



Original Research

# Effects of Visual Feedback During Recumbent Stepping in Individuals With Chronic Stroke



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## KEYWORDS

Feedback, sensory;  
Rehabilitation;  
Stroke

**Abstract Objective:** To investigate the effects of intermittent visual feedback (using the Balanced Power program on the NuStep Transitt) during recumbent stepping on strength, balance, and functional mobility in individuals with chronic stroke.

**Design:** Quasi-experimental 1-group pretest-posttest study.

**Setting:** Human performance research laboratory.

**Participants:** Adults (N=11; 7 female; mean age, 58.7±13.6y), >6 months post stroke.

**Interventions:** Eight 45-minute training sessions on the NuStep Transitt (visits 2-9) twice a week (5-minute warm-up and cooldown with 35 minutes of training [5min with and then without visual feedback regarding left/right lower extremity percentage effort]). Visits 1 and 10: pre- and post assessment.

**Main Outcome Measures:** Self-selected and fast gait speeds; maximum voluntary contractions (MVCs) of knee extension and flexion and ankle dorsiflexion and plantarflexion; and 5 times sit-to-stand (5TSTS).

**Results:** Significant improvements in 5TSTS (14.2s,  $P = .007$ ) and fast gait (hemi: 4.9 cm [ $P = .024$ ], nonhemi: 4.5cm ( $P = .019$ ) stride length; nonhemi step length 2.3 cm ( $P = .024$ ]). MVC and self-selected gait parameters showed no significant changes.

**Conclusions:** The NuStep Transitt is a valuable tool that provides real-time feedback about percentage of use of the hemiparetic leg. This intervention study has demonstrated that the addition of visual feedback about left/right percentage effort while exercising on the Transitt

**List of abbreviations:** 5TSTS, 5 times sit-to-stand; ICC, intraclass correlation coefficient; MVC, maximum voluntary contraction.

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has significant and clinically relevant effects on the functional mobility of individuals with chronic stroke.

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Goodman has defined stroke as “a sudden, devastating focal vascular event that results in the destruction of surrounding brain tissue.”<sup>1</sup> (p1507) The neuromuscular changes that occur as a result of stroke significantly affect an individual’s strength, coordination, balance, and functional mobility and/or gait. Ambulatory individuals with chronic stroke demonstrated significant weakness in not only their paretic limb but their nonparetic limb when compared with age-matched controls,<sup>2</sup> most notably the ankle dorsiflexors, knee flexors, and hip extensors. Common gait deviations displayed by individuals with hemiparesis include slower gait speed, decreased step/stride length, asymmetrical gait pattern, and increased energy expenditure. In particular, individuals demonstrated the following deficits in the hemiparetic leg: decreased swing initiation, decreased force production of plantar flexors during preswing/toe-off, and compensatory strategies for forward propulsion through swing phase.<sup>3</sup>

The NuStep<sup>a</sup> is a recumbent stepper found in many physical therapy clinics. Its most common clinical uses are warming up, cooling down, general aerobic activity, and light strengthening. Benefits of this recumbent stepping system include a safer seated position for patients (compared with upright cardio machines), whole-body training using all 4 extremities, and cardiovascular and physiological improvements.<sup>4</sup> Recumbent stepping appeared to facilitate gait recovery<sup>5</sup> and improve leg strength and stair climbing ability in people with chronic stroke.<sup>6</sup> Recumbent stepping and walking had highly correlated muscle activation patterns, which demonstrated recumbent stepping and gait had similar neural programming.<sup>7</sup> Exercising on the NuStep has been shown to cause improved strength and motor function, increased balance, and decreased impairments in people with chronic stroke.<sup>8</sup> The NuStep Transitt model includes several features previously unavailable in older NuStep models, most notably force plates in the pedals and handles and a tablet that displays real-time feedback of performance through various targeted programs. One of these programs, “Balanced Power,” enables individuals to receive visual feedback in real time about the force production of each of their extremities and how similar the force production is between the right and left sides.

