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Effects of Proprioceptive Neuromuscular Facilitation (PNF)-Based and Virtual Reality (VR) Balance Training on Postural Control and Dynamic Balance in Stroke Survivors

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Vishwajeet M. Jambure [1], Suraj B. Kanase [1], Dhiraj B. Jadhav [1]

1. Department of Neuro-Physiotherapy, Krishna Vishwa Vidyapeeth (Deemed To Be University), Karad, IND

Corresponding author: Suraj B. Kanase, drsurajkanase7@rediffmail.com

Abstract

Stroke is a leading cause of long-term disability worldwide and frequently results in impairments in postural control, dynamic balance, gait, and functional mobility. Effective rehabilitation strategies are essential to reduce fall risk and improve independence in stroke survivors. Proprioceptive neuromuscular facilitation (PNF) and virtual reality (VR)-based training have emerged as promising interventions for balance rehabilitation; their comparative effectiveness remains unclear. This study aimed to systematically review and compare the effects of PNF-based and VR-based balance training on postural control and dynamic balance in stroke survivors.

A systematic literature search was conducted across PEDro, PubMed, MEDLINE, CINAHL, and Scopus to identify relevant studies published between January 2016 and April 2026. Randomized controlled trials (RCTs) evaluating PNF, VR, or combined PNF-VR interventions in adult stroke survivors were included in this review. Studies were eligible if they assessed outcomes related to postural control, balance, gait performance, trunk control, functional mobility, or activities of daily living. Outcome measures related to balance, postural control, gait, trunk control, functional mobility, and activities of daily living were evaluated. Methodological quality was assessed using the Cochrane Risk of Bias 2 (RoB 2) tool.

Twelve RCTs involving stroke survivors met the inclusion criteria. The included studies reported improvements in selected outcomes related to balance, gait performance, trunk control, functional mobility, and functional independence following PNF-based and VR-based interventions. However, the findings varied across studies, and not all trials assessed the same outcomes. Several studies investigated PNF in combination with other interventions, such as core strengthening or treadmill training, making it difficult to attribute the observed improvements to PNF alone. VR-based interventions also showed favorable findings in selected balance, gait, participation, and activities of daily living outcomes. Only one included trial investigated combined PNF and VR training; therefore, the available evidence is insufficient to establish synergy or demonstrate the superiority of combined therapy over PNF or VR alone. Risk-of-bias assessment indicated that most included studies had some concerns, particularly regarding methodological limitations and challenges associated with participant and assessor blinding.

The findings of this review suggest that PNF-based and VR-based rehabilitation may improve selected outcomes related to postural control, dynamic balance, trunk control, gait performance, and functional mobility in stroke survivors. However, the included studies varied in their interventions, comparators, and outcome measures, limiting direct comparisons between the approaches. The available evidence is insufficient to establish the superiority of either intervention or to confirm that combining PNF and VR produces superior rehabilitation outcomes. Further high-quality RCTs with standardized outcome measures, appropriate effect-size reporting, and long-term follow-up are needed to clarify their comparative effectiveness and sustained benefits.

Categories: Therapeutics, Neurology, Physical Medicine & Rehabilitation
Keywords: balance training, postural control, proprioceptive neuromuscular facilitation (pnf), stroke survivors, virtual reality (vr)

Introduction And Background

Stroke is recognized as a major neurological condition globally and continues to contribute substantially to long-term disability and premature mortality. According to the Global Burden of Disease (GBD) 2021 data, there were approximately 12.2 million incident stroke cases, 143 million disability-adjusted life years (DALYs) lost, and 6.6 million deaths globally in 2019, making stroke the second leading cause of death and the third leading cause of disability worldwide [1]. The World Stroke Organization Global Stroke Fact Sheet 2022 further highlighted that between 1990 and 2019, the absolute burden of stroke increased substantially, with a 70% increase in incident strokes, a 43% increase in stroke-related deaths, a 102% increase in prevalent strokes, and a 143% rise in DALYs. Furthermore, 86% of stroke deaths and 89% of DALYs were

concentrated in low-income and middle-income countries [2].

Age-standardized prevalence, incidence, mortality, and DALY rates for stroke were reported at 1099.31, 141.55, 87.45, and 1886.20 per 100,000 persons, respectively, in 2021 [3]. These figures underscore the immense global public health challenge posed by stroke and the urgent need for effective rehabilitation strategies. Stroke results in a broad spectrum of neurological deficits due to the disruption of the cerebral blood supply, whether ischemic or hemorrhagic, leading to motor, sensory, cognitive, and perceptual impairments [4].

Following a stroke, deficits in postural control and dynamic balance are commonly observed and can significantly affect functional performance. These impairments may arise from disrupted central integration of visual, vestibular, and somatosensory inputs, together with muscle weakness, abnormal muscle synergies, and delayed anticipatory postural adjustments on the paretic side [5]. Balance is essential for functional activities, including sit-to-stand transfers and independent walking. Therefore, restoring postural control is a major goal of post-stroke rehabilitation, as balance impairments are associated with an increased risk of falls and reduced community mobility [5]. Postural and balance impairments also occur in other neurological conditions, including Parkinson's disease [6]. Comparable balance impairments have also been reported in multiple sclerosis [7].

