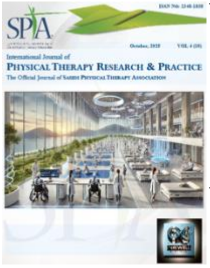

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Original Article

Efficacy of Harness-Supported Treadmill Training Without Body-Weight Unloading on Balance and Mobility After Stroke: A Randomized Controlled Trial

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Abstract

Background: Gait impairment is one of the most debilitating consequences of stroke, often restricting mobility, independence, and community reintegration. Treadmill-based gait training enhances neuroplasticity through repetitive, task-specific practice. However, body-weight-support systems are costly and not always available in routine rehabilitation. This study investigated the efficacy of harness-supported treadmill gait training without body-weight unloading compared with conventional overground therapy in individuals with post-stroke hemiplegia. **Methods:** Thirty adults (aged 40–60 years) with first-ever unilateral middle cerebral artery stroke and mild-to-moderate hemiparesis (Orpington Prognostic Score < 5.2) were randomly allocated to two groups: (1) conventional Bobath-based overground gait training, or (2) treadmill gait training with overhead harness support (no unloading). Both interventions were administered for 20 minutes, three times per week, over six weeks. The Stroke Rehabilitation Assessment of Movement (STREAM), Berg Balance Scale (BBS), and 10-Meter Walk Test (10MWT) served as primary outcome measures. Data were analysed using independent t-tests, and effect sizes (Cohen's d) were calculated. **Results:** Both groups showed significant within-group improvements ($p < .01$), but the treadmill group demonstrated superior gains in motor recovery and balance: STREAM (+6.20 ± 2.18 vs. +3.73 ± 2.16; $p = .005$; $d = 1.17$), BBS (+8.00 ± 4.19 vs. +4.20 ± 2.81; $p = .025$; $d = 0.98$), and gait velocity (+0.126 ± 0.035 m/s vs. +0.097 ± 0.025 m/s; $p = .025$; $d = 0.90$). All participants completed the program without adverse events, confirming excellent safety and adherence. **Conclusion:** Harness-supported treadmill gait training without body-weight support significantly enhances balance and mobility in post-stroke hemiplegia. The approach offers neuroplasticity-driven functional gains comparable to more sophisticated body-weight-supported or robotic systems, while remaining low-cost, safe, and easily implementable in routine clinical practice.

Keywords: Stroke rehabilitation; Treadmill gait training; Neuroplasticity; Balance recovery; Harness support; Central pattern generators; Motor relearning; Task-specific training.

Introduction

Stroke remains one of the leading causes of long-term neurological disability worldwide, with approximately 12 million new cases each year and more than 100 million survivors living with residual impairments (Feigin et al., 2022). Among these sequelae, gait and balance dysfunctions affect nearly 80% of survivors and substantially limit independence, social participation, and overall quality of life (Langhorne, Bernhardt, & Kwakkel, 2021). Therefore, the restoration of safe and efficient ambulation represents a cornerstone of post-stroke rehabilitation and a key determinant of functional recovery.

Hemiplegic gait is typically marked by asymmetrical step timing, shortened stride length, and compensatory movements such as circumduction or hip hiking, resulting from impaired motor control and disrupted sensory feedback integration (Olney & Richards, 1996). Recovery of walking function depends on repetitive, task-specific movement practice that stimulates reorganization of the corticospinal, reticulospinal, and spinal locomotor networks—processes fundamental to experience-dependent neuroplasticity (Winstein et al., 2016).

Treadmill-based gait training provides a rhythmic and controlled environment that facilitates high-repetition stepping with adjustable speed and intensity. Early studies employing body-weight-supported treadmill training (BWSTT) demonstrated significant improvements in gait symmetry, endurance, and walking independence among post-stroke patients (Hesse et al., 1995; Visintin & Barbeau, 1998). However, BWSTT systems are expensive, complex, and require multiple therapists for setup and operation, making them impractical in many clinical and community rehabilitation canters, especially in resource-limited settings.