Visual feedback is a commonly used form of feedback in all stages of rehabilitation after stroke. Visual feedback related to force of exertion included using visual gain to engage motor correction processes<sup>9</sup> and was shown to increase force production more than verbal or no feedback.<sup>10</sup> Also, the center of mass frontal-plane sway in the gait of individuals with chronic stroke has been shown to be reduced through the use of visual feedback while walking.<sup>11</sup> The use of visual feedback during cycle ergometry in the population with chronic stroke showed significant improvements in neuromuscular control measured

via electromyography and the quality of cycling performance.<sup>5</sup> Currently, there is limited research on the effects of recumbent stepper training in the population with chronic stroke despite its common use in the clinic. The newly available Transitt includes real-time visual feedback, and the effectiveness of this novel addition to recumbent stepping warrants investigation.

The objective of this study was to investigate the effects of training with the NuStep Transitt’s Balanced Power program on lower extremity strength, balance, and functional mobility and/or gait in individuals with chronic stroke.

## Methods

Eleven individuals (4 male; 7 female; mean age, 58.7±13.6y) with chronic stroke were recruited from the community to participate in this quasi-experimental 1-group pretest-posttest study. Study procedures were approved by the Institutional Review Board of Wayne State University. Written informed consent was obtained from all individuals prior to study participation.

## Inclusion and exclusion criteria

Inclusion criteria were (1) aged 18-90 years, (2) greater than 6 months post stroke, and (c) able to follow simple 2 step commands. Exclusion criteria were (1) bilateral involvement and (2) any musculoskeletal, neurologic, or cardiopulmonary conditions that could hinder the participant’s ability to use the NuStep and participate fully and safely.

## Pre- and post assessment

During the baseline evaluation, participants completed a demographics questionnaire (age, hemiplegic side, number of strokes, self-reported amount of physical activity [sedentary, 5-30min 3×/wk, or >30min 3×/wk] and perception of health [excellent, very good, good, fair, poor], and assistive device use). Participants completed pre- and postintervention evaluations (visits 1 and 10), which included assessments of functional mobility, balance, the lower extremity motor and sensory Fugl-Meyer Assessment, gait, and lower extremity strength. Height, weight, and vitals (heart rate, pulse oximetry, blood pressure) were recorded.

## Functional mobility

The average of 3 trials of the 5 times sit-to-stand test (5TSTS) was recorded. Participants were instructed to

stand up and sit down 5 times from a standard chair with their arms crossed. The 5TSTS has been found to have excellent intrarater reliability (intraclass correlation coefficient [ICC] range, 0.970-0.976), interrater reliability (ICC, 0.999), and test-retest reliability (ICC range, 0.989-0.999) and has also been shown to be a reliable measurement tool that correlates with knee flexor muscle strength in persons with chronic stroke.<sup>12</sup>

## Balance

The rhythmic weight shifting program on the BalanceMaster<sup>b</sup> was used to assess dynamic balance (medial-lateral and anterior-posterior) during slow, medium, and fast speeds. Dynamic, rather than static balance measures have been shown to be valid indicators of functional balance performance in patients with stroke.<sup>13,14</sup>

## Lower-extremity motor recovery and sensation

Lower-extremity motor recovery and sensation were evaluated using the Fugl-Meyer Assessment. The Fugl-Meyer has been shown to have high test-retest reliability (0.98-0.99),<sup>15</sup> interrater reliability, and construct validity.<sup>16</sup> Lastly, participants completed a brief session on the Transitt to determine self-selected speed.

## Spatial/temporal parameters for gait

The GAITRite<sup>c</sup> computerized gait analysis system was used to record 3 trials of self-selected and fast (“walk as quickly but safely as you can”) gait speeds. For each trial, spatial and temporal parameters (gait speed, step and stride length) were recorded. Participants were allowed to use assistive devices for the gait trials per their request (the same footwear and device were used for the pre- and posttesting). The GAITRite has been found to be a valid and reliable tool for measuring selected spatial and temporal parameters of gait.<sup>17</sup>

## Lower extremity strength

The average of 3 trials of maximum voluntary contractions (MVCs) of knee extension, knee flexion, ankle dorsiflexion, and ankle plantarflexion were recorded using a Lafayette Manual Muscle Testing System<sup>d</sup> handheld dynamometer. Bilateral lower extremities were tested with order randomization of left/right assessment. Handheld dynamometry has been shown to have good to excellent reliability and validity for the assessment of isometric lower extremity strength.<sup>18</sup>

## Testers

Pre- and postintervention assessments of all participants were completed by the same 2 student research assistants, whose competency was verified by multiple training and check-off sessions. A third student research assistant (also trained and verified by the lead author, a licensed physical

therapist) monitored the participant during the 8 training sessions.

