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PHYSICAL THERAPY–GUIDED VIRTUAL REALITY REHABILITATION STRATEGIES TO ENHANCE BALANCE, GAIT PERFORMANCE, AND FUNCTIONAL OUTCOMES IN POST-STROKE PATIENT POPULATIONS

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Abstract

Background: Stroke-related balance and gait impairments significantly reduce independence, mobility, and quality of life. Virtual reality (VR)–based rehabilitation has emerged as a promising strategy to enhance motor recovery by integrating multisensory feedback, task-specific training, and high patient engagement. **Objective:** To synthesize randomized controlled trial (RCT) evidence on the effects of VR-based rehabilitation on balance, gait, and functional outcomes in post-stroke populations. **Methods:** A systematic search of PubMed, Scopus, Web of Science, CINAHL, and CENTRAL (2016–2025) identified RCTs involving VR interventions—immersive, semi-immersive, or non-immersive—delivered alone or combined with conventional physiotherapy. Eligible studies assessed at least one quantitative balance, gait, or functional mobility outcome. Two reviewers independently screened, extracted data, and assessed methodological quality using the PEDro scale. **Results:** Nine RCTs (316 participants) met inclusion criteria. VR modalities included Nintendo Wii–based programs, immersive head-mounted displays, VR-augmented robotic-assisted gait training, and treadmill-based VR gait training. Eight of nine trials demonstrated significant balance gains (e.g., Berg Balance Scale, Functional Reach Test) in VR groups compared with controls. Most studies also reported gait improvements (Timed Up and Go, 10-meter walk velocity, Dynamic Gait Index) and functional benefits in daily living activities, trunk control, and lower limb motor function. VR was generally well tolerated with high adherence and no serious adverse events. One large trial found VR outcomes comparable to high-intensity non-VR treadmill training. **Conclusion:** VR-based rehabilitation is effective for improving balance, gait, and functional outcomes after stroke, particularly when integrated with conventional therapy. Variability in VR systems, dosage, and outcome measures warrants further research to establish standardized protocols.

Keywords: Stroke Rehabilitation, Virtual Reality, Balance, Gait, Functional Outcomes, Randomized Controlled Trials.

INTRODUCTION

Stroke is a leading cause of long-term disability resulting in persistent motor impairments, balance deficits, and gait disturbances that substantially limit functional independence and quality of life (Arienti et al., 2019).

Balance and gait dysfunctions not only impede mobility but also increase the risk of falls, social isolation, and reduced participation in daily activities. Rehabilitation strategies targeting these impairments are therefore a central component of post-stroke care.

Virtual reality (VR) has emerged as an innovative rehabilitation approach that integrates multisensory feedback, task-specific training, and high levels of patient engagement. Evidence indicates that VR-based interventions can enhance motor learning and functional recovery by exploiting neural plasticity and providing enriched, interactive environments for practice (Hao et al., 2021).

Neurophysiological studies demonstrate that VR can induce beneficial changes in cortical connectivity, interhemispheric balance, and motor cortex activation, correlating with improvements in functional outcomes.

Systematic reviews have consistently reported that VR-based rehabilitation yields positive effects on both upper- and lower-limb motor function, balance, and gait in stroke populations, with additional benefits in activities of daily living when compared with conventional therapy alone (Zhang et al., 2021).

Moreover, VR interventions may produce greater improvements when integrated with conventional physiotherapy, as they facilitate repetitive, intensive, and engaging training sessions tailored to individual needs (Cano Porras et al., 2018).

Beyond stroke, VR-based balance and gait rehabilitation has demonstrated efficacy across multiple neurological conditions, including Parkinson’s disease, multiple sclerosis, and traumatic brain injury, further supporting its adaptability and therapeutic potential (Marquer et al., 2014).

However, despite the growing body of evidence, the absence of standardized protocols and variability in methodological quality across studies remain challenges to its widespread clinical adoption.

Given the substantial prevalence of post-stroke balance and gait impairments and the promising evidence for VR-based rehabilitation, this systematic review aims to synthesize randomized controlled trial evidence on the effects of VR-based interventions on balance, gait, and functional outcomes in post-stroke populations.

