Original Article

DOI: 10.7860/JCDR/2026/86182.23279

Physiotherapy Section

Exploring the Impact of Hip, Ankle and Stepping Strategy Training on Balance and Gait Parameters among Individuals with Neurological Conditions: A Scoping Review

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ABSTRACT

Introduction: Co-ordinated hip, ankle, and stepping strategies play a crucial role in postural control, which is often impaired in patients with neurological conditions such as stroke, multiple sclerosis, Parkinson's disease, and Diabetic Peripheral Neuropathy (DPN). Despite their widespread clinical use, the available evidence has not been systematically mapped to determine their effects on balance and gait parameters.

Aim: To collate, synthesise, and report existing evidence on the effects of hip, ankle, and stepping strategy training (SST) on balance and gait parameters among individuals with neurological conditions.

Materials and Methods: This scoping review followed PRISMA-ScR guidelines. The review protocol was registered on the Open Science Framework (OSF) with the registration DOI: 10.17605/OSF.IO/CAF63. Three electronic databases—PubMed, Scopus, and ScienceDirect—were searched for studies published in the English language. The search strategy included relevant keywords, Boolean operators (AND, OR, NOT), Medical Subject Headings (MeSH) terms, and filters such as publication year range, randomised clinical trials, and language.

Results: Fourteen studies were included in this scoping review. Study characteristics were summarised based on the populations investigated, types of postural-strategy training employed (hip, ankle, and stepping strategies), and intervention duration. Ankle Strategy Training (AST) on unstable surfaces demonstrated significant improvements in Centre Of Pressure (COP) sway. When combined with Hip Strategy Training (HST), greater improvements were observed in proximal extremity control and limits of stability. Several studies also reported that perturbation-based training enhanced reactive balance by increasing tolerance to perturbation intensity, improving confidence during community mobility, reducing fall risk behaviours, and enhancing gait parameters.

Conclusion: Postural-strategy training improves balance and gait parameters in individuals with neurological conditions. Each strategy offers distinct benefits, while multistrategy training yields greater functional improvements than single-strategy interventions.

Keywords: Diabetic neuropathy, Neurological rehabilitation, Postural balance, Stroke

INTRODUCTION

Postural control and somatosensory integration are commonly impaired in individuals with neurological disorders such as Parkinson's disease, stroke, multiple sclerosis, and DPN, leading to balance impairments, gait disturbances, and reduced quality of life [1]. Postural control is essential for maintaining the body's Centre Of Mass (COM) within the Base Of Support (BOS) through the integration of sensory input from the somatosensory, visual, and vestibular systems [2].

Humans primarily rely on three balance strategies to maintain postural stability: hip, ankle, and stepping strategies [3]. The hip strategy involves coordinated activation of the hip musculatur, particularly the extensors and abductors- to counteract large perturbations, while the ankle strategy utilises ankle musculature such as the gastrocnemius and tibialis anterior to respond to smaller perturbations [4]. In the stepping strategy, a compensatory step is taken to widen the BOS when perturbations exceed the corrective capacity of the hip and ankle strategies. The effectiveness of these strategies is often compromised in individuals with neurological disorders, resulting in poor postural control and gait dysfunction [5].

Stroke survivors frequently adopt maladaptive or compensatory stepping strategies due to proprioceptive deficits, muscle weakness, delayed motor responses, and impaired hip or ankle control [6]. Stepping responses are also impaired in Parkinson's disease as a result of lower limb rigidity, bradykinesia, and impaired anticipatory postural adjustments [7]. Individuals with multiple sclerosis tend to rely more on hip and stepping strategies and less on ankle strategies because of slowed nerve conduction, impaired muscle activation, and sensory deficits associated with demyelination [8].

The DPN, a metabolic disorder affecting peripheral nerves, leads to diminished joint proprioception, reduced tactile sensation and loss of sensory feedback from the feet and hands. These impairments contribute to compromised postural control, altered gait patterns, and an increased risk of falls [9].

