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Improved ankle and knee control with a dual-channel functional electrical stimulation system in chronic hemiplegia

A case report

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The aim of this report is to describe the effects of a dual-channel functional electrical stimulation (FES) system applied daily as an orthotic device to the dorsiflexors and hamstrings muscles in a subject with chronic hemiparesis. Prior to the application of FES, the patient's gait was characterized by a footdrop and knee hyperextension during stance. Measurements of gait performance were collected before FES application, after a conditioning period of six weeks, and following ten months of daily use. Outcomes included lower limb kinematics and temporal gait measures. The kinematic assessments indicated significant benefits for gait with the dorsiflexors and hamstrings FES, as compared to no stimulation and peroneal FES alone. In addition to improved ankle control, knee hyperextension was reduced during stance, and the self-selected comfortable gait velocity increased following ten months of daily use. The results of this report suggest that dual-channel FES for the dorsiflexors and hamstrings muscles may affect ankle and knee control beyond that which can be attributed to peroneal stimulation alone. The positive effects observed in this case study point to the potential of dual-channel FES as a viable treatment option in the rehabilitation of patients with similar impairments.

Key words: Gait - Hemiparesis - Rehabilitation - Electric Stimulation.

Hemiplegic gait is characterized by poor motor control, slow and asymmetrical steps, delayed and disrupted equilibrium reactions, and reduced weight bearing on the paretic limb [1, 2] The joint kinematics of hemiplegic patients are characterized by large inter-individual variability and differ from those of unimpaired individuals in both the stance and swing phases of gait.[3] Thus, for example, an estimated 20% of all patients post stroke exhibit impaired control of the ankle musculature, resulting in a "footdrop".[4] The footdrop may be accompanied by diminished knee flexion, frequently termed stiff knee gait [5] which further limits the individual's ability to clear the foot during the swing phase of gait. Consequently, individuals often exhibit compensatory movements, such as excessive hip flexion, as well as exaggerated frontal plane movements, such as hip circumduction and hip hiking, resulting in increased energy expenditure.[3, 6]

Different types of knee patterns characterize the stance phase of the hemiplegic gait. Some patients demonstrate increased knee flexion during the stance phase, particularly at initial contact (knee crouch). This may be due to weakness of the quadriceps muscle, spasticity of the knee flexors, or plantar flexion spasticity and/or contracture.[7] However, between 40-68% of patients with hemiparesis following a stroke exhibit knee hyperextension (genu-recurvatum) in mid- to late stance and delayed movement into knee flexion in preparation for the swing phase.[8]

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The pathophysiology of knee hyperextension is not well understood, and several hypotheses are suggested in the literature. In some cases, knee hyperextension may be caused by early calf muscle activity, resulting in the knee being pulled posteriorly into hyperextension.[7] It has also been suggested that knee hyperextension is a compensatory mechanism to provide a stable limb during stance in cases of knee extensor weakness or spasticity, as well as proprioceptive deficits.[3, 9] Weakness of the hamstrings muscles has also been mentioned as a cause for knee hyperextension, since contraction of the knee flexors muscles is needed to control knee flexion, especially if the extensors are spasti [10] It is also common to see several etiologies in the same patiet.[7, 9, 10]

Functional electrical stimulation (FES) has been used for many years to assist patients who present with gait difficulties resulting from hemiplegia.[11] Due to technological advances and commercially available systems, peroneal FES for footdrop correction is becoming an accepted and effective orthotic devic[12][12] Several studies have also reported on the contribution of FES to knee control by stimulation of the hamstrings muscles. For example, in a randomized control trial by Daly *et al.*[13] 32 subjects (>1 year after stroke) were assigned to either an FES or a no-FES group. In the FES group, eight muscles including the hamstrings were stimulated during a training period of 1.5 hours provided 4 times a week for 12 weeks. The results demonstrated statistical significant greater improvement in knee flexion coordination in the FES group. In another study, Yan *et al.*[14] applied multichannel electrical stimulation to the quadriceps, hamstrings, tibialis anterior, and medial gastrocnemius muscles of 46 subjects with acute stroke. The subjects lay on their side with the affected lower extremity supported by a sling, while the FES activation sequence mimicked normal gait. All subjects in the FES group were able to walk after treatment, with 84.6% of them returning home, in comparison to 53.3% in the placebo group and 46.2% in the control group.