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METHODOLOGY

A literature search was undertaken to identify randomized controlled trials evaluating the effects of virtual reality–based rehabilitation on balance, gait, and functional outcomes in patients with stroke and related neurological conditions. The databases PubMed, Scopus, Web of Science, CINAHL, and Cochrane Central Register of Controlled Trials (CENTRAL) were searched from 2016 to 2025. Search terms combined Medical Subject Headings (MeSH) and free-text keywords such as virtual reality, exergaming, Nintendo Wii, stroke rehabilitation, gait, balance, functional mobility, and randomized controlled trial, using Boolean operators and truncation to optimize retrieval. The reference lists of relevant reviews and eligible studies were also screened to capture additional publications. Studies were included if they were randomized controlled trials involving adult participants diagnosed with stroke in any recovery phase, or other neurological disorders if balance and gait outcomes were assessed. Eligible interventions consisted of immersive, semi-immersive, or non-immersive virtual reality–based rehabilitation programs, either as stand-alone therapy or combined with conventional physiotherapy, compared with non-VR interventions such as conventional physical therapy, neurodevelopmental therapy, or vestibular rehabilitation.

Only studies reporting at least one quantitative outcome related to balance, gait, or functional mobility were considered. Excluded were quasi-experimental or observational designs, pediatric populations, interventions focusing exclusively on upper limb rehabilitation without gait or balance assessment, and conference abstracts without full-text availability. Two reviewers independently screened titles and abstracts, with potentially relevant full texts retrieved for detailed evaluation. Disagreements were resolved through discussion or consultation with a third reviewer. Data from the included studies were extracted using a standardized form, capturing author and year, country, sample size, participant characteristics, intervention and comparator details, outcome measures, and main findings. Methodological quality was assessed independently by two reviewers using the Physiotherapy Evidence Database (PEDro) scale, which examines aspects such as randomization, allocation concealment, blinding, completeness of follow-up, and statistical reporting. Discrepancies in quality scoring were resolved by consensus. A narrative synthesis approach was used rather than a meta-analysis. Findings were organized by primary outcomes, including balance and gait performance, and secondary outcomes, such as functional independence, dizziness reduction, and participation in daily activities. To aid interpretation, summary tables were constructed to present study characteristics and main findings, allowing comparisons across trials (Table 1 and 2).

RESULTS

A total of nine randomized controlled trials met the inclusion criteria, with 316 participants in different phases of stroke recovery, with one study conducted in Parkinson’s disease patients for comparative purposes. The sample sizes of the included studies ranged from 23 to 68 participants, with intervention durations varying between 4 and 12 weeks.

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Most trials assessed chronic stroke populations, while two focused on subacute stroke patients, and one on Parkinson's disease–related balance impairments.

Intervention Characteristics

The interventions primarily consisted of virtual reality (VR)–based rehabilitation strategies, either as stand-alone therapy or in combination with conventional physical therapy. The VR modalities included Nintendo Wii–based programs, immersive VR systems, VR-augmented robot-assisted gait training (RAGT), treadmill-based VR gait training using GRAIL, virtual reality reflection therapy (VRRT), and other customized VR balance and gait training protocols. Control interventions generally comprised conventional physiotherapy, neurodevelopmental therapy, vestibular rehabilitation therapy (VRT), or functional gait exercises without VR components. Session frequencies ranged from two to five sessions per week, with durations of 30–60 minutes.

Outcomes Assessed

Balance was the most frequently reported primary outcome, measured by the Berg Balance Scale (BBS), Tinetti Performance-Oriented Mobility Assessment (POMA), Functional Reach Test (FRT), and postural sway parameters. Gait and mobility were evaluated using the Timed Up and Go (TUG) test, 10-meter walk velocity, Dynamic Gait Index (DGI), and Functional Gait Assessment (FGA). Additional functional measures included the Motricity Index, Trunk Control Test (TCT), Functional Ambulation Classification (FAC), and activities of daily living indices. Some trials also measured dizziness (Dizziness Handicap Inventory), cognitive dual-task performance, and participation outcomes (Utrecht Scale for Evaluation of Rehabilitation-Participation).