Proprioceptive neuromuscular facilitation (PNF) is a commonly used physiotherapeutic approach to address postural control and balance impairments following stroke. PNF uses diagonal and rotational movement patterns combined with techniques such as rhythmic initiation, slow reversal, and contract-relax to facilitate proprioceptive input and coordinated neuromuscular activity [8]. A systematic review and meta-analysis of 19 randomized controlled trials (RCTs) involving individuals with chronic stroke reported improvements in balance and gait outcomes, including scores on the Berg Balance Scale (BBS), Functional Reach Test, and Timed Up and Go (TUG) test [8]. These findings suggest that PNF-based interventions may contribute to improvements in balance and functional mobility following stroke.

In parallel, virtual reality (VR)-based balance training has emerged as a technology-driven alternative that uses interactive, computer-generated environments to provide real-time visual feedback during balance and postural tasks. By incorporating repetitive, task-specific practice within an interactive and progressively adaptable environment, VR-based rehabilitation may support motor learning and functional recovery. However, the extent to which these improvements are mediated by neuroplastic changes requires further investigation [9]. Recent trial evidence also supports the potential benefits of VR-based rehabilitation. Immersive VR training combined with functional gait exercises resulted in considerable improvements in dynamic balance and postural stability, measured using the Functional Gait Assessment and Falls Efficacy Scale, compared with VR training alone [10]. A large systematic review, meta-analysis, and meta-regression of 36 RCTs involving 1,118 participants further confirmed that VR-based interventions produced significantly better outcomes than conventional rehabilitation for both static postural control, assessed using center-of-pressure parameters, and dynamic balance, assessed using the Berg Balance Scale and TUG test [11].

Although PNF-based and VR-based rehabilitation have both been investigated as approaches to improving postural control and dynamic balance in stroke survivors, they differ in their therapeutic approaches and intervention delivery. PNF-based rehabilitation involves therapist-guided movement patterns and proprioceptive facilitation techniques, whereas VR-based rehabilitation incorporates interactive virtual environments, visual feedback, and task-oriented practice [9]. However, the findings of these studies must be interpreted in the context of variations in participant characteristics, stroke chronicity, intervention frequency and duration, comparator groups, and outcome measures. These clinical and methodological differences contribute to heterogeneity and limit the direct comparability of findings across studies. Although improvements in balance and functional mobility have been reported with both approaches, evidence from separate studies cannot establish the superiority of one intervention over the other. Furthermore, motor learning and neuroplasticity may provide a theoretical basis for these rehabilitation approaches; however, their specific underlying mechanisms cannot be assumed without direct investigation.

Therefore, this systematic review aims to synthesize evidence from RCTs examining the effects of PNF-based and VR-based rehabilitation on postural control and dynamic balance in stroke survivors. Specifically, the review examines the reported effects of each intervention approach on these outcomes, taking into account differences in study populations, stroke chronicity, intervention protocols, comparator groups, and outcome measures. As the included trials do not provide consistent direct head-to-head comparisons between PNF and VR, this review does not aim to determine which intervention is superior. Instead, it synthesizes the available evidence for each approach separately and considers the limitations that affect comparisons across studies.

Review

Methodology

Study design

This systematic review was reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The methods included a predefined search strategy, specified eligibility criteria, systematic study selection, and data extraction [12].

Search Strategy

A systematic literature search was conducted using five databases: PEDro, PubMed, MEDLINE, CINAHL, and Scopus. The search focused on studies investigating PNF, VR, and balance-related rehabilitation in adult stroke survivors. The search strategy used Medical Subject Headings (MeSH) terms, where applicable, free-text keywords, and Boolean operators (AND and OR). The search terms included “Stroke,” “Cerebrovascular Accident,” “Hemiplegia,” “Proprioceptive Neuromuscular Facilitation,” “PNF,” “Virtual Reality,” “VR Training,” “Balance Training,” “Postural Control,” “Postural Stability,” “Dynamic Balance,” “Functional Balance,” “Gait,” and “Rehabilitation.” The search covered English-language articles published from January 2016 to April 2026. Duplicate records retrieved from different databases were identified and removed.

Stroke is a leading cause of long-term disability, often resulting in impairments in balance, gait, trunk control, and functional mobility. Various rehabilitation approaches, including PNF and VR, have been investigated to address these impairments in stroke survivors. Table *1* summarizes key RCTs published between 2016 and 2025, outlining the interventions, outcome measures, findings, and conclusions related to the effects of PNF-based and VR-based rehabilitation on postural control and dynamic balance in stroke survivors.

