Authors:

Ray-Yau Wang, PT, PhD
Pei-Yi Lin, PT
Chao-Chung Lee, PT, MS
Yea-Ru Yang, PT, PhD

Affiliations:

From the Institute and Faculty of Physical Therapy, National Yang-Ming University, Taipei, Taiwan (R-YW, P-YL, Y-RY); Department of Education and Research (R-YW) and Section of Physical Therapy (Y-RY), Taipei City Hospital, Taipei, Taiwan; and Department of Physical Medicine & Rehabilitation, Taipei Veterans General Hospital, Taipei, Taiwan (C-CL).

Correspondence:

All correspondence and requests for reprints should be addressed to Yea-Ru Yang, Associate Professor, Institute & Faculty of Physical Therapy, National Yang-Ming University, 155, Sec 2, Li Nong St., Shih-Pai, Taipei, Taiwan.

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RESEARCH ARTICLE

Gait and Balance Performance Improvements Attributable to Ankle–Foot Orthosis in Subjects with Hemiparesis

ABSTRACT

Wang R-Y, Lin P-Y, Lee C-C, Yang Y-R: Gait and balance performance improvements attributable to ankle–foot orthosis in subjects with hemiparesis. Am J Phys Med Rehabil 2007;86:556–562.

Objective: To assess the change in the balance performance and the improvement in the gait performance of subjects with hemiparesis, as a result of their wearing an ankle–foot orthosis.

Design: This was a cross-sectional control trial. Fifty-eight subjects with hemiparesis of a duration of less than 6 mos participated in this study. Each subject was evaluated for the balance and gait performance with and without an ankle–foot orthosis on the affected side. The balance activities were evaluated by the Balance Master System, and the gait performance was measured using GAITRite.

Results: The increase in movement velocity and the change in maximal excursion toward the affected side during the balance testing were found to be correlated significantly with the change in walking speed as a result of wearing an ankle–foot orthosis ($r = 0.274$, $P = 0.039$; $r = 0.325$, $P = 0.020$; respectively). Only the change in maximal excursion toward the affected side was found to be significantly correlated with the change in nonaffected step length ($r = 0.381$, $P = 0.010$).

Conclusion: The maximal excursion toward the affected side improved as a result of wearing an ankle–foot orthosis. This correlated with an increase in step length on the nonaffected side and, hence, an improvement in the walking speed of the subjects with hemiparesis.

Key Words: Ankle–Foot Orthosis, Balance, Gait, Hemiparesis

Attaining gait ability remains a challenge for hemiparetic patients. Considerable time and effort are required for ambulation training and orthotic management.[1] The spatiotemporal gait parameters of hemiparetic patients are significantly different from those of healthy subjects. That is, the walking speed of hemiparetic patients is slower, the cadence is lower, their step length is shorter, and the stance phase of the uninvolved leg is longer.[2]

Ankle–foot orthosis (AFO) is typically recommended to stroke patients to compensate for the effects of impairments to their walking and thus assist their rehabilitation following stroke. In particular, it is used in cases where there is inadequate dorsiflexion in swing and mediolateral subtalar instability during stance.[3,4] Patients with hemiparesis are generally inefficient in the heel-strike and pushoff phases of their gait.[5] Major AFO studies in the past on hemiparetic subjects emphasized the gait spatiotemporal, kinematic, and kinetic parameters. Gok et al.[6] found that AFO changed the plateau pattern of curve to the usual double peak pattern in their six subjects, indicating better heel strike and more effective pushoff. They also observed an increase in ankle dorsiflexion at heel strike and midswing.[6] Improvements in walking speed,[7,8] gait pattern,[9] and stride length[10] have been documented. Franceschini et al.[11] found that AFO significantly improved self-selected speed, stride cycle time, stance, and double-support time in their nine studied hemiparetic subjects, with postonset duration ranging from 2 to 244 mos. After a systematic literature review, Leung and Moseley[12] suggest that AFO might improve the velocity, stride length, gait pattern, and walking efficiency of people with hemiplegia who could walk without an AFO.

