

BRIEF REPORT

Locomotor Adaptability Task Promotes Intense and Task-Appropriate Output From the Paretic Leg During Walking



David J. Clark, ScD,^{a,b} Richard R. Neptune, PhD,^c Andrea L. Behrman, PhD,^d Steven A. Kautz, PhD^{e,f,g}

From the ^aBrain Rehabilitation Research Center, Malcom Randall Veterans Affairs Medical Center, Gainesville, FL; ^bDepartment of Aging and Geriatric Research, University of Florida, Gainesville, FL; ^cDepartment of Mechanical Engineering, The University of Texas at Austin, Austin, TX; ^dDepartment of Neurological Surgery, University of Louisville, Louisville, KY; ^eRalph H. Johnson Veterans Affairs Medical Center, Charleston, SC; ^fDepartment of Health Sciences and Research, Medical University of South Carolina, Charleston, SC; and ^gDivision of Physical Therapy, Department of Health Professions, Medical University of South Carolina, Charleston, SC.

Abstract

Objective: To test the hypothesis that participants with stroke will exhibit appropriate increase in muscle activation of the paretic leg when taking a long step with the nonparetic leg compared to during steady-state walking, with a consequent increase in biomechanical output and symmetry during the stance phase of the modified gait cycle.

Design: Single-session observational study.

Setting: Clinical research center in an outpatient hospital setting.

Participants: Adults with chronic poststroke hemiparesis (N=15).

Interventions: Participants walked on an instrumented treadmill while kinetic, kinematic, and electromyogram data were recorded. Participants performed steady-state walking and a separate trial of the long-step adaptability task in which they were instructed to intermittently take a longer step with the nonparetic leg.

Main Outcome Measures: Forward progression, propulsive force, and neuromuscular activation during walking.

Results: Participants performed the adaptability task successfully and demonstrated greater neuromuscular activation in appropriate paretic leg muscles, particularly increased activity in paretic plantarflexor muscles. Propulsion and forward progression by the paretic leg were also increased.

Conclusions: These findings support the assertion that the nonparetic long-step task may be effective for use in poststroke locomotor rehabilitation to engage the paretic leg and promote recovery of walking.

Archives of Physical Medicine and Rehabilitation 2016;97:493-6

© 2016 by the American Congress of Rehabilitation Medicine

A major goal of locomotor rehabilitation after stroke is to induce recovery of coordinated paretic limb control through experience-dependent neuroplasticity. This requires an intense, repetitive, and task-specific dosage of walking therapy. However, engaging the paretic leg during locomotor rehabilitation is challenging because

of the common use of compensatory biomechanical strategies. Thus, practice of steady-state walking may fail to deliver the appropriate training stimulus needed to optimize recovery. Indeed, some previous studies¹⁻³ have reported that steady-state walking or pedaling does not improve paretic limb coordination and may reinforce compensatory patterns.

A potentially beneficial approach to achieve an intense and targeted training stimulus in the paretic leg is through the use of locomotor adaptability tasks. Locomotor adaptability involves modifying typical walking to meet task objectives and environmental demands.⁴ Adaptability tasks often require increased

Supported by the National Institutes of Health (grant nos. HD-46820 and GM-109040) and the U.S. Department of Veterans Affairs Rehabilitation Research and Development Service (Merit Review B3983R and Career Development Awards B4888M and B7176W). The contents do not represent the views of the U.S. Department of Veterans Affairs or the U.S. government.
Disclosures: none.

biomechanical output during specific subtasks of gait. For example, it has been shown in healthy adults that taking an isolated longer step requires the stance leg to increase its support and propulsion of the body, which requires an increase in plantarflexor output.⁵ This particular subtask of gait is important after stroke because impaired support and propulsion contribute to slow and asymmetrical walking.^{6,7}

This study seeks to determine whether a long-step adaptability task is effective for increasing neuromuscular output of the paretic leg plantarflexors during walking after stroke. We hypothesize that participants will increase activation in paretic plantarflexor muscles when taking a nonparetic long step compared to during steady-state walking, with a consequent increase in paretic leg biomechanical output and symmetry during the stance phase of the modified gait cycle. If confirmed, this finding will support the use of a long-step adaptability task to train the generation of propulsion in future rehabilitation studies and will warrant investigation of other adaptability tasks that may similarly increase neuromuscular output for other subtasks of gait.

Methods

Participants

Participants with chronic poststroke hemiparesis due to unilateral stroke were recruited for this study. Participants were required to be capable of walking 10m in the laboratory without the use of an assistive device. Exclusion criteria included significant pain, contractures, major sensory deficits, or cardiorespiratory symptoms that would prevent compliance with the study protocol. Study procedures were approved by the institutional review board of the University of Florida.

