Immediate effects of stance and swing phase training on gait in patients with stroke

（脳卒中後片麻痺者における歩行立脚期と遊脚期を想定した練習の即時効果）

青木（佐久間）　香

主論文

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Immediate effects of stance and swing phase training on gait in patients with stroke

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Short title: Immediate effects of stance and swing phase training

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ABSTRACT

Objective: To compare the effects of gait trainings targeting the stance (stance training) and the swing phases (swing training) among the subjects with stroke, and quantify the characteristics in the subjects who benefitted from either the stance training or the swing training.

Methods: Sixteen subjects with stroke performed the stance training, which focused on the center of pressure to move from the heel to the forefoot and the swing training, which focused on improvement of hip flexion in the swing phase. To investigate the immediate effects of the stance training and the swing training, the instrumented gait analysis was performed before and after training. To quantify the characteristics, subjects were divided into two groups based on the gait speed change. These two groups were compared using clinical examinations.

Results: After the stance training, the center of pressure displacement of the paretic limb was increased compared with the swing training. Subjects who benefitted from the stance training had slower timed up and go and weaker paretic hip muscle strength than those who benefitted from the swing training.

Conclusions: Stance training may be more effective in subjects with slower Timed Up and Go outcomes and weaker hip muscles.

Keywords: gait, rehabilitation, stroke.

Introduction

Many patients experience motor and sensory impairments after stroke [1] which cause gait disturbances [1-3]. The ability to perform activities of daily living [2] and participation and quality of life [4, 5] depends on gait ability to a great extent. Previous studies have shown that after a certain period, the effects of training for improving functional ability are not maintained [6, 7]; continuous training is needed to improve the quality of life of patients with stroke [8]. Therefore, an effective yet simple at-home training to improve gait ability in patients with chronic stroke is needed.

Gait speed is an objective evaluation of gait performance [9, 10]. In normal gait, the center of pressure (COP) moves from the heel to the forefoot which leads to push-off and the swing phase. In patients with stroke, slow gait speed is associated with decreased COP displacement [11, 12], ankle plantar flexion angle [13], and ankle plantar flexor muscle work [14] during the stance phase, as well as a prolonged pre-swing phase [15]. These deficiencies are believed to result from motor impairment [16, 17] and muscle weakness [16, 18, 19] of the lower extremity.

Trainings that separately target specific components of the gait cycle, such as the stance and swing phases, are commonly used to improve the gait kinematics in patients with stroke. In normal gait, training that focused on COP to move to the forefoot resulted in increased ankle push off [20]. Therefore, if slow gait speed in subjects with stroke is caused by a deficiency in the stance phase, stance phase training (ST) may improve gait speed. On the other hand, applying controlled assistance force to the swing has also been found to improve gait speed [21]. Hence, if slow gait speed in subjects with stroke is caused by a deficiency in the swing phase, swing phase training (SW) may improve gait speed. We suspect that the appropriate training for each subject differs depending on the motor impairments of the lower extremity or gait disturbances.

The purpose of this study was to investigate the immediate effects of ST and SW on gait. Depending on which training, ST or SW, was effective in improving gait speed, the subjects were divided into two groups. To quantify gait characteristics present in each subject, and thus determine if certain characteristics predetermine the relative success of ST or SW, we compared these two groups by using gait clinical examinations.

Methods

Design overview

We used single-blind randomized cross-over studies for both ST and SW, with each performed approximately 1 month apart. A randomization sequence was computer generated by a research assistant. The subjects were divided into Group A or Group B. Group A received ST in period 1 and SW in period 2, while Group B received SW in period 1 and ST in period 2.

To investigate the immediate effects of ST and SW on gait, we performed a three-dimensional gait analysis before and after each training. Before the instrumented gait analysis, subjects underwent a clinical examination.

Participants

Subjects were recruited using an Internet website and posters. The subjects satisfied the following criteria: (1) hemiparesis resulting from a unilateral cortical or sub-cortical brain lesion, (2) >6 months since onset, and (3) able to walk more than 3 m without ankle-foot orthosis. The exclusion criteria for the subjects were: (1) a history of other neurologic, respiratory, cardiovascular, or orthopedic problems that would influence their participation in this study, (2) brainstem or cerebellar lesions, and (3) inability to provide informed consent.