## Training protocol

Visits 2-9 consisted of 45 minutes of individualized training on the Transitt twice a week for 4 weeks for a total of 8 visits (a common schedule in outpatient therapy). The Numeric Rating Scale of perceived pain was recorded at the start and end of each session. Vitals (blood pressure, heart rate, pulse oximetry) were assessed at the start of each visit. After completion of the numeric rating scale and vitals, the participant was seated on the Transitt and their feet were securely strapped into the pedals. The seat was adjusted to ensure 5-10 degrees of knee flexion in the fully extended stepping position, preventing possible knee hyperextension, and this position was kept consistent throughout subsequent visits. Each participant pedaled on the Transitt at the lowest resistance level (upper extremities resting on the armrests of the seat) throughout the study. Participants performed a 5-minute warm-up on the Transitt by moving their lower extremities at a comfortable, self-selected speed (chosen each session by the participant as a speed they could comfortably maintain for 5 min). This was followed by 35 minutes of visual feedback training alternating with training without visual feedback (5min each), with rest breaks provided as needed. The visual feedback “Balanced Power” program screen displayed real-time left/right percentage effort (fig 1). Participants were instructed to carefully observe the screen, which gave them both percentage and bar format visual input regarding amount of force produced by each lower extremity. The no-feedback program displayed a pace-partner track (the same program used for warm-up and cooldown). Before each no-feedback training, the participants were instructed to remember what it felt like to step in a more symmetrical fashion (closer to the desired 50-50 they achieved during the visual feedback training) and to try to replicate the feeling without the visual feedback. Once 40 minutes was reached, participants performed a 5-minute cooldown identical to the warm-up. At the end of each session, average rating of perceived exertion (6-20)<sup>19</sup> and adverse events (pain, fatigue, falls) were recorded.

## Statistical analysis

Descriptive statistics were used to report participants’ demographics and survey-based data. Wilcoxon signed-rank tests were used to compare the pre- and post-evaluation assessments for each participant. Use of nonparametric analyses were determined by establishing a nonnormal distribution (using Kolmogorov-Smirnov tests). SPSS Version 25<sup>e</sup> was used for data analysis. Effect size ( $r$ ), or the magnitude of differences between pre- and post measurement, was conducted using the formula  $r = Z / (\sqrt{Nobs})$ . Significance was set at  $P < .05$ . To control for type I error, a Benjamini-Hochberg procedure was conducted for outcomes with multiple comparisons (gait, MVC) to determine the critical value for statistical significance. All

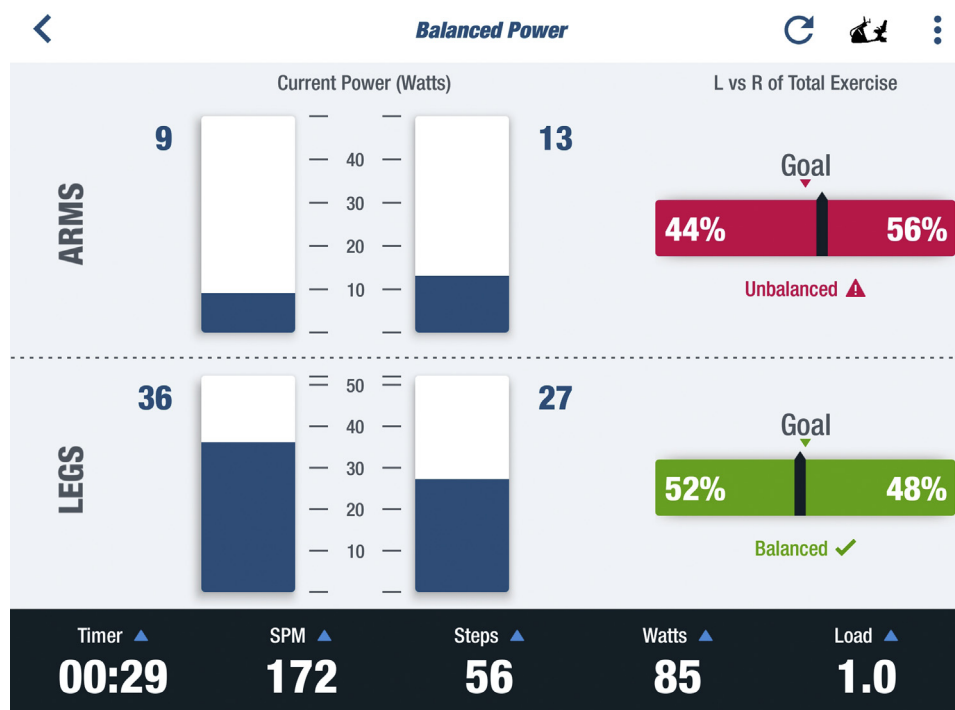


Fig 1 Visual feedback “Balanced Power” program screen.