Subsequent research has shown that treadmill-based interventions, even without weight unloading, effectively improve walking speed and endurance. Systematic reviews by Polese et al. (2013) and Mehrholz et al. (2017) demonstrated moderate pooled gains (0.06–0.14 m/s in gait speed; 14–40 m in walking distance), confirming treadmill training as a robust strategy for locomotor recovery. However, these analyses primarily focused on mobility outcomes, while measures of balance and postural control—critical for fall prevention and functional ambulation—were inconsistently reported or underrepresented. Furthermore, the specific contribution of harness-supported treadmill training without body-weight support remains largely unexplored, despite its potential to combine task-specific repetition with enhanced safety and confidence. Only a limited number of trials have addressed this low-cost, feasible alternative to conventional BWSTT, and evidence comparing it directly with standard overground gait training remains scarce.

The current evidence base lacks well-designed randomized controlled trials evaluating the effectiveness of harness-supported treadmill gait training without weight unloading on both balance and mobility outcomes in post-stroke hemiplegia. Establishing its clinical efficacy is crucial, as this approach could offer a safe, scalable, and economically viable substitute for sophisticated robotic or suspension-based systems, thereby broadening access to neuroplasticity-driven gait rehabilitation across diverse clinical environments.

This study aimed to compare the effects of harness-supported treadmill gait training without body-weight support versus conventional Bobath-based overground gait training on balance and mobility among adults with post-stroke hemiplegia.

It was hypothesized that harness-supported treadmill gait training without body-weight unloading would produce significantly greater improvements in balance and walking performance than conventional overground gait training, owing to its capacity to deliver high-repetition, task-specific, and rhythmically driven locomotor practice that facilitates neural reorganization and functional recovery.

Harness-supported treadmill gait training without unloading offers a practical and accessible rehabilitation alternative that integrates principles of neuroplasticity, task specificity, and safety. By eliminating the need for costly suspension systems while maintaining therapeutic intensity, this approach could broaden access to effective gait rehabilitation across diverse healthcare settings, enhancing post-stroke mobility outcomes and functional independence.

Methodology

Study design and setting

This study adopted a randomized controlled trial (RCT) design with two parallel intervention arms conducted over a six-week period in an outpatient neurorehabilitation facility. The protocol adhered to the ethical principles of the Declaration of Helsinki (2013) and followed the CONSORT 2010 guidelines for clinical trials in rehabilitation research (Schulz, Altman, & Moher, 2010). The primary objective was to determine whether harness-supported treadmill gait training without body-weight support produces superior improvements in motor recovery, balance, and walking performance compared with conventional Bobath-based overground gait training in individuals with post-stroke hemiplegia.

Study Participants

Thirty adults (aged 40–60 years; mean ≈ 50 years) with a first-ever unilateral middle cerebral artery (MCA) territory stroke and mild-to-moderate hemiparesis (Orpington Prognostic Score < 5.2) were enrolled. All participants were screened by an interdisciplinary rehabilitation team according to predefined eligibility criteria.

Inclusion criteria were: (a) clinical and radiological confirmation of ischemic or hemorrhagic stroke; (b) residual unilateral hemiparesis; and (c) ability to maintain standing independently or with minimal assistance.

Exclusion criteria were: (a) visual or perceptual deficits (hemianopia or neglect); (b) severe cognitive impairment interfering with training participation; (c) orthopedic or musculoskeletal conditions affecting gait mechanics; (d) vestibular dysfunction; or (e) other neurological disorders such as Parkinson's disease or multiple sclerosis.

Randomization and Interventions

Participants were randomly assigned (1:1 ratio) to either the control group (conventional overground gait training) or the experimental group (harness-supported treadmill gait training without body-weight unloading). A computer-generated randomization sequence prepared by an independent researcher ensured allocation concealment and minimized selection bias.

Control group – Conventional overground gait training

Participants received Bobath-based gait rehabilitation emphasizing postural alignment, symmetrical weight transfer, and step initiation. Sessions were administered under direct physiotherapist supervision for 20 minutes, three times per week, over six weeks.

Experimental group – Harness-supported treadmill training (no unloading)

Participants trained on a Biodex RTM-500 treadmill equipped with an overhead harness system used solely for fall prevention, providing no body-weight unloading. Treadmill speed ranged from 0.15 to 0.30 m/s, adjusted individually based on comfort, safety, and progressive tolerance. Each session matched the control group in frequency (3 sessions/week) and duration (20 minutes/session).