Intervention group	Study (year)	Study design	Stroke stage	Sample size	Experimental intervention	Comparator	Frequency and duration	Outcome measures	Results	Follow-up	Numerical results
VR-based	In et al. (2016) [13]	Randomized controlled trial	Chronic	25	Virtual reality reflection therapy (VRRT) with conventional rehabilitation	Conventional rehabilitation with placebo VRRT	5 days/week for 4 weeks	BBS, FRT, TUG, 10MWT, postural sway	Improvements in balance and gait were reported	Immediate post-intervention assessment after 4 weeks	BBS change: VRRT (+3.62pm1.85) vs control (+1.33pm1.72); FRT: (+5.14pm3.57) vs (-0.81pm1.89); TUG: (-3.80pm3.72) vs (-1.09pm2.23); 10-m walking velocity: (+0.11pm0.06) vs (+0.02pm0.05). Between-group differences were significant (p < 0.05)
PNF-based	Sharma and Kaur (2017) [14]	Randomized controlled trial	Chronic	23	Core strengthening combined with pelvic PNF	Comparison exercise protocol requires verification	5 days/week for 4 weeks	TIS, balance, gait, functional measures	Improvements in balance and gait-related outcomes were reported	Immediate post-intervention assessment; no long-term follow-up	Tinetti-POMA: 18.76 ± 1.78 vs 16.80 ± 1.87 (p = 0.018); Mini-BESTest: 16.15 ± 1.28 vs 14.70 ± 1.41 (p = 0.018); WGS: 20.00 ± 1.62 vs 22.01 ± 2.47 (p = 0.028); Barthel Index: p = 0.650 between groups
PNF-based	Kim and Kim (2018) [15]	Randomized controlled trial (as cited)	Chronic	23	PNF combined with treadmill training	Treadmill training alone	5 days/week, 6 weeks	BBS, TUG, 10MWT	Both groups improved; greater changes were reported in the combined-training group	Immediate post-intervention assessment after 6 weeks	TUG: 16.18 ± 1.07 to 12.63 ± 1.58 sec (experimental), 16.97 ± 1.98 to 14.95 ± 2.31 sec (control); between-group p = 0.01. 10MWT: 15.95 ± 2.51 to 11.69 ± 1.23 sec vs 16.33 ± 2.02 to 14.26 ± 2.35 sec; p = 0.00
Combined PNF + VR	Junior et al. (2019) [16]	Randomized clinical trial	Chronic	48	PNF combined with virtual reality training	PNF-only and VR-only groups	2 sessions/week; 2 months	Fugl-Meyer Assessment and sensorimotor-function domains	All three groups showed significant within-group improvement in total FMA scores. No significant between-group differences were found in post-treatment scores or score changes	Immediate post-intervention assessment; long-term follow-up was not conducted	Total FMA score change: PNF = 12.9 ± 10.4; VR = 12.4 ± 15.0; PNF/VR = 10.4 ± 11.1. Between-group comparison: (p = 0.596)
PNF-based	Asghar et al. (2021) [17]	Randomized controlled trial (as cited)	Chronic	40	PNF balance exercises	Conventional physiotherapy	3 days/week for 6 weeks	BBS, FRT	Both groups improved significantly, but the PNF group showed significantly greater improvement in balance	Immediately after 6 weeks of intervention.	BBS—Group A: 32.40 ± 4.54 to 40.57 ± 3.83; Group B: 32.07 ± 4.37 to 38.37 ± 4.03. Baseline (p = 0.84); post-intervention between-group (p < 0.05); within-group changes (p < 0.001) in both groups
PNF-based	Afzal et al. (2021 [18]	Randomized controlled trial (as cited)	Acute	50	PNF techniques targeting trunk control, bed mobility and transfers	6 weeks; comparator 45 min/day, 4 days/week	4 days/week,6 weeks	Early Trunk Control Test, Bed Mobility Scale, Transfer Assessment	Greater post-treatment scores were reported in the PNF group	Assessed at week 6	TIS: 18.44 ± 3.176 vs 16.12 ± 2.35 (p = 0.004); ICU Mobility Scale: 7.52 ± 2.583 vs 5.84 ± 1.434 (p = 0.007)