Using a within-subject standard deviation of 0.07 m/s [22], the total sample size of 10 subjects provides 80 % power to detect a treatment difference in gait speed for a delta of 0.175 m/s [23], assuming a 0.05 significance level [24].

All subjects provided informed consent before participation in this study. This study was approved by the institutional review board of Kyoto University (E1912).

Stance phase training

ST focused on the lower extremity to move like inverted pendulum, resulted in COP to move from the heel to the forefoot, and increased ankle push off. It included a session targeting three specific components of the gait cycle. Each component was repeated five times. After three sessions, the subjects walked on the 3-m walkway ten times paying attention to movement they performed during the stance phase. We performed the instrumented gait analysis before and after the training. The subjects rested for 5 min between sessions.

First, the subjects initially stood with both limbs; to simulate the mid-stance phase, subjects elevated their non-paretic limb by moving the COP on the paretic limb.

Second, to simulate initial contact, the subjects shifted weight from the non-paretic limb to the paretic limb. The subjects confirmed that the COP moved from the heel to the center of the plantar surface on the paretic limb.

Finally, to simulate the overall stance phase, the subjects stepped forward with their nonparetic limb. The subjects confirmed that the COP moved from the heel to the forefoot on the paretic limb.

Swing phase training

SW focused on improvement of hip flexion in swing phase. It included targeting three specific components of the gait cycle. Each component was repeated five times. After three sessions, the subjects walked on the 3-m walkway paying attention to their movements during the swing phase. We performed the instrumented gait analysis before and after the training. The subjects rested for 5 min between sessions.

First, the subjects flexed their hip joint of the paretic side from 0 to 30 degrees in the standing position.

Second, to simulate the initial swing phase, the subjects flexed their paretic hip joint from −10 to 0 degrees.

Finally, to simulate the overall swing phase, the subjects flexed their paretic hip joint from −10 to 30 degrees.

Gait analysis

The kinematic and kinetic measurements were recorded as the subjects walked at their self-selected speeds before and after each training. The subjects were not allowed to wear an ankle-foot orthosis, but were allowed to use an assistive walking device such as a T-cane.

Reflective markers were attached to the body of each subject according to the Vicon Plug-In Gait marker placement protocol. We used a 8-camera Vicon motion system (VICON MX; Vicon Motion System Corp., Oxford, UK) to record body kinematics at a sampling rate of 200 Hz and four force plates (Force plate 9286A; Kistler Corp., Winterthur, Switzerland) to record the ground reaction force at a sampling rate of 1000 Hz. Before data collection, each camera was calibrated, and the force plates were balanced.

The kinematics data were low-pass filtered with a Woltring filter. The force plate data were low-pass filtered with a fourth-order Butterworth filter with a cutoff frequency of

10 Hz. The gait parameters (gait speed, stride length and time, and step length and time), and the gait kinematics (maximum hip flexion and extension angle, flexion angular speed, and ankle dorsiflexion angle) were calculated from the kinematics data. The joint power (maximum hip flexion power in the pre-swing phase and ankle plantarflexion power in the terminal stance phase) were calculated by the kinematics and ground reaction force data and normalized for body weight (W/kg). The COP displacement was defined as the anterior-posterior displacement between the initial and final COP points during a single support phase used in the ground reaction force data, which was normalized for foot length. Mean values from three trials were calculated and used for analysis.

Clinical examination

The subjects underwent a clinical examination that included a Timed Up and Go test (TUG) [25], a Fugl-Meyer Assessment (FMA) of motor recovery in the lower extremity [26], cutaneous sensory testing using the ten test [27], a modified Ashworth scale [28], and muscle strength testing of the lower extremities. We used a handheld dynamometer (Mobie; Sakaimed Corp., Tokyo, Japan) to measure maximum isometric muscle strength in flexion and extension of the hip, knee, and ankle. Each muscle strength was measured twice for 3 seconds. All muscle strength was normalized for body weight (Nm/kg). The mean muscle strength for two trials was used for analysis.