*P* values were ordered and ranked from smallest to largest with ties sharing ranking. The Benjamini-Hochberg critical value was calculated using the formula  $(i/m) \cdot Q$  where  $i$  = the individual *P* values rank,  $m$  = the total number of tests conducted, and  $Q$  = the false discovery rate of 20%. A 20% false discovery rate was chosen, rather than 25%, because of the low risk of running additional experiments and to avoid missing important findings in this study (type II error).

## Results

All participants completed the 10 visits of the study, and no adverse events were reported. Table 1 shows the descriptive characteristics of the participants. There was a significant difference between baseline and postevaluation measures in the 5TSTS from 32.0-17.8 seconds with a large effect size ( $z = -2.40$ ,  $P = .007$ ,  $r = -0.54$ ). Three participants had significant improvements of time according to the minimal clinically important difference value of 2.3 seconds.<sup>20</sup> Four of the 11 participants improved their 5TSTS score by at least 25%, which is the cutoff for real change in patients with multiple sclerosis.<sup>21</sup> Table 2 shows the changes in 5TSTS, BalanceMaster directional control and velocity, and Fugl-Meyer Lower Extremity function and sensation. Table 3 shows the critical values to achieve significance using the Benjamini-Hochberg procedure for the MVC and gait parameters.

There were improvements in gait parameters measured by the GAITRite: fast gait showed significant changes for stride length on the hemiparetic ( $z = -1.99$ ,  $P = .024$ ,  $r = -0.42$ ) and nonhemiparetic legs ( $z = -2.09$ ,  $P = .019$ ,  $r = -0.45$ ) and increased step length on the nonhemiparetic

side ( $z = -1.99$ ,  $P = .024$ ,  $r = -0.42$ ). All gait changes had a medium effect size. There were no significant changes in any MVC from pre- to post intervention. Table 4 shows the changes in MVC and gait parameters.

## Discussion

This study demonstrates that intermittent use of the “Balanced Power” visual feedback program on the NuStep Transitt with individuals with chronic stroke can have significant and clinically relevant effects after 8 treatment sessions. Significant improvements for fast gait revealed a more normalized gait, specifically increased symmetry between the hemiparetic and nonhemiparetic legs. This was observed as increased step and stride length of the nonhemiparetic limb and increased stride length of the paretic limb. These findings translate to increased time spent in mid to late stance on the hemiparetic leg, allowing the nonhemiparetic leg to complete the swing phase without rushing. Subjectively, several participants did report increased confidence in stance ability of the hemiparetic leg. This additional time resulted in reduced lower-extremity asymmetry, which is a common gait deviation seen in individuals with stroke.

The significant change in the mean 5TSTS can translate to improvements in functional mobility and transfers. The mean performance times (in seconds) for the 5TSTS varies among patient populations: 20.3 in Parkinson disease,<sup>22</sup> 13.4 for healthy elderly persons, 16.4 for elderly with balance issues,<sup>23</sup> and 17.9 for persons with chronic stroke.<sup>24</sup> Participants in this study improved 5TSTS from 32.0 to 17.8 seconds after the NuStep Transitt intervention, which closely matches the results of Ng’s study.<sup>24</sup> Improvements

**Table 1** Participant characteristics (N=11)

Characteristics	Mean $\pm$ SD	Range
Age (y)	58.7 $\pm$ 13.6	30-80
BMI	24.3 $\pm$ 3.7	18.4-29.9
Time since stroke onset (y)	11.9 $\pm$ 13.5	1-49
Self-selected gait velocity (m/s)	0.93 $\pm$ 0.35	0.52-1.54
Average Fugl-Meyer score		
Motor leg (max=34)	25.1 $\pm$ 5.7	14-31
Sensation leg (max=12)	9.4 $\pm$ 3.0	4-12
Characteristics	n/N	%
Sex		
Male	4/11	36
Female	7/11	64
Hemiparetic side		
Right	3/11	27
Left	8/11	73
Amount of physical activity/exercise		
Sedentary	1/11	9
5-30 min 3 $\times$ /wk	0/11	0
More than 30 min 3 $\times$ /wk	10/11	91
Self-report current state of health		
Excellent	2/11	18
Very good	5/11	46
Good	4/11	36
Fair	0/11	0
Poor	0/11	0