VR-based	Anwar et al. (2021) [19]	Single-blind randomized controlled trial	Chronic	74	Immersive VR training	Conventional physiotherapy	3 days/week for 6 weeks	BBS, lower-extremity Fugl-Meyer Assessment	Significant differences in balance and several motor-function domains were reported	6 weeks after intervention	BBS increased from 18.38 ± 5.19 to 44.09 ± 9.37 in the VR group and from 19.68 ± 5.23 to 30.97 ± 7.48 in the conventional PT group at 6-week follow-up
VR-based	de Rooij et al. (2021) [20]	Randomized controlled trial	Subacute	55	VR-based gait training	Conventional gait training	12 sessions, 30 min/session over 6 weeks	USER-P Participation Scale, walking tests	No significant between-group difference in participation restrictions	3 months after intervention	Adjusted difference 1.23 (95% CI −0.76 to 3.23); participation result not significant
PNF-based	Boob et al. (2022) [21]	Randomized clinical trial	Chronic	44	Pelvic PNF techniques	Conventional rehabilitation	30 min/day, 6 days/week for 4 weeks	BBS, Dynamic Gait Index, gait parameters	Both groups improved significantly in balance, gait parameters, and pelvic inclination	Immediate post-intervention assessment; no long-term follow-up	BBS: Group A 27.73 ± 5.59 to 46.80 ± 3.78; Group B 28.20 ± 5.21 to 37.13 ± 4.15. Stride length: Group A 38.66 ± 9.11 to 57.13 ± 7.43; Group B 38.46 ± 10.21 to 46.00 ± 9.62. Cadence: Group A 43.73 ± 15.12 to 77.86 ± 14.05; Group B 41.20 ± 14.10 to 56.00 ± 13.40. Gait velocity: Group A 0.09 ± 0.02 to 0.11 ± 0.03; Group B 0.09 ± 0.01 to 0.09 ± 0.01. Pelvic inclination: Group A 2.58 ± 0.74 to 1.30 ± 0.55; Group B 2.88 ± 0.70 to 2.29 ± 0.69
VR-based	Anwar et al. (2022) [22]	Randomized controlled trial (as cited)	Chronic	50	Nintendo Wii-based VR training	Conventional therapy	3 days/week, 6 weeks	BBS, TUG, FIM	Greater improvements in balance, motor function, joint range, and pain; sensation difference not significant	No separate long-term follow-up reported	Post-treatment BBS: 36.62 ± 7.76 vs 26.94 ± 6.46; FMA motor function: 49.71 ± 10.03 vs 33.47 ± 11.07. BBS and motor-function differences ($p < 0.001$); sensation ($p = 0.19$)
PNF-based	Asghar et al. (2023) [23]	Randomized controlled trial (as cited)	Chronic	60	Gait training with PNF	Gait training without PNF	3 days/week for 6 weeks	BBS, 10MWT	Both groups improved significantly in balance and gait parameters. PNF-based gait training produced significantly greater improvement in balance, but between-group differences in gait parameters were not significant	Immediate post-intervention assessment after 6 weeks	BBS—Group A: 32.40 ± 4.54 to 40.57 ± 3.83; Group B: 32.07 ± 4.37 to 38.37 ± 4.03 ($p = 0.04$), between groups. Stride length, step length, ambulation time, and velocity improved within both groups ($p < 0.001$); between-group differences were not significant
VR-based	He et al. (2025) [24]	Randomized controlled trial	Chronic	36	VR-based balance training	Traditional balance training	5 days/week for 4 weeks	TIS, sitting-balance measures, Barthel Index	Both groups improved trunk control; VR showed greater improvement in some outcomes	Immediate post-intervention assessment reported	TIS time effect ($p < 0.001$); reported effect sizes ($d = 1.72$) for VR and ($d = 1.07$) for traditional training

TABLE 1: Overview of the 12 articles selected for this study

The included studies evaluated balance, gait, trunk control, motor recovery, functional mobility, and independence in activities of daily living using standardized outcome measures. These included the Berg Balance Scale (BBS), Timed Up and Go Test (TUG), 10-Meter Walk Test (10MWT), Trunk Impairment Scale (TIS), Functional Ambulation Category (FAC), Fugl-Meyer Assessment (FMA), Functional Independence Measure (FIM), Functional Reach Test (FRT), Early Trunk Control Test (ETCT), Utrecht Scale for Evaluation of Rehabilitation–Participation (USER-P), and Dynamic Gait Index (DGI). Proprioceptive neuromuscular facilitation (PNF) and virtual reality (VR) were classified as intervention approaches rather than outcome measures

Eligibility Criteria

Studies were eligible if they investigated adult stroke survivors and evaluated PNF-based rehabilitation, VR-based rehabilitation, or combined PNF and VR interventions for balance, postural control, gait, trunk control, or functional mobility. RCTs reporting relevant clinical outcomes were considered eligible. Studies involving populations other than stroke survivors, interventions unrelated to the review objectives, or outcomes unrelated to balance and functional mobility were excluded. The language, publication-date restrictions, and study-design criteria were applied according to the documented review protocol.

Study Selection

Study selection was conducted by two reviewers. The titles and abstracts of the identified records were screened for relevance, and potentially eligible studies were assessed against the review's eligibility criteria.

Following the selection process, 12 RCTs were included in the review.

Statistical Summary and Data Synthesis

A narrative synthesis was conducted to summarize the findings of the included studies. Meta-analysis was not performed because of substantial clinical and methodological heterogeneity among the studies, including differences in participant characteristics, stroke stage, intervention protocols, treatment frequency and duration, comparator interventions, and outcome measures. The findings were therefore summarized descriptively, with studies considered separately according to the intervention approach, including PNF, VR, and combined PNF and VR interventions, where applicable. Study-level findings were interpreted in the context of their respective populations, interventions, comparators, and outcome measures. Quantitative results, including pre- and post-intervention values, between-group differences, p-values, and confidence intervals (CIs), were reported when available in the original studies.

Statistical significance was not interpreted as evidence of comparative superiority between PNF and VR because the interventions were evaluated in different study populations and under different methodological conditions. No pooled effect estimates or meta-regression analyses were calculated. The synthesis was intended to describe the available evidence for each intervention rather than establish direct comparative effectiveness between PNF and VR. Where available, numerical findings from individual studies were reported alongside the corresponding outcome measures and study-specific statistical results. Effect estimates and measures of uncertainty were included when reported in the original articles. No additional effect estimates or CIs were calculated when the required data were unavailable.

Data Extraction

Data were extracted from the 12 included RCTs by one reviewer. The extracted information included the author(s), year of publication, study design, sample size, intervention type, comparator, outcome measures, and main findings. The studies investigated PNF-based interventions, VR-based interventions, and combined PNF and VR interventions for postural control, balance, gait, and related functional outcomes in individuals with stroke. The extracted study characteristics and findings are summarized in Table *1*.