Procedures

Participants walked on a treadmill with independent forceplates embedded on the left and right sides.^a Reflective markers were attached to anatomical landmarks using a modified Helen Hayes marker set and recorded using a 12-camera motion capture system.^b Surface electromyogram (EMG) was recorded bilaterally with bipolar Ag-AgCl electrodes^c placed on the tibialis anterior, soleus, medial gastrocnemius, vastus medialis, rectus femoris, lateral hamstrings, medial hamstrings, and gluteus medius. Kinetic and kinematic data were acquired at 200Hz and EMG data were acquired at 2000Hz using VICON Workstation v4.5.^b Data were analyzed using MATLAB 7.0^d and JMP statistical software (v8.0).^e

Participants performed two 30-second walking trials. The treadmill speed was chosen by each participant as being comfortable and typical of his/her regular walking speed. They then performed a 1-minute trial at the same speed but were instructed to take a long step with the nonparetic leg approximately every fifth gait cycle. This allowed participants to regain a steady-state walking pattern before taking the next long step. Participants wore a safety harness secured to an overhead support, and some individuals used a semirigid ankle brace to provide medial/lateral joint stability without restricting plantarflexion or

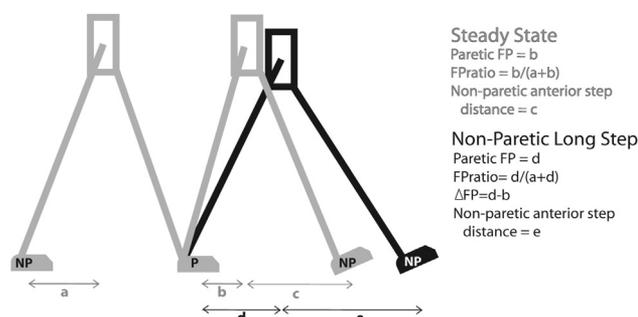


Fig 1 Illustrative comparison of forward progression and anterior step distance during steady-state walking (in gray) and nonparetic long-step task (in black). Abbreviations: FP, forward progression; NP, nonparetic; P, paretic.

dorsiflexion. Participants did not hold onto a railing or use any other assistive device.

Data analysis

Ground reaction force and kinematic data were low-pass filtered (20 and 10Hz, respectively) with a fourth-order Butterworth filter with zero phase lag. Pelvis and foot center-of-mass (COM) locations were obtained by fitting the marker trajectories to an 8-segment musculoskeletal model using Visual3D.^f

Forward progression of the body during the single-limb support phase was expressed by calculating the horizontal distance between the pelvis COM and the trailing foot COM at the instant of leading foot heel strike (see “a,” “b,” and “c” in fig 1). A forward progression ratio was calculated as [paretic/(paretic+nonparetic)] to quantify the symmetry of forward progression for each walking condition. Anterior step distance was calculated as the difference between the pelvis COM and the leading foot COM at the instant of leading foot heel strike (see “c” and “d” in fig 1). Step length is equivalent to the sum of the forward progression and anterior step distance measurements. Propulsion was calculated as the time integral of the anteriorly directed horizontal component of the ground reaction force.

EMG signals were high-pass filtered (40Hz) with a fourth-order Butterworth filter, then debiased and rectified. Paretic leg EMG and propulsion were averaged over the second half of the paretic leg single-limb support phase. This phase of the gait cycle was selected because it is a key period of forward progression in which the paretic leg alone is supporting the body. Therefore, nonparetic compensatory contributions to support and propulsion will not influence the results. EMG amplitude was normalized for each participant by calculating a percent change between steady-state walking and the long-step task.

Statistics

Comparisons between steady-state walking and the long-step task for each variable were made using repeated-measures *t* tests (1-tailed, consistent with directional hypotheses). Associations between continuous variables were evaluated using the Pearson correlation test. Statistical significance was accepted at $P < .05$.

Results

Fifteen adults (8 men and 7 women) participated in this study. The mean age was 59.9 ± 11.9 years, and time since stroke was

List of abbreviations:

COM center of mass
EMG electromyogram

39.8±34.3 months (range, 9–117mo). The preferred overground walking speed was .54±.25m/s, and the lower extremity Fugl-Meyer score was 23.7±5.7 (out of 34 possible points).

During steady-state walking, 13 of 15 participants (87%) exhibited lower paretic forward progression (see “a” in fig 1) than nonparetic forward progression (see “b” in fig 1). The remaining 2 participants (13%) had approximately symmetrical forward progression from both the paretic and nonparetic sides. On average, the forward progression distances for nonparetic forward progression and paretic forward progression during steady-state walking were 15.10±4.22 and 8.73±5.07cm, respectively ($P<.001$). The group average forward progression ratio was .35±.11 (where .50 indicates symmetry). Paretic forward progression had a significant positive correlation with self-selected overground walking speed ($r=.71$; $P=.003$). Paretic forward progression was not associated with age ($P=.33$) or time since stroke ($P=.62$).

All study participants successfully performed the long-step task with at least a small increase (ie, ≥10%) in paretic forward progression relative to steady-state walking. On average, paretic forward progression increased 113% for the nonparetic long step relative to steady-state walking ($P<.001$). This change in forward progression was positively correlated with an increase in anterior step distance by the nonparetic leg (see “c” and “e” in fig 1) ($r=.70$; $P=.003$). The average forward progression ratio during the nonparetic long-step task increased to .54±.11, indicating improved symmetry, as compared with the ratio of .35 observed during steady-state walking.

Propulsion by the paretic leg increased 319% for the nonparetic long step compared to steady-state walking (2.08±2.42Ns vs 8.71±5.12Ns; $P<.0001$). EMG amplitude observed from the paretic leg also increased significantly for most muscles between steady-state walking and the nonparetic long-step. These muscles included tibialis anterior (46.9%±62.4%; $P=.04$), soleus (54.7%±66.0%; $P=.01$), medial gastrocnemius (35.4%±50.4%; $P=.04$), vastus medialis (49.6%±50.2%; $P=.01$), and rectus femoris (33.6%±30.1%; $P=.02$). Of these muscles, the correlation between the change in the EMG and the change in propulsion was not significant, but a trend was evident for the soleus ($r=.53$; $P=.08$), medial gastrocnemius ($r=.62$; $P=.05$), and vastus medialis ($r=.52$; $P=.08$). The changes observed for the soleus and medial gastrocnemius also were positively correlated with the change in forward progression by the paretic leg ($r=.76$; $P=.02$ for each muscle).

Discussion

The primary finding of this study is that a long-step task with the nonparetic leg is effective in inducing an appropriate increase in paretic leg neuromuscular activation and biomechanical output during the stance phase of walking. Consistent with the strategy for taking a longer step in healthy adults, participants with post-stroke hemiparesis were able to use the paretic leg to increase propulsion during the stance phase of walking.⁵ The EMG results are consistent with the known role of each respective muscle in supporting body weight and generating propulsion during the stance phase of walking.⁸ There was considerable variability in the magnitude of task-dependent changes in EMG among participants, but the directionality of change (ie, increased activity during the long-step task) was largely consistent. This finding supports the assertion that participants used a strategy of more

intense activation of the paretic leg and did not need to rely solely on a strategy of limb flexion by the leading nonparetic leg to increase step length.⁵

Study limitations

This study examined only a long-step adaptability task. Other adaptability tasks (eg, high step and turning) may also be effective in engaging the paretic limb during walking rehabilitation, but were not addressed here.

Conclusions

The nonparetic long-step task may be effective for use in post-stroke locomotor rehabilitation to more effectively engage the paretic leg and induce neuroplastic recovery. These findings add to other potential benefits of using adaptability tasks in rehabilitation, including more effective engagement of cerebral circuits of locomotor control^{9,10} and high functional importance of adaptability tasks.⁴

Suppliers

- Techmachine.
- VICON.
- Konigsberg Instruments.
- The Mathworks.
- SAS Institute.
- C-Motion, Inc.

Keywords

Electromyography; Rehabilitation; Stroke; Walking

Corresponding author

David J. Clark, ScD, Brain Rehabilitation Research Center (151A), Malcom Randall Veterans Affairs Medical Center, 1601 SW Archer Rd, Gainesville, FL 32608. *E-mail address:* davidclark@ufl.edu.

References

- Kautz SA, Duncan PW, Perera S, Neptune RR, Studenski SA. Coordination of hemiparetic locomotion after stroke rehabilitation. *Neurorehabil Neural Repair* 2005;19:250-8.
- Combs SA, Dugan EL, Ozimek EN, Curtis AB. Effects of body-weight supported treadmill training on kinetic symmetry in persons with chronic stroke. *Clin Biomech* 2012;27:887-92.
- Den Otter AR, Geurts AC, Mulder T, Duysens J. Gait recovery is not associated with changes in the temporal patterning of muscle activity during treadmill walking in patients with post-stroke hemiparesis. *Clin Neurophysiol* 2006;117:4-15.
- Balasubramanian CK, Clark DJ, Fox EJ. Walking adaptability after a stroke and its assessment in clinical settings. *Stroke Res Treat* 2014; 2014:591013.

5. Varraine E, Bonnard M, Pailhous J. Intentional on-line adaptation of stride length in human walking. *Exp Brain Res* 2000;130: 248-57.
6. 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.
7. 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.
8. Clark DJ, Ting LH, Zajac FE, Neptune RR, Kautz SA. Merging of healthy motor modules predicts reduced locomotor performance and muscle coordination complexity post-stroke. *J Neurophysiol* 2010; 103:844-57.
9. Clark DJ, Kautz SA, Bauer AR, Chen YT, Christou EA. Synchronous EMG activity in the piper frequency band reveals the corticospinal demand of walking tasks. *Ann Biomed Eng* 2013;41:1778-86.
10. Clark DJ, Rose DK, Ring SA, Porges EC. Utilization of central nervous system resources for preparation and performance of complex walking tasks in older adults. *Front Aging Neurosci* 2014;6:217.