Effects on Balance and Gait

Eight of the nine studies reported statistically significant improvements in balance outcomes in VR groups compared with control interventions. Karasu et al. show greater gains in BBS, FRT, and postural sway measures in the Wii group versus conventional therapy. Marques-Sule et al. reported superior improvements in TUG, POMA, and BBS in the VR plus physiotherapy group. Anwar et al. found VR training enhanced BBS scores and lower extremity motor function compared to conventional physiotherapy. Similarly, in et al. observed significant improvements in both dynamic and static balance parameters with VRRT. Gait performance improvements were consistently observed in VR-based groups in most trials. Kayabinar et al. found VR-augmented RAGT improved dual-task gait speeds, though not significantly superior to RAGT alone in functional outcomes. Peláez-Vélez et al. reported significant gains in gait ability and trunk control with immersive VR. de Rooij et al., however, found no significant difference in community participation or gait outcomes between VR gait training and non-VR treadmill training. Sana et al. noted that VR yielded greater improvements in gait than VRT, whereas VRT was more effective for dizziness reduction. In the Parkinson's disease study by Feng et al., VR rehabilitation outperformed conventional therapy in BBS, TUGT, and FGA scores, supporting VR's applicability to other neurological disorders.

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Functional and Secondary Outcomes

Several trials demonstrated improvements in daily living activities and functional independence following VR interventions. Marques-Sule et al. found within-group gains in Barthel Index and Frenchay Activity Index scores in the VR group. Peláez-Vélez et al. showed significant enhancements in motricity, trunk control, and ambulation classification. Anwar et al. reported improvements in joint range of motion and pain reduction alongside balance and gait gains.

Safety and Feasibility

All studies reported VR-based interventions as safe and well-tolerated, with no serious adverse events. Patient adherence was high, and qualitative feedback highlighted increased motivation and engagement with VR-based therapy compared to conventional approaches.

Table 1: Summary of VR Stroke Rehabilitation Studies

Citation	Sample Size	Study Design	Study Aim	Study Population	Method
Utkan Karasu et al., 2018	23	Randomized Controlled Trial	To investigate the efficacy of Nintendo Wii Fit-based balance rehabilitation as adjunctive therapy to conventional rehabilitation in stroke patients.	Stroke patients meeting inclusion criteria	Random assignment to experimental (Nintendo Wii + conventional rehab) or control (conventional rehab only), assessed at baseline, post-treatment, and 4 weeks follow-up
Kayabinar B et al., 2021	30	Randomized Controlled Single-Blind Trial	To investigate the effects of VR-augmented robot-assisted gait training on dual-task performance and functional measures in chronic stroke patients.	Chronic stroke patients aged 40-65, Functional Ambulation Classification ≥3, MMSE ≥24	Study group: VR + RAGT; Control group: RAGT only; both groups received neurodevelopmental therapy, 12 sessions over 6 weeks
Marques-Sule E et al., 2021	29	Randomized Controlled Clinical Trial	To assess whether a Nintendo Wii-based virtual rehabilitation program added to conventional physical therapy improves functionality, balance, and daily activities in chronic stroke survivors.	Chronic stroke survivors	Two groups: conventional PT only vs VR with Nintendo Wii + conventional PT, 4 weeks, 2 sessions/week

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de Rooij IJM et al., 2021	55	Assessor-Blinded Randomized Controlled Trial	To examine the effect of VR gait training compared to non-VR gait training on participation in community-living people after stroke.	Community-living stroke survivors, 2 weeks to 6 months post-stroke	VRT group: treadmill-based GRAIL VR; Control: treadmill + functional gait exercises; 12 sessions over 6 weeks
Peláez-Vélez FJ et al., 2023	24	Pilot Randomized Controlled Trial	To analyze effects of traditional neurological physiotherapy combined with VR in post-stroke patients.	Stroke patients within 6 months, age 18-80, able to maintain standing	Control: neuro physiotherapy; Experimental: neuro physiotherapy + VR, 6 weeks, VR 3 sessions/week
Anwar N et al., 2021	68	Randomized Clinical Trial	To compare effects of VR training and conventional PT on balance and lower extremity function in stroke patients.	Post-stroke patients	VR group: VR-based balance/lower limb rehab; Control: conventional PT; 60 min, 3 days/week for 6 weeks
Sana V et al., 2023	34	Randomized Controlled Trial	To evaluate comparative effects of vestibular rehabilitation vs VR on dizziness, balance, and gait in subacute stroke patients.	Subacute stroke patients aged 40-70	VRT group vs VR group; 24 sessions, 3/week for 8 weeks
Feng H et al., 2019	28	Single-Blinded Randomized Controlled Trial	To investigate the effect of VR technology on balance and gait in Parkinson's disease patients.	Parkinson's disease patients, age 50-70	Experimental: VR training; Control: conventional PT; 45 min/session, 5 days/week for 12 weeks
In T et al., 2016	25	Randomized Controlled Trial	To investigate whether VR reflection therapy improves balance and gait in chronic stroke patients.	Chronic stroke patients	VRRT group: conventional rehab + VRRT; Control: conventional rehab + placebo VRRT; 30 min/day, 5 days/week for 4 weeks