It is also common for hemiparetic patients to suffer alterations in their postural stability or balance.[13] Turnbull and associates[14] found that even functionally ambulant hemiparetic patients demonstrated marked limitations in their capacity to shift weight, and possessed a reduced range of weight shift. The greater the weight the paretic limb was able to bear, the greater the distance the patient could shift the weight. Dettman and colleagues[15] found a significant relationship between postural instability and walking performance. However, there have been few studies that have specifically addressed the effects of AFO on the balance dynamics of hemiparetic patients. Chen et al.[16] found that AFO had significant effects on long-term hemiparetic patients with respect to lateral weight shifting and weight bearing through their affected side. In an earlier study, the present authors noted that after being provided with an AFO, patients with hemiparesis of recent onset experienced an increase in their gait speed and cadence, and an improvement in their dynamic standing balance. However, the effectiveness of wearing an AFO has been found to be minimal for patients with hemiparesis of long duration.[17] Mojica et al.[18] found that wearing an AFO significantly reduced body sway and increased the maximum walking speed of eight poststroke hemiparetic patients. But a clear correlation between the improvements in body sway and gait variables has not yet been established, because of small sample size and the heterogeneity of the patients.[18] Therefore, the present study was aimed at assessing a large group of hemiparetic individuals within 6 mos poststroke for changes in the balance performance and improvement in the gait performance as a result of wearing AFOs.

METHODS

All subjects who participated in this study were referred from medical centers and district hospitals near the Taipei area in Taiwan. The diagnosis, age, sex, affected side, and onset time of hemiparesis were obtained from patient interviews and medical charts. Ankle muscle strength was evaluated using a handheld dynamometer (PowerTrack II; JTech Medical). All tests undertaken were isometric tests in which the dynamometer was held stationary by the examiner while each subject exerted a maximum force against it. The ankle dorsiflexor strength and ankle plantarflexor strength were obtained in the supine position. The lower-extremity function of all the subjects was evaluated using the Fugl–Meyer leg subscale, which included 17 items (the highest possible score was 34 points).[19] The criteria for subject selection were as follows: 1) a diagnosis of unilateral hemiparesis secondary to a cerebrovascular accident, with symptoms having lasted less than 6 mos; 2) the ability to walk for 10 m without an assistive device; 3) never having worn an AFO before this study; 4) the ability to follow simple verbal commands or instructions; and 5) having no history of significant orthopedic problems that would interfere with gait and balance performance tested in our study. Fifty-eight subjects participated in this study, and all gave their informed consent before participation. All procedures performed in this study were approved by the human subject review board of Taipei Veterans General Hospital.

Each subject performed all measurement tests within 2 hrs. The tests were carried out both with and without an AFO on the affected foot. There was a 5-min rest period between each test, and the testing sequences were randomized. The AFO used in this study was a standard, posterior leaf type weighing 125 g, with a setting in neutral position. The orthosis came in three different sizes, and each subject wore the size that fitted them best. Before measurement, the subjects took a short time to familiarize themselves with their newly prescribed AFO.

Measurement of Standing Balance

The Balance Master System was used in the study to test standing balance.[17,20,21] The difference of the weight-bearing distribution (%) between each leg was recorded while the subjects stood as still as possible. Limit of stability (LOS) testing was used to record the subjects' dynamic balance—that is, their ability to control the movement (maximum excursion) and speed (movement velocity) of their center of gravity (COG) during tasks that required weight shifts toward different directions. During this assessment, the location of the patient's COG was displayed on screen as a cursor. The patient controlled the cursor by weight shifting. To perform the assessment task, the patient needed to move quickly and precisely to make the cursor reach the target. Three directions—anterior, affected side, and nonaffected side—were included in the test. The subjects were instructed to stand with their arms at their sides and to not move their feet throughout the testing procedure. Movement velocity was the average speed in degrees per second of the rhythmic movement along the specified direction. Maximal excursion was measured as the distance of the movement toward the designated target, expressed as a percentage of maximum LOS distance.[17]

Assessment of Gait

The GAITRite system (CIR System, Inc.) was used to measure the subjects' gait performance.[22,23] The validity and reliability of GAITRite system have been well established.[22,23] The GAITRite system provided temporal (time) and spatial (distance) gait parameters via an electronic walkway connected to the serial port of a personal computer. The standard GAITRite walkway contained six sensor pads encapsulated in a roll-up carpet with an active area 3.66 m long and 0.61 m wide. As the subject walked through the walkway, the sensors captured each footfall as a function of time and transferred the gathered information to a personal computer to process the raw data into footfall patterns. The computer computed the temporal and spatial gait parameters. The gait parameters included in our study were gait speed, cadence, cycle time, swing time, stance time, single-support time, double-support time, step length, stride length, and base width. Subjects were asked to walk three times through a 10-m hallway, at a comfortable speed, without any assistive device. The GAITRite walkway was placed in the middle of the 10-m hallway to eliminate the effect of acceleration or deceleration.