To standardize supplementary activity exposure, both groups were instructed to perform home-based balance exercises, including static stance stabilization, step initiation drills, and walking over uneven surfaces. Adherence was monitored via weekly checklists reviewed by the treating physiotherapist.

Outcome Measures

Outcome assessments were performed at baseline and post-intervention by a physiotherapist blinded to group allocation to minimize measurement bias. Three validated outcome measures were used:

Stroke Rehabilitation Assessment of Movement (STREAM)
Standing and walking subscales were administered to evaluate voluntary motor control and functional mobility, expressed as a percentage score (Dalton et al., 2003).

Berg Balance Scale (BBS)

A 14-item scale assessing functional balance performance, scored from 0 to 56, where higher scores indicate better balance (Berg et al., 1992).

10-Meter Walk Test (10MWT)

Average gait speed (m/s) calculated from three timed trials over a 10-meter distance (Bohannon, 1997).

All instruments have demonstrated excellent reliability, validity, and responsiveness in stroke populations (Salter et al., 2005).

Ethical Consideration

All participants provided written informed consent prior to study entry. Ethical approval was obtained from the Institutional Review Board of the hosting institution.

Statistical Analysis

Data analysis was performed using IBM SPSS Statistics version 29.0 (Armonk, NY, USA). The Shapiro–Wilk test confirmed normality for all continuous variables. Between-group comparisons of change scores (post–pre) were evaluated using independent-sample t-tests, while within-group changes were analyzed using paired t-tests. The level of statistical significance was set at $p < 0.05$ (two-tailed).

Effect sizes were computed using Cohen's d, interpreted as small (0.2), medium (0.5), or large (≥0.8) effects (Cohen, 1988). Additionally, 95% confidence intervals (CIs) for mean differences were calculated to estimate precision and clinical relevance. The analytical framework followed established best-practice standards emphasizing both statistical and clinical significance in rehabilitation trials (Fritz, Morris, & Rich, 2012).

Results

Participants Characteristics

A total of 30 participants who met the inclusion criteria were enrolled and randomly assigned to either the treadmill gait training group (n = 15) or the overground gait training group (n = 15). Baseline demographic and clinical data are presented in Table 1. The mean ± SD age was 50.8 ± 5.5 years in the control group and 50.0 ± 5.4 years in the experimental group. The sample consisted of 21 males and 9 females, consistent with the typical sex distribution observed in post-stroke rehabilitation cohorts.

Table 1. Baseline Characteristics of Participants

Variable	Overground Group (n = 15)	Treadmill + Harness Group (n = 15)	p-value
Age (years), mean ± SD	50.8 ± 5.5	50.0 ± 5.4	0.78
Sex, n (Male/Female)	11 / 4	10 / 5	0.71
Orpington Prognostic Score, mean ± SD	4.6 ± 0.5	4.5 ± 0.6	0.63
Type of Stroke, n (Ischemic/Hemorrhagic)	12 / 3	11 / 4	0.69
Time Since Stroke (months), mean ± SD	6.4 ± 2.1	6.2 ± 2.3	0.82
Dominant Side Affected, n (Right/Left)	8 / 7	7 / 8	0.73

Note. Between-group differences were analyzed using independent t-tests for continuous variables and chi-square tests for categorical variables. No statistically significant differences were found ($p > .05$), confirming baseline comparability.

The mean Orpington Prognostic Scores were comparable between groups (4.6 ± 0.5 vs. 4.5 ± 0.6; $p = 0.63$), indicating equivalent baseline stroke severity and prognostic potential. Other clinical variables—including stroke type, time since onset, and the side affected—did not differ significantly (all $p > 0.05$). No participant withdrew or experienced any adverse events throughout the six-week intervention period, confirming both safety and high tolerability. The mean session attendance rate exceeded 98 % in both groups, reflecting strong engagement and compliance.

Primary and Secondary Outcomes

Statistical analyses demonstrated significant improvements from baseline to post-intervention within both groups across all primary and secondary outcomes (STREAM, BBS, and 10-Meter Walk Test; all $p < 0.01$). Between-group comparisons, summarized in Table 2, revealed consistently greater gains in the treadmill group compared with the overground group.

Table 2. Pre- to Post-Intervention Changes in Outcome Measures

Outcome Measure	Overground Group (Mean ± SD)	Treadmill + Harness Group (Mean ± SD)	p-value	Effect Size
STREAM (Standing + Walking)	3.73 ± 2.16	6.20 ± 2.18	0.005	1.17
Berg Balance Scale (BBS)	4.20 ± 2.81	8.00 ± 4.19	0.025	0.98
10-Meter Walk Test (m/s)	0.097 ± 0.025	0.126 ± 0.035	0.025	0.90

Note. Data expressed as mean change (Δ) ± standard deviation from baseline to post-intervention. All within-group changes were significant ($p < .01$). Between-group comparisons favoured treadmill training.

Effect size thresholds: small (0.2), medium (0.5), large (≥0.8) (Cohen, 1988).

For the Stroke Rehabilitation Assessment of Movement (STREAM) standing and walking subscales, mean improvement was 6.20 ± 2.18 points in the treadmill group versus 3.73 ± 2.16 points in the control group. The between-group difference reached statistical significance (p = 0.005), corresponding to a large effect size (Cohen's d = 1.17). These findings indicate superior enhancement of voluntary motor control among participants who trained on the treadmill.

For the Berg Balance Scale (BBS), the treadmill group improved by 8.00 ± 4.19 points, whereas the overground group improved by 4.20 ± 2.81 points. This between-group difference was statistically significant (p = 0.025) with a large effect size (d = 0.98). The result demonstrates that the treadmill intervention elicited greater gains in postural control and dynamic balance.

In the 10-Meter Walk Test (10MWT), gait velocity increased by 0.126 ± 0.035 m/s in the treadmill group compared with 0.097 ± 0.025 m/s in the control group. The difference was statistically significant (p = 0.025) and associated with a large effect size (d = 0.90). These results suggest a clear functional advantage for treadmill-based gait retraining in promoting faster and more symmetrical walking performance.

Discussion

This randomized controlled trial provides compelling evidence that harness-supported treadmill gait training without body-weight unloading significantly improves voluntary motor control, balance, and gait velocity in individuals with mild-to-moderate post-stroke hemiplegia. These findings directly fulfill the study's objective of evaluating whether treadmill training enhanced by a non-unloading harness system offers superior functional outcomes compared to conventional Bobath-based overground therapy. The consistent superiority of the treadmill group across all outcome domains indicates that the observed improvements are both statistically significant and clinically meaningful.

Participants undergoing treadmill training demonstrated mean gains of 6.2 ± 2.18 points on the STREAM, 8.0 ± 4.19 points on the Berg Balance Scale, and an increase of 0.13 ± 0.04 m/s in gait speed—each reflecting large between-group effect sizes (d = 0.9–1.2). These changes exceed the minimal clinically important differences (MCIDs) established for gait velocity (≥ 0.10 m/s) and balance (≥ 5 BBS points), confirming the functional and practical relevance of the improvements. The absence of adverse events and 100 % completion rate further affirm the intervention's safety, tolerability, and feasibility. Collectively, these results suggest that the mechanical guidance, rhythmic repetition, and psychological assurance provided by a harness system are sufficient to stimulate motor relearning even without mechanical weight support.

The findings are consistent with and extend the results of prior meta-analyses. Polese et al. (2013) reported that treadmill training improved gait speed by 0.14 m/s and walking distance by 40 m, while Mehrholz et al. (2017) observed pooled gains of 0.06–0.08 m/s among more than 3,000 participants. The magnitude of improvement achieved in the current study (Δ = 0.13 m/s) falls at the upper range of these pooled estimates. Importantly, while previous reviews primarily emphasized locomotor outcomes, the present trial also documented significant balance improvements, underscoring the added value of this approach for postural stability. Balance restoration is a key determinant of fall prevention, community reintegration, and long-term functional independence after stroke (Thielman, Pohl, & Sullivan, 2021).