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Table 2: Main Findings of VR Stroke Rehabilitation Studies

Citation	Balance/Gait Findings	Statistical Outcomes	Conclusion/Implication
Karasu et al., 2018	Both groups improved in balance, but experimental group (Nintendo Wii) showed greater improvement.	Significant group-time interaction in Berg Balance Scale, Functional Reach Test, and postural sway parameters.	Nintendo Wii Fit can be a useful adjunct to traditional rehab for balance in stroke.
Kayabinar B et al., 2021	VR + RAGT improved dual-task gait speeds and performance.	No significant difference between groups in functional measures after treatment.	VR-augmented RAGT can enhance dual-task performance but not superior for overall functional outcomes.
Marques-Sule E et al., 2021	VR with Nintendo Wii improved functionality, balance, and daily activities.	Significant between-group differences in TUG, POMA, BBS.	VR Wii plus conventional PT yields greater gains than PT alone.
de Rooij IJM et al., 2021	No significant difference between VR gait training and non-VR gait training for participation outcomes.	Both interventions were safe and well-tolerated.	VR gait training may be a valuable addition but not superior for participation improvement.
Peláez-Vélez FJ et al., 2023	VR + physiotherapy improved motricity, trunk control, balance, and gait.	Significant improvements in Motricity Index, Trunk Control Test, Tinetti, BBS, and FAC.	VR is a useful complement to traditional therapy for post-stroke recovery.
Anwar N et al., 2021	VR training more effective than conventional PT for restoring balance and lower extremity function.	Significant differences in Berg Balance Scale, Fugl-Meyer motor, joint pain, and ROM.	Supports VR as a better option for balance and lower limb rehab in stroke patients.
Sana V et al., 2023	Both VR and VRT improved dizziness, balance, and gait.	VR more effective for balance and gait; VRT better for dizziness reduction.	Different rehab methods target different post-stroke symptoms effectively.
Feng H et al., 2019	VR rehabilitation improved balance and gait in PD patients.	VR group outperformed conventional PT group in BBS, TUGT, and FGA.	VR offers greater benefits for gait and balance in Parkinson’s disease.
In T et al., 2016	VRRT improved dynamic and static balance, and gait ability more than control.	Significant improvements in BBS, FRT, TUG, postural sway, and 10m walk velocity.	VRRT can enhance lower limb function in chronic stroke beyond conventional therapy.

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DISCUSSION

The present review included nine randomized controlled trials evaluating the effectiveness of virtual reality (VR)–based rehabilitation on balance, gait, and functional outcomes in post-stroke patients. Across these trials, VR interventions ranged from Nintendo Wii–based exergames to immersive head-mounted displays and VR-augmented robotic gait training. Intervention durations varied between 4 and 12 weeks, with sessions delivered two to five times per week. Most studies targeted chronic stroke populations, although some included subacute phases. The primary outcomes assessed included balance measures such as the Berg Balance Scale (BBS) and Functional Reach Test (FRT), and gait measures such as the Timed Up and Go (TUG) test, 10-meter walk velocity, and Dynamic Gait Index (DGI).

The synthesis of results from the included trials indicated that VR interventions generally produced significant improvements in balance and gait compared with control interventions. Eight of the nine trials demonstrated statistically significant gains in BBS scores, walking velocity, or TUG times in VR groups. Some studies also reported functional benefits in activities of daily living, trunk control, and lower limb motor function. The interventions were well tolerated, with no serious adverse events reported, and adherence rates were high. However, one large trial found no significant advantage of VR over high-intensity non-VR treadmill training in participation outcomes, suggesting that the comparative benefit of VR may depend on the quality and intensity of the control intervention. These findings align closely with the fully immersive VR trial by Truijen et al. (2022), which reported superior improvements in gait performance, dynamic balance, and upper limb dexterity compared with standard rehabilitation. Similar to several trials in this review that used immersive or semi-immersive systems, Truijen et al. attributed these benefits to the multisensory feedback and task specificity offered by VR.

The pooled evidence from the meta–meta-analysis by Demeco et al. (2023) also supports our review's conclusions, showing significant improvements in both upper limb function and balance after VR training in stroke survivors. The magnitude of the pooