A Backward Walking Training Program to Improve Balance and Mobility in Acute Stroke: A Pilot Randomized Controlled Trial

Dorian K. Rose, PT, PhD, Lou DeMark, PT, DPT, NCS, Emily J. Fox, PT, DPT, PhD, NCS, David J. Clark, ScD, and Peter Wludyka, PhD

Background and Purpose: Strategies to address gait and balance deficits early poststroke are minimal. The postural and motor control requirements of Backward Walking Training (BWT) may provide benefits to improve balance and walking speed in this population. This pilot study (1) determined the feasibility of administering BWT during inpatient rehabilitation and (2) compared the effectiveness of BWT to Standing Balance Training (SBT) on walking speed, balance, and balance-related efficacy in acute stroke.

Methods: Eighteen individuals 1-week poststroke were randomized to eight, 30-minute sessions of BWT or SBT in addition to scheduled therapy. Five-Meter Walk Test, 3-Meter Backward Walk Test, Activities-Specific Balance Confidence Scale, Berg Balance Scale, Sensory Organization Test, and Function Independence Measure—Mobility were assessed pre- and postintervention and at 3 months poststroke.

Results: Forward gait speed change (BWT: 0.75 m/s; SBT: 0.41 m/s), assessed by the 5-Meter Walk Test, and backward gait speed change (BWT: 0.53 m/s; SBT: 0.23 m/s), assessed by the 3-Meter Backward Walk Test, preintervention to 1-month retention were greater for BWT than for SBT ($P < 0.05$). Group difference effect size from preintervention to 1-month retention was large for Activities-Specific Balance Confidence Scale, moderate for Berg Balance Scale and Function Independence Measure—Mobility, and small for Sensory Organization Test.

Discussion and Conclusions: Individuals 1-week poststroke tolerated 30 min/d of additional therapy. At 1-month postintervention, BWT resulted in greater improvements in both forward and backward walking speed than SBT. Backward walking training is a feasible important addition to acute stroke rehabilitation. Future areas of inquiry should examine BWT as a preventative modality for future fall incidence.

Video Abstract available for more insights from the authors (see Video, Supplemental Digital Content 1, http://links.lww.com/JNPT/A193).

Key words: *balance, gait, locomotion, rehabilitation, stroke*

(*JNPT* 2018;42: 12–21)

INTRODUCTION

Impairments of motor control and subsequent functional limitations in ambulation ability are among the most common manifestations of stroke. Although 60% of individuals poststroke are considered independent walkers by activities of daily living indices such as the Functional Independence Measures or the Barthel Index, significant disability persists because of limitations in community ambulation skills.[1] Residual deficits in balance also persist with a 73% incidence of falls in the first 6 months following hospital discharge among individuals with mild to moderate impairment.[2] To address walking challenges that stroke survivors encounter, rehabilitation providers use multiple therapeutic approaches. Strategies empirically studied and implemented (to varying degrees) in clinical practice include lower extremity strengthening,[3] motor imagery,[4] or virtual reality exercises[5] to challenge balance and gait, cycling,[6] electrical stimulation of lower extremity musculature,[7] and gait training with body weight support on a treadmill.[8] Despite these multiple approaches, ambulatory deficits remain a persistent and debilitating problem. In addition, the majority of gait and balance intervention investigations study community-dwelling individuals discharged from rehabilitation and in the chronic phase of recovery. Knowledge regarding effective strategies that can be safely implemented early, in the first few weeks poststroke, is limited.

Balance-related efficacy, a psychological characteristic based on Bandura's Social Cognitive Theory,[9] refers to perceived confidence in successfully performing common activities without losing balance. Low balance–related efficacy and its corollary, fall-related efficacy, lead to a cascade of consequences including self-imposed activity restriction resulting

---

Department of Physical Therapy, University of Florida, Gainesville (D.K.R., E.J.F.); Malcom Randall VA Medical Center, Gainesville, Florida (D.K.R., D.J.C.); Brooks Rehabilitation, Jacksonville, Florida (D.K.R., L.D., E.J.F.); Department of Aging, University of Florida, Gainesville (D.J.C.); and University of North Florida, Jacksonville (P.W.).

This manuscript was presented in poster format at APTA CSM 2014 in Las Vegas, Nevada.

This work was funded in part by the Brooks Community Health Foundation.

The authors declare no conflict of interest.

Supplemental digital content is available for this article. Direct URL citation appears in the printed text and is provided in the HTML and PDF versions of this article on the journal's Web site (www.jnpt.org).

Correspondence: Dorian K. Rose, PT, PhD, Department of Physical Therapy, College of Public Health and Health Professions, University of Florida, PO Box 100154, Gainesville, FL 32610 (dkrose@phhp.ufl.edu).

ISSN: 1557-0576/18/4201-0012
DOI: 10.1097/NPT.0000000000000210

in a higher risk of subsequent falls,[10] further decline in physical function, and reduced social interaction.[11] This cascade, in turn, can lead to an overall decrease of independence and quality of life, including an increased risk of recurrent stroke.[10,12] Delbaere et al[13] suggested a pattern between reduced activity and decreased muscle strength and balance, leading to further declines in activities of daily living, increased fall incidence, and fear of falling with additional decline in physical activity perpetuating this vicious cycle. Previous investigations have suggested that enhancing self-efficacy in addition to functional walking capacity may lead to greater improvements in physical function than enhancement of functional walking capacity alone.[14,15] An effective strategy to improve dynamic balance and self-efficacy that could effectively interrupt this vicious cycle is needed in poststroke rehabilitation.

Backward walking is an intervention that may be valuable for enhancing balance and self-efficacy to improve mobility function after stroke. It has been used in orthopedic rehabilitation as it produces less mechanical strain on the knee joint[16] while backward running is an effective means for increasing strength and power of the quadriceps.[17] Backward walking to improve gait and dynamic balance poststroke is a more recent application[18-21] and appears to offer a number of potential benefits.

Individuals poststroke fall not only during forward steady-state walking but also when turning or during a transfer,[22,23] both of which often require a backward step. A benefit of backward walking training is that it challenges postural stability requisite for such tasks. Straube et al[24] trained individuals poststroke in variable stepping contexts (sideways, backward) and reported subsequent improvements in dynamic balance activities. They contrast these balance improvements following variable step training to studies of forward walking alone that resulted in nonsignificant balance gains[25] and suggest that postural stability is not sufficiently challenged during forward walking training. During backward walking, visual cues, although present,[26] do not provide information on the target to be reached, nor the resources to anticipate ground conditions. This variation in optic flow as well as the simple novelty of the task leads to alterations in spine and pelvis stabilization to maintain dynamic balance.[27] Therefore, backward walking training, due to its greater postural demands,[28] may be superior to a more traditional forward walking training to improve gait and dynamic balance and decrease fall incidence in individuals poststroke.

