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Differences in self-selected and fastest-comfortable walking in post-stroke hemiparetic persons

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ABSTRACT

Post-stroke hemiparetic walking is typically asymmetric. Assessment of symmetry is often performed at either self-selected or fastest-comfortable walking speeds to gain insight into coordination deficits and compensatory mechanisms. However, how walking speed influences the level of asymmetry is unclear. This study analyzed relative changes in paretic and non-paretic leg symmetry to assess whether one speed is more effective at highlighting asymmetries in hemiparetic walking and whether there is a systematic effect of speed on asymmetry. Forty-six subjects with chronic hemiparesis walked at their self-selected and fastest-comfortable speeds on an instrumented split-belt treadmill. Relative proportions (paretic leg value/(paretic + non-paretic leg value)) were computed at each speed for step length (PSR), propulsion (PP), and joint moment impulses at the ankle and hip. Thirty-six subjects did not change their step length symmetry with speed, while three subjects changed their step length values toward increased asymmetry and seven changed toward increased symmetry. Propulsion symmetry did not change uniformly with speed for the group, with 15 subjects changing their propulsion values toward increased asymmetry while increasing speed from their self-selected to fastest-comfortable and 11 decreasing the asymmetry. Both step length and propulsion symmetry were correlated with ankle impulse proportion at self-selected and fastest-comfortable speed (cf., hip impulse proportion), but ratios (self-selected value/fastest-comfortable value) of the proportion measures (PSR and PP) showed that neither step length nor propulsion symmetry correlated with the ankle impulse proportions. Thus, the individual kinetic mechanisms used to increase speed could not be predicted from PSR or PP.

1. Introduction

Stroke is the leading cause of long-term disability, with less than 50% of survivors being able to walk in the community [1]. Hemiparesis secondary to stroke contributes significantly to reduce walking performance, with hemiparetic subjects walking at slower speeds relative to healthy subjects [2,3]. While rehabilitation assessment often measures a subject's self-selected walking speed as an indication of walking performance, recent work has indicated that novel insights may be gained by challenging hemiparetic subjects to walk at their fastest-comfortable speed [4–7]. Some evidence suggests that walking at their fastest speed provides a better assessment by exacerbating their neuromotor impairments, making them easier to identify than at their self-selected speed, and may improve coordination. Jonkers et al. [6] found that low functioning (i.e., high severity) hemiparetic subjects could not increase ankle plantarflexor and hip flexor power to increase walking speed because they had already saturated their power output at their self-selected speed. In contrast, high functioning (i.e., low severity) hemiparetic subjects could increase both ankle plantarflexor and hip flexor power output to increase speed similar to healthy control subjects. Their study showed that comparison of walking performance at self-selected and fastest-comfortable speeds can elucidate factors limiting the ability to increase speed in hemiparetic subjects, but they had a relatively small sample size ($n = 12$) and did not assess subjects with moderate severity. Jonsdottir et al. [8] showed that each subject ($n = 39$) is functionally different and adopted a different strategy to increase gait speed. However, their study did not address the involvement of the non-paretic leg, which is often important for increasing walking speed. On the other hand, Lamontagne and Fung [9] concluded that "fast walking induces

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speed-dependent adaptations that improve the overall walking pattern of stroke subjects, with no observable deleterious effects." Thus, the ability of different speeds to reveal different information regarding impairment is not well understood and an increased understanding could improve assessment of gait related motor impairments.

Quantitative measures that can discern the underlying impairments of hemiparetic walking at self-selected and fastest-comfortable speeds are needed in the clinic. Since healthy walking is characterized by symmetry of spatiotemporal, kinematic and kinetic parameters between legs, measures based on symmetry should potentially provide insight into compensatory mechanisms. For example, step length symmetry (previously defined [10] as PSR = paretic step length/(paretic + non-paretic step length)) has been shown to correlate with hemiparetic severity and asymmetry in anterior–posterior ground reaction forces (A–P GRFs) [10]. In addition, the propulsion symmetry (previously defined [5] as PP = positive paretic A–P impulse (time integral of the positive A–P GRF)/(paretic + non-paretic positive A–P impulses)), has been shown to be a quantitative measure of the paretic leg's contribution to forward propulsion [5]. Comparison of step length and propulsion symmetry at self-selected and fastest-comfortable speeds may identify a test condition that exacerbates impairments to improve detection. For example, hemiparetic subjects may walk more asymmetrically with increased speed such that analysis at their fastest-comfortable speed would better elucidate their underlying impairments.