Statistical analysis

To evaluate correlations between the gait speed, kinematics and kinetics, we first determined correlations of gait speed with the joint angle, joint power, and COP displacement of the paretic limb using the spearman rank correlation coefficients.

Secondly, each of the before training values for gait parameters, kinematics, joint power and COP displacement were subtracted from the after-training values. To analyze the difference in the immediate effects between ST and SW, a repeated measures analysis of variance and a post hoc test were used [29, 30] to analyze the training, carryover, and period effects in the subtracted gait kinematics, joint power, and COP displacement data. We used data from the subjects completed each period.

Finally, to investigate the characteristic of the subjects who benefitted from each training, based on the subtracted gait speed, subjects were divided into two groups: one group contained the subjects who benefitted from ST, and the other group contained subjects who benefitted from SW. The subjects who benefitted from ST were those who showed a greater increase in gait speed after ST than after SW, while the subjects who benefitted from SW were those who showed a greater increase in gait speed after SW than after ST. We then compared the two groups using a t-test for TUG and a muscle strength test of the lower extremities. Using the Mann-Whitney U test, we compared the two groups on the FMA of motor recovery, cutaneous sensory testing, and the modified Ashworth scale. A significance level of 0.05 was used for all comparisons, with no adjustment for multiple comparisons.

Results

Sixteen subjects were enrolled in this study. Four subjects dropped out of this study (Figure 1); three of the subjects could not reschedule their period 2, and one subject refused to participate in period 2. Twelve of 16 subjects received both trainings (Table 1).

Correlations between gait speed and gait kinematics and kinetics

There were significant correlations between the gait speed and (1) the paretic hip flexion power in pre-swing phase ($r = 0.76$), (2) paretic ankle plantar flexion power in the terminal stance phase ($r = 0.82$), (3) COP displacement of the paretic limb during the single stance phase ($r = 0.86$). There were no significant correlations between the gait speed and the gait kinematics.

Difference in the immediate effects between stance and swing phase training

The immediate effects between ST and SW are described in Table 2. There were no significant carryover and period effects in any parameter.

The training effects were found in the COP displacement of the paretic limb ($p = 0.03$, $F = 5.52$), and the subtracted COP displacement following ST was increased compared with that following SW. There were no significant effects in either parameter.

Characteristics of subjects who benefitted from each training

The characteristics of the subjects who benefitted from ST and the subjects who benefitted from SW are summarized in Table 3. Six subjects showed a greater increase in gait speed after ST than after SW, and the other six subjects showed a greater increase in gait speed after SW than after ST. TUG (95% CI, 4.4 to 20.8, statistical power = 0.94), paretic hip flexor muscle strength (95% CI, −0.4 to −0.0, statistical power = 0.84), and paretic hip extensor muscle strength (95% CI, −0.8 to −0.1, statistical power = 0.74) were lower in the subjects who benefitted from ST than in those who benefitted from SW.

Discussion

One difference in the immediate effects between ST and SW was the COP displacement of the paretic limb, which was increased after ST compared with that after SW. This may, however, be a chance finding due to the large number of comparisons performed with no adjustment for multiple comparisons.

Subjects who benefitted from ST had slower TUG and weaker paretic hip flexor and extensor strength than those who benefitted from SW.

This is the first study that identified the difference in the effects between ST and SW.

Correlations between gait speed and gait kinematics and kinetics

As found by previous studies [11, 31], small paretic ankle plantar flexion power in the terminal stance phase and small COP displacement of the paretic limb during single stance phase were associated with slow gait speed. Therefore, in this study, decreasing COP displacement and ankle plantar flexion power in the terminal stance phase was proportional to decreasing gait speed.