Abbreviation: BMI, body mass index (calculated as weight in kilograms divided by height in meters squared).

in times for the 5TSTS test may result in improved transfer ability and functional performance, and improved balance as the 5TSTS test has correlations to lower-extremity strength.<sup>25,26</sup>

The visual feedback component of training on the NuStep Transitt was vital to retraining balanced use of the lower extremities. People with chronic stroke could be unaware of the learned nonuse of their hemiparetic leg and develop a temporal asymmetry skewed toward reliance on the uninvolved leg.<sup>27</sup> The real-time visual feedback of the Transitt's Balanced Power protocol encouraged a 50:50 symmetrical use of the lower extremities, which translated to improvements in strength and functional mobility and/or gait.

The techniques used in this study are practical for clinicians to administer. Older models of the NuStep do not have the visual feedback capacities found in the Transitt, but it is expected the Transitt will be in more settings in the near future. For those clinicians with access to a Transitt, the protocol used in this study can be implemented immediately, thereby circumventing the usual lengthy gap between research study and clinical implementation.<sup>28</sup> The ease and feasibility of this protocol should promote a faster rate of knowledge translation.

The clinically significant changes in strength, gait, and sit-to-stand ability in patients with chronic stroke show this treatment protocol on the NuStep Transitt is feasible. These improvements can increase safety and quality of life for individuals with chronic stroke by normalizing gait and improving balance and transfer ability.

### Study limitations

The use of a single-group pre-post design limits the ability to generalize these findings to broader populations. Without a randomized controlled trial, we cannot determine if the visual feedback enhanced the outcomes or if similar changes would have been seen in a group who did not receive visual feedback. Because this was an intervention study with 10 visits per participant, time constraints impeded the sample size. Having 11 higher-functioning participants limits generalizability. One subject was a

**Table 2** Changes in 5TSTS, Balance Master, and Fugl-Meyer

Assessments	Time	Mean $\pm$ SD	Minimum	Maximum	P Value (1-tailed)
5TSTS (s)	Pretest	32.0 $\pm$ 55.0	8.14	187.0	.007*
	Posttest	17.8 $\pm$ 20.4*	6.12	74.0	
BMDC-LR	Pretest	70.31 $\pm$ 23.76	3.40	85.00	.121
	Posttest	77.55 $\pm$ 9.59	57.00	89.00	
BMDC-FB	Pretest	54.80 $\pm$ 31.16	1.80	84.00	.407
	Posttest	62.00 $\pm$ 20.28	25.00	82.00	
BMV-LR	Pretest	4.91 $\pm$ 1.04	2.50	6.50	.492
	Posttest	11.9 $\pm$ 23.60	2.70	83.00	
BMV-FB	Pretest	3.60 $\pm$ 1.66	1.00	6.50	.270
	Posttest	7.69 $\pm$ 13.41	1.80	48.00	
F-M LE	Pretest	25.09 $\pm$ 5.67	14	31	.312
	Posttest	25.27 $\pm$ 5.73	15	31	
F-M Sens	Pretest	9.36 $\pm$ 3.04	4	12	.500
	Posttest	9.55 $\pm$ 2.73	6	12	

Abbreviations: BMDC-FB, BalanceMaster Directional Control Forward-Back; BMDC-LR, BalanceMaster Directional Control Left-Right; BMV-FB, BalanceMaster Velocity Forward-Back; BMV-LR, BalanceMaster Velocity Left-Right; F-M LE, Fugl-Meyer Lower Extremity Function; F-M Sens, Fugl-Meyer Sensation.

\*  $P < .05$ .