Previous studies have shown that hip flexor and ankle plantarflexor muscle strength were the most important factors contributing to increases in speed, suggesting that rehabilitation interventions focused on increasing output from the hip and ankle muscles may increase a subject's fastest-comfortable speed [6,11]. Thus, analysis of ankle and hip joint moment impulses (i.e., the time integral of the corresponding joint moment) at both self-selected and fastest-comfortable speed may help identify the mechanisms used to increase speed.

The purpose of this study was to analyze step length and propulsion symmetry at self-selected and fastest-comfortable speeds during treadmill walking to determine whether testing hemiparetic subjects at both self-selected and fastest-comfortable gait speeds is required to fully elucidate their impairments, or whether a rehabilitation assessment at one's self-selected speed is sufficient to identify underlying impairments (e.g., Kollen et al. [4]). This will also reveal whether there are consistent changes in step length and propulsion symmetry with walking speed that would limit their utility as an outcome measure for rehabilitation interventions that target improved walking function. In addition, the relationships between changes in step length and propulsion symmetry with changes in ankle and hip joint moment impulses will be analyzed to identify the compensatory mechanisms used by hemiparetic subjects to increase from their self-selected to fastest-comfortable speed.

2. Methods

2.1. Subjects

This study consisted of 46 subjects (30 men, 16 women; average age 60.7 (11.2 S.D.) years) with chronic hemiparesis who were part of a larger ongoing study at the Brain Rehabilitation Research Center at the Malcolm Randall VA Medical Center in Gainesville, FL. Inclusion criteria for the hemiparetic subjects were hemiparesis secondary to a single unilateral stroke, free of significant lower extremity joint pain and major sensory deficits, able to ambulate independently with an assistive device over 10 m on a level surface, walk on a daily basis in the home, no significant lower limb contractures, and no significant cardiovascular impairments contraindicative to walking. Subjects were excluded from the study if they had any orthopedic or other neurologic (i.e., in addition to that caused by stroke) conditions. All subjects signed informed consent and the Institutional Review Board of the University of Florida and the University of Texas approved the protocol.

2.2. Experimental set-up and procedure

At the beginning of the test session, subjects performed three 30 s walking trials on an instrumented split-belt treadmill (Tecmachine[1]) at their self-selected speed. Subjects then performed two 30 s walking trials at their fastest-comfortable speed. All trials were performed without use of an assistive device or ankle-foot orthosis while a safety harness mounted to the laboratory ceiling supported the subjects in the event of loss of balance (no bodyweight was offloaded by the harness). Three-dimensional GRF and kinematic data were recorded for 30 s after the subject had reached steady-state. Retro-reflective markers were recorded using a twelve-camera motion capture system (Vicon Motion Systems[2]) to assess bilateral 3D kinematics at 100 Hz. A modified Helen Hayes marker set was used to define each body segment with triads of markers located on each foot, shank and thigh segment attached to plastic rigid plates to reduce measurement error. The GRF data were measured at 2000 Hz.

2.3. Data analysis

The kinematic and GRF data were processed using Visual 3D.[3] Raw kinematic and GRF data were low-pass filtered using a fourth-order zero-lag Butterworth filter with cutoff frequencies of 6 Hz and 20 Hz, respectively. All data were time normalized to 100% of the paretic leg gait cycle. Step length symmetry (PSR = paretic step length/(non-paretic + paretic step length)) and propulsion symmetry (PP = positive paretic A–P impulse/(positive non-paretic + paretic A–P impulse)) were determined for each subject at their self-selected and fastest-comfortable speed. A value of 0.5 in both measures indicates perfect symmetry.

