken twice in each direction. The two measurements were used in the reliability analysis. The greater of the two measurements was used in all other analyses. The subjects were allowed to use their usual ankle-foot orthosis during the MSL test.

Physical impairments that might affect walking ability were evaluated using the Stroke Impairment Assessment Set[15–17]. The motor functions were assessed through hip flexion, knee extension, and foot pat (rapid foot tapping). Motor function was evaluated in stages from 0 to 5, with higher scores indicating better function. Trunk function was evaluated using the Functional Assessment for Control of Trunk[18]. This treatment-oriented measure includes two static sitting balance items and eight dynamic sitting balance items. The static sitting balance items assess the ability to maintain the sitting position with and without upper limb support. The dynamic sitting balance items assess the ability to: reach with an upper limb, lift the pelvis from a table, move the buttocks in the frontal plane, move the buttocks in the sagittal plane, flex the hips individually, flex the hips together, rotate the upper trunk, and flex the shoulder of the non-paretic upper limb. The maximum score is 20, with higher scores indicating better trunk function.

Walking ability in the home was evaluated using the Functional Ambulation Category (FAC), which includes walking on uneven terrain and walking up and down stairs[19]. Walking ability was rated on the following six-point scale: (0) unable to walk or requires the help of two persons to walk; (1) ambulatory with firm continuous contact with one person; (2) ambulatory with the intermittent or continuous support of one person; (3) ambulatory on level surfaces with verbal supervision or stand-by help from one person without physical contact; (4) independent ambulation only on level surfaces; and (5) independent ambulation anywhere, including stairs. Walking ability was also evaluated using gait speed in the 10-m walk test and the Timed Up and Go (TUG) time[20–22]. For the 10-m walk test, participants walked in a straight line at a comfortable speed for 16 m, including 3-m runways at the start and end of a 10-m test walkway. Gait speed was calculated from the time required to walk across the 10-m walkway. The TUG time was the amount of time required to stand from a seated position, walk forward 3 m, turn around, walk back to the chair, and sit down. The participants completed these tasks at a comfortable speed and used their usual walking aid and ankle-foot orthosis. All tests were examined by one rater on the same day.

Data were statistically analyzed using SPSS version 22.0 J for Windows. The test-retest reliability of the two administrations of the MSL test was evaluated using the intraclass correlation coefficient, model 1,1 [ICC(1,1)][23]. The independent samples t test was used to compare step distance by sex. Step distance was compared across limbs and step directions using two-way repeated-measures analysis of variance (ANOVA) and the Bonferroni post hoc test. For each step direction, the difference in the step distance of the paretic and non-paretic limb was calculated (paretic limb minus non-paretic limb). This stepping laterality was compared across the three directions using one-way repeated-measures ANOVA. Pearson correlation coefficients were calculated for all pairwise combinations of step distance in the front, side, and back directions of the two limbs.

A conservative estimate of the minimal detectable change at the 95% confidence level (MDC_{95}) is 8.128 cm (3.2 inches)[10]. Therefore, subjects were classified into three groups according to the stepping laterality in step distance to the front: a paretic step distance >8.128 cm and longer than the non-paretic step distance (longer paretic step group), stepping laterality between −8.128 cm and 8.128 cm (symmetric group), or a paretic step distance >8.128 cm and shorter than the non-paretic step distance (longer non-paretic step group). One-way ANOVA and Tukey's post hoc tests were used to compare walking ability across the three groups. The Kruskal-Wallis and Mann-Whitney U tests with Bonferroni adjustments were used to compare motor impairment across the three groups.

Receiver operating characteristic curves were generated to compare the diagnostic validity of step distance to the front to distinguish FAC 5 from FAC ≤4. Optimal cut-off points were determined by sensitivity, specificity, positive predictive value, and negative predictive value. The level of significance was chosen as $p < 0.05$.