The paired t testing was used to compare the balance and gait performance between wearing and not wearing the AFO. The correlations between the changes in balance ability and in gait performance with the AFO were assessed by Pearson correlation coefficients. A level of $P < 0.05$ was considered statistically significant. All statistical analyses were carried out with SPSS version 10.0 for Windows.

RESULTS

Fifty-eight subjects who met our selection criteria—44 males and 14 females—participated in this study. Among them, 34 had right hemiparesis, and 24 had left hemiparesis; 19 had sustained hemorrhagic strokes, and 39 had sustained infarctions. The mean age of the subjects was 60.36 $\pm$ 13.95 yrs (range: 26–84 yrs); the mean onset duration was 3.29 $\pm$ 1.17 mos (range: 1–6 mos); the mean dorsiflexor strength measurements (in pounds) on the patients' affected and nonaffected sides were 26.72 $\pm$ 11.57 (range: 12.95–45.19) and 40.02 $\pm$ 7.24 (range: 32.71–47.39), respectively; the mean plantarflexor strength measurements on the affected and nonaffected sides were 39.64 $\pm$ 16.86 (range: 18.33–68.50) and 53.72 $\pm$ 13.53 (range: 28.00–82.27), respectively; and the mean Fugl–Meyer leg score was 25.12 $\pm$ 3.97 (range: 17–32). Furthermore, because the testing sequences were randomized, we compared the demographic characteristics between the subjects who were first tested wearing the AFO and those who were first tested without wearing the AFO. There were no statistically significant differences between these groups for age, stroke onset, stroke type, gender, hemiparetic side, ankle muscle strength, or Fugl–Meyer leg score (Table 1).

Patients' weight bearing was more evenly distributed when wearing the AFO than when not wearing the AFO. The weight-bearing differences were 12.12 $\pm$ 8.25 and 8.86 $\pm$ 9.31% for without AFO and with AFO, respectively ($P = 0.044$). Table 2 shows the LOS test results for increase in movement velocity toward the affected (3.39 $\pm$ 1.62 deg/sec without AFO and 4.53 $\pm$ 1.48 deg/sec with AFO, $P = 0.040$) and toward the nonaffected side (3.93 $\pm$ 2.20 deg/sec without AFO and 5.64 $\pm$ 5.87 deg/sec with AFO, $P = 0.012$). Table 2 also documents the increase in maximal excursion toward the affected side (68.70 $\pm$ 23.61% without AFO and 74.81 $\pm$ 20.46% with AFO, $P = 0.046$). The increases were significant as a result of wearing an AFO. The improvements in the patients' weight distribution and dynamic standing balance were further confirmation of our previous study results.[17] The mean comfortable speed increased from 62.83 $\pm$ 26.71 to 66.94 $\pm$ 29.47 cm/sec (mean of change: 4.45 $\pm$ 10.71 cm/sec, $P = 0.006$) after wearing an AFO (Table 3). Among the spatiotem-

TABLE 1 Comparisons of demographic characteristics between subjects performing the tests without the ankle–foot orthosis (AFO) first and subjects performing the tests with the AFO first

	Without AFO First (n = 29)	With AFO First (n = 29)	P Value
Age, yrs	60.38 ± 12.59 (30–84)	60.34 ± 15.41 (26–81)	0.99
Months after stroke	3.24 ± 1.35 (1–6)	3.34 ± 0.97 (2–6)	0.74
Gender			
Male	24 (82.76%)	20 (68.97%)	0.36
Female	5 (17.24%)	9 (31.03%)	
Hemiplegic side			
Right	16 (55.17%)	18 (62.07%)	0.79
Left	13 (44.83%)	11 (37.93%)	
Stroke type			
Infarction	18 (62.07%)	21 (72.41%)	0.58
Hemorrhage	11 (37.93%)	8 (27.59%)	
Ankle strength, pounds			
Affected dorsiflexors	25.98 ± 11.14 (14.10–38.84)	27.45 ± 12.98 (12.95–45.19)	0.42
Nonaffected dorsiflexors	41.4 ± 6.52 (36.82–47.39)	38.65 ± 8.68 (32.71–46.75)	0.63
Affected plantarflexors	40.01 ± 15.63 (18.33–51.50)	39.35 ± 18.52 (21.33–68.50)	0.75
Nonaffected plantarflexors	55.94 ± 10.62 (33.33–66.50)	51.49 ± 17.42 (28.00–82.27)	0.34
Fugl–Meyer leg score	25.41 ± 3.81 (18–32)	24.83 ± 4.16 (17–32)	0.58

Data were expressed as mean ± SD (range) or frequency (percentage).

poral parameters measured, the patients' step length (mean of change: 2.69 ± 5.87 cm, $P = 0.010$ for the affected side; mean of change: 1.98 ± 5.06 cm, $P = 0.008$ for the nonaffected side), stride length (mean of change: 4.87 ± 9.55 cm, $P = 0.002$), and base width (mean of change: −1.55 ± 3.55 cm, $P = 0.002$) showed significant improvements after wearing an AFO (Table 3). Other gait parameters did not change significantly (Table 3).

The change in the patients' movement velocity and maximal excursion toward the affected side were found to correlate significantly with the change in walking speed as a result of wearing an AFO ($r = 0.274$, $P = 0.039$; $r = 0.325$, $P = 0.020$; respectively) (Table 4). However, only the change in maximal excursion toward the affected side correlated significantly with the change in step length of the nonaffected side ($r = 0.381$, $P = 0.010$) and the change in stride length ($r = 0.360$, $P = 0.012$) (Table 4). Also, the change in weight distribution was found to correlate negatively with the change in step length of the affected side ($r = -0.325$, $P = 0.015$) and the change in stride length ($r = -0.264$, $P = 0.026$) (Table 4).

DISCUSSION

In the present study, we found that the increase in hemiparetic patients' walking speed when wearing an AFO was correlated significantly with an improvement in their dynamic balance control on their af-

TABLE 2 Comparisons of balance performance between wearing and not wearing ankle–foot orthosis (AFO) in subjects with hemiparesis (n = 58)

	Without AFO	With AFO	Changes	P Value	95% Confidence Interval
Weight-bearing difference, %	12.12 ± 8.25	8.86 ± 9.31	−3.26 ± 4.43	0.044*	−3.863, −0.660
Movement velocity, deg/sec					
Anterior	2.53 ± 1.44	2.66 ± 1.19	0.13 ± 1.41	0.498	−0.506, 0.249
Affected	3.39 ± 1.62	4.53 ± 1.48	1.14 ± 1.61	0.040*	0.060, 1.919
Nonaffected	3.93 ± 2.20	5.64 ± 5.87	1.71 ± 6.22	0.012*	0.482, 2.418
Maximal excursion (%)					
Anterior	64.88 ± 20.72	68.20 ± 18.41	3.32 ± 17.19	0.180	−10.926, 1.717
Affected	68.70 ± 23.61	74.81 ± 20.46	6.11 ± 14.20	0.046*	−5.873, −1.663
Nonaffected	78.70 ± 19.52	78.84 ± 21.58	0.14 ± 18.58	0.955	−4.790, 5.070

Data were expressed as mean ± SD.
Changes: with AFO − without AFO.
* $P < 0.05$ *vs.* without AFO.

TABLE 3 Comparisons of spatiotemporal gait parameters between wearing and not wearing ankle–foot orthosis (AFO) in subjects with hemiparesis (n = 58)

	Without AFO	With AFO	Changes	*P* Value	95% Confidence Interval
Speed, cm/sec	62.83 ± 26.71	66.94 ± 29.47	4.45 ± 10.71	0.006**	1.226, 6.977
Cadence	88.62 ± 19.06	90.31 ± 22.98	1.75 ± 13.97	0.357	−1.955, 5.331
Cycle time, secs	1.45 ± 0.49	1.45 ± 0.48	0.00 ± 0.18	0.962	−0.047, 0.045
Swing time, secs					
Affected	0.52 ± 0.15	0.53 ± 0.19	0.01 ± 0.08	0.355	−0.011, 0.030
Nonaffected	0.39 ± 0.08	0.40 ± 0.10	0.02 ± 0.09	0.276	−0.011, 0.039
Stance time, secs					
Affected side	0.93 ± 0.38	0.92 ± 0.34	−0.01 ± 0.17	0.620	−0.057, 0.035
Nonaffected side	1.06 ± 0.47	1.06 ± 0.49	−0.00 ± 0.17	0.874	−0.041, 0.048
Single-support time, secs					
Affected	0.39 ± 0.08	0.40 ± 0.10	0.02 ± 0.09	0.276	−0.011, 0.039
Nonaffected	0.52 ± 0.15	0.53 ± 0.19	0.01 ± 0.08	0.355	−0.011, 0.030
Double- support time, secs	0.54 ± 0.36	0.53 ± 0.35	−0.01 ± 0.19	0.775	−0.057, 0.042
Step length, cm					
Affected	42.29 ± 12.27	44.58 ± 13.19	2.69 ± 5.87	0.010*	0.571, 4.016
Nonaffected	39.98 ± 12.08	41.82 ± 14.63	1.98 ± 5.06	0.008**	0.493, 3.186
Stride length, cm	82.53 ± 22.95	86.86 ± 26.47	4.87 ± 9.55	0.002**	1.616, 7.043
Base width, cm	15.45 ± 4.70	13.95 ± 4.97	−1.55 ± 3.55	0.002**	−2.428, −0.566