This finding aligns with the findings of previous studies [31] that decreased paretic hip flexion power in the pre-swing phase was related to slow gait speed. If the hip flexion power compensates for decreased ankle plantar flexion power in the terminal stance phase [32], SW cannot improve gait speed. This is because decreased ankle plantar flexion power remains. Therefore, we should consider an increase in both ankle plantar flexion power and the hip flexion power in the training.

Difference in the immediate effects between stance and swing phase training

The training effects were changes to the COP displacement of the paretic limb; the subtracted COP displacement following ST was longer than SW. Since the smaller COP displacement of the paretic limb is correlated with slower gait speed, and most of the subjects in the current study had slow gait speed, ST intended to move COP from the heel to the forefoot may be effective in improving COP displacement.

There were no significant training effects on the other parameters. These results indicate that the effects between ST and SW may differ depending on the physical characteristics of subjects. Therefore, when selecting either ST or SW, the characteristics of the subjects must be identified.

Characteristics in subjects who benefitted from either stance or swing phase training

Subjects who benefitted from ST had a slower TUG and weaker hip flexor and extensor muscle strength in their paretic side than those who benefitted from SW. ST aims to improve the stance phase on the paretic side. Slower TUG is known to correlate with slower gait speed and weaker plantar flexor strength [25]. In addition, previous studies have indicated that hip extensor muscle strength contributes to the rise of the center of mass during the initial contact [33], and hip flexor muscle strength contributes to accelerating hip flexion during the initial swing [34]. Therefore, it is reasonable to conclude that for subjects with these characteristics, ST was effective in increasing gait speed. On the other hand, the subjects who benefitted from SW had greater hip flexor and extensor muscle strength to flex hip joint effectively compared to the subjects who benefitted from ST. Therefore, SW aiming to improve swing phase may have been effective in translating the energy gained at push off to the swing phase effectively, resulting in improvement of gait speed.

Because improving gait ability requires repeated training, robotic-assisted locomotor training and treadmill training can be used for patients with lower functioning of gait. However, it is difficult for patients in the community to undergo these trainings. Over-ground gait training improves gait ability to the same degree as robotic-assisted locomotor training and treadmill training [35, 36]. Therefore, we developed an effective yet simple at-home training to improve gait ability in patients with chronic stroke. Our results indicated that ST may better treat patients with slower TUG (approximately 22.0 s), and decreased hip flexor (approximately 0.4 Nm/kg) and extensor (approximately 0.5

Nm/kg) strength. SW may better treat patients with faster [37] TUG (approximately 9.4 s), better hip flexor (approximately 0.7 Nm/kg), and hip extensor (approximately 1.0 Nm/kg) strength.

Study limitation

Two limitations of this study must be mentioned. First, the subjects recruited in our study were community-dwelling and were able to walk more than 3 m. Therefore, our results may not be applicable to patients with severe stroke, who are unable to live in the community or have greater disability in gait.

Second, our study investigated immediate effects. Therefore, the long-term effects are not clear. Further studies are necessary to determine the long-term effects.

Conclusion

ST may be more effective for subjects with stroke with slower TUG and decreased hip muscle strength, whereas SW may be effective for subjects with greater TUG ability and increased hip muscle strength.

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Figure 1 Flowchart and sequence of the study procedure

ST, stance training; SW, swing training.