RESULTS

Table 1 shows the characteristics of the 39 subjects. Their mean (SD) age was 69.9 (9.8) years, and the duration since stroke onset was 1,562.4 (1,182.0) days. The mean gait speed in the 10-m walk test was 0.5 (0.3) m/s, and the TUG time was 36.1 (24.0) s. The MSL test had excellent test-retest reliability (ICC(1,1) = 0.939–0.957; Table 2). There was no significant difference in sex in each step direction. There was no significant effect of stepping limb on step distance ($F = 0.735$, $p = 0.483$), but there was a significant effect of step direction ($F = 19.969$, $p < 0.01$). For the paretic limb, front step distance was significantly longer than those of the side and back step distances ($p < 0.01$). For the non-paretic limb, front step distance was significantly longer than those of the side and back step distances ($p < 0.01$). Step distances were significantly correlated across all pairwise combinations of direction and side (Table 3). There was no significant effect of step direction on the stepping laterality in step distance (F = 0.735, p = 0.482). The stepping lateralities in the front, side, and back directions were 0.9 ± 8.6 [−1.9 to 3.8] cm, −0.2 ± 9.0 [−3.1 to 2.8] cm, and 0.0 ± 7.0 [−2.3 to 2.2] cm, respectively (mean ± SD [95% confidence interval]).

Table 4 shows the motor function and walking ability of the longer paretic step group, symmetric group, and longer non-paretic step group. Gait speed, TUG time, and FAC were better in the longer non-paretic step group than in the symmetric group and the longer paretic step group.

The cut-off value of the paretic front step distance which distinguished FAC 5 from FAC ≤4 was 33 cm. The sensitivity, specificity, positive predictive value, and negative predictive values were 0.81, 0.91, 0.87, and 0.88, respectively. The cut-off value of the non-paretic front step distance which distinguished FAC 5 from FAC ≤4 was also 33 cm. The sensitivity, specificity, positive predictive value, and negative predictive values were 0.93, 0.91, 0.88, and 0.95, respectively.

Table 1. Characteristics of the subjects

	Mean ± SD Median [first–third quartile]
Age (years)	69.9±9.8
Gender: male/female (n)	23/16
Duration since stroke onset (days)	1562.4±1182.0
Paretic side: right/left (n)	27/12
SIAS	
Hip-Flexion	4 [2–4]
Knee-Extension	3 [2–4]
Foot-Pat	3 [1–4]
FACT	10 [6–14]
Gait speed (m/sec)	0.5±0.3
TUG (s)	36.1±24.0
FAC	4 [3–5]

FAC: functional ambulation category; FACT: functional assessment for control of trunk; TUG: timed up and go test; SIAS: stroke impairment assessment set

DISCUSSION

We investigated the reliability of the MSL test and the difference in step distance between the paretic and non-paretic limbs for steps to the front, side, and back. Pardo reported that the test-retest reliability of the MSL test in the front direction was excellent for both the paretic and the non-paretic limbs[10]. In this study, test-retest reliability was excellent in each step direction (ICC > 0.900). Step distance

Table 2. Reliability and step distance in each direction

		ICC (1,1)	95% CI	Step distance (cm)	Step limb	Step direction	Limb × Direction
Paretic	Front	0.943	0.895, 0.970	26.1±20.4§§††	n.s	**	n.s
	Side	0.939	0.888, 0.968	20.7±16.9§§			
	Back	0.957	0.919, 0.977	19.1±17.0††			
Non-paretic	Front	0.951	0.909, 0.974	25.1±24.1§§††			
	Side	0.954	0.915, 0.976	20.8±21.3§§			
	Back	0.946	0.899, 0.971	19.1±19.0††			

ICC: Intraclass correlation coefficients.
Values are mean ± SD.
**Significantly different according to ANOVA ($p < 0.01$)
§§Significantly different from the front and side ($p < 0.01$)
††Significantly different from the side and back ($p < 0.01$)

Table 3. Correlation between paretic and non-paretic step distances in each direction

		Paretic					Non-paretic					
		Front	Side		Back		Front		Side		Back	
Paretic	Front		0.930	**	0.946	**	0.938	**	0.892	**	0.941	**
	Side				0.931	**	0.896	**	0.914	**	0.893	**
	Back						0.890	**	0.855	**	0.931	**
Non-paretic	Front								0.955	**	0.966	**
	Side										0.929	**
	Back											

Values are Pearson correlation coefficients.
**$p < 0.01$

Table 4. Motor function and gait abilities of the three groups

	Longer paretic step Group (n=7)	Symmetric Group (n=26)	Longer non-paretic step Group (n=6)	Group
Hip-Flexion	3 [2.5–3.5]	4 [2–4]	4.5 [4–5]	
Knee-Extension	2 [2–3.5]	2.5 [2–4]§	4.5 [4–5]§	*
Foot-Pad	2 [1.5–2.5]	3 [2–4]	4.5 [4–5]	
FACT	8 [5.5–11]	9.5 [6–15]	13.5 [11–14]	
Gait speed (m/sec)	0.23± 0.12†¶	0.46± 0.28¶§	0.86± 0.17†§	**
TUG (s)	51.1± 19.8†¶	36.9± 24.7¶	15.1± 2.8†	**
FAC	2 [2–3.5]†¶	4 [3–5]¶§	5 [5–5]†§	**