Data were expressed as mean ± SD.
Changes: with AFO − without AFO.
* $P < 0.05$; ** $P < 0.01$ *vs.* without AFO.

fected side. This finding concurs with that of a previous study by Mojica et al.,[18] who have demonstrated that the use of AFO by hemiparetic stroke patients resulted in a significant decrease in body sway and improved walking capacity.[18] Because of the small sample size and heterogeneity of the patients, however, Mojica et al.[18] could not obtain a clear correlation between the improvements in body sway and gait variables. In the present study, with a larger sample group, we demonstrated a clear, significant correla-

TABLE 4 Correlations (r) between changes in balance performance and gait parameters, resulting from wearing the AFO in subjects with hemiparesis (n = 58)

		Movement Velocity, deg/sec			Maximal Excursion, %		
Correlations	Weight-Bearing Difference, %	Anterior	Affected	Nonaffected	Anterior	Affected	Nonaffected
Speed, cm/sec	0.111	0.109	0.274*	0.142	0.069	0.325*	−0.054
Cadence	0.061	0.107	0.062	0.196	0.014	0.238	−0.086
Cycle time, secs	−0.007	0.198	0.084	0.126	0.022	−0.106	0.137
Swing time, secs							
Affected	−0.102	−0.050	−0.028	0.073	0.025	−0.025	0.149
Nonaffected	0.107	0.088	0.148	−0.006	0.028	0.179	0.162
Stance time, secs							
Affected	0.063	−0.230	−0.101	0.022	0.011	−0.102	0.068
Nonaffected	−0.090	0.146	−0.063	−0.164	0.020	−0.060	0.093
Single-support time, secs							
Affected	0.107	0.088	0.148	−0.006	0.028	0.179	0.162
Nonaffected	−0.202	−0.050	−0.028	0.073	0.025	−0.025	0.149
Double-support time, secs	−0.009	−0.193	−0.056	−0.136	0.024	−0.064	−0.011
Step length, cm							
Affected	−0.325*	−0.131	−0.004	0.040	0.060	0.072	0.067
Nonaffected	−0.183	−0.052	−0.097	−0.097	0.037	0.381*	0.021
Stride length, cm	−0.264*	0.076	−0.022	0.003	0.075	0.360*	0.057
Base width, cm	0.189	0.006	0.055	−0.084	0.189	0.035	−0.008

* $P < 0.05$.

tion between the improvement in hemiparetic patients' dynamic balance control and an increase in their walking speed when using AFO.

Previous studies have indicated that stroke patients showed excessive postural sway and inadequate weight-shifting capacity in the frontal plane.[24,25] It has been suggested that patients' frontal plane balance is particularly responsive to balance training and recovery.[24,25] Chen et al.[16] found that the use of AFOs by hemiparetic patients had significant effects on lateral weight shifting and weight bearing through their affected side. The greater the weight borne by the affected leg, the greater the range the subject could shift the weight to allow the opposite leg to move forward and, consequently, to take a step. According to present and our previous[17] studies, the use of AFO has shown significant effects on weight bearing during quiet standing, and in movement velocity during the LOS test toward both the affected and the nonaffected side, and maximal excursion toward the affected side. In the present study, we further documented that the change in maximal excursion toward the affected side correlated significantly with the change in step length of the nonaffected side ($r = 0.381$, $P = 0.010$) and walking speed ($r = 0.325$, $P = 0.020$) when wearing an AFO. Sackley and Lincoln[26] demonstrated that improved stance symmetry was associated with superior ability to perform functional tasks. Walker et al.[27] further found that, in addition to balance improvement, hemiparetic patients' walking speed was faster after balance training. It is thus suggested that improvement in weight bearing and in maximal excursion on the affected side, as a consequence of wearing AFO, contributes to the increase in step length on the nonaffected side and, hence, an improvement in walking speed. In the present study, in addition to improved maximal excursion toward the affected side, we also have noted that patients' movement velocity increased toward the affected and nonaffected side when wearing the AFO. The effect of improved movement velocity with respect to gait velocity was more significant toward the affected side ($r = 0.274$, $P < 0.05$) than toward the nonaffected side ($r = 0.142$, NS). According to these findings, we speculate that the improvement in walking speed is attributable to the improved balance control in the affected side that occurs as a result of wearing an AFO.