Despite these promising results with multi-channel FES used as a treatment modality, there are presently no reports on the effects of a dual-channel FES used daily as an orthotic device to assist in ankle as well as knee control.

The aim of the present report was to describe the short- and long-term effects of such a dual-channel FES system applied daily to the dorsiflexors and hamstrings muscles of a patient affected by chronic hemiplegia, with limited walking ability. In addition, the potential mechanisms underlying the kinematic and functional improvements observed following 10 months of daily FES application are discussed.

Case report

The subject presented in this case is a 40-year-old married woman with three children, who worked as a graphic designer prior to undergoing a fronto-temporal craniotomy to treat cavernous malformations. Following surgery, she presented with left spastic hemiparesis and was admitted to a rehabilitation center for a two-month period of intensive rehabilitation. This was followed by a year of physiotherapy conducted twice a week in an outpatient clinic, focusing primarily on gait rehabilitation. When the subject first came to our clinic (17 months postsurgery), she walked using a specially designed elastic band (Dictus, Erimed International KB, Sweden) in her shoe to assist in maintaining the foot in dorsiflexion. The subject was barely able to walk without the Dictus, and her gait was characterized by a flat and inverted foot at initial contact (IC), and knee hyperextension during mid- to terminal stance.

The initial evaluation (T0) included a two-minute walk test (2MWT) and a 10-m walk over an obstacle course with no orthotic aid. In the 2MWT, average gait speed (m/s) was determined while the subject was instructed to walk back and forth along a 50-meter hallway for two minutes as far as she could at her self-selected normal walking speed, turning around each time she reached the end of the walkway. To imitate daily life situations, average gait speed was also determined by measuring the time spent to walk 10 m over an obstacle course, using the protocol described in the Emory Functional Ambulation Profil.[15]

After the initial evaluation, the subject was fitted with the L300Plus (Bioness Inc., Valencia, CA, USA). The system consists of lower leg and thigh cuffs, a gait sensor, and a control unit (Figure 1). Each cuff integrates two electrodes and a stimulation unit. The electrodes of the lower leg cuff were positioned over the common peroneal nerve and the tibialis anterior muscle in order to provide dorsiflexion of the foot. The electrodes of the thigh cuff were positioned over the hamstrings muscle in order to assist with knee control during stance. The gait sensor, located under the heel, uses an algorithm to detect gait events (*e.g.*, heel strike and toe-off) in real time.

During the fitting process, the stimulation parameters (*e.g.*, intensity, pulse frequency) and the timing of the stimulation were set. Peroneal stimulation (symmetrical biphasic, intensity 40mA, phase duration 200 µs, pulse rate 30 Hz) was timed from initial swing to mid-stance, while the hamstrings stimulation (symmetrical biphasic, intensity 47 mA, phase duration 300 µs, pulse rate 45 Hz) was configured from mid-stance to initial swing. At completion of the fitting process, the subject received the system for daily use, which

Figure 1.—The NESS L300Plus.

started with a six-week adaptation period. During this period, the subject increased her daily use with the system according to a fixed protocol, so that by the end of the fourth week, she was able to use the system for the entire day.