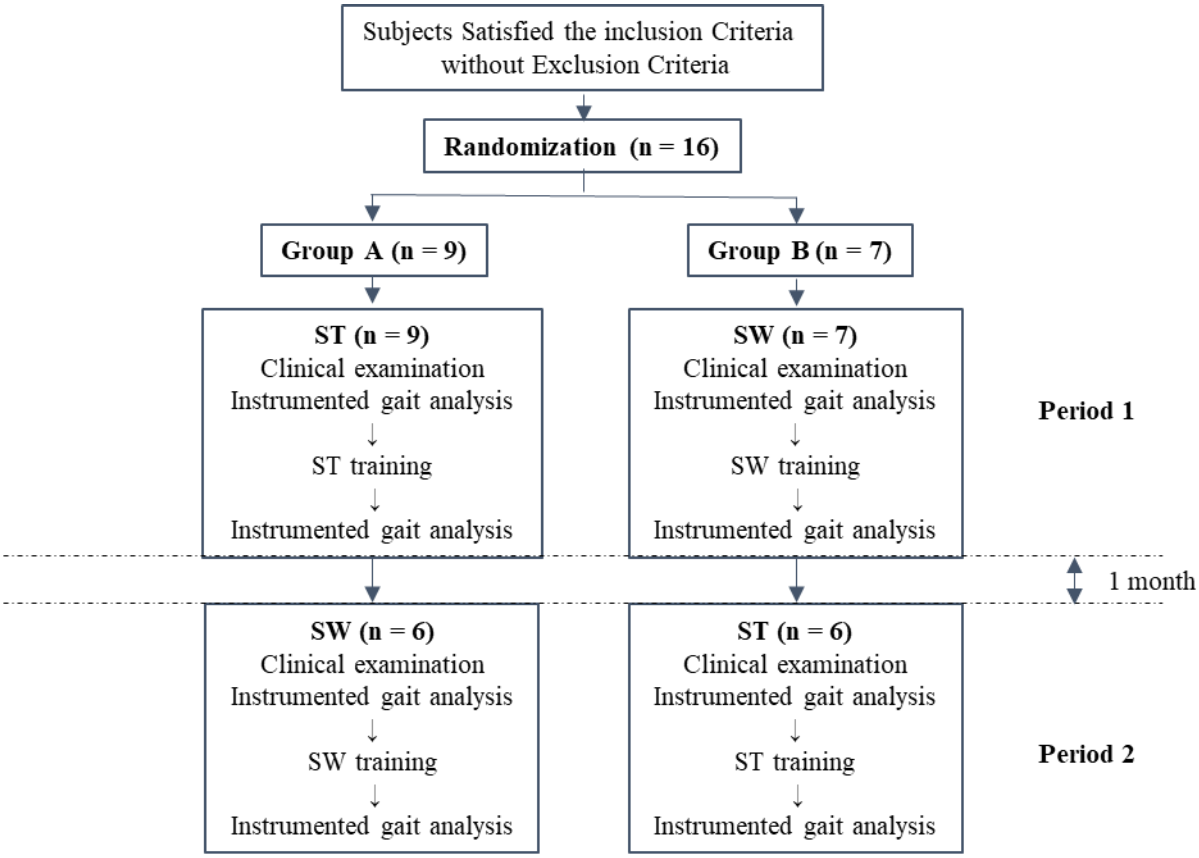

Table 1 Subjects characteristics

	Age (years)	Sex	Height (cm)	Weight (kg)	FMA (maximum Score: 34)	Time since onset (years)	Paretic side
1	78	M	170.3	65	33	16	L
2	68	M	169.3	67.8	33	1	R
3	83	M	166.7	68.7	29	1	L
4	73	M	160.0	56.9	30	12	R
5	56	M	173.4	51.8	26	1	L
6	64	M	173.2	72.2	20	10	L
7	50	M	187.3	57.9	34	2	R
8	67	M	171.2	61.9	32	5	R
9	66	M	165.8	57	29	7	R
10	71	M	170.0	68.6	21	20	R
11	61	M	166.0	60.3	20	11	R
12	59	M	169.7	72.5	24	5	L
Value	66.3 (8.5)		170.2 (6.0)	63.4 (6.2)	22.8 (4.1)	7.6 (5.8)	

Values are means (standard deviation) unless otherwise indicated.
M, male; FMA, Fugl-Meyer Assessment of motor recovery in the lower extremity; R, right; L, left.