Values are mean ± SD or median [first–third quartile]. The subjects were classified into three groups according to the stepping laterality front step distance (Longer paretic step group, Symmetric group, Longer non-paretic step group).
*Statistically significant difference between groups ($p < 0.05$)
**Statistically significant difference between groups ($p < 0.01$)
†Statistically significant difference between longer paretic step group and longer non-paretic step group ($p < 0.05$)
¶Statistically significant difference between longer paretic step group and symmetric group ($p < 0.05$)
§Statistically significant difference between longer non-paretic step group and symmetric group ($p < 0.05$)

didn't differ significantly between the paretic and non-paretic limb. This indicates that patients with stroke adapt to motor impairment[24], and can perform similar length steps with the paretic and non-paretic limb. On the other hand, step distances significantly differed between the front, side and back directions. It is possible that poor coordination of limb segments, poor posture in stepping, the effect of visual information, and insufficient experience of stepping to the side and back caused the differences in step distances across directions.

We classified participants into three groups according to the stepping laterality in step distance to the front, with reference to a previous study[10]. The longer non-paretic step group had better walking ability than the symmetric group and the longer paretic step group. Gait speed is associated with cycle length in gait[25]. Moreover, weight-bearing by the paretic limb improves gait and balance ability[26]. The step distance of the non-paretic limb indicates the weight shift ability of the paretic lower limb, and good weight shift ability in the paretic limb is necessary for large step distances by the non-paretic limb. Therefore, the longer paretic step group had limited weight-bearing ability for the paretic limb and the longer non-paretic step group had adequate weight-bearing ability for the paretic limb, indicating that step distance of the non-paretic limb is important for walking ability. On the other hand, most measures of motor function of the paretic limb didn't differ among the three groups. Functional mobility wasn't strongly correlated with impairments of motor function in the paretic-lower limb[27]. Therefore, it is possible that motor function of the paretic-lower limb does not affect the stepping laterality in step distance between the paretic and non-paretic limbs. However, the number of participants was small, and this limits the generalizability of our results.

Correlations between step distances in the different directions were high. Therefore, we calculated cut-off scores for the paretic front step distance and non-paretic front step distance to distinguish FAC 5 from FAC ≤4. The cut-off score was 33 cm for the paretic front step distance and non-paretic front step distance. FAC can discriminate independent walkers, and thus step distance to the front is useful because it can rapidly be evaluated in small spaces.

A limitation of this study is that participants had chronic hemiparesis, and most had low walking ability. Therefore, our results might not be reflected by stroke patients with good walking ability. In addition, it is possible that the classification of the subjects into three groups using the MDC_{95} of the MSL test may not have been appropriate. The MDC_{95} of a previous study was too large to usefully classify the participants in our study into three groups[10]. Subjects of the previous study had high gait ability, a mean gait speed of 0.8 m/seconds[10], which is equivalent to that of community walkers[21].

To conclude, we investigated the reliability of the MSL test and the differences in step distance across stepping limbs and step directions. The test-retest reliability coefficients were excellent for all step directions (ICC = 0.939–0.957). Step distances were similar in the two limbs but different across step directions. Front step distance was longer than side and back step distance. In addition, paretic step distance shorter than non-paretic step distance indicated good walking ability. Paretic front step distance and non-paretic front step distance may be useful for discriminating independent walkers.

REFERENCES

1) Glaister BC, Bernatz GC, Klute GK, et al.: Video task analysis of turning during activities of daily living. Gait Posture, 2007, 25: 289–294. [Medline] [CrossRef]
2) Harris JE, Eng JJ, Marigold DS, et al.: Relationship of balance and mobility to fall incidence in people with chronic stroke. Phys Ther, 2005, 85: 150–158. [Medline]
3) Simpson LA, Miller WC, Eng JJ: Effect of stroke on fall rate, location and predictors: a prospective comparison of older adults with and without stroke. PLoS ONE, 2011, 6: e19431. [Medline] [CrossRef]