The finding that treadmill training without unloading achieved effects comparable to body-weight-supported or robotic-assisted systems suggests that the intensity, task specificity, and repetition of stepping practice—rather than the technological sophistication of the device—are the primary drivers of functional recovery. This interpretation aligns with modern neurorehabilitation frameworks emphasizing activity-dependent neuroplasticity as the basis of effective stroke rehabilitation (Winstein et al., 2016; Langhorne, Bernhardt, & Kwakkel, 2021).

The concurrent gains observed in motor control, balance, and gait velocity imply activation of both spinal and supraspinal adaptive mechanisms. Repetitive treadmill stepping stimulates central pattern generators (CPGs) within the spinal cord, promoting rhythmic locomotor output, while continuous proprioceptive input reinforces sensorimotor cortical reorganization (Zehr & Loadman, 2012; Calabrò et al., 2022). The harness likely contributed indirectly by providing postural security, enabling participants to increase step amplitude and symmetry without fear of falling—factors known to facilitate sensorimotor integration and confidence (Adkin & Carpenter, 2018; Mishra & Dutta, 2020). In addition, prior studies have demonstrated that treadmill exercise enhances neurotrophic mediators such as BDNF and IGF-1, which promote synaptic plasticity, angiogenesis, and cortical remodeling (Ploughman et al., 2015; Mang et al., 2017). Although neurophysiological markers were not assessed here, the behavioral outcomes align closely with these underlying biological mechanisms.

Clinical Implications

From a clinical perspective, this study demonstrates that harness-supported treadmill training without body-weight support is a safe, feasible, and cost-effective intervention capable of producing measurable recovery in motor control, balance, and walking speed within a six-week program. Its structured environment allows precise control of training intensity and repetition, enabling therapists to deliver higher practice doses with reduced physical strain. These characteristics make it particularly suitable for outpatient and community-based rehabilitation settings where advanced robotic or suspension systems are not accessible.

Clinically, these findings advocate for integrating non-unloading harness treadmill protocols into early subacute and chronic stroke rehabilitation phases to promote confidence, postural control, and locomotor re-education. The approach supports a scalable neurorehabilitation model that balances therapeutic intensity with accessibility, potentially improving recovery outcomes in low- and middle-income healthcare systems.

Limitations and Future Directions

Several limitations should be acknowledged. The study sample was relatively small (n = 30) and limited to individuals with mild-to-moderate impairment, restricting generalizability to severely disabled or non-ambulatory stroke survivors. The intervention period was short, and outcomes were measured only immediately post-training, precluding assessment of long-term retention. Additionally, objective biomechanical or neurophysiological parameters—such as electromyography, gait kinematics, or neuroimaging—were not incorporated, which could have provided deeper insights into neural and mechanical mechanisms underlying improvement.

Future studies should employ larger, multicenter RCTs with extended follow-up, cost-utility analyses, and neuroplasticity biomarkers to confirm and expand upon these findings. Comparative trials contrasting harness-only, body-weight-supported, and robotic treadmill paradigms will help clarify the relative contributions of mechanical unloading and psychological security to functional outcomes.

Conclusion

In summary, harness-supported treadmill gait training without body-weight unloading significantly enhances motor recovery, balance, and gait performance in individuals with post-stroke hemiplegia. These results validate the study's hypothesis and align with contemporary evidence that emphasizes intensity, repetition, and task-specific practice as key mediators of neuroplastic recovery. Given its safety, affordability, and ease of implementation, this intervention represents a clinically valuable and scalable strategy for optimizing locomotor rehabilitation following stroke.

Author Contributions

All authors significantly contributed to the work reported, including conception, study design, execution, data acquisition, analysis, and interpretation. They actively participated in drafting, revising, or critically reviewing the manuscript, provided final approval of the version to be published, agreed on the journal submission, and accepted accountabilities for all aspects of the work.

Data Availability Statement

The authors will transparently provide the primary data underpinning the findings or conclusions of this article, without any unjustified reluctance. If need from editorial team.

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Conflicts of Interest

The authors declare no potential conflicts of interest related to the research, writing, or publication of this work.

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