A second benefit is that it engages cerebral pathways that are damaged by stroke, potentially enhancing neuroplastic recovery. Compared with forward walking, backward walking is more effective at inducing cerebral activation.[29,30] An increased oxygenated hemoglobin response during backward compared with forward walking in healthy adults, consistent with increased cortical processing, was observed in the supplementary motor area, primary motor cortex, and superior parietal lobule.[30] During backward walking, the absence of peripheral visual feedback and visual flow that is used to plan movement during forward gait is absent.[31] Lack of visual information may require a reweighting of sensory feedback to control the stepping pattern.[30] This reweighting process, with greater reliance on other feedback systems, in turn may require additional cortical resources to evaluate the sensory feedback that is available. Given the known role of novelty and task challenge in promoting neuroplasticity,[32] backward walking, a more novel motor skill relative to walking forward, may promote cortical neural plasticity by more intensely engaging the circuits damaged by stroke.

Third, backward walking allows patients to practice coordinated locomotion independent of the abnormal compensatory movement patterns that are characteristic of forward walking after stroke. In healthy adults, mean electromyographic activity is generally higher in backward than in forward walking. For example, concentric activation of hip extensor/knee flexor muscles is greater during early swing phase when walking backward.[16,33] Training under conditions with a greater demand for muscle activation may facilitate activity in muscles weakened secondary to stroke and be beneficial for improving lower limb coordination. An advantage of training backward walking poststroke is that a backward step requires hip extension with knee flexion to bring the lower extremity posterior to the trunk. This movement combination is often difficult due to the emergence of the predominant flexion synergy[34] that occurs following central nervous system damage. Repetitive backward stepping deviates from the predominant flexor synergy pattern and may improve muscle activation and subsequent motor control. These benefits are likely to transfer to improved muscle activation and appropriate kinematics during forward walking. Given these potential benefits of backward walking, we conducted a pilot study to first investigate the feasibility of applying this novel intervention early poststroke and then evaluate its effectiveness in improving gait and balance.

The purposes of this study were to (1) determine the feasibility of administering a Backward Walking Training (BWT) program in an acute inpatient rehabilitation setting and (2) compare the effectiveness of BWT to a more conventional but equally progressive and structured program, Standing Balance Training (SBT), on walking speed, balance, and balance-related efficacy in acute stroke.

METHODS

Participants

Admissions to Brooks Rehabilitation Hospital, Jacksonville, Florida, were screened for study eligibility, conducted by rehabilitation personnel not involved in the study intervention. Inclusion criteria were (1) diagnosis of first stroke in previous 30 days, (2) older than 18 years, (3) able to maintain upright standing posture with moderate assistance, (4) anticipated inpatient rehabilitation length of stay 2 to 3 weeks, (5) anticipated remaining in the geographic area for the study duration, and (6) vision within functional limits (deemed adequate for gait training). Potential participants were excluded if presented with (1) absence of significant balance impairment, defined by Berg Balance Scale (BBS) score greater than 45/56, (2) lower extremity joint or weight-bearing pain, (3) other neurological diagnoses, (4) inability to follow 2-step command, (5) contraversive pushing syndrome, or (6) cerebellar stroke. Individuals who met the study's inclusion and exclusion criteria were invited to participate.

Study Design

Participants provided written informed consent to participate in the protocol approved by the Institutional Review Board at the University of Florida. Participants followed standard rehabilitation protocol of the hospital (termed Usual Care), including physical, occupational, and speech therapy. Content of Usual Care was determined by participants' rehabilitation therapists. For all participants, backward walking was not permitted as part of usual care. Therapy time, but not content, was recorded. Participants were randomized to BWT or SBT and were assessed at 3 time points by evaluators blinded to group assignment: preintervention, postintervention, and at 3 months poststroke. The preintervention evaluation was conducted on day 2 of hospital admission and postintervention evaluation conducted the day after the final intervention session.

Intervention

Following randomization, participants received eight, 30-minute study intervention sessions, administered by the study physical therapist (L.D.). Intervention was administered Monday to Friday. An 8-session intervention was dictated by anticipated inpatient length of stay such that all intervention sessions were delivered during the inpatient period. Study intervention began on day 3 of hospital admission. The protocols were standardized and each session recorded in an exercise log to ensure progression of intensity across the sessions. Patients were encouraged to remain upright for the entire 30-minute session; however, intensity of each session was patient-specific with rest breaks provided upon therapist discretion and patients' tolerance to activity (ie, vital signs). Participants wore a gait belt during all intervention sessions. Sessions were scheduled to not interfere with participants' Usual Care.

Backward Walking Training

Backward Walking Training consisted of backward walking over ground without use of assistive devices to promote optimal posture, weight bearing through the lower limbs, and lower limb motor recovery. Assistance was provided by the intervention therapist as needed for weight shift, guidance of the paretic lower extremity, and maintenance of balance during gait. A therapy aide provided postural assistance if needed. Progression of intensity occurred by decreasing physical assistance and increasing gait speed and distance. Over the intervention sessions, participants were encouraged to perform continuous backward walking with increased cadence and/or step length as well as overall distance, while maintaining balance (Table 1). We intentionally administered BWT over ground so that results could be more readily translated to a variety of clinical settings that may not have access to treadmill-based rehabilitation systems (Figure 1A and Table 1).

Standing Balance Training

Standing Balance Training served as an active control and consisted of both static and dynamic standing tasks including quiet stance, dual-task with upper extremity (UE) manipulation, and reaching for targets both within and outside the patient's base of support. Standing Balance Training closely mimicked BWT in that it required upright postural

Table 1. Backward Walking Training and Standing Balance Training Intervention

Backward Walking Training

1. The intervention therapist was seated on a rolling stool on the side of the involved limb to assist with foot clearance, limb progression, and backward locomotion. The rehabilitation aide provided hand-held support for the participant as needed to ensure sufficient dynamic postural control during backward walking.
2. Once the patient was able to independently advance his or her involved limb backward, the intervention therapist repositioned himself behind the patient providing assistance at his or her pelvis for dynamic balance and weight shift. The research assistant provided standby/hand-held assistance as needed to ensure adequate postural stability and safety.
3. Once the patient was able to independently advance his or her limb and adequately weight shift for sufficient backward locomotion, the therapist provided standby assist as needed for loss of balance.
    - Patients who lost their balance greater than 50% of the time were provided intermittent hand-held assist as needed from the therapist to ensure adequate intensity without disruption of the backward walking task.