The improvement in our study in patients' walking speed was not, as expected, attributable to the improved maximal excursion range in the anterior direction. The maximal excursion in the forward direction was not changed significantly after wearing an AFO. The test of maximal excursion in the forward direction was within the inverted pendulum model of the upright stance. The limitations in the anterior–posterior movement of the ankle joint, because of the wearing of an AFO, may have resulted in it having a minimal effect on the maximal balance range in the forward direction. However, the patients' ability for forward weight shifting, as indicated by the forward maximal excursion in our study group, was 64.88 ± 20.72% without an AFO and 68.20 ± 18.41% with one; this was significantly less than the forward maximal excursion for normal, similar-aged adults (88.79 ± 17.91; mean age, 71.9 ± 6.7 yr old) that we reported in our other related study (Wang et al., unpublished data, 2005). It is important for clinicians to take note of the insufficient control over anterior weight shifting and the limitations of AFOs on their forward movement control in subjects with hemiparesis.

The results of this study reveal a statistically significant improvement in the hemiparetic patients' dynamic balance control and walking speed when wearing an AFO. However, given the small percentage of the increase in walking speed, it is noteworthy that, despite the clear statistical significance, the clinical significance of AFOs in gait performance might remain limited.

We also have noted that the step length of the patients' affected side increased and the base width decreased during walking when they were wearing AFOs, even though neither factors significantly affected walking speed. Ankle dorsiflexion at heel strike and at midswing has been shown to increase when patients have donned the plastic AFO.[6] The increased ankle dorsiflexion at midswing may result in an increased step length. The decreased base width during walking may further support the improvement of dynamic balance control during the wearing of an AFO.

In our study, AFOs affected spatial parameters (step length and stride length) but not temporal parameters. Franceschini et al.[11] and Churchill et al.[28] have already documented the improvement in temporal parameters during walking while wearing an AFO. On examining the characteristics of our subjects and the characteristics of these previous study subjects, we noted that the walking speed of our subjects (66.9 ± 29.4 cm/sec) was faster than that of their subjects (31 ± 2.0 cm/sec for Churchill et al.'s[28] subjects, and 25.8 ± 11.5 cm/sec for Franceschini et al.'s[11] subjects). According to the study by Perry et al.[29] on the classification of walking handicaps in stroke populations, the walking ability of our subjects fell into the functional walking category of *least-limited community* (58 ± 18 cm/sec), whereas Churchill et al.'s[28] and Franceschini et al.'s[11] subjects were categorized as *limited household* (23 ± 16 cm/sec) or *unlimited household* (26 ± 11 cm/sec) ambulators. Further research is needed to investigate the effect of the AFO on subjects with different walking abilities or speed.

In summary, for subjects with hemiparesis of less than 6-mo duration and with a relatively fast walking speed, wearing an AFO can still improve gait speed. We found that this improvement correlated significantly with the dynamic balance control of the patients' affected side. The results of our previous study have shown that wearing an AFO had a minimal effect on subjects with long-duration (>12 mos) hemiparesis.[17] Therefore, it may be beneficial to prescribe an AFO to patients in the early stage, rather than the late stage, of stroke recovery. Patients wearing an AFO could improve their dynamic balance control and, thus, increase their walking speed. Furthermore, it is suggested that AFOs may play an important role in the functional improvement of hemiparetic stroke patients. Use of AFOs at discharge has been associated with the walking and stairs component of the FIM instrument and the Berg balance scale score.[30] The present study has only investigated the immediate effects of using an AFO. It is possible that more sustained use of an AFO would affect these parameters as well; further studies are needed to examine this possibility.

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