Table 2 Effects between stance and swing training

		ST (n=12)		SW (n=12)		Within-subject difference (ST−SW) LSMean (CI)
		Before training After training	After training − before training	Before training After training	After training − before training	
Gait parameter	Speed (m/s)	0.70 (0.33) 0.76 (0.32)	0.06 (0.07)	0.70 (0.28) 0.78 (0.35)	0.08 (0.12)	0.03 (−0.05 to 0.11) p = 0.48
	Stride time (s)	1.28 (0.34) 1.27 (0.27)	−0.01 (0.11)	1.23 (0.29) 1.23 (0.32)	0.00 (0.12)	0.02 (−0.07 to 0.11) p = 0.68
	Stride length (m)	0.83 (0.30) 0.91 (0.30)	0.07 (0.07)	0.82 (0.28) 0.89 (0.32)	0.07 (0.07)	0.01 (−0.06 to 0.07) p = 0.79
	Paretic step time (s)	0.74 (0.28) 0.73 (0.20)	−0.00 (0.09)	0.72 (0.20) 0.71 (0.25)	−0.00 (0.09)	0.02 (−0.08 to 0.12) p = 0.62
	Nonparetic step time (s)	0.55 (0.10) 0.54 (0.08)	−0.01 (0.05)	0.52 (0.10) 0.51 (0.10)	−0.00 (0.05)	0.01 (−0.03 to 0.05) p = 0.53
	Paretic step length (m)	0.42 (0.15) 0.47 (0.15)	0.05 (0.04)	0.41 (0.16) 0.44 (0.18)	0.02 (0.05)	0.02 (−0.03 to 0.06) p = 0.45
	Nonparetic step length (m)	0.39 (0.15) 0.44 (0.15)	0.04 (0.03)	0.40 (0.13) 0.43 (0.15)	0.03 (0.04)	0.00 (−0.03 to 0.04) p = 0.79
Gait kinematic	Paretic hip flexion (°)	22.4 (8.1) 23.5 (7.7)	1.1 (2.3)	22.8 (9.8) 23.8 (11.5)	1.0 (2.9)	0.1 (−2.1 to 2.4) p = 0.91
	Nonparetic hip flexion (°)	29.3 (9.3) 30.1 (9.2)	0.8 (2.3)	29.1 (9.4) 28.2 (9.9)	−1.0 (2.4)	1.2 (−0.8 to 3.1) p = 0.23
	Paretic hip flexion angular speed (°/s)	109.8 (57.2) 121.3 (58.4)	11.6 (11.3)	121.3 (56.0) 132.8 (57.9)	11.5 (23.8)	0.7 (−15.5 to 14.2) p = 0.93
	Paretic hip extension (°)	8.4 (7.9) 9.1 (8.6)	0.7 (2.5)	7.9 (11.3) 9.2 (12.1)	1.3 (3.1)	0.8 (−1.3 to 2.9) p = 0.42
	Nonparetic hip extension (°)	12.0 (8.1) 12.9 (8.8)	0.8 (1.6)	12.5 (11.0) 14.3 (10.8)	1.8 (2.1)	1.0 (−0.7 to 2.7) p = 0.23
	Paretic ankle dorsiflexion (°)	11.0 (4.9) 11.3 (4.2)	0.3 (1.2)	11.1 (6.0) 11.6 (6.0)	0.5 (1.1)	0.7 (−0.4 to 1.8) p = 0.19
	Nonparetic ankle dorsiflexion (°)	16.9 (3.3) 16.3 (3.6)	−0.6 (1.2)	16.4 (4.3) 15.9 (4.3)	−0.5 (2.1)	0.0 (−1.3 to 1.4) p = 1.0
Joint power	Paretic hip power (W/kg)	1.2 (1.6) 0.9 (0.8)	−0.3 (1.2)	0.8 (0.8) 1.0 (0.8)	0.1 (0.4)	0.4 (−0.4 to 0.9) p = 0.36