Standing Balance Training

1. Weight shift side to side (paretic/nonparetic lower extremity)
    a. Feet apart/firm surface
    b. Feet together/firm surface
    c. Feet apart/foam surface
    d. Feet together/foam surface
2. Weight shift forward and backward (heel/toe)
    a. Stand with feet hip-width apart/firm surface
    b. Stand with feet together/firm surface
    c. Stand with feet hip-width apart/foam surface
    d. Stand with feet together/foam surface
3. Feet apart—firm or foam[a] surface
    a. Eyes open and count up to 60 s/firm
    b. Eyes open and count up to 60 s/foam
    c. Eyes open and move head up and down 10 times/firm
    d. Eyes open and move head up and down 10 times/foam
    e. Eyes open and move head side to side 10 times/firm
    f. Eyes open and move head side to side 10 times/foam
    g. Eyes closed and count up to 60 s/firm
    h. Eyes closed and count up to 60 s/foam
    i. Eyes closed and move head up and down 10 times/firm
    j. Eyes closed and move head up and down 10 times/foam
    k. Eyes closed and move head side to side 10 times/firm
    l. Eyes closed and move head side to side 10 times/foam
4. Feet Together—firm or foam surface
    a. Eyes open and count up to 60 s/firm
    b. Eyes open and count up to 60 s/foam
    c. Eyes open and move head up and down 10 times/firm
    d. Eyes open and move head up and down 10 times/foam
    e. Eyes open and move head side to side 10 times/firm
    f. Eyes open and move head side to side 10 times/foam
    g. Eyes closed and count up to 60 s/firm
    h. Eyes closed and count up to 60 s/foam
    i. Eyes closed and move head up and down 10 times/firm
    j. Eyes closed and move head up and down 10 times/foam
    k. Eyes closed and move head side to side 10 times/firm
    l. Eyes closed and move head side to side 10 times/foam
5. Feet in half tandem—firm or foam surface
    a. Eyes open and count up to 60 s/firm
    b. Eyes open and count up to 60 s/foam
    c. Eyes open and move head up and down 10 times/firm
    d. Eyes open and move head up and down 10 times/foam
    e. Eyes open and move head side to side 10 times/firm
    f. Eyes open and move head side to side 10 times/foam
    g. Eyes closed and count up to 60 s/firm
    h. Eyes closed and count up to 60 s/foam
    i. Eyes closed and move head up and down 10 times/firm
    j. Eyes closed and move head up and down 10 times/foam
    k. Eyes closed and move head side to side 10 times/firm
    l. Eyes closed and move head side to side 10 times/foam

(*continues*)

Table 1. Backward Walking Training and Standing Balance Training Intervention (*Continued*)

6. Feet in full tandem—firm or foam surface
    a. Eyes open and count up to 60 s/firm
    b. Eyes open and count up to 60 s/foam
    c. Eyes open and move head up and down 10 times/firm
    d. Eyes open and move head up and down 10 times/foam
    e. Eyes open and move head side to side 10 times/firm
    f. Eyes open and move head side to side 10 times/foam
    g. Eyes closed and count up to 60 s/firm
    h. Eyes closed and count up to 60 s/foam
    i. Eyes closed and move head up and down 10 times/firm
    j. Eyes closed and move head up and down 10 times/foam
    k. Eyes closed and move head side to side 10 times/firm
    l. Eyes closed and move head side to side 10 times/foam
7. Standing reaching for objects within base of support—firm surface
    a. Feet apart: Sagittal, frontal, and transverse planes
    b. Feet together: Sagittal, frontal, and transverse planes
8. Standing reaching for objects outside base of support—firm surface
    a. Feet apart: Sagittal, frontal, and transverse planes
    b. Feet together: Sagittal, frontal, and transverse planes
9. Single leg stance—firm surface
    a. Nonparetic leg
    b. Paretic leg

[a] Airex Foam Pad (Sins, Switzerland).

control and provided a balance challenge. The study therapist chose initial tasks from a standardized task bank (Table 1) and progressed participants according to their ability to maintain standing balance during each task. Participants were encouraged to perform tasks without UE support; however, they were permitted to take support if needed. To ensure progression in exercise intensity levels, patients were advanced to a more difficult standing balance task if they were able to maintain stance without losing balance for a given task at least 50% of the time. To ensure participant engagement, at least 5 different tasks were included in each session. Somatosensory and visual systems were challenged by standing on foam and closing eyes as participants were progressed (Figure 1B and Table 1).

Outcome Measures

Feasibility

Participants' ability to complete each 30-minute intervention session and to progress in the daily intervention was recorded as well as participant recruitment, retention, and adverse event occurrence.

5-Meter Walk Test

Gait speed was assessed with the 5-Meter Walk Test which has demonstrated responsiveness in the stroke population.[35] Time to ambulate was recorded with a stopwatch. Participants completed the distance 2 times at their self-selected speed to obtain an average gait speed. Balance assistance was provided if needed, but no assistance was provided for lower extremity advancement. At each study time point, the assessment was completed with the least restrictive assistive and orthotic device.

Figure 1. A. Backward Walking Training intervention; B. Standing Balance Training intervention. Eight, 30-minute interventions were conducted in addition to participant's inpatient Usual Care. Interventions were conducted in the inpatient rehabilitation unit and progressed daily. This figure is available in color in the article on the journal website.

3-Meter Backward Walk Test

Backward walking speed was assessed with the 3-Meter Backward Walk Test.[36] Time to ambulate backward 3 m was recorded with a stopwatch. Two trials at their self-selected speed were averaged. Balance assistance was provided if needed, but no assistance was provided at the lower extremities. At each study time point, the assessment was completed with the least restrictive assistive and orthotic device.

Berg Balance Scale

The 14-item scale assessed static and dynamic standing balance, ability to sit, stand up, and transfer. The BBS is valid,[37] reliable,[37] and sensitive to change[38] in people with acute stroke.

Activities-Specific Balance Confidence Scale

This 16-item self-report questionnaire, reliable[39] and valid[40] in the stroke population, assessed self-efficacy (self-reported confidence) in maintaining balance for activities such as bending, reaching, and walking. This measure has good reliability and internal consistency.

Functional Independence Measure—Mobility[41]:

Mobility domains include locomotion, stairs, WC transfers, toilet transfers, and shower/tub transfers and are a reliable and valid measure in stroke rehabilitation.[42]

Sensory Organization Test[43]

Balance is assessed while participants stood on a force plate under 6 different conditions (three 20-second trials/conditions) that required integration of visual, somatosensory, and vestibular input to maintain postural control (NeuroCom Balance Master).The participant wore a safety harness to prevent falls.