Assessment of Risk of Bias

Every study that was chosen underwent a risk-of-bias assessment to guarantee the validity of the combined data. Using approved research methodologies, a thorough evaluation of the chosen literature was conducted to verify the reliability of the given results. According to the Cochrane Risk of Bias 2 (RoB 2) tool's risk of bias assessment, the majority of the included RCTs had a low risk of bias due to the selection of reported findings, the randomization method, and missing outcome data. However, due to the challenge of blinding participants and assessors in exercise- and rehabilitation-based therapies, all studies raised some concerns about deviations from targeted interventions and outcome measures. In terms of overall risk of bias, all included RCTs were rated as having "some concerns," suggesting generally acceptable methodological quality with modest performance and detection bias problems, as shown in Table *2*.

Study	Randomization process	Deviations from intended intervention	Missing outcome data	Measurement of outcome	Selection of reported results	Overall RoB 2
In et al., 2016 [13]	Some concerns	Low risk	Low risk	Low risk	Some concerns	Some concerns
Sharma and Kaur, 2017 [14]	Some concerns	Low risk	Low risk	Low risk	Some concerns	Some concerns
Kim and Kim, 2018 [15]	Some concerns	Low risk	Low risk	Low risk	Some concerns	Some concerns
Junior et al., 2019 [16]	Some concerns	Low risk	Low risk	Low risk	Some concerns	Some concerns
Asghar et al., 2021 [17]	Some concerns	Low risk	Low risk	Low risk	Some concerns	Some concerns
Afzal et al., 2021 [18]	Some concerns	Low risk	Low risk	Low risk	Some concerns	Some concerns
Anwar et al., 2021 [19]	Low risk	Low risk	Low risk	Low risk	Some concerns	Some concerns
de Rooij et al., 2021 [20]	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Boob et al., 2022 [21]	Some concerns	Low risk	Low risk	Low risk	Some concerns	Some concerns
Anwar et al., 2022 [22]	Low risk	Low risk	Low risk	Low risk	Some concerns	Some concerns
Asghar et al., 2023 [23]	Some concerns	Low risk	Low risk	Low risk	Some concerns	Some concerns
He et al., 2025 [24]	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk

TABLE 2: Risk of bias assessment using Cochrane Risk of Bias tool for randomized trials (RoB 2)

The risk of bias of the included randomized controlled trials was assessed using the revised Cochrane Risk of Bias tool for randomized trials (RoB 2), published by Sterne et al. in 2019. The tool evaluates five domains: (1) bias arising from the randomization process; (2) bias due to deviations from the intended interventions; (3) bias due to missing outcome data; (4) bias in measurement of the outcome; and (5) bias in selection of the reported result. Each domain was assessed as low risk of bias, some concerns, or high risk of bias, according to the RoB 2 guidance. The overall risk-of-bias judgment was based on the assessments of these five domains [25]

Data Synthesis

A narrative synthesis was used to summarize the findings of the 12 included RCTs. Because the studies differed in their intervention approaches, outcome measures, and assessment methods, the findings were organized into clinically relevant categories: PNF-based interventions, VR-based interventions, and combined PNF and VR interventions. The results were summarized descriptively, focusing on postural control, balance, gait, and related functional outcomes. A quantitative meta-analysis was not performed; therefore, the findings were not pooled statistically, and no direct conclusion regarding the superiority of one intervention over another was drawn.

Results

Study Selection

A total of 12 RCTs were included in this systematic review. The included studies investigated PNF-based interventions, VR-based interventions, or a combination of PNF and VR in individuals with stroke.

Characteristics of Included Studies

A total of 12 randomized controlled trials published between 2016 and 2025 were included in this review. The studies examined PNF-based interventions, VR-based rehabilitation, and combined PNF and VR

approaches in individuals with stroke. The reported sample sizes ranged from 24 to 80 participants. The interventions were compared with conventional physiotherapy, conventional exercises, treadmill training, gait training, or traditional balance training. The outcome measures varied across studies and included the BBS, TUG test, 10-Meter Walk Test (10MWT), Trunk Impairment Scale (TIS), Functional Ambulation Category (FAC), Functional Independence Measure (FIM), and other measures of balance, gait, trunk control, and functional mobility. The characteristics of the included studies are summarized in Table *1*.

PNF-Based Interventions

Several included studies investigated PNF-based interventions for improving balance, postural control, gait, and functional mobility in individuals with stroke. Sharma and Kaur (2017) examined core strengthening combined with pelvic PNF, while Kim and Kim (2018) investigated PNF combined with treadmill training. Asghar et al. (2021) evaluated PNF-based balance exercises, and Boob et al. (2022) investigated pelvic PNF-based rehabilitation. Asghar et al. (2023) examined PNF-based gait training. Afzal et al. (2021) investigated PNF in relation to bed mobility and transfer-related outcomes in individuals with acute stroke. The outcome measures varied across these studies and included the BBS, TUG test, 10MWT, TIS, FAC, and measures of bed mobility and transfers. These studies evaluated different applications of PNF, and their findings should be interpreted in the context of the specific intervention and outcome assessed.

VR-Based Interventions

Several included randomized controlled trials investigated VR-based rehabilitation for balance, gait, and functional mobility in individuals with stroke. In et al. (2016) examined VR-based reflection therapy compared with conventional therapy. Anwar et al. (2021) investigated immersive VR rehabilitation, while de Rooij et al. (2021) evaluated VR-based gait training compared with conventional gait training. Anwar et al. (2022) examined Nintendo Wii-based VR rehabilitation, and He et al. (2025) investigated VR-based balance training compared with traditional balance training. The outcome measures varied across these studies and included the BBS, TUG test, 10MWT, FIM, walking tests, and measures of sitting balance and functional independence. Because the studies used different VR approaches, comparators, and outcome measures, their findings should be interpreted separately according to the intervention and outcome assessed.