	Nonparetic hip power (W/kg)	1.1 (0.6) 1.3 (0.6)	0.2 (0.3)	1.2 (0.8) 1.4 (0.5)	0.2 (0.6)	0.0 (−0.3 to 0.3) p = 0.94
	Paretic ankle power (W/kg)	1.5 (1.3) 1.6 (1.4)	0.2 (0.5)	1.4 (1.2) 1.6 (1.5)	0.3 (0.4)	0.1 (−0.2 to 0.4) p = 0.60
	Nonparetic ankle power (W/kg)	2.4 (1.3) 2.7 (1.3)	0.2 (0.4)	2.4 (1.1) 2.7 (1.3)	0.3 (0.7)	0.1 (−0.4 to 0.6) p = 0.67
COP	Paretic	0.36 (0.16) 0.40 (0.18)	0.04 (0.07)	0.35 (0.16) 0.33 (0.17)	−0.02 (0.07)	0.06 (0.01 to 0.12) p = 0.03*
	Nonparetic	0.45 (0.13) 0.53 (0.14)	0.08 (0.07)	0.44 (0.13) 0.49 (0.12)	0.05 (0.05)	0.02 (−0.02 to 0.07) p = 0.33

Values are means (standard deviation) unless otherwise indicated. Asterisk indicates a 0.05 significance level.

ST, stance phase training; SW, swing phase training; LSMean, least square mean; CI, 95% confidence interval; hip flexion, maximum hip flexion during stance phase; hip extension, maximum hip extension during stance phase; hip flexion angular speed, maximum hip flexion angular speed in pre-swing phase; ankle dorsiflexion, maximum ankle dorsiflexion during stance phase; hip power, maximum hip flexion power in pre-swing phase; ankle power, maximum ankle plantarflexion power in terminal stance phase; COP, anterior-posterior center of pressure displacement during single support phase.

Table 3 Characteristics of subjects who benefitted from either stance or swing training

	Subjects who benefitted from ST (n=6)	Subjects who benefitted from SW (n=6)	CI
TUG (s)	22.0 (6.7)	9.4 (2.0)	4.4 to 20.8*
FMA (maximum Score: 34)	23 (16, 27)	25.5 (16, 28)	−6.9 to 5.2
Cutaneous sensory (maximum Score: 10)	7.5 (1, 10)	9.3 (3, 10)	−6.6 to 2.8
Modified Ashworth Scale (maximum Score: 4)	1 (0, 3)	2 (0, 3)	−1.9 to 1.1
Paretic hip flexor (Nm/kg)	0.4 (0.1)	0.7 (0.2)	−0.4 to −0.0*
Nonparetic hip flexor (Nm/kg)	0.7 (0.2)	0.8 (0.2)	−0.3 to 0.2
Paretic hip extensor (Nm/kg)	0.5 (0.3)	1.0 (0.3)	−0.8 to −0.1*
Nonparetic hip extensor (Nm/kg)	0.7 (0.3)	1.0 (0.3)	−0.7 to 0.1
Paretic knee flexor (Nm/kg)	0.4 (0.2)	0.5 (0.2)	−0.4 to 0.2
Nonparetic knee flexor (Nm/kg)	0.6 (0.3)	0.7 (0.2)	−0.4 to 0.2
Paretic knee extensor (Nm/kg)	0.6 (0.1)	0.7 (0.2)	−0.3 to 0.1
Nonparetic knee extensor (Nm/kg)	0.8 (0.1)	0.8 (0.1)	−0.2 to 0.1
Paretic ankle dorsiflexor (Nm/kg)	0.2 (0.2)	0.3 (0.2)	−0.2 to 0.2
Nonparetic ankle dorsiflexor (Nm/kg)	0.4 (0.1)	0.5 (0.1)	−0.2 to 0.1
Paretic ankle plantar flexor (Nm/kg)	0.5 (0.3)	0.5 (0.2)	−0.4 to 0.3
Nonparetic plantar flexor (Nm/kg)	0.7 (0.2)	0.9 (0.3)	−0.6 to 0.1

FMA, cutaneous sensory testing, modified Ashworth Scale values are median (minimum, maximum). Other values are means (standard deviation). Asterisk indicates a 0.05 significance level. Subjects who benefitted from ST, subjects with a greater increase in gait speed following ST compared to SW; subjects who benefitted from SW, subjects with a greater gait speed following SW compared to ST. CI, 95% confidence interval; TUG, Timed Up and Go test; FMA, Fugl-Meyer Assessment of motor recovery in the lower extremity; cutaneous sensory, cutaneous sensory testing using the ten test.