Fall Incidence

While an inpatient, falls were recorded by participants' entire rehabilitation team, including nursing. Upon discharge, participants were provided monthly calendars to record any falls[44] and self-addressed postcards to return to study personnel. If a postcard was received, participants were contacted and administered a Fall Characterization Questionnaire. In addition, participants were queried regarding fall incidence at their 3-month poststroke assessment. If a fall occurred at any time during study participation, a Fall Characterization Questionnaire was administered. This 16-item questionnaire was developed for a previous stroke randomized controlled trial[8] and queried participants regarding extent of injury if any, type of medical attention sought if any, subsequent activity limitation, and fall location.

Data Analysis

Descriptive statistics were calculated for all variables. Normality was confirmed by visual inspection of Q-Q plots. Average ±SD was reported for preintervention, postintervention, and the 3-month retention assessment for each of the outcome variables. Outcome variables were modeled using 2-way group (BWT, SBT) × Time analysis of variance with repeated measures on time (preintervention, postintervention, and 3-month retention). Mauchly Sphericity Test confirmed the appropriateness of the repeated measures analysis. As we had a small sample size for this feasibility study, effect sizes of group differences (BWT vs SBT) from preintervention to the 1-month retention session for each of the outcome measures were calculated as Cohen *d*.[45]

RESULTS

Eighteen individuals admitted to the inpatient stroke unit consented to participate. There were no differences between groups in demographics and preintervention measures except for age (Table 2) and Functional Independence Measure—Mobility (FIM-M) (Table 3) with the BWT group being younger with a higher initial FIM-M score ($P < 0.05$).

Usual Care

There was no significant difference in the amount of usual care physical therapy (BWT: 13 ± 3 hours, SBT: 15 ± 4 hours; $P > 0.05$), occupational therapy (BWT: 9 ± 5 hours, SBT: 8 ± 4 hours; $P > 0.05$), or speech therapy (BWT: 7 ± 3 hours, SBT: 8 ± 2 hours; $P > 0.05$) between groups over the 8-session study intervention.

Feasibility

Recruitment

The primary reasons for study ineligibility were (1) previous stroke and (2) inability to stand. This speaks to the challenge of conducting exercise-based intervention research acutely following stroke. Twelve participants who were eligible declined to participate as they were unable to commit to the added demands of study participation.

Intervention

Participants in both intervention groups tolerated an additional 30 minutes of exercise, at just 1 week poststroke, in addition to their prescribed scheduled therapy. All participated in the full 30 minutes at session 1, were compliant with the intervention, and progressed throughout the 8 sessions as described. Individuals in the BWT group increased their distance walked 197 ± 155 m (range: 27-543 m) across the 8 sessions (Table 4). Individuals in the SBT group progressed, on average, 5 levels of exercise difficulty (Table 5). For example, a participant progressed from 1(a) Weight Shift side to side with feet apart on a firm surface to 7(a) Standing reaching for objects, within base of support, feet apart on a firm surface. There

Table 2. Demographics of the Study Sample

	BWT (n = 8)	SBT (n = 8)
Age ± SD, y	53.8 ± 12.1	66.6 ± 7.3[a]
Mean time from stroke onset ± SD (d)	8.5 ± 4.2	7.8 ± 3.3
Affected hemisphere	5 Left 3 Right	5 Left 3 Right
Sex (male/female)	4 males/4 females	2 males/6 females
Race	5 W; 3 AA	6 W; 2 AA

Abbreviations: AA, African American; BWT, Backward Walking Training; SBT, Standing Balance Training; W, white.

[a] Statistically significant difference at $P < 0.05$.

Table 3. Outcome Measures at Each Assessment

Outcome	Group	Preintervention	Postintervention	Retention
5MWT (m/s)	SBT	0.23 ± 0.15	0.36 ± 0.22	0.64 ± 0.40[a]
	BWT	0.23 ± 0.12	0.71 ± 0.36	0.98 ± 0.48
3MBWT (m/s)	SBT	0.10 ± 0.06	0.16 ± 0.10	0.33 ± 0.27[a]
	BWT	0.10 ± 0.06	0.55 ± 0.33	0.63 ± 0.37
ABC Scale (%)	SBT	39.2 ± 19.1	48.1 ± 29.2	54.9 ± 29.4
	BWT	32.6 ± 23.4	64.4 ± 29.0	68.1 ± 34.4
BBS (range: 0-56)	SBT	14.8 ± 12.5	36.1 ± 11.8	43.2 ± 9.7
	BWT	11.4 ± 10.7	41.9 ± 11.8	48.0 ± 12.5
FIM-M (range: 5-35)	SBT	5.6 ± 2.1	18.0 ± 6.6	26.8 ± 4.5
	BWT	8.0 ± 2.3[b]	23.6 ± 7.6	30.4 ± 6.1
SOT	SBT	21.0 ± 16.9	40.6 ± 21.0	63.8 ± 11.3
	BWT	27.0 ± 20.8	55.8 ± 21.3	64.8 ± 18.2

Abbreviations: ABC, activities-specific balance confidence; BBS, Berg Balance Scale; BWT, Backward Walking Training; 5MWT, 5-Meter Walk Test; FIM-M, Functional Independence Measure-Mobility; SBT, Standing Balance Training; SOT, Sensory Organization Test; 3MBWT, 3-Meter Backward Walk Test.

[a] Statistically significant difference in the change between groups from preintervention to retention ($P \leq 0.05$).

[b] Statistically significant difference between groups at preintervention ($P < 0.05$).

were no adverse events in either group. Two participants were withdrawn during the intervention phase, neither related to the study intervention—one due to uncontrolled hypertension and the other to unexpected, early discharge. Sixteen participants completed the study intervention and the immediate postintervention assessment.

Retention

Six participants, 3 from each group, were unable to return for their 3-month poststroke retention assessment (Figure 2). Two had moved from the area, 3 declined to come in for the retention assessment, and 1 was unable to be contacted. There was no significant difference ($P > 0.05$) in initial 5-Meter Walk Test or FIM-M scores between those who were retained for the 3-month assessment and those who were not, evidence that functional status did not play a role in study retention.