Gait parameters such as cadence, step length, stride length, and step width are affected across neurological disorders. Hip and ankle strategies are particularly important during weight transfer and single-leg support phases of gait [10]. AST includes exercises targeting ankle joint mobility and musculature to enhance balance, proprioception, neuromuscular control, cadence, and stride length in neurological populations [11]. HST, which involves closed-kinetic-chain exercises focusing on strengthening hip and trunk musculature, has demonstrated improvements in balance, hip proprioception, and functional independence [12].

The SST, often based on perturbation exercises that promote rapid stepping and step initiation, has shown significant benefits in postural control, balance enhancement, and fall prevention [13]. Perturbation-Based Balance Training (PBBT) integrates multiple postural strategies to improve compensatory reactions, gait patterns, and fall risk in individuals with stroke and Parkinson's disease. Positive outcomes have been reported in gait velocity, cadence, step length, and stride length [14]. Similarly, hip and ankle strategy exercises combined with biofeedback have demonstrated improvements in balance and gait parameters among individuals with DPN [15].

Despite these findings, the existing literature lacks comprehensive evidence comparing the effects of hip, ankle, and stepping strategies on balance and gait outcomes across neurological conditions. Most existing reviews focus on one or two strategies or examine a single neurological population [16-18]. Therefore, this scoping review addresses these gaps by mapping current evidence and summarising postural-strategy training protocols. The objective of this review was to explore the impact of hip, ankle, and SST on balance and gait parameters in individuals with neurological disorders.

MATERIALS AND METHODS

The present scoping review followed PRISMA guidelines extended for scoping review (PRISMA-ScR) to ensure methodological transparency [19]. This scoping review was conducted in six stages: first, formulation of the research question; second, systematic literature searching across relevant databases; third, selection of studies based on predefined eligibility criteria; fourth, data extraction and charting; fifth, synthesis of findings; and finally, reporting of results. The review was conducted from July to November 2025. The review protocol was registered with the OSF under the registration Doi: 10.17605/OSF.IO/CAF63 [20].

Research Question

The research question was framed using the PCC (Population, Concept, Context) framework [21]. The population comprised individuals with neurological disorders, the concept focused on hip, ankle, and stepping strategies, and the context involved improving balance and gait parameters. Accordingly, the research question was:

What is the existing evidence on the impact of hip, ankle, and SST on balance and gait parameters in individuals with neurological conditions?

Search Strategy

The literature search followed PCC-based guidelines [22,23]. MEDLINE (via PubMed) and Google Scholar search engine were initially used for exploratory searching, after which a refined search strategy was developed for PubMed, Scopus, and ScienceDirect. The strategy aimed to maximise relevant study inclusion while minimising irrelevant results.

Search terms included specific keywords, Boolean operators (AND, OR, NOT), MeSH terms, and filters such as publication year range, randomised clinical trials, and language. Keywords included: "hip strategy," "ankle strategy," "stepping strategy," "balance," "gait parameters," "neurological conditions," "stroke," "diabetic peripheral neuropathy," "Parkinson's disease," "multiple sclerosis," "traumatic brain injury," and "postural control." Spelling variations and related terms (e.g., "neurological disorders," "reactive balance") were also used to ensure comprehensive coverage.

Study Selection

Inclusion criteria:

1. Participants diagnosed with neurological conditions such as stroke, DPN, multiple sclerosis, and Parkinson's disease;
2. Studies evaluating hip, ankle, SST, or combinations of these strategies;
3. Study designs including pilot studies, Randomised Clinical Trials (RCTs), Randomised Controlled Trials, and quasi-experimental studies;
4. Use of quantitative outcome measures for balance and gait parameters;
5. Articles published in English.

Exclusion criteria:

1. Studies involving neurological conditions not affecting balance or gait;
2. Interventions unrelated to postural-strategy training (e.g., pharmacological or unrelated rehabilitation methods);
3. Case reports, reviews, conference proceedings, case series, protocols, book chapters, and editorials.