Ratios of step length and propulsion symmetry were determined for each subject to evaluate relative changes in symmetry between the paretic and non-paretic legs as subjects increased from their self-selected to fastest-comfortable speed. The step length symmetry speed ratio was determined as each subject's step length symmetry at self-selected speed divided by the value at their fastest-comfortable speed. The propulsion symmetry speed ratio was similarly determined as each subject's propulsion symmetry at self-selected speed over that at their fastest-comfortable speed. Changes in these two speed ratios from self-selected to fastest-comfortable speed were considered significant only if their values fell outside the relative symmetry range, which was defined as 0.9–1.1. Speed ratios > 1.1 indicate greater relative paretic values at self-selected speeds.

To provide insight into the kinetic mechanisms used to increase speed, an inverse dynamics analysis was performed using Visual 3D to determine intersegmental joint moments normalized by each subject's body weight. Ankle plantarflexor and hip flexor moment impulses (i.e., time integral of the corresponding moment over the propulsion phase) were computed for each leg. Proportions of paretic ankle moment impulse and hip moment impulse were defined as the paretic moment impulse divided by the sum of the paretic and non-paretic moment impulses. The proportions were tested to determine if they were correlated with step length and propulsion symmetry at the self-selected speed. If a significant relationship existed at the self-selected speed, then the corresponding ankle and hip moment speed ratios were determined as the proportion at self-selected speed over the proportion at their fastest-comfortable speed. Ankle and hip moment speed ratios > 1.1 indicates greater relative paretic moment impulses at their self-selected speeds.

To assess whether self-selected speed alone could predict underlying impairments, subjects were placed into subgroups based on step length symmetry at their self-selected speed. Subjects walking with PSR < 0.45 (i.e., shorter paretic than non-paretic steps) at their self-selected speed were placed in the low self-selected step length symmetry group, and subjects walking with PSR > 0.55 (i.e., longer non-paretic than paretic steps) at their self-selected speed were placed in the high self-selected step length symmetry group. The symmetric self-selected step length symmetry group consisted of subjects with PSR values between 0.45 and 0.55 at their self-selected speed.

In order to identify whether assessment at their self-selected speed was sufficient to reliably predict fastest-comfortable speed, a regression analysis was performed to test for a linear relationship between each subject's self-selected speed and change in speed (fastest-comfortable–self-selected). To test for a relationship between the step length symmetry speed ratio and the propulsion symmetry speed ratio, a Pearson correlation coefficient was determined and analyzed such that $p < 0.05$ indicated a significant correlation.

3. Results

The average self-selected and fastest-comfortable walking speeds for the subjects were 0.46 (0.25 S.D.) m/s and 0.70 (0.37 S.D.) m/s, respectively (Table 1). Individual subject data can be found in Appendix A. Eighteen subjects walked with longer paretic than non-paretic steps at their self-selected speed (PSR > 0.55) and

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[2] Vicon, 14 Minns Business Park, West Way, Oxford, OX2 OJB, UK.
[3] C-Motion, Inc., 20030 Century Blvd, Suite 104, Germantown, MD 20874.

Table 1
Average, standard deviation (S.D.), and range for speed, PSR and PP at self-selected and fastest-comfortable walking speeds.

	Self-selected			Fastest-comfortable		
	Speed (m/s)	PSR	PP	Speed (m/s)	PSR	PP
Average	0.45	0.57	0.35	0.69	0.53	0.33
S.D.	0.25	0.21	0.23	0.38	0.15	0.22
Range	0.15–1.00	0.36–1.61	0.01–0.80	0.15–1.90	0.29–1.23	0.00–0.73

were grouped in the high self-selected step length symmetry subgroup. Seven subjects walked with shorter paretic steps at their self-selected speed (PSR < 0.45) and were grouped in the low self-selected step length symmetry subgroup. Twenty-one subjects walked with symmetric step lengths at their self-selected speed ($0.45 \leq$ PSR ≤ 0.55) and were grouped in the symmetric self-selected step length symmetry subgroup.