Outcome Measures

A 2-way analysis of variance (Group × Time) with repeated measures on time was conducted with data imputation used to replace missing values for those lost to follow-up

Table 4. Progression of BWT Intervention in Meters Walked and Assistance Required/Session

	Session No.							
	1	2	3	4	5	6	7	8
S1	213 m PT[a]: 1 Aide[a]: 1	244 m PT: 2 Aide: 2	183 m PT: 1 Aide: 1	244 m PT: 2 Aide: 3	296 m PT: 2 Aide: 3	317 m PT: 2 Aide: 3	366 m PT: 3 Aide: 4	351 m PT: 3 Aide: 1
S2	91 m PT: 1 Aide: 1	134 m PT: 1 Aide: 1	146 m PT: 2 Aide: 1	152 m PT: 2 Aide: 1	171 m PT: 3 Aide: 2	256 m PT: 3 Aide: 3	226 m PT: 3 Aide: 4	259 m PT: 3 Aide: 4
S3	75 m PT: 1 Aide: 1	107 m PT: 2 Aide: 3	91 m PT: 2 Aide: 3	122 m PT: 3 Aide: 2	122 m PT: 2 Aide: 4	198 m PT: 3 Aide: 4	203 m PT: 3 Aide: 4	229 m PT: 3 Aide: 4
S4	166 m PT: 3 Aide: 2	183 m PT: 3 Aide: 2	217 m PT: 3 Aide: 2	128 m PT: 3 Aide: 3	207 m PT: 3 Aide: 4	207 m PT: 2 Aide: 4	213 m PT: 3 Aide: 4	259 m PT: 3 Aide: 4
S5	28 m PT: 0 Aide: 1	34 m PT: 0 Aide: 1	53 m PT: 0 Aide: 0	73 m PT: 0 Aide: 1	57 m PT: 0 Aide: 0	60 m PT: 1 Aide: 1	47 m PT: 2 Aide: 2	55 m PT: 2 Aide: 3
S6	128 m PT: 2 Aide: 3	183 m PT: 2 Aide: 3	244 m PT: 2 Aide: 3	335 m PT: 2 Aide: 3	305 m PT: 2 Aide: 3	472 m PT: 2 Aide: 3	762 m PT: 2 Aide: 3	671 m PT: 2 Aide: 3
S7	41 m PT: 0 Aide: 0	78 m PT: 0 Aide: 0	125 m PT: 0 Aide: 0	146 m PT: 0 Aide: 1	207 m PT: 1 Aide: 1	219 m PT: 1 Aide: 2	216 m PT: 1 Aide: 2	259 m PT: 2 Aide: 3
S8	67 m PT:[b] Aide:[b]	122 m PT:[b] Aide:[b]	152 m PT:[b] Aide:[b]	195 m PT:[b] Aide:[b]	244 m PT:[b] Aide:[b]	274 m PT:[b] Aide:[b]	290 m PT:[b] Aide:[b]	305 m PT:[b] Aide:[b]

Abbreviations: m, meters; PT, physical therapist; S, subject.

[a] Assistance key: 0: maximum assistance; 1: moderate assistance; 2: minimal assistance; 3: supervision; 4: no assistance needed.

[b] Missing data.

Table 5. Progression of SBT Intervention—Most Challenging Exercise Attained/Session[a]

	Session No.							
	1	2	3	4	5	6	7	8
S1	5a	4g	5b	4f	5b	5g	6a	9b
S2	5g	5g	5a	5a	7a	5g	7a	7a
S3	4g	8a	5g	5k	7b	7b	5k	7a
S4	4g	6a	6g	6a	7b	6a	8b	6k
S5	3c	4k	6e	5k	5k	8b	6k	8b
S6	3a	3a	3g	3g	3g	3g	3g	4a
S7	5k	5k	5k	6a	6k	6g	7b	7b
S8	4a	4a	4a	4k	8a	4k	7b	7b

Abbreviation: S, subject.

[a] Exercises described in Table 1.

at retention. For forward walking 5-Meter Walk Test, BWT participants improved from 0.23 ± 0.12 to 0.98 ± 0.48 m/s from preintervention to retention. This compares with an SBT group gain from 0.23 ± 0.15 to 0.64 ± 0.40 (Group × Time interaction; $P = 0.05$; Figure 3 and Table 5). The increase in forward walking speed was, therefore, 0.75 m/s for the BWT group compared with a 0.41 m/s increase for the SBT group, which constitutes a large effect size of $d = 0.90$. For backward walking 3MWT, BWT participants improved from 0.10 ± 0.06 to 0.63 ± 0.37 m/s from preintervention to retention compared with an SBT group gain of 0.10 ± 0.06 to 0.33 ± 0.27 m/s (Group × Time interaction; $P = 0.03$; Figure 4 and Table 5).The increase in backward walking speed was, therefore, 0.53 m/s for the BWT group compared with a 0.23 m/s increase for the SBT group, constituting a moderate effect size of $d = 0.66$. The BWT group's Activities-Specific Balance Confidence Scale score improved from 32.6 ± 23.4% to 68.1 ± 34.4% between preintervention and retention compared with a 39.2 ± 19.1% to 54.9 ± 29.4% gain for the SBT group (Figure 5 and Table 5). This BTW group 35.5% increase compared with an SBT group 15.7% increase constituted a large effect size of $d = 1.1$ The difference in BBS gains for the BWT group (11.4 ± 10.7-48.0 ± 12.5) compared with the SBT group (14.8 ± 12.5-43.2 ± 9.7) revealed a moderate effect size of $d = 0.70$ ($P > 0.05$; Table 5). Differences in the FIM-M change between preintervention and retention for the BWT group (8.0 ± 2.3-30.4 ± 6.1) compared with the SBT group (5.6 ± 2.1-26.8 ± 4.5) produced a moderate effect size of $d = 0.47$ ($P > 0.05$; Table 5). Sensory Organization Test between group differences constituted a small effect size of $d = 0.37$ ($P > 0.05$; Table 5).

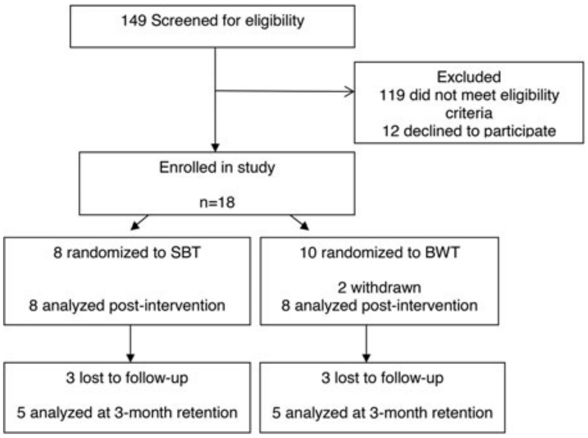

Figure 2. Flow of participants through the trial according to the CONSORT statement. BWT indicates Backward Walking Training; SBT, Standing Balance Training.