After six weeks of conditioning (T1), lower limb kinematics were collected using the Vicon^{R} motion analysis system while the patient walked on a treadmill. Motion analysis was applied according to the biomechanical model PlugInGait, developed by Vicon^{R} (based on the work of Kadaba *et al.*),[16] with three markers spatially defining each segment (*i.e.*, pelvis, thigh, shank and foot). Changes in the lower extremity alignment were captured and processed by six computerized cameras at 120 Hz acquisition rate. Gait was assessed under three conditions**,** with and without the FES system, and with peroneal stimulation alone, while the patient walked on a treadmill at her self-selected walking speed. The subject was instructed to walk as naturally as possible and was allowed to hold onto the treadmill handrails. An emergency stop switch was available to both the subject and the clinician. The first assessment was always performed without FES, and the self-selected walking speed in this condition was used for both subsequent FES conditions. The main outcomes included peak knee and hip extension angles determined during stance, maximal knee and hip flexion angles during swing, and the degree of ankle dorsiflexion at IC. In addition, the percentage of the gait cycle during which the knee was hyperextended was calculated.

The subject continued to use the system, and follow-up visits were performed every two months. An additional assessment (T2) was performed after ten months from the time the FES was introduced to the patient. The evaluation included the 2MWT, obstacle course and gait kinematics analysis in the three conditions as performed at T1.

Results

The 2 min gait velocity without FES was 0.66 m/s at baseline (T0) and 0.72 m/s at the 10-month assessment (T2). The difference in the obstacle course velocity between the two assessments was negligible, with 0.41 m/s and 0.42 m/s at T0 and T2, respectively. The patient's self-selected walking speed on the treadmill without FES was 0.33 m/s at the completion of the conditioning period (T1) and 0.44 m/s after ten months (T2).

Table I summarizes the results of all measured kinematic gait outcomes, with normative data, of

TABLE I.—*Kinematic measures of paretic limb (mean ± SD).*

Outcome measure	T1			T2			Normative Data
	No stimulation	Peroneal stimulation	Peroneal and hamstrings stimulation	No stimulation	Peroneal stimulation	Peroneal & hamstrings stimulation	
Ankle dorsiflexion at initial contact (deg)	-0.05±2.5	4.6±2.0	5.2±1.68	-11.8±2.8	7.4±1.4	8.7±1.3	-2±3
Peak knee extension during stance (deg)	-4.2±0.6	-3.42±0.8	-1.0±0.4	-7.8±0.5	-5.6±4.7	-4.0±1.0	3.2±6
Stride duration in which knee was hyper-extended (%)	35.9±2.6	37.8±24	18.7±8.3	44±2	43.3±1.7	36.9±3.0	Not provided
Peak knee flexion during swing (deg)	61.1±1.1	55.2±1.5	64.0±1.6	55.7±2.0	52.5±2.5	57.9±1.8	58.7±4.9
Peak hip extension during stance (deg)	3.8±1.0	4.1±0.6	4.5±1.0	-4.1±1.1	-1.6±2.1	-4.3±0.6	-9.1±7
Peak hip flexion during swing (deg)	43.1±0.8	40.7±2.2	45.0±1.5	38.2±1.5	36.8±1.5	36.7±1.1	33.7±6.4