Subjects with greater step length asymmetry at their self-selected speed walked more slowly at their fastest-comfortable walking speeds. Specifically, fastest-comfortable walking speeds were negatively correlated with step length symmetry at self-selected speed ($p = 0.008$). Fastest-comfortable walking speeds were also correlated with propulsion symmetry at self-selected speed, but positively and much less strongly correlated ($p = 0.049$). In addition, the difference in gait speed from self-selected to fastest-comfortable was correlated with self-selected speed ($p = 0.006$) (Fig. 1). However, it explained only a small proportion of the variance ($r^2 = 0.161$).

Seventy-eight percent of subjects (36 of 46) did not change their step length symmetry values beyond the relative symmetric region (step length symmetry speed ratio between 0.9 and 1.1, vertically shaded region in Fig. 2) going from their self-selected to fastest-comfortable speed. Seven subjects became more symmetric as one subject who walked with shorter relative paretic steps at their self-selected speed (self-selected PSR < 0.45) walked with more symmetric step lengths with increases in speed (step length symmetry speed ratio < 0.9) (Fig. 2) and six subjects who walked with longer relative paretic steps at their self-selected speed (self-selected PSR > 0.55) walked with more symmetric step lengths with increases in speed (step length symmetry speed ratio > 1.1) (Fig. 2). Three subjects who were initially asymmetric became even more asymmetric (two subjects with initially shorter paretic steps took even shorter steps and one subject who was initially asymmetric with a longer paretic step who became more asymmetric with a longer non-paretic step). We considered one subject with a step length symmetry speed ratio greater than 1.1 to not have changed symmetry values as both PSR values were in the symmetric range ($0.45 \leq$ PSR ≤ 0.55).

While 26 subjects changed their propulsion symmetry values beyond the symmetric region (propulsion symmetry speed ratio between 0.9 and 1.1, horizontal shaded region in Fig. 2) as they increased walking speed from their self-selected to fastest-comfortable speed, the changes were often small in absolute terms (Appendix A, Table 1) as propulsion symmetry values were much smaller on average than step length symmetry values (mean value of 0.35 versus 0.55 at self-selected speed, respectively). Fifteen of these subjects generated more paretic propulsion relative to the non-paretic leg at their self-selected speed than their fastest-comfortable speed (propulsion symmetry speed ratio > 1.1). Eleven subjects generated less relative paretic propulsion at their self-selected speed than their fastest-comfortable speed (propulsion symmetry speed ratio < 0.9). That there was no systematic effect of increased speed on the propulsion symmetry measure was confirmed by a paired *t*-test that revealed that propulsion symmetry was unchanged ($p = 0.20$) at self-selected speed (0.35 ± 0.22) and fastest-comfortable speed (0.34 ± 0.22).

While some subjects changed their symmetry, both step length and propulsion, these changes were not systematic and the two speed ratios were not correlated ($p = 0.76$) (Fig. 2). Step length symmetry at self-selected speed was related to the proportion of ankle joint moment impulse but not hip joint moment impulse. At self-selected speed, there was strong support for a negative correlation between ankle impulse and step length symmetry ($p = 0.001$) and a non-significant positive correlation between ankle impulse and propulsion symmetry ($p = 0.18$). Hip impulse was not correlated with step length symmetry ($p = 0.70$) or propulsion symmetry ($p = 0.66$) at self-selected speed. Thus, only

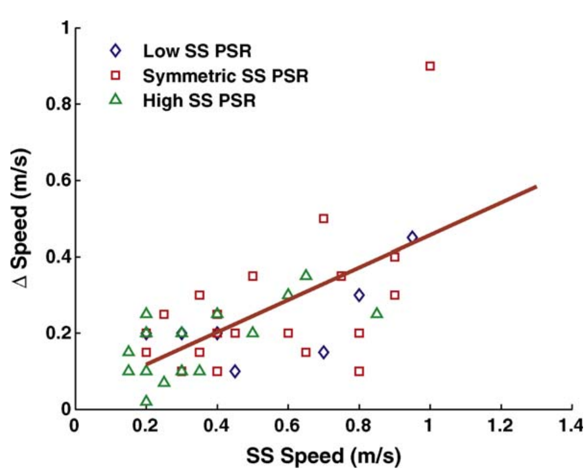

Fig. 1. Change in walking speed (fastest-comfortable–self-selected) versus self-selected walking speed.