Retrieved studies were collated and uploaded into Mendeley reference management software to remove duplicates [24]. Initial screening was performed based on titles and abstracts, followed by full-text screening using eligibility criteria. Screening was conducted independently by two reviewers, with disagreements resolved through discussion. The study selection process was illustrated using a PRISMA flow diagram [25].

Data Extraction and Quality Assessment

Data were extracted independently by two reviewers using the Joanna Briggs Institute (JBI) data extraction template [26]. Extracted information included study design, participant characteristics, interventions, intervention duration, outcome measures, and key findings. Although critical appraisal is not mandatory in scoping reviews according to JBI methodology, methodological quality was assessed using the PEDro scale to provide supplementary quality information [23]. Studies with excellent or good PEDro scores and sample sizes greater than 50 were classified as Level 1 evidence, whereas studies with fair or poor scores and sample sizes below 50 were considered Level 2 evidence [27].

Result Preparation

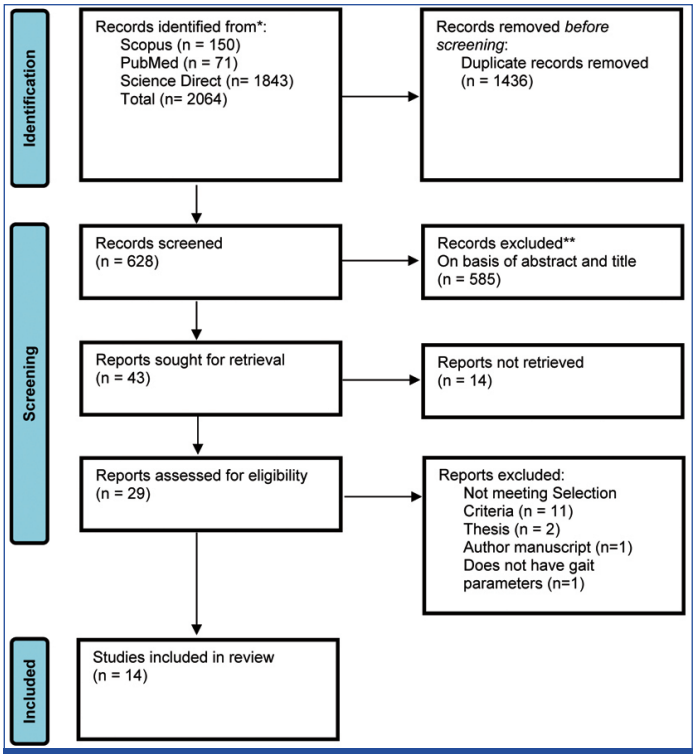
Findings were organised and synthesised in a structured manner aligned with the objectives of the review. Extracted data were mapped to present an overview of hip, ankle, and SST and their effects on balance and gait outcomes in neurological populations. Qualitative synthesis and tabular presentation were used to consolidate current evidence.

RESULTS

The initial database search across PubMed, Scopus, and ScienceDirect yielded 2,064 articles. After duplicate removal using Mendeley, 628 articles were screened based on titles and abstracts. Screening using Rayyan software resulted in the exclusion of 585 articles. The remaining 43 full-text articles were assessed for eligibility, of which 14 studies met the inclusion criteria and were included in the review [Table/Fig-1] [12,28-40].

Among the included studies, seven were RCTs [12,28,32,34,36,39,40], four were pilot RCTs [30,31,35,38], and three were single-group pilot studies [29,33,37]. Methodological quality and levels of evidence based on PEDro scores are presented in [Table/Fig-2].

The included studies were published between 2016 and 2025 across 10 countries. Participants comprised individuals with Parkinson's disease (n=63), multiple sclerosis (n=16), stroke (n=233), and DPN (n=123). Interventions targeted hip strategy, ankle strategy, stepping strategy, or combinations thereof. Sample sizes ranged from 6 to 78 participants, intervention frequency varied from 2 to 5 days per week, and intervention frequency ranged from 2.5 to 12 weeks [Table/Fig-3].