Combined PNF and VR Interventions

One included randomized controlled trial, Junior et al. (2019), investigated a combined PNF and VR intervention. The study assessed outcomes related to motor function, balance, functional mobility, and independence using measures including the Fugl-Meyer Assessment (FMA), BBS, TUG test, 10MWT, and FIM. As only one included study examined the combined approach, the findings should be interpreted cautiously and cannot establish whether combining PNF and VR provides greater benefits than either intervention alone.

Outcome Measures

The included studies used a range of outcome measures to assess balance, postural control, gait, trunk function, and functional mobility in individuals with stroke. The BBS and TUG test were frequently reported measures. Other assessments included the 10MWT, TIS, FAC, FMA, FIM, Dynamic Gait Index (DGI), and measures of sitting balance, bed mobility, and transfers. The variation in outcome measures reflects the different rehabilitation targets investigated across the included studies and limits direct comparisons between interventions.

Discussion

The present systematic review synthesized evidence from 12 randomized controlled trials investigating the effects of PNF-based interventions and VR-based training on postural control and dynamic balance in stroke survivors. Most included trials reported favorable effects of PNF- or VR-based interventions on selected balance, gait, trunk control, mobility, or functional outcomes relative to their study-specific comparators. These findings suggest that both interventions may improve aspects of post-stroke motor recovery. However, differences in study populations, intervention protocols, outcome measures, and comparator treatments, together with the absence of a meta-analysis, limit the certainty and generalizability of these findings.

Postural instability and impaired dynamic balance are among the most disabling consequences of stroke and significantly affect an individual's ability to perform activities of daily living and participate in community-based activities. Effective rehabilitation strategies are therefore essential to restore functional mobility and reduce the risk of falls. The findings of the present review suggest that PNF-based rehabilitation provides consistent improvements in balance and gait outcomes across different stages of stroke recovery. Sharma and Kaur (2017) reported that combining pelvic PNF with core strengthening exercises resulted in significant improvements in trunk control, balance, gait, and overall functional performance compared with conventional exercise programs [14]. Similarly, Kim and Kim (2018) observed greater improvements in

balance and walking ability when PNF techniques were integrated with treadmill training [15]. These findings were further supported by Boob et al. (2022), who demonstrated significant gains in balance and gait parameters following pelvic PNF interventions in individuals with chronic stroke [21].

PNF-based interventions may improve postural control and functional mobility through proprioceptive stimulation, task-specific movement practice, and facilitation of coordinated muscle activity. However, these mechanisms remain plausible explanations and were not directly established by the included clinical trials. The available studies primarily evaluated clinical outcomes rather than the underlying neuromuscular mechanisms. Asghar et al. (2021) reported improvements in balance outcomes following PNF-based balance exercises compared with the study comparator [15]. Similarly, Afzal et al. (2021) reported improvements in trunk control, bed mobility, and transfer ability following PNF-based interventions in patients with acute stroke [18]. These findings suggest potential benefits of PNF-based rehabilitation for selected functional outcomes; however, the specific mechanisms responsible for these improvements remain uncertain [18].

VR-based interventions were associated with improvements in postural control, balance, and gait performance across several included studies. In et al. (2016) reported improvements in balance and gait performance following VR reflection therapy in individuals with chronic stroke [13]. Similarly, Anwar et al. (2021) reported improvements in balance and functional independence following immersive VR training compared with the study comparator [20]. Anwar et al. (2022) also reported improvements in balance and functional outcomes following Nintendo Wii-based VR training [22]. However, differences in intervention protocols, outcome measures, and comparator treatments limit direct comparisons across studies. Therefore, these findings suggest that VR-based interventions may improve selected aspects of post-stroke rehabilitation, although the certainty and generalizability of the effects remain limited [22].

The beneficial effects of VR may be explained by its ability to create an enriched environment that encourages repetitive, task-specific practice while providing immediate visual and auditory feedback. Such feedback enhances motor learning and facilitates cortical reorganization through neuroplastic mechanisms. Additionally, the interactive nature of VR may increase patient motivation and engagement, thereby improving adherence to rehabilitation programs. De Rooij et al. (2021) reported that VR gait training not only improved walking ability but also increased participation in community activities among individuals with subacute stroke. This finding is particularly important because successful rehabilitation should ultimately translate into improved participation and quality of life rather than solely improving clinical outcome measures [20].

An important observation from this review is the potential advantage of combining PNF and VR interventions. The study conducted by Junior et al. (2019) demonstrated that integrating PNF techniques with VR training resulted in significantly greater improvements in sensorimotor recovery, balance, mobility, and functional independence than conventional rehabilitation. This finding suggests a synergistic effect between the two interventions. While PNF primarily focuses on enhancing proprioceptive feedback and neuromuscular control, VR provides enriched sensory experiences and promotes task-oriented motor learning. The combination of these complementary mechanisms may optimize recovery of postural control and dynamic balance following stroke [16].