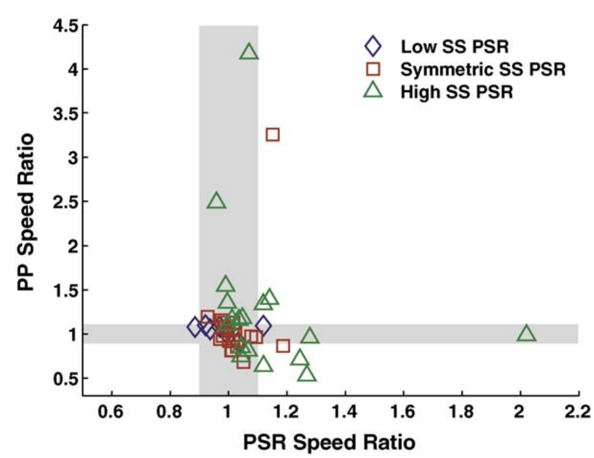

Fig. 2. Propulsive symmetry speed ratio (PP at self-selected/PP at fastest-comfortable) versus step length symmetry speed ratio (PSR at self-selected/PSR at fastest-comfortable). Shaded areas represent approximate symmetry between speeds (0.9–1.1). Speed ratios > 1.1 indicates greater relative paretic values at self-selected speeds. Speed ratios < 0.9 indicates lesser relative paretic values at self-selected speeds. Shaded regions (0.9–1.1) represent the relative symmetric region for speed ratios (i.e., little change in measures between self-selected and fastest-comfortable speed).

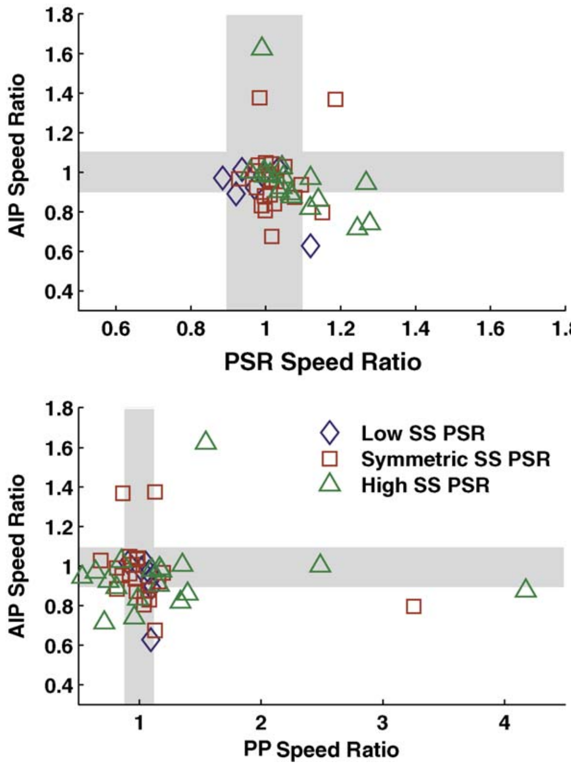

Fig. 3. Ankle moment impulse proportion (AIP) speed ratio (AIP at self-selected/AIP at fastest-comfortable) versus (A) step length symmetry (PSR) and (B) propulsion symmetry (PP). Shaded areas represent approximate symmetry between speeds (0.9–1.1). Speed ratios > 1.1 indicates greater relative paretic values at self-selected speeds. Speed ratios < 0.9 indicates lesser relative paretic values at self-selected speeds. Shaded regions (0.9–1.1) represent the relative symmetric region for speed ratios (i.e., little change in measures between self-selected and fastest-comfortable speed).

ankle joint moment impulse was investigated as a potential mechanism of changes in step length symmetry.

There was weak evidence for changes in ankle joint moment impulse being related to changes in step length symmetry ($p = 0.15$) but not to changes in propulsion symmetry ($p = 0.73$) (Fig. 3). Twenty subjects significantly changed their proportion of paretic ankle moment impulse values with increased walking speed (Fig. 3). Of these 20 subjects, only three (two from the symmetric self-selected step length symmetry group and one asymmetric with longer paretic steps) obtained an ankle moment speed ratio above 1.1, implying the remaining 17 subjects had a significantly lower paretic ankle moment impulse at their fastest-comfortable speed.

4. Discussion

In agreement with Jonsdottir et al. [8] who studied overground walking, we found that the change in speed could not be determined from the self-selected speed alone during treadmill walking. The step length symmetry at self-selected speed did negatively correlate with fastest-comfortable speed, indicating that persons walking with longer paretic steps at their self-selected speed walked at slower fastest-comfortable speeds. However, subjects in each respective group walked with a wide range of self-selected speeds and demonstrated diverse changes in speed from self-selected to fastest-comfortable. These results suggest that rehabilitation assessment at one's self-selected speed alone may not be sufficient to identify underlying impairments in hemiparetic walking.

We anticipated that analyzing subjects at their fastest-comfortable speed would move them toward a more asymmetrical walking pattern and help elucidate the compensatory mechanisms used to increase walking speed. However, only 3 of the 46 subjects had increased step length asymmetry with increases in speed and only 15 of the 46 subjects had increased propulsion asymmetry with increases in speed. In addition, 26 of the 46 subjects either moved toward or retained a symmetric step length pattern with increases in speed (i.e., the low self-selected step length symmetry group showed a weak trend to move toward symmetry with increases in gait speed by increasing relative paretic step length, and the high self-selected step length symmetry group also showed a weak trend to move toward symmetry by decreasing relative step length). Thus, there was not a single speed, self-selected or fastest-comfortable, which uniformly exacerbated the subjects' neuromotor impairments. Note also that we did not find evidence for uniform amelioration of impairment with increased speed as suggested by Lamontagne and Fung [9]. Instead our results suggest, consistent with the analysis of the paretic leg done by Jonsdottir et al. [8], that there is no consistent pattern as to which speed best reveals underlying impairments. Thus, both self-selected and fastest-comfortable speeds may be needed to fully identify underlying impairments.

There was also not a correlation between the step length symmetry speed ratio (self-selected value/fastest-comfortable value) and the propulsion symmetry speed ratio. Based on previous work by Balasubramanian et al. [10], we anticipated that subjects who decreased their relative paretic step lengths at their fastest-comfortable speeds would increase their relative paretic propulsion and conversely, that subjects who increase their relative paretic step lengths at their fastest-comfortable speeds would decrease their relative paretic propulsion. However, we found that there was no clear relationship between changes in step length symmetry and propulsion symmetry with increases in speed. Note that step length symmetry and propulsion symmetry had a strong negative correlation at both self-selected and fastest-comfortable speeds ($p < 0.0001$), suggesting a similar relationship for step length symmetry and propulsion symmetry at each speed. The lack of correlation likely reflects that the intrasubject changes in propulsion symmetry with speed were of small magnitude relative to the intersubject variability in propulsion symmetry. This suggests that different information may be required to fully understand hemiparetic walking at self-selected and fastest-comfortable speeds. Additional measures such as joint moment impulses, leg angle [12] and double support time [13] have been shown to be important gait parameters to understand the mechanics of hemiparetic walking. Future studies should investigate the relationship between these measures and step length symmetry and propulsion symmetry. In addition, these symmetry measures are limited in that they do not quantitatively assess the output of each leg in walking; rather they provide a comparison between legs with increases in speed. Future work should compare the relationship between these changes in leg symmetry and absolute changes in output of each leg.

We anticipated that trends would become apparent between the joint impulse speed ratios and step length symmetry and propulsion symmetry speed ratios. However, the kinetic mechanisms used to increase speed could not be predicted from step length symmetry and propulsion symmetry, although a weak trend was suggested for increased ankle moment impulse to result in decreased step length asymmetry. We believe that the analysis of step length symmetry and propulsion symmetry at self-selected and fastest-comfortable speeds in coordination with joint impulses may also be insufficient to elucidate the range of mechanisms used to increase speed because joint output may increase to achieve a compensatory mechanism not directly related to speed (e.g., toe clearance and stability). Leg angle, which is strongly correlated with propulsion generation [12], and double support time, which is related to swing initiation [13], may prove more critical to understanding hemiparetic walking with increases in speed. Thus, future work should examine these measures in coordination with step length symmetry, propulsion symmetry and joint impulse proportions.

The purpose of this study was to analyze step length symmetry and propulsion symmetry at self-selected and fastest-comfortable speeds during treadmill walking to determine the speed at which testing of hemiparetic subjects should be performed to best elucidate their impairments. Previous work had suggested that it was not necessary to measure fastest-comfortable speed since it could be predicted from self-selected speed [4]. However, it was not clear whether the impairments identified at one's self-selected speed are consistent with those identified at their fastest-comfortable speed, or perhaps if walking at their fastest-comfortable speed would exacerbate impairments and allow the identification of deficits not revealed at their self-selected speed. Our results suggest that different information is gained regarding impairments at each speed, with some subjects exacerbating and others ameliorating the self-selected speed impairments while walking at their fastest-comfortable speed. Additionally, our results reveal that there is no systematic effect of speed on either step length or propulsion symmetry. This suggests that they are potentially promising outcome measurements for rehabilitation interventions since they appear to be insensitive to walking speed while remaining sensitive to walking specific motor impairment. The heterogeneity of response to change in speed may offer hope for providing a window into different underlying impairments. Further progress in using asymmetry data to understand the underlying impairments of hemiparetic walking will likely require identification of subgroups of subjects that respond similarly at each speed.

Acknowledgements

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Appendix A

See Table A1.

Table A1
Speed, PSR and PP individual subject and group average and standard deviation (S.D.) data at self-selected and fastest-comfortable walking speeds.

Subject	Self-selected			Fastest-comfortable		
	Speed (m/s)	PSR	PP	Speed (m/s)	PSR	PP
1	0.7	0.466	0.219	1.2	0.473	0.194
2	0.25	0.554	0.226	0.32	0.548	0.194
3	0.8	0.522	0.270	0.9	0.522	0.293
4	0.2	0.446	0.641	0.4	0.399	0.585
5	0.15	0.583	0.690	0.3	0.288	0.698
6	0.15	0.578	0.050	0.25	0.516	0.079
7	0.35	0.512	0.366	0.5	0.525	0.316
8	0.5	0.483	0.532	0.85	0.472	0.511
9	0.15	0.905	0.173	0.25	0.708	0.180
10	0.4	0.596	0.538	0.65	0.602	0.348
11	0.7	0.449	0.557	0.85	0.434	0.614
12	0.2	0.733	0.164	0.45	0.589	0.230
13	0.8	0.435	0.653	1.1	0.448	0.603
14	0.3	0.577	0.126	0.4	0.578	0.114
15	0.4	0.414	0.741	0.6	0.468	0.687
16	0.2	0.638	0.279	0.22	0.596	0.067
17	0.3	0.400	0.804	0.5	0.435	0.731
18	0.45	0.520	0.123	0.65	0.514	0.151
19	0.3	0.719	0.091	0.4	0.686	0.077
20	0.2	0.639	0.309	0.4	0.571	0.231
21	0.45	0.362	0.704	0.55	0.365	0.695
22	0.3	0.561	0.096	0.4	0.585	0.039
23	0.4	0.529	0.221	0.6	0.503	0.323
24	0.35	0.479	0.492	0.65	0.480	0.475
25	0.4	0.519	0.052	0.5	0.534	0.056
26	0.9	0.512	0.406	1.2	0.498	0.472
27	0.4	0.505	0.366	0.65	0.468	0.376
28	0.3	0.524	0.532	0.4	0.530	0.492
29	0.75	0.506	0.377	1.1	0.499	0.382
30	0.85	0.556	0.186	1.1	0.533	0.249
31	1	0.500	0.550	1.9	0.502	0.514
32	0.2	1.185	0.006	0.3	1.039	0.005
33	0.65	0.577	0.199	1	0.540	0.245
34	0.6	0.560	0.123	0.9	0.537	0.144
35	0.95	0.407	0.544	1.4	0.435	0.517
36	0.9	0.459	0.594	1.3	0.468	0.606
37	0.3	0.719	0.066	0.5	0.567	0.123
38	0.2	0.460	0.581	0.35	0.388	0.672
39	0.6	0.468	0.547	0.8	0.461	0.485
40	0.25	0.507	0.415	0.5	0.546	0.347
41	0.35	0.567	0.196	0.45	0.569	0.145
42	0.5	0.590	0.186	0.7	0.569	0.160
43	0.8	0.513	0.230	1	0.509	0.283
44	0.2	0.530	0.145	0.4	0.460	0.045
45	0.65	0.468	0.637	0.8	0.461	0.693
46	0.4	0.491	0.227	0.6	0.448	0.235
Avg	0.46	0.548	0.353	0.70	0.519	0.341
S.D.	0.25	0.137	0.222	0.37	0.109	0.219

Conflict of interest

None.

References

[1] Perry J, Garrett M, Gronley JK, Mulroy SJ. Classification of walking handicap in the stroke population. Stroke 1995;26:982–9.
[2] Richards CL, Malouin F, Dean C. Gait in stroke: assessment and rehabilitation. Clin Geriatr Med 1999;15:833–55.
[3] Turnbull GI, Charteris J, Wall JC. A comparison of the range of walking speeds between normal and hemiplegic subjects. Scand J Rehabil Med 1995;27:175–82.
[4] Kollen B, Kwakkel G, Lindeman E. Hemiplegic gait after stroke: is measurement of maximum speed required? Arch Phys Med Rehabil 2006;87:358–63.
[5] Bowden MG, Balasubramanian CK, Neptune RR, Kautz SA. Anterior–posterior ground reaction forces as a measure of paretic leg contribution in hemiparetic walking. Stroke 2006;37:872–6.
[6] Jonkers I, Delp S, Patten C. Capacity to increase walking speed is limited by impaired hip and ankle power generation in lower functioning persons post-stroke. Gait Posture 2009;29:129–37.
[7] Milot MH, Nadeau S, Gravel D. Muscular utilization of the plantarflexors, hip flexors and extensors in persons with hemiparesis walking at self-selected and maximal speeds. J Electromyogr Kinesiol 2007;17:184–93.
[8] Jonsdottir J, Recalcati M, Rabuffetti M, Casiraghi A, Boccardi S, Ferrarin M. Functional resources to increase gait speed in people with stroke: strategies adopted compared to healthy controls. Gait Posture 2009;29:355–9.
[9] Lamontagne A, Fung J. Faster is better: implications for speed-intensive gait training after stroke. Stroke 2004;35:2543–8.
[10] Balasubramanian CK, Bowden MG, Neptune RR, Kautz SA. Relationship between step length asymmetry and walking performance in subjects with chronic hemiparesis. Arch Phys Med Rehabil 2007;88:43–9.
[11] Nadeau S, Arsenault AB, Gravel D, Bourbonnais D. Analysis of the clinical factors determining natural and maximal gait speeds in adults with a stroke. Am J Phys Med Rehabil 1999;78:123–30.
[12] Peterson CL. Inappropriate flexor synergies influence walking mechanics that reduce plantar flexor contributions to propulsion in persons with post-stroke hemiparesis. MS Thesis, The University of Texas at Austin; 2007.
[13] Chen G, Patten C, Kothari DH, Zajac FE. Gait differences between individuals with post-stroke hemiparesis and non-disabled controls at matched speeds. Gait Posture 2005;22:51–6.