[Table/Fig-1]: PRISMA flowchart showing studies inclusion and exclusion at each review step.

Four studies employed AST alone, while one combined AST with HST [37-40]. Across these studies, AST significantly improved dynamic balance outcomes {assessed using Functional Reach Test (FRT), Timed Up And Go (TUG) and Berg Balance Scale (BBS)}, COP control, limits of stability, and ankle power during stance phases. Improvements in gait speed were generally non significant. AST performed on unstable surfaces demonstrated greater COP improvements, and when combined with HST, superior outcomes were observed compared with AST alone, suggesting synergistic effects [31-35].

Two studies investigated HST combined with trunk stabilisation exercises or AST in stroke populations [12,40]. HST resulted in significant improvements in static and dynamic balance, COP control, and limits of stability (p-value <0.001). Given the reliance on ankle strategies due to proximal muscle weakness in neurological populations, combining HST with AST produced greater benefits than AST alone [40].

Eight studies utilised stepping strategy or perturbation-based training using manual perturbations (e.g., waist pulls) or treadmill-induced perturbations to elicit stepping responses [28-35]. Perturbation training improved balance, cadence, and gait speed. It also enhanced reactive balance, tolerance to perturbation intensity, confidence during community ambulation, fall avoidance behaviours, and overall gait performance.

Nine studies assessed gait parameters such as stride length, cadence, walking speed, and performance on the 10-metre

Author, year, reference	1	2	3	4	5	6	7	8	9	10	11	Total PEDro scoring	Sample size ≥50	Level of evidence
Almasoudi AO et al., 2024 [12]	Yes	1	0	1	0	0	0	1	1	1	1	6	No	2
Park KH et al., 2016 [36]	Yes	1	0	1	0	0	0	0	0	1	0	3	No	2
Handelzalts S et al., 2019 [28]	Yes	1	0	1	0	0	1	0	1	1	1	6	No	2
Dusane S and Bhatt T, 2020 [29]	Yes	1	0	1	0	0	1	1	0	1	1	6	No	2
Lanza MB et al., 2024 [30]	Yes	1	0	1	0	0	0	0	0	1	1	4	No	2
Esmaeili V et al., 2020 [31]	Yes	1	0	1	0	0	1	0	1	1	1	6	No	2
Fan S et al., 2025 [32]	Yes	1	0	1	0	0	1	1	0	1	1	6	No	2
Park S et al., 2019 [40]	Yes	0	0	1	0	0	1	1	0	1	1	5	No	2
Maden T et al., 2022 [33]	Yes	1	0	1	0	0	0	0	1	0	1	4	No	2
Rodriques C et al., 2016 [37]	Yes	1	0	1	0	0	1	1	0	1	1	6	No	2
Steib S et al., 2017 [35]	Yes	1	1	1	0	0	1	1	1	1	1	8	No	2
Taniuchi R et al., 2022 [38]	Yes	1	0	1	0	0	1	1	0	1	1	6	No	2
Monteiro RL et al., 2022 [39]	Yes	1	1	1	0	0	1	0	1	1	1	7	Yes	1
Abdelaal A et al., 2022 [34]	Yes	0	1	1	0	0	1	1	0	1	1	6	No	2

[Table/Fig-2]: PEDro scoring of individual article and level of evidence [12,28-40].