4) Hill KD, Bernhardt J, Maltese D, et al.: A new test of dynamic standing balance for stroke patients: reliability, validity and comparison with healthy elderly. Physiother Can, 1996, 48: 257–262. [CrossRef]
5) Fujisawa H, Takeda R: A new clinical test of dynamic standing balance in the frontal plane: the side-step test. Clin Rehabil, 2006, 20: 340–346. [Medline] [CrossRef]
6) Blennerhassett JM, Jayalath VM: The Four Square Step Test is a feasible and valid clinical test of dynamic standing balance for use in ambulant people poststroke. Arch Phys Med Rehabil, 2008, 89: 2156–2161. [Medline] [CrossRef]
7) Miyamoto K, Takebayashi H, Takimoto K: The criterion-related validity of the ten step test compared with motor reaction time. J Phys Ther Sci, 2008, 20: 261–265. [CrossRef]
8) Cho BL, Scarpace D, Alexander NB: Tests of stepping as indicators of mobility, balance, and fall risk in balance-impaired older adults. J Am Geriatr Soc, 2004, 52: 1168–1173. [Medline] [CrossRef]
9) Medell JL, Alexander NB: A clinical measure of maximal and rapid stepping in older women. J Gerontol A Biol Sci Med Sci, 2000, 55: M429–M433. [Medline] [CrossRef]
10) Pardo V, Knuth D, McDermott B, et al.: Validity, reliability and minimum detectable change of the maximum step length test in people with stroke. J Neurol Sci, 2013, 325: 74–78. [Medline] [CrossRef]
11) Janet H, Carr RB: Shepherd: Neurological Rehabilitation: Optimizing motor performance. Churchill Livingstone, 2010.
12) Shigematsu R, Okura T: A novel exercise for improving lower-extremity functional fitness in the elderly. Aging Clin Exp Res, 2006, 18: 242–248. [Medline] [CrossRef]
13) Protas EJ, Mitchell K, Williams A, et al.: Gait and step training to reduce falls in Parkinson's disease. NeuroRehabilitation, 2005, 20: 183–190. [Medline]
14) You YY, Her JG, Ko K, et al.: Effects of standing on one leg exercise on gait and balance of hemiplegia patients. J Phys Ther Sci, 2012, 24: 571–575. [CrossRef]
15) Wade DT: Measurement in Neurological Rehabilitation. Oxford: Oxford University Press, 1992, pp 50–58.
16) Chino N: Stroke Impairment Assessment Set (SIAS)—A new evaluation instrument for stroke patients. Jpn J Rehabil Med, 1994, 31: 119–125. [CrossRef]
17) Chino N, Sonoda S, Domen K, et al.: Functional Evaluation of Stroke Patients. Tokyo: Springer-Verlag Tokyo, 1996, pp 33–44.
18) Okuda Y, Ogino Y, Ozawa Y, et al.: Development and Reliability of Functional Assessment for Control of Trunk (FACT). Rigakuryoho Kagaku, 2006, 21: 357–362 (in Japanese). [CrossRef]
19) Holden MK, Gill KM, Magliozzi MR: Gait assessment for neurologically impaired patients. Standards for outcome assessment. Phys Ther, 1986, 66: 1530–1539. [Medline]
20) Wolf SL, Catlin PA, Gage K, et al.: Establishing the reliability and validity of measurements of walking time using the Emory Functional Ambulation Profile. Phys Ther, 1999, 79: 1122–1133. [Medline]
21) Perry J, Garrett M, Gronley JK, et al.: Classification of walking handicap in the stroke population. Stroke, 1995, 26: 982–989. [Medline] [CrossRef]
22) Podsiadlo D, Richardson S: The timed "Up & Go": a test of basic functional mobility for frail elderly persons. J Am Geriatr Soc, 1991, 39: 142–148. [Medline]
23) Shrout PE, Fleiss JL: Intraclass correlations: uses in assessing rater reliability. Psychol Bull, 1979, 86: 420–428. [Medline] [CrossRef]
24) Latasha ML, Anson JG: What are "normal movements" in atypical populations? Behav Brain Sci, 1996, 19: 44–68.
25) Roth EJ, Merbitz C, Mroczek K, et al.: Hemiplegic gait. Relationships between walking speed and other temporal parameters. Am J Phys Med Rehabil, 1997, 76: 128–133. [Medline] [CrossRef]
26) Kim TW, Kim YW: Treadmill sideways gait training with visual blocking for patients with brain lesions. J Phys Ther Sci, 2014, 26: 1415–1418. [Medline] [CrossRef]
27) Ng SS: Contribution of subjective balance confidence on functional mobility in subjects with chronic stroke. Disabil Rehabil, 2011, 33: 2291–2298. [Medline] [CrossRef]