**Table 3** Benjamini-Hochberg Critical Values to Determine Threshold for Significance

Maximum Voluntary Contraction	Side	<i>P</i> Value (1-tailed)	Rank	(i/m)Q*
Ankle plantarflexion	Hemi	.027	1	0.025
Knee extension	Hemi	.087	2	0.050
Ankle plantarflexion	Nonhemi	.120	3	0.075
Knee flexion	Nonhemi	.188	4	0.100
Knee extension	Nonhemi	.260	5	0.125
Ankle dorsiflexion	Nonhemi	.311	6	0.150
Knee flexion	Hemi	.327	7	0.175
Ankle dorsiflexion	Hemi	.416	8	0.200
Gait Parameters	Velocity	<i>P</i> Value (1-tailed)	Rank	(i/m)Q*
Stride length nonhemi	Fast	.019 <sup>†</sup>	1	0.020
Stride length hemi	Fast	.024 <sup>†</sup>	2.5	0.050
Step length nonhemi	Fast	.024 <sup>†</sup>	2.5	0.050
Stride length nonhemi	SS	.034	4	0.080
Step length nonhemi	SS	.042	5	0.100
Stride length hemi	SS	.051	6	0.120
Velocity	Fast	.053	7	0.140
Step length hemi	Fast	.074	8	0.160
Step length hemi	SS	.103	9	0.180
Velocity	SS	.115	10	0.200

Abbreviations: Fast, fast gait speed; i, individual *P* value rank; m, total no. of tests conducted; Q, false discovery rate of 20%; SS, self-selected gait speed.

\* False discovery rate set at 0.2.

<sup>†</sup> Significant findings.

potential outlier for the 5TSTS because they improved from 187 to 74 seconds (60% decrease in timing) from pre- to post intervention. The other 10 subjects had 5TSTS scores below 31 seconds both pre- and post intervention. In addition, there are possible differences across participants and student researchers for the 8 training sessions, which could have potentially affected the data and results. Finally, throughout the course of this study, there were many subjective accounts from participants expressing other lifestyle improvements either during or after completion of their time in this study that were not recorded because of our lack of subjective outcome measures. Future studies should include participants with more severe impairments

because the Transitt is ideally suited for lower-level (non-ambulatory) stroke survivors.

## Conclusions

This intervention study demonstrated the addition of visual feedback about left/right percentage effort while exercising on the NuStep Transitt had significant and clinically relevant effects on the strength and functional mobility and/or gait of individuals with chronic stroke. Future studies with a larger sample size and/or other neurologic conditions are warranted to confirm these findings and the feasibility of this intervention across other populations.

**Table 4** Changes in Strength and Gait Parameters

Variables		Pretest, mean ± SD	Range	Posttest, mean ± SD	Range
MVC hemi side (lb)	Knee extension	44.9±20.5	2.8-71.0	49.1±20.6	13.8-84.8
	Knee flexion	29.4±15.5	6.0-54.9	29.6±14.1	6.6-54.3
	Ankle dorsiflexion	29.4±15.6	7.8-63.7	29.6±13.7	10.9-53.7
	Ankle plantarflexion	41.5±14.8	20.2-62.4	48.2±8.4	38.0-62.5
Fast gait speed	Step length hemi (cm)	60.5±16.3	37.8-84.2	62.8±18.2	34.9-86.7
	Step length nonhemi (cm)	58.0±16.9	34.3-85.4	60.3±18.5*	34.9-86.7
	Stride length hemi (cm)	118.7±32.3	81.9-169.2	123.6±35.2*	81.9-171.5
	Stride length nonhemi (cm)	118.7±32.6	81.1-169.6	123.2±35.9*	81.1-173.9
Self-selected gait speed	Velocity (m/s)	1.25±5.1	0.7-2.1	1.31±0.5	0.7-2.1
	Step length hemi (cm)	52.2±14.4	30.3-73.9	53.7±15.3	31.2-75.9
	Step length nonhemi (cm)	50.8±14.7	32.5-77.3	53.0±16.3	34.6-79.4
	Stride length hemi (cm)	103.3±28.3	69.6-146.8	107.0±30.9	69.9-151.2
	Stride length nonhemi (cm)	103.3±28.3	69.5-147.9	107.3±31.4	70.2-152.9
	Velocity (m/s)	0.93±0.4	0.5-1.5	0.97±0.4	0.6-1.6

\* Significant change from pre- to posttest using Benjamini-Hochberg procedure for multiple comparisons.

## Suppliers

- a. NuStep; NuStep LLC.
- b. BalanceMaster; NeuroCom International.
- c. GAITRite; CIR Systems Inc.
- d. Lafayette Manual Muscle Testing System; Lafayette Instrument.
- e. SPSS Version 25; IBM.

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