Author/Year	Study design/ Country	Population/Sample size	Postural-strategy training	Duration	Outcome measures	Key findings
Handelzalts S et al., 2019 [28]	Randomised controlled trial, Israel	34 Subacute stroke patients PBBT- 18 WS and GT- 16	Stepping strategy (Perturbation-based balance Training)	30 minute session for 5 days/week for 2.5 weeks	• Fall threshold • BBS • 6 min. walk test • ABC • 10 min. walk test	PBBT group showed more significant improvement in reactive balance and balance confidence.
Dusane S and Bhatt T, 2020 [29]	Experimental block design, USA	12 Chronic stroke patients	Stepping strategy {Slip-Trip Perturbation Training (STPT)}	Not mentioned	• COM Position and velocity • Step length • Trunk angle	STPT showed more significant improvement in reactive responses.
Lanza MB et al., 2024 [30]	A pilot randomised control study, USA	30 Chronic stroke patients Perturbation- 18 Voluntary- 12	Stepping strategy {Lateral External Perturbation Training (LEPT)}	3 days/week for 6 weeks	• Step initiation time, Step length, Step velocity, Step clearance • ABC • Community balance and mobility scale	LEPT showed more significant improvement in protective stepping response then voluntary step training.
Esmaeili V et al., 2020 [31]	Randomised controlled pilot trial, Canada	21 Chronic stroke Perturb- 11 Non Perturb- 10	Stepping strategy {Unpredictable Perturbation Gait Training (UPGT)}	3 days/week for 3 weeks	• Mini BESTest • 10 m walk test • ABC • Knee dynamometery	Intense UPGT improved balance ability and community integration in chronic stroke patients.
Fan S et al., 2025 [32]	Randomised controlled trial, China	30 Stroke patients Perturbation- 10 Unloading-10 Control- 10	Stepping strategy [Hip Unloading Perturbation Training (HUPT)]	20 minute session for 5 days/week for 2 weeks	• BBS • 10 m walk test • Timed Up And Go (TUG) Test	HUPT showed positive trend but not statistical significant in improving balance and walking efficiency.

Maden T et al., 2022 [33]	Pilot study, Turkey	10 Multiple sclerosis patient	Stepping strategy (Perturbation Training)	45 minute session for 2 days/week for 6 weeks	• Romberg test • Single limb stance test • Functional reach test • Lateral reach test • Timed Up And Go (TUG) test • Four square step test	Manual Physical Therapy (PT) without computerised systems showed significant results in improving balance, walking, and fear of falling.
Abdelaal A et al., 2022 [34]	Randomised controlled trial, Saudi Arabia	45 Diabetic neuropathy patients Experimental group-23 Control group-22	Stepping strategy (Antigravity Treadmill Training)	30 minute session for 3 days/week for 12 weeks	• Step length and time • Double support time • Cadence • Velocity • Stability index	ATT with traditional physiotherapy showed significant improvement in gait and balance.
Steib S et al., 2017 [35]	Single blind randomised controlled pilot trial, Germany	43 Parkinson's patients Experimental group- 21 Control group-22	Stepping strategy (Perturbation Treadmill)	35 minute session for 2 days/week for 8 weeks	• Gait speed • 6 m walk test • Mini BESTest • Timed Up And Go (TUG) test • COP sway • Activity specific balance confidence • 2 m walk test	PT showed favorable results in gait speed, COP sway, 2m walk test, and Timed Up And Go (TUG) test, but not favorable in 6m walk test and mini BESTest.
Park KH et al., 2016 [36]	Randomised controlled trial, South Korea	30 Stroke patients Group 1- 10 Group 2- 10 Group 3- 10	Ankle Strategy Training (AST) exercises	15 minute session for 3 days/week	• COP sway • BBS • Functional reach test • Timed Up And Go (TUG) test	Ankle Strategy Training (AST) showed significant improvement in COP and balance.
Rodriques C et al., 2016 [37]	Pilot study, USA	6 Multiple sclerosis patients	Home based Ankle Strategy Training (AST)	2 days/week for 8 weeks	• AP limits of stability • Gait speed • Dynamometer	HBAST showed feasible results in improving gait, balance, and muscular performance.
Taniuchi R et al., 2022 [38]	Pilot randomised controlled trial, Japan	20 Parkinson's patients Experimental group-10 Control group-10	Ankle Strategy Training (AST)	40 minute session for 5 days/week for 2 weeks	• Timed Up And Go (TUG) test • Walking speed • Barthal index • Unified Parkinson's disease rating scale	It showed significant improvement in backward response.
Monteiro RL et al., 2022 [39]	Randomised controlled trial, Brazil	78 Diabetic neuropathy patients Experimental group-39 Control group-39	Ankle Strategy Training (AST) by foot ankle exercises	12 weeks	• Daily Physical Activity (Steps) • Gait speed • Michigan Neuropathy Screening • Ankle ROM, Tactile Threshold, Vibration	It showed positive effects in fast gait speed, ankle ROM, vibration, and quality of life in diabetic neuropathy patient's then usual care.
Park S et al., 2019 [40]	Randomised controlled clinical trial, South Korea	30 Stroke patients AST Group- 15 HAST Group- 15	Ankle and Hip Strategy Training (HST)	30 minute session for 3 days/week for 6 weeks	• COP and limits of stability by BioRescue	Hip Strategy Training (HST) with ankle strategy shows significant improvement in COP and limits of stability.
Almasoudi AO et al., 2024 [12]	Randomised controlled trial, Saudi Arabia	46 Stroke patients Experimental group-23 Control group-23	Hip Strategy Training (HST) with trunk exercises	30 minute session for 4 days/week for 6 weeks	• Trunk impairment scale • BBS • FIM	Showed positive impact on trunk control, static and dynamic balance, and functional independence.

[Table/Fig-3]: Evidence map of selected studies [12,28-40].
PBBT: Perturbation based balance training; WS&GT: Weight shifting and gait training; BBS: Berg balance scale; ABC: Activity specific balance confidence scale; COM: Center of mass; Mini BESTest: Balance evaluation systems test; COP: Center of pressure; ROM: Range of motion; AST: Ankle strategy training; HAST: Hip strategy training; e.g., FIM: Functional independence measure

and 6-metre walk tests [28-32,34-36,38]. Perturbation training demonstrated superior improvements in gait speed and postural stability during walking. In individuals with DPN, AST also produced significant gait speed improvements. No serious adverse effects were reported across the included studies.

DISCUSSION

This scoping review discusses existing evidence on hip, ankle, and stepping (perturbation-based) training and their effects on balance and gait parameters in individuals with neurological conditions. Among the 14 included studies, findings indicate that strategy-based training- whether applied individually or in combination- demonstrated significant improvements in balance and gait outcomes across various neurological impairments affecting postural control and mobility.

The results suggest that balance is a multidimensional construct requiring coordinated use of hip, ankle, and stepping strategies. Individuals with impaired postural control often rely predominantly on the ankle strategy due to proximal lower limb weakness. However, targeted postural-strategy training led to improvements beyond those achieved through conventional balance exercises, highlighting the importance of strategy-specific interventions.

Studies focusing on AST reported significant improvements in static balance, dynamic balance, and postural sway. Park KH et al., demonstrated that a short 15-minute AST session on unstable surfaces resulted in greater reductions in COP sway in both anteroposterior and mediolateral directions, along with improved BBS and TUG scores compared with conventional balance exercises and control groups [36]. Similarly, Jeon SN and Choi JH, reported positive effects of AST combined with sensory augmentation through visual feedback on dynamic balance [41].

Together, these findings indicate that AST combined with visual feedback enhances Centre Of Pressure (COP) control and clinical balance performance. Visual feedback provides real-time biofeedback regarding body sway, enabling the central nervous system to recalibrate postural alignment more effectively. It enhances proprioceptive input from the ankle joint, facilitating muscular activation that reduces postural sway and optimises COP regulation. Repeated feedback-based training promotes motor learning via cerebellar and cortical adaptation, resulting in sustained balance improvements [42].

Studies examining HST reported complementary benefits in improving limits of stability, balance, and functional independence. Park S et al., found that combining HST with AST produced greater improvements in COP sway and limits of stability compared with AST alone [40]. Almasoudi O et al., demonstrated enhanced balance, trunk control, and functional independence following HST combined with trunk stabilisation exercises, suggesting that proximal muscle training is essential when AST alone is insufficient [12].