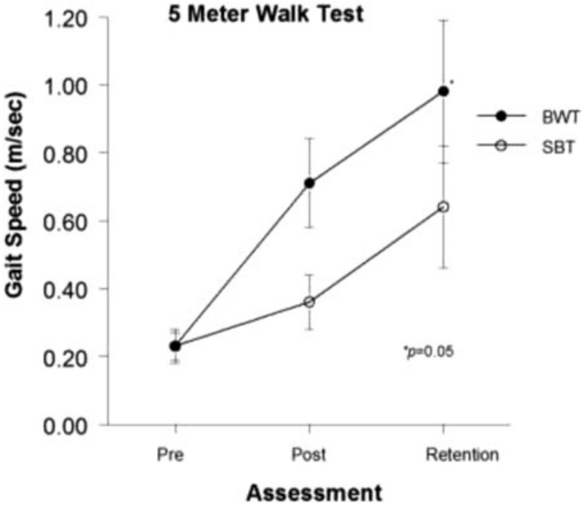

Figure 3. Forward gait speed (5MWT) at each assessment time point. The change in speed from preintervention to 3-month assessment was greater for BWT than for SBT ($P = 0.05$). BWT indicates Backward Walking Training; 5MWT, 5-Meter Walk Test; SBT, Standing Balance Training.

Fall Incidence

There were too few falls over the study's short time course to draw comparisons between groups. During the intervention phase, there was 1 recorded fall in the BWT group and

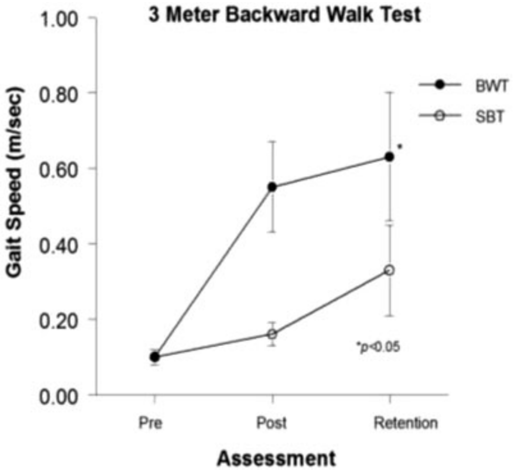

Figure 4. Backward gait speed (3MBWT) at each assessment time point. The change in speed from preintervention to 3-month assessment was significantly greater for the BWT group than for the SBT group ($P = 0.03$). BWT indicates Backward Walking Training; SBT, Standing Balance Training; 3MBWT, 3-Meter Backward Walk Test.

Figure 5. Activities-Specific Balance Confidence Scale scores at each assessment time point. The BTW group increased 35.5% preintervention to retention compared with a 15.7% SBT group increase that constituted a large effect size, $d = 1.1$. BWT indicates Backward Walking Training; SBT, Standing Balance Training.

no falls in the SBT group. During the 3-month retention phase following discharge from inpatient rehabilitation, there were 2 recorded falls in the BWT group and 4 in the SBT group.

DISCUSSION

This pilot study assessed the feasibility of conducting a clinical trial in early poststroke rehabilitation and compared the effectiveness of BWT with SBT on walking speed, balance, and balance self-efficacy in acute stroke. Results indicate that BWT is a feasible intervention to conduct during inpatient rehabilitation. Participants were able to actively engage and systematically progress through this novel, additional intervention with no complaints of fear or excessive fatigue. During the intervention phase, 2 participants from the BWT group were withdrawn, neither explicitly related to the experimental intervention.

These results provide evidence that BWT early poststroke contributes to the acquisition of important functional skills and improved balance self-efficacy. Backward Walking Training improved both forward and backward gait speed significantly more than SBT, and this difference was retained nearly 2 months after completing the intervention (ie, at 3 months poststroke). The BWT group demonstrated greater improvement in balance self-efficacy (confidence) following intervention than the SBT group although this difference was not significant at 3 months poststroke. While BWT had a differential effect on balance self-efficacy, balance function as measured by the BBS improved equitably in both groups. Designing low-tech exercise options for individuals early poststroke is frequently a challenge. This pilot study demonstrated that BWT is a viable intervention early poststroke with the potential to provide gains in forward walking speed, balance, and balance self-efficacy.

The 2 interventions were similar in many respects. In addition to dose, both were delivered without external equipment, required upright posture with minimal to no upper extremity support, and were continually progressed. Despite these similarities, BWT preferentially transferred into greater walking function and balance confidence for patients early poststroke.

Backward Walking Training improved both forward and backward gait-speed significantly more than SBT. The increase in backward walking speed following BWT is in accordance with the motor learning theory of task-specific training. In contrast, greater improvements in balance were not observed in the SBT group—both groups improved equitably. This could be due to the postural control required to maintain balance during BWT transferred to the static and dynamic postural requirements assessed in our balance measure. In addition, greater utilization of sensory inputs that may benefit balance responses as well as greater muscle activation during BWT[16,33] may have contributed to improved balance control.

Interestingly, forward walking speed also improved to a greater degree for the BWT group than for the SBT group. This result may seem to confound the task-specificity theory, but it actually provides empirical evidence to support previous evidence from both the animal literature[46-48] and healthy adults[49,50] that the neural control of forward and backward walking may largely originate from the same basic neural circuitry, thus facilitating performance gains across both tasks.

In addition, the increased cerebral activation inherent in backward walking may have better engaged damaged cerebral circuits, leading to neuroplastic recovery that generalized to gains in forward walking ability. Future studies should empirically measure cerebral activation in individuals poststroke during BWT compared with other rehabilitation approaches. Backward Walking Training may have also facilitated activation of key muscles such as hip extensors, which are important contributors to forward walking speed.[51-53]

Fritz et al[54] determined that backward walking velocity in elderly adults was a better predictor of fall risk than forward walking velocity. In their cohort of 62, 100% of those identified as fallers (determined by self-reported falls in the previous 6 months) had a backward walk gait speed of less than 0.60 m/s, suggesting that this may be a critical threshold for the detection of fall risk. In our 3-month retention cohort, average backward walking gait speed for those trained in the BWT program was 0.63 m/s, compared with 0.33 m/s in the SBT group. Three of 5 BWT participants achieved a backward walking speed of greater than 0.60 m/s. In contrast, just 1 of 5 SBT participants achieved backward walking speed of greater than 0.60 m/s. Although study design did not permit following participants longitudinally for longer than 3 months to record fall incidence, we would hypothesize that our BWT group, who on average had exceeded this threshold for backward walking speed, would experience fewer falls than those in the SBT group.

Balance-related efficacy is an important variable to measure and address in poststroke rehabilitation secondary to its relationship to physical activity, mobility, and falls.[13,55-57] The BWT group demonstrated greater improvement in balance-related efficacy as measured by the Activities-Specific Balance Confidence Scale than the SBT group despite not explicitly performing traditional balance exercises.

We specifically targeted this intervention for delivery early after stroke onset to assess whether participants could tolerate an additional 30 minutes of exercise in addition to their present rehabilitation plan of care. We recognize that natural recovery, observed within the first 3 months poststroke, may have contributed to observed improvements in both groups. The results from this small sample should be interpreted with caution as the BWT trained group was younger and had a higher initial FIM-M score.