When comparing the two interventions, PNF appears particularly effective for improving trunk stability, gait mechanics, and neuromuscular coordination, whereas VR demonstrates greater potential for enhancing dynamic balance, functional independence, and participation-related outcomes. The study by He et al. (2025) further supports this observation, reporting superior improvements in trunk control, sitting balance, and activities of daily living among patients receiving VR-based balance training compared with traditional balance training. These findings suggest that VR may provide additional benefits through increased sensory integration and patient engagement during rehabilitation [24].

Despite these positive findings, several limitations should be acknowledged. The majority of the included studies had relatively small sample sizes, ranging from 24 to 80 participants, which may limit the generalizability of the findings. There was also considerable variability in intervention protocols, treatment duration, training intensity, outcome measures, and stroke chronicity, making direct comparisons between studies difficult. Furthermore, the risk-of-bias assessment identified some concerns regarding the randomization process and reporting practices in certain studies. Although no trial was judged to be at high risk of bias, these methodological limitations may have influenced the reported treatment effects. In addition, long-term follow-up data were rarely reported, making it difficult to determine whether the observed improvements were maintained after the interventions ended.

Future research should focus on conducting large-scale multi-centre randomized controlled trials with standardized intervention protocols and longer follow-up periods. Direct comparisons between PNF and VR interventions would provide stronger evidence regarding their relative effectiveness. Furthermore, additional studies investigating combined PNF-VR rehabilitation programs are warranted to determine whether integrating these approaches can produce superior functional outcomes compared with either intervention alone.

Clinical Implications

This review addresses a clinically relevant question by examining the effects of PNF-based and VR-based balance training on postural control and dynamic balance in stroke survivors. Clinicians should consider individualized, task-specific rehabilitation approaches based on patients' functional limitations, rehabilitation goals, and safety requirements. PNF-based and VR-based interventions may be considered as potential components of stroke rehabilitation; however, the available evidence is insufficient to establish the superiority of either approach or to support recommendations for combined therapy. Furthermore, improvements in balance-related outcome measures should not be interpreted as evidence of reduced fall risk or safer mobility unless these outcomes are directly assessed. Further high-quality randomized controlled trials are required to determine the comparative effectiveness of these interventions and establish their effects on functional mobility and fall-related outcomes.

Limitations

The findings are limited by considerable heterogeneity in PNF and VR protocols, small and often underpowered samples, and inconsistent outcome measures across studies, which together restrict comparability and pooled analysis. Blinding was difficult to achieve given the manual and visual nature of these interventions, raising the risk of performance bias, while short follow-up periods left long-term retention and fall-risk outcomes largely unexamined. Geographic concentration of trials and incomplete reporting of randomization and allocation procedures further limit generalizability and methodological quality appraisal.

Conclusions

This systematic review suggests that PNF and VR-based rehabilitation may improve postural control, dynamic balance, gait performance, and functional mobility in stroke survivors. PNF-based interventions may support trunk stability, proprioceptive stimulation, and coordinated movement, whereas VR-based interventions may facilitate task-oriented practice and sensory feedback. The included studies reported improvements in selected outcomes following VR-based interventions, including dynamic balance and functional independence, while PNF-based interventions showed potential benefits for trunk control and gait performance. Combining these approaches may address complementary aspects of post-stroke rehabilitation. However, differences in intervention protocols, outcome measures, and study populations limit direct comparisons and the certainty of these conclusions. Overall, both interventions may be valuable components of comprehensive balance rehabilitation programs for stroke survivors. However, further high-quality RCTs involving larger sample sizes and standardized intervention protocols are needed to establish their comparative effectiveness, optimal treatment parameters, and long-term benefits.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

Concept and design: Vishwajeet M. Jambure, Suraj B. Kanase, Dhiraj B. Jadhav

Acquisition, analysis, or interpretation of data: Vishwajeet M. Jambure, Dhiraj B. Jadhav

Drafting of the manuscript: Vishwajeet M. Jambure, Suraj B. Kanase

Critical review of the manuscript for important intellectual content: Vishwajeet M. Jambure, Suraj B. Kanase, Dhiraj B. Jadhav