These findings suggest that AST is particularly effective for managing small perturbations, whereas HST is more beneficial for controlling larger disturbances and supporting functional activities requiring proximal stability.

Studies focusing on stepping strategy or perturbation-based training showed marked improvements in dynamic and reactive balance as well as compensatory stepping responses. Handelzalts S et al., reported greater improvements in reactive balance in the PBBT group compared with weight-shifting gait training among stroke patients [28]. Dusane S and Bhatt T, demonstrated positive effects of slip–trip perturbation training on cadence, balance, and trunk control in individuals with chronic stroke [29]. Lanza MB et al., compared perturbation training with voluntary stepping training and found superior improvements in step length, step velocity, and balance outcomes with perturbation training [30]. Collectively, these studies indicate that perturbation-based training effectively enhances stepping reactions crucial for fall prevention, outperforming voluntary stepping and conventional gait training approaches.

In stroke populations, evidence suggests that HST and AST improve COP sway, limits of stability, and gait speed [40], whereas perturbation training more strongly enhances dynamic balance and stepping responses [30]. In Parkinson's disease, perturbation training and AST improved dynamic balance and reduced retropulsion- a common and hazardous issue in this population [35,38]. Among individuals with DPN and multiple sclerosis, AST improved gait speed, step length, cadence, ankle muscle strength, and balance, highlighting the importance of distal sensorimotor restoration in these conditions [37,39].

A study combining hip and AST demonstrated broader functional improvements compared with single-strategy protocols, suggesting synergistic effects when multiple postural control mechanisms are trained simultaneously [40]. Although some studies reported benefits from isolated strategy training, real-world applicability was limited due to small sample sizes and pilot study designs [29,33,37].

From a clinical physiotherapy perspective, this review suggests that HST should be prioritised in patients with proximal muscle weakness or large postural instability. AST is more appropriate for distal sensorimotor deficits and mild instability. Perturbation training should be incorporated for fall prevention and reactive balance enhancement, particularly in older adults. Importantly, multistrategy training programmes appear to produce greater synergistic and additive benefits than single-strategy interventions.

The strength of this review lies in its comprehensive synthesis of postural-strategy training following PRISMA-ScR and JBI methodological guidelines, integrating clinically relevant evidence.

Limitation(s)

Several limitations should be acknowledged. Many included studies had small sample sizes, low to moderate PEDro scores, short intervention durations, and limited long-term follow-up. Most studies were single-centre trials with a predominant focus on stroke populations, limiting generalisability. Outcome-related limitations included inconsistent balance measures with varying sensitivity to postural-strategy changes and gait parameter variability without standardised kinematic analysis. At the review level, publication bias may be present, as only English-language RCTs were included. Additionally, heterogeneity in terminology was noted, with eight studies focusing on stepping strategies and six on hip and ankle strategies.

CONCLUSION(S)

This scoping review demonstrated that postural-strategy training positively influences balance and gait outcomes in individuals with neurological conditions. HST primarily enhances proximal control and limits of stability, AST improves COP regulation and dynamic balance, and stepping or perturbation-based training significantly enhances reactive balance and fall prevention. Evidence suggests that combined multistrategy training yields greater functional benefits than isolated strategy interventions.

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PLAGIARISM CHECKING METHODS: [Jain H et al.]
- Plagiarism X-checker: Jan 02, 2026
- Manual Googling: Jan 30, 2026
- iThenticate Software: Feb 01, 2026 (3%)

ETYMOLOGY: Author Origin

EMENDATIONS: 6

AUTHOR DECLARATION:
- Financial or Other Competing Interests: None
- Was Ethics Committee Approval obtained for this study? NA
- Was informed consent obtained from the subjects involved in the study? NA
- For any images presented appropriate consent has been obtained from the subjects. NA

Date of Submission: **Jan 01, 2026**
Date of Peer Review: **Jan 13, 2026**
Date of Acceptance: **Feb 03, 2026**
Date of Publishing: **May 01, 2026**