While this study demonstrated feasibility of delivering this intervention in an inpatient rehabilitation facility, it also revealed challenges in enrolling patients in a clinical trial just days following stroke onset. Not all potential participants approached regarding study participation agreed, primarily secondary to being overwhelmed as to the acute onset of their disability and unsure of what to expect regarding the rehabilitation process. In this pilot study, without personnel dedicated to track participants after inpatient discharge when they are no longer in daily contact with the rehabilitation team, we were unable to obtain retention data on our full intervention cohort. A future full study to examine the retention effects of an acutely administered BWT program will need to include rigorous retention strategies. Finally, our outcome assessments were limited to those readily available and used in the clinical setting. Future studies will assess mechanisms underlying the observed improvements.

CONCLUSIONS

This study demonstrated patients in the acute phase of stroke recovery can tolerate and participate in a 30-minute exercise session beyond their inpatient rehabilitation plan of care. When this exercise is Backward Walking Training, it translates not only into faster backward walking speed, which may be a key to fall prevention, but also to improved forward gait speed and increased balance self-efficacy. Future areas of inquiry should include an examination of BWT as a preventative modality for future fall incidence.

ACKNOWLEDGMENTS

The authors thank the study participants and Brooks Rehabilitation Hospital Stroke Service and Brooks Medical Director, Trevor Paris, MD. Funding for this study was provided by the Brooks Community Health Foundation.

REFERENCES

1. Rundek T, Mast H, Hartmann A, et al. Predictors of resource use after acute hospitalization: The Northern Manhattan Stroke Study. *Neurology*. 2000;55:1180–1187.
2. Forster A, Young J. Incidence and consequences of falls due to stroke: a systematic inquiry. *BMJ*. 1995;311:83–86.
3. Hammami N, Coroian FO, Julia M, et al. Isokinetic muscle strengthening after acquired cerebral damage: a literature review. *Ann Phys Rehabil Med*. 2012;55:279–291.
4. Guerra ZF, Lucchetti ALG, Lucchetti G. Motor imagery training after stroke: a systematic review and meta-analysis of randomized controlled trials. *J Neurol Phys Ther*. 2017;41(4):205–214.
5. McEwen D, Taillon-Hobson A, Bilodeau M, Sveistrup H, Finestone H. Virtual reality exercise improves mobility after stroke: an inpatient randomized controlled trial. *Stroke*. 2014;45(6):1853–1855.
6. Yang HC, Lee CL, Lin R, et al. Effect of biofeedback cycling training on functional recovery and walking ability of lower extremity in patients with stroke. *Kaohsiung J Med Sci*. 2014;30:35–42.
7. Bethoux F, Rogers HL, Nolan KJ, et al. The effects of peroneal nerve functional electrical stimulation versus ankle-foot orthosis in patients with chronic stroke: a randomized controlled trial. *Neurorehabil Neural Repair*. 2014;28(7):688–697.
8. Duncan PW, Sullivan KJ, Behrman AL, et al. Body-weight-supported treadmill rehabilitation after stroke. *N Engl J Med*. 2011;364:2026–2036.
9. Bandura A. *Self-Efficacy: The Exercise of Control*. New York, NY: WH Freeman and Company; 1997.
10. King MB, Tinetti ME. Falls in community-dwelling older persons. *J Am Geriatr Soc*. 1995;43:1146–1154.
11. Murphy SL, Williams CS, Gill TM. Characteristics associated with fear of falling and activity restriction in community-living older persons. *J Am Geriatr Soc*. 2002;50:516–520.
12. Hyndman D, Ashburn A, Stack E. Fall events among people with stroke living in the community: circumstances of falls and characteristics of fallers. *Arch Phys Med Rehabil*. 2002;83:165–170.
13. Delbaere K, Crombez G, Vanderstraeten G, Willems T, Cambier D. Fear-related avoidance of activities, falls and physical frailty. A prospective community-based cohort study. *Age Ageing*. 2004;33:368–373.
14. Salbach NM, Mayo NE, Robichaud-Ekstrand S, Hanley JA, Richards CL, Wood-Dauphinee S. Balance self-efficacy and its relevance to physical function and perceived health status after stroke. *Arch Phys Med Rehabil*. 2006;87:364–370.
15. Schmid AA, Van Puymbroeck M, Altenburger PA, et al. Balance and balance self-efficacy are associated with activity and participation after stroke: a cross-sectional study in people with chronic stroke. *Arch Phys Med Rehabil*. 2012;93:1101–1107.
16. Thorstensson A. How is the normal locomotor program modified to produce backward walking? *Exp Brain Res*. 1986;61:664–668.
17. Flynn TW, Soutas-Little RW. Mechanical power and muscle action during forward and backward running. *J Orthopaedic Sports Phys Ther*. 1993;17:108–112.
18. Takami A, Wakayama S. Effects of partial body weight support while training acute stroke patients to walk backwards on a treadmill—a controlled clinical trial using randomized allocation. *J Phys Ther Sci*. 2010;22:177–187.
19. Weng CS, Wang J, Pan XY, et al. [Effectiveness of backward walking treadmill training in lower extremity function after stroke]. *Zhonghua yi xue za zhi*. 2006;86:2635–2638.
20. Yang YR, Yen JG, Wang RY, Yen LL, Lieu FK. Gait outcomes after additional backward walking training in patients with stroke: a randomized controlled trial. *Clin Rehabil*. 2005;19:264–273.
21. DeMark L, Spigel PM, Osborne J, Beneciuk J, Rose DK. Case series: a backward walking training program to improve balance, forward gait speed, and decrease fall risk in acute stroke. *J Neurol Phys Ther*. 2013;37:146.
22. Harris JE, Eng JJ, Marigold DS, Tokuno CD, Louis CL. Relationship of balance and mobility to fall incidence in people with chronic stroke. *Phys Ther*. 2005;85:150–158.
23. Simpson LA, Miller WC, Eng JJ. Effect of stroke on fall rate, location and predictors: a prospective comparison of older adults with and without stroke. *PLoS One*. 2011;6:e19431.
24. Straube DD, Holleran CL, Kinnaird CR, Leddy AL, Hennessy PW, Hornby TG. Effects of dynamic stepping training on nonlocomotor tasks in individuals poststroke: a clinical trial. *Phys Ther*. 2014;94:921–933.
25. Bowden MG, Behrman AL, Neptune RR, Gregory CM, Kautz SA. Locomotor rehabilitation of individuals with chronic stroke: difference between responders and nonresponders. *Arch Phys Med Rehabil*. 2013;94:856–862.
26. Assaiante C, Marchand AR, Amblard B. Discrete visual samples may control locomotor equilibrium and foot positioning in man. *J Motor Behav*. 1989;21:72–91.
27. Nadeau S, Amblard B, Mesure S, Bourbonnais D. Head and trunk stabilization strategies during forward and backward walking in healthy adults. *Gait Posture*. 2003;18:134–142.
28. Katsavelis D, Mukherjee M, Decker L, Stergiou N. Variability of lower extremity joint kinematics during backward walking in a virtual environment. *Nonlinear Dyn Psychol Life Sci*. 2010;14:165–178.