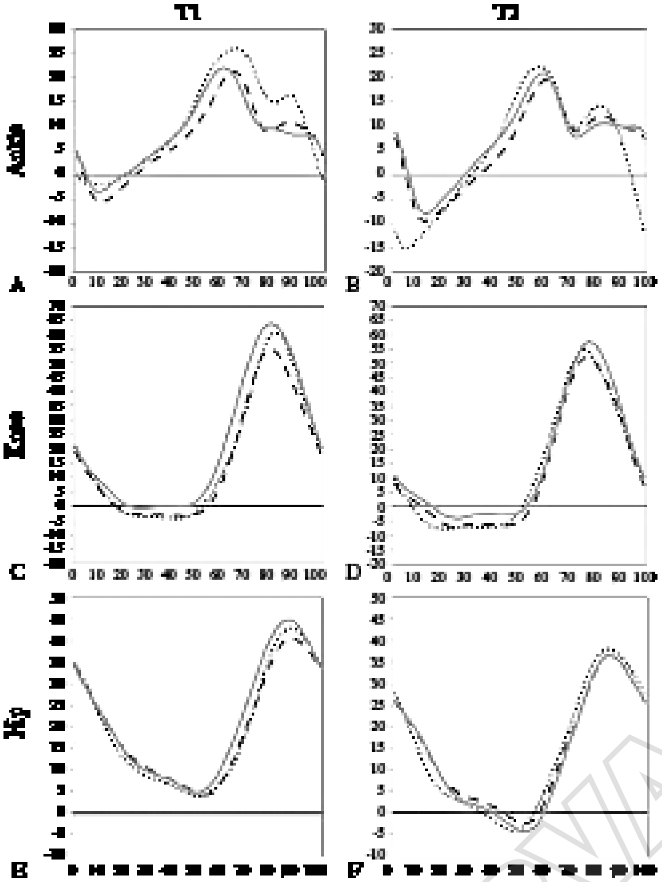

Figure 2.—Sagittal plane movement of the ankle, knee and hip at T1 and T2. Round dot: no stimulation; broken line: peroneal FES; solid line: peroneal and hamstrings FES.

healthy subjects, from the literature presented as a reference as target vals.[17] Sagittal plane movements of the ankle, knee and hip at T1 and T2 are illustrated in Figure 2.

At T1, the subject exhibited almost a neutral ankle angle in the sagittal plane at IC with no stimulation, and slight dorsiflexion with both FES conditions. The effect of the peroneal FES was more obvious at T2. Without stimulation, the subject presented dorsiflexors inadequacy, with a footdrop from the terminal swing to IC, while IC with the heel was demonstrated in both FES conditions. However, some overcorrection was observed in terms of dorsiflexion angle at IC in the FES conditions.

In both kinematic evaluations (T1 and T2) and under all gait conditions (*i.e.*, no stimulation; peroneal stimulation; peroneal and hamstring stimulation), the subject presented knee hyperextension during stance, which was greater and extended for a longer period at T2. For example, with no stimulation, peak knee stance hyperextension was -2±0.6 at T1 and -7.8±0.5 at T2, and hyperextension duration was 35.9±2.6% at T1 and 44±2% at T2.

However, the degree of knee hyperextension was reduced by either of the FES conditions, with a greater reduction observed during dual-channel stimulation (L300Plus). Unlike the degree of hyperextension, the percentage of the stride phase during which the knee was hyperextended was found to improve (decrease) only with the L300Plus.

Maximum knee flexion at swing phase was close to normal in all conditions at T1 and T2, with the greatest knee flexion angle observed with the L300Plus. Compared to normal values, the hip range of motion at T1 was most clearly characterized by decreased stance phase hip extension and excessive hip flexion during swing in all three conditions. Improved performance was demonstrated at T2, with the hip extension and flexion closest to normal (-4.3±0.6; 36.7±1.1, respectively) during dual-channel stimulation.

Discussion

To the best of our knowledge, this is the first report of prolonged daily use with a dual-channel FES intended to assist with ankle and knee control in a patient with chronic hemiparesis. Our patient's gait was characterized by very slow walking pace, diminished ankle control mainly during IC, and knee hyperextension during mid- to terminal stance. Her gait pattern with peroneal and hamstrings FES improved significantly at each assessment , as demonstrated by the reduction in the amplitude and duration of knee hyperextension during stance (at T1 as well as at T2) and the elimination of footdrop at T2. Furthermore, a carryover effect was noted after ten months of walking with the system, as the subject's gait speed was improved even without FES (from 0.66 m/s to 0.72 at the 2MWT, and from 0.33 m/s to 0.44 m/s on the treadmill).

Previous work has suggested that peroneal stimulation may enhance kinematic aspects of gait.[12] It has also been suggested that extending the dorsiflexors stimulation to mid-stance may contribute to knee stability and to the reduction of knee hyperextensn.[18] This report demonstrates for the first time that hamstrings stimulation may have a substantial additional effect on knee control, as both the degree of hyperextension and the duration of this pathological pattern improved primarily during the dual-channel stimulation.

Knee control deficits which are exhibited by knee hyperextension during the stance may influence the entire gait pattern rendering it both spatially and temporally asymmetric. As knee flexion is initiated during the pre-swing phase, knee hyperextension makes it difficult to achieve the knee flexion necessary for foot clearance during the swing phase.[17] By extending the limb, genu-recurvatum also increases the external mechanical work linked to elevation of the body's center of mass, consequently raising the energy cost of gait. Moreover, genu-recurvatum may be painful as a result of stress to the ligaments and tendons at the back of the knee.[10] While knee hyperextension is frequently encountered in patients with hemiparesis, not much is suggested in the literature in terms of management strategies, probably due to the various possible etiologies.[10]

It should be noted that the positive results demonstrated in this report are beyond the range reported as being a minimal detectable change when examining kinematic changes in patients with similar pathologies.[19] Several mechanisms may explain the observed effects. Activation of the hamstrings muscles with FES in the mid- to terminal stance, causing a concentric contraction of the hamstrings muscles, may have simply pulled the knee out of the hyperextended position. In addition, the hamstrings and dorsiflexors stimulation may have decreased the spasticity of the quadriceps and calf muscles that was contributing to the hyperextension *via* reciprocal inhibition.[20] Furthermore, as suggested by a recently published systematic review,[21] the somatosensory input derived from the stimulation may have also improved motor function by increasing the subject's self-awareness of lower limb motion during ambulation.

While, as noted earlier, knee hyperextension was reduced by dual channel stimulation at each assessment, the level of knee hyperextension was aggravated at T2 compared to T1. This may be explained by the increased gait velocity at T2 (0.44 m/s at T2 *vs.* 0.33 m/s at T1). Similar results were reported by Mulroy *et al.*[22] with a group of stroke patients who presented knee hyperextension (-5.5°) at admission to rehabilitation. They improved their gait velocity at a six-month test, while the amount of knee hyperextension attained in the stance phase increased (-7.4°). It is assumed that at faster speed, it is more difficult to control the contraction of the knee flexors muscles needed to assist with knee stability. Another possible explanation may be the improved hip joint kinematics observed in T2, which is reflected by the increased hip extension during stance. This improvement probably contributed to the increased gait velocity due to greater stride length. However, in turn it also increased the knee extensor moment contributing to the higher level of hyperextension.

Although our subject was able to ambulate in the community, her initial walking velocity was very slow. This finding supports those of previous studies, which reported a slow walking velocity in hemiplegic patients with reduced knee motn.[23, 24] The self-selected gait speed on the treadmill was slower than the over-ground speed at both T1 and T2, which is also consistent with the findings of previous studies.[25, 26] The subject improved her gait speed by 0.1m/sec on the treadmill and by 0.06m/sec over-ground. The enhanced gait speed may be associated with a better function as noted by Perera *et al.*[27] who estimated a change of 0.04-0.06 m/s in gait speed as a small meaningful change. The results at T2 also showed improved stance phase hip extension and closer-to-normal hip flexion, as compared to the excessive hip flexion at T1, thus reflecting a more efficient sagittal plane movement. Nevertheless, the results at 10 months without stimulation did not show a markedly increased gait speed on the obstacle course. This finding is not in accordance with Laufer *et al.*[28] who tested a group of 16 individuals with chronic hemiplegia and demonstrated an improvement of gait speed in a similar obstacle test condition after one year of use with peroneal stimulation. One possible explanation for the resistance to change in the present report may be related to the level of motor control needed to negotiate obstacles and to the poor level of ambulation of our patient relative to the patients in the study by Laufer *et al.*,[28] whose initial gait speed was significantly higher.

Although the subject used an orthotic device for a relatively long duration prior to this intervention due to difficulties with ankle control, the analysis at T1 did not demonstrate dorsiflexion deficits at IC nor in terminal swing when tested without an orthotic device. In contrast, a definite footdrop was observed in T2. The low gait speed at T1 may have contributed to the subject's ability to avoid a footdrop at the earlier assessment. In addition, as can be seen in Figure 2, the knee was more extended in the terminal swing at T2 than at T1. Consequently, the dorsiflexors had to overcome a greater resistance of the gastrocnemius muscle at T2, which resulted in dorsiflexors inadequacy.

The ultimate goals of rehabilitation are to regain functional abilities and participation in all aspects of life that are meaningful to the individual.[29] Although this was not formally tested, it is important to mention that after six months of using the FES, the patient started to increase her social reintegration. Not only did she start working in a voluntary capacity as a secretary to the manager of a children's rehabilitation center, she also enrolled in an advanced course in computer skills. Although the patient's report of increased activity cannot be exclusivity attributed to FES, it supports the results of a previous study showing increased participation with the use of FES.[30] It should be stressed in this regard that the daily use of a multichannel FES is not trivial. The location of the cuff under the clothing may be cumbersome, and difficulties may arise in relation to factors such as electrodes positioning, user interface, and overall convenience. The fact that our patient chose to continue with both stimulators indicates that she found the assistance it offered to be meaningful.

Conclusions

The results of this report suggest that dual-channel FES for the dorsiflexors and hamstrings muscles may have important effects on ankle as well as knee control beyond that which can be attributed to peroneal stimulation alone. The positive effects observed in this report point to the potential of dual-channel FES as a means to enhance functional gait in patients with similar impairments. Further studies are needed to validate these results.

References

1. Tyson SF. Trunk kinematics in hemiparetic gait and the effect of walking aids. Clin Rehabil 1999;13:295-300.
2. Dias D, Laíns J, Pereira A, Nunes R, Caldas J, Amaral C *et al*. Can we improve gait skills in chronic hemiplegics? A randomised control trial with gait trainer. Eura Medicophys 2007;43:499-504.
3. Woolley SM. Characteristics of gait in hemiplegia. Top Stroke Rehabil 2001;7:1-18.
4. Wade D, Wood W, Heller A, Maggs J, Langton Hewer R. Walking after stroke: measurement and recovery over the first 3 months. Scand J Rehabil Med 1987;19:25-30.
5. Kerrigan DC, Karvosky ME, Riley PO. Spastic paretic stiff-legged gait: joint kinetics. Am J Phys Med Rehabil 2001;80:244-9.
6. Kerrigan DC, Frates E, Rogan S, Riley P. Hip hiking and circumduction: quantitative definitions. Am J Phys Med Rehabil 2000;79:247.
7. Lucareli PR, D'Andrea Greve JM. Knee joint dysfunctions that influence gait in cerebrovascular injury. Clinics (Sao Paulo) 2008;63:443-50.
8. Morris ME, Matyas TA, Bach TM, Goldie PA. Electrogoniometric feedback: its effect on genu recurvatum in stroke. Arch Phys-Med Rehabil 1992;73:1147-54.
9. Kerrigan DC, Deming LC, Holden MK. Knee recurvatum in gait: a study of associated knee biomechanics.Arch Phys Med Rehabil 1996;77:645-50.
10. Bleyenheuft C, Bleyenheuft Y, Hanson P, Deltombe T. Treatment of genu recurvatum in hemiparetic adult patients: a systematic literature review. Ann Phys Rehabil Med 2010;53:189-99.
11. Mauritz KH. Gait training in hemiparetic stroke patients.Eura Medicophys 2004;40:165-78.
12. van Swigchem R, Weerdesteyn V, van Duijnhoven HJ, den Boer J, Beems T, Geurts AC. Near-normal gait pattern with peroneal electrical stimulation as a neuroprosthesis in the chronic phase of stroke: a case report. Arch Phys Med Rehabil 2011;92:320-4.
13. Daly JJ, Roenigk K, Holcomb J, Rogers JM, Butler K, Gansen J *et al*. A randomized controlled trial of functional neuromuscular stimulation in chronic stroke subjects. Stroke 2006;37:172-8.
14. Yan T, Hui-Chan CW, Li LS. Functional electrical stimulation improves motor recovery of the lower extremity and walking ability of subjects with first acute stroke: a randomized placebo-controlled trial. Stroke 2005;36:80-5.
15. Wolf SL, Catlin PA, Gage K, Gurucharri K, Roberston R, Stepahen K. Establishing the reliability and validity of measurements of walking time using the Emory functional ambulation profile. Phys Ther 1999;79:1122-33.
16. Kadaba MP, Ramakrishnan HK, Wootten ME. Measurement of lower extremity kinematics during level walking. J Orthop Res 1990;8:383-91.
17. Perry J. Gait Analysis: Normal and Pathological Function. 2nd ed. SLACK Incorporated; 2010.
18. Hausdorff JM, Ring H. Effects of a new radio frequency-controlled neuroprosthesis on gait symmetry and rhythmicity in patients with chronic hemiparesis. Am J Phys Med Rehabil 2008;87:4-13.
19. Kesar TM, Binder-Macleod SA, Hicks GE, Reisman DS. Minimal detectable change for gait variables collected during treadmill walking in individuals post-stroke. Gait Posture 2011;33:314-7.
20. Veltink PH, Ladouceur M, Sinkjaer T. Inhibition of the triceps surae stretch reflex by stimulation of the deep peroneal nerve in persons with spastic stroke. Arch Phys Med Rehabil 2000;81:1016-24.
21. Laufer Y, Elboim-Gabyzon M. Does sensory transcutaneous electrical stimulation enhance motor recovery following a stroke? A Systematic Review. Neurorehabil Neural Repair 2011;25:799-809.
22. Mulroy S, Gronley J, Weiss W, Newsam C, Perry J. Use of cluster analysis for gait pattern classification of patients in the early and late recovery phases following stroke. Gait Posture 2003;18:114-25.
23. Kerrigan D, Karvosky M, Riley P. Spastic paretic stiff-legged gait: joint kinetics. Am J Phys Med Rehabil 2001;80:244.
24. Sulzer JS, Gordon KE, Dhaher YY, Peshkin MA, Patton JL.

Preswing knee flexion assistance is coupled with hip abduction in people with stiff-knee gait after stroke. Stroke 2010;41:1709-14
25. Kautz SA, Bowden MG, Clark DJ, Neptune RR. Comparison of motor control deficits during treadmill and overground walking poststroke. Neurorehabil Neural Repair 2011;25:756-65.
26. Bayat R, Barbeau H, Lamontagne A. Speed and temporal-distance adaptations during treadmill and overground walking following stroke. Neurorehabil Neural Repair 2005;19:115-124.
27. Perera S, Mody SH, Woodman RC, Studenski SA. Meaningful change and responsiveness in common physical performance measures in older adults. J Am Geriatr Soc 2006;54:743-9.
28. Laufer Y, Ring H, Sprecher E, Hausdorff JM. Gait in Individuals with Chronic Hemiparesis: One-Year Follow-up of the Effects of a Neuroprosthesis That Ameliorates Foot Drop. J Neurol Phys Ther 2009;33:104-110.
29. WHO: International classification of functioning, disability and health: ICF. Geneva: WHO; 2001.
30. Laufer Y, Hausdorff JM, Ring H. Effects of a foot drop neuroprosthesis on functional abilities, social participation and gait velocity: A one-year follow-up. Am J Phys Med Rehabil 2009;88:14-20.

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