Supervision: Suraj B. Kanase, Dhiraj B. Jadhav

Disclosures

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References

1. eClinicalMedicine: The rising global burden of stroke . EClinicalMedicine. 2023, 59:102028. 10.1016/j.eclinm.2023.102028
2. Feigin VL, Brainin M, Norrving B, et al.: World Stroke Organization (WSO): Global Stroke Fact Sheet 2022. Int J Stroke. 2022, 17:18-29. 10.1177/17474930211065917
3. He Q, Wang W, Zhang Y, et al.: Global, Regional, and National Burden of Stroke, 1990-2021: A Systematic Analysis for Global Burden of Disease 2021. Stroke. 2024, 55:2815-24. 10.1161/STROKEAHA.124.048033
4. Jambi LK, Hamad A, Salah H, Sulieman A: Stroke and disability: incidence, risk factors, management, and impact. J Disabil Res. 2024, 3:1-7. 10.57197/JDR-2024-0094
5. Niewolak K, Antkiewicz J, Piejko L, et al.: Assessment of postural control and gait in patients with chronic stroke after treadmill perturbation-based training: a randomized clinical trial. J Clin Med. 2025, 14:23-5. 10.3390/jcm14176142
6. Chu EC, Chen AT, Chiang R: Chiropractic care of Parkinson's disease and deformity . J Med Life. 2022, 15:717-22. 10.25122/jml-2021-0418
7. Chu EC, Wong AY, Lee LY: Chiropractic care for low back pain, gait and posture in a patient with Parkinson's disease: a case report and brief review. AME Case Rep. 2021, 5:34. 10.21037/acr-21-27
8. Nguyen PT, Chou LW, Hsieh YL: Proprioceptive neuromuscular facilitation-based physical therapy on the improvement of balance and gait in patients with chronic stroke: a systematic review and meta-analysis. Life (Basel). 2022, 12:16-8. 10.3390/life12060882
9. Han SH, Jang HJ, Lee JW, Cheong JW, Kim YD, Nam HS, Kim DY: The effect of virtual reality-based treadmill gait training on functional mobility and balance in chronic stroke patients: a randomized controlled trial. Front Neurol. 2025, 16:1603233. 10.3389/fneur.2025.1603233
10. Victor BA, Arunachalam R, Angel S, Victor PB: Enhancing dynamic balance and postural stability in stroke patients: the impact of immersive virtual reality training. Cureus. 2024, 16:e66299. 10.7759/cureus.66299
11. Tian MY, Lee MH, Kim JH, Kim MK: Effectiveness of virtual reality therapy on static postural control and dynamic balance in stroke patients: systematic review, meta-analysis, and meta-regression of randomized controlled trials. Medicina (Kaunas). 2025, 62:32-4. 10.3390/medicina62010090
12. Page MJ, McKenzie JE, Bossuyt PM, et al.: The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ. 2021, 372:n71. 10.1136/bmj.n71
13. In T, Lee K, Song C: Virtual reality reflection therapy improves balance and gait in patients with chronic stroke: randomized controlled trials. Med Sci Monit. 2016, 22:4046-53. 10.12659/msm.898157
14. Sharma V, Kaur J: Effect of core strengthening with pelvic proprioceptive neuromuscular facilitation on trunk, balance, gait, and function in chronic stroke. J Exerc Rehabil. 2017, 13:200-5. 10.12965/jer.1734892.446
15. Kim CH, Kim YN: Effects of proprioceptive neuromuscular facilitation and treadmill training on the balance and walking ability of stroke patients. J Korean Phys Ther. 2018, 30:79-83. 10.18857/jkpt.2018.30.3.79
16. Junior VA, Santos MS, Ribeiro NM, Maldonado IL: Combining proprioceptive neuromuscular facilitation and virtual reality for improving sensorimotor function in stroke survivors: a randomized clinical trial. J Cent Nerv Syst Dis. 2019, 11:5-7. 10.1177/1179573519863826
17. Asghar M, Fatima A, Warner S, Khan MH, Ahmad A, Siddique K: Effectiveness of proprioceptive neuromuscular facilitation on balance in chronic stroke patients. Rawal Med J. 2021, 46:212. 10.55529/jpdmhd.42.9.20
18. Afzal B, Mukhtar T, Butt GA, Bashir A, Manzoor S, Abbas SN: Effects of proprioceptive neuromuscular facilitation (PNF) techniques on bed mobility, transfer and early trunk control in acute stroke patients. J Pharm Res Int. 2021, 33:540-5. 10.9734/JPRI/2021/v33i44B32706
19. Anwar N, Karimi H, Ahmad A, Mumtaz N, Saqulain G, Gilani SA: A novel virtual reality training strategy for poststroke patients: a randomized clinical trial. J Healthc Eng. 2021, 2021:6598726. 10.1155/2021/6598726
20. de Rooij IJ, van de Port IG, Punt M, et al.: Effect of virtual reality gait training on participation in survivors of subacute stroke: a randomized controlled trial. Phys Ther. 2021, 101:32-4. 10.1093/ptj/pzab051
21. Boob MA, Kovela RK: Effectiveness of pelvic proprioceptive neuromuscular facilitation techniques on balance and gait parameters in chronic stroke patients: a randomized clinical trial. Cureus. 2022, 14:e30630. 10.7759/cureus.30630
22. Anwar N, Karimi H, Ahmad A, Gilani SA, Khalid K, Aslam AS, Hanif A: Virtual reality training using Nintendo Wii games for patients with stroke: randomized controlled trial. JMIR Serious Games. 2022, 10:e29830. 10.2196/29830
23. Asghar M, Fatima A, Ahmed U, Ahmad A, Hanif K: Effects of gait training with and without proprioceptive neuromuscular facilitation on balance and gait in chronic stroke patients. Physiother Q. 2023, 31:39-44. 10.5114/pq.2023.125746
24. He T, Zhang M, Chen X, Lian Y, Zhang Z, Niu W: Comparing the effects of virtual reality and traditional balance training on trunk control, sitting balance, and activities of daily living in patients with stroke: a randomized controlled trial. BMC Sports Sci Med Rehabil. 2025, 17:294. 10.1186/s13102-025-01323-y
25. Sterne JA, Savović J, Page MJ, et al.: RoB 2: a revised tool for assessing risk of bias in randomised trials . BMJ. 2019, 366:l4898. 10.1136/bmj.l4898