29. Godde B, Voelcker-Rehage C. More automation and less cognitive control of imagined walking movements in high- versus low-fit older adults. *Front Aging Neurosci*. 2010 Sep 1;2. pii:139.
30. Kurz MJ, Wilson TW, Arpin DJ. Stride-time variability and sensorimotor cortical activation during walking. *Neuroimage*. 2012;59:1602–1607.
31. Reynolds RF, Day BL. Visual guidance of the human foot during a step. *J Physiol*. 2005;569:677–684.
32. Plautz EJ, Milliken GW, Nudo RJ. Effects of repetitive motor training on movement representations in adult squirrel monkeys: role of use versus learning. *Neurobiol Learn Memory*. 2000;74:27–55.
33. Winter DA, Pluck N, Yang JF. Backward walking: a simple reversal of forward walking? *J Motor Behav*. 1989;21:291–305.
34. Duysens J, De Groote F, Jonkers I. The flexion synergy, mother of all synergies and father of new models of gait. *Front Comput Neurosci*. 2013;7:14.
35. Salbach NM, Mayo NE, Higgins J, Ahmed S, Finch LE, Richards CL. Responsiveness and predictability of gait speed and other disability measures in acute stroke. *Arch Phys Med Rehabil*. 2001;82:1204–1212.
36. Carter V, James J, Cornwall MW. The 3-Meter Backward Walk Test and its ability to predict fall history in older individuals. *J Neurol Phys Ther*. 2014;38:64.
37. Berg K, Wood-Dauphinee S, Williams JI. The balance scale: reliability assessment with elderly residents and patients with an acute stroke. *Scand J Rehabil Med*. 1995;27:27–36.
38. English CK, Hillier SL, Stiller K, Warden-Flood A. The sensitivity of three commonly used outcome measures to detect change amongst patients receiving inpatient rehabilitation following stroke. *Clin Rehabil*. 2006;20:52–55.
39. Botner EM, Miller WC, Eng JJ. Measurement properties of the Activities-Specific Balance Confidence Scale among individuals with stroke. *Disabil Rehabil*. 2005;27:156–163.
40. Salbach NM, Mayo NE, Hanley JA, Richards CL, Wood-Dauphinee S. Psychometric evaluation of the original and Canadian French version of the Activities-Specific Balance Confidence Scale among people with stroke. *Arch Phys Med Rehabil*. 2006;87:1597–1604.
41. Granger CV, Hamilton BB, Linacre JM, Heinemann AW, Wright BD. Performance profiles of the functional independence measure. *Am J Phys Med Rehabil AssocAcad Physiatr*. 1993;72:84–89.
42. Hsueh IP, Lin JH, Jeng JS, Hsieh CL. Comparison of the psychometric characteristics of the functional independence measure, 5 item Barthel Index, and 10 item Barthel Index in patients with stroke. *J Neurol Neurosurg Psychiatry*. 2002;73:188–190.
43. Oliveira CB, Medeiros IR, Greters MG, et al. Abnormal sensory integration affects balance control in hemiparetic patients within the first year after stroke. *Clinics*. 2011;66:2043–2048.
44. Lamb SE, Jorstad-Stein EC, Hauer K, Becker C, Prevention of Falls Network Europe, Outcomes Consensus Group. Development of a common outcome data set for fall injury prevention trials: the prevention of falls network Europe consensus. *J Am Geriatr Soc*. 2005;53:1618–1622.
45. Cohen J. A power primer. *Psychol Bull*. 1992;112:155–159.
46. Buford JA, Smith JL. Adaptive control for backward quadrupedal walking. III. Stumbling corrective reactions and cutaneous reflex sensitivity. *J Neurophysiol*. 1993;70:1102–1114.
47. Perell KL, Gregor RJ, Buford JA, Smith JL. Adaptive control for backward quadrupedal walking. IV. Hindlimb kinetics during stance and swing. *J Neurophysiol*. 1993;70:2226–2240.
48. Shah PK, Gerasimenko Y, Shyu A, et al. Variability in step training enhances locomotor recovery after a spinal cord injury. *Eur J Neurosci*. 2012;36:2054–2062.
49. Duysens J, Tax AA, Murrer L, Dietz V. Backward and forward walking use different patterns of phase-dependent modulation of cutaneous reflexes in humans. *J Neurophysiol*. 1996;76:301–310.
50. Lamb T, Yang JF. Could different directions of infant stepping be controlled by the same locomotor central pattern generator? *J Neurophysiol*. 2000;83:2814–2824.
51. Kim CM, Eng JJ, Whittaker MW. Level walking and ambulatory capacity in persons with incomplete spinal cord injury: relationship with muscle strength. *Spinal Cord*. 2004;42:156–162.
52. Milot MH, Nadeau S, Gravel D. Muscular utilization of the plantarflexors, hip flexors and extensors in persons with hemiparesis walking at self-selected and maximal speeds. *J Electromyogr Kinesiol*. 2007;17: 184–193.
53. Requiao LF, Nadeau S, Milot MH, Gravel D, Bourbonnais D, Gagnon D. Quantification of level of effort at the plantarflexors and hip extensors and flexor muscles in healthy subjects walking at different cadences. *J Electromyogr Kinesiol*. 2005;15:393–405.
54. Fritz NE, Worstell AM, Kloos AD, Siles AB, White SE, Kegelmeyer DA. Backward walking measures are sensitive to age-related changes in mobility and balance. *Gait Posture*. 2013;37:593–597.
55. Hellstrom K, Lindmark B, Wahlberg B, Fugl-Meyer AR. Self-efficacy in relation to impairments and activities of daily living disability in elderly patients with stroke: a prospective investigation. *J Rehabil Med*. 2003;35:202–207.
56. Tsai SF, Yin JH, Tung TH, Shimada T. Falls efficacy among stroke survivors living in the community. *Disabil Rehabil*. 2011;33:1785–1790.
57. Friedman SM, Munoz B, West SK, Rubin GS, Fried LP. Falls and fear of falling: which comes first? A longitudinal prediction model suggests strategies for primary and secondary prevention. *J Am Geriatr Society*. 2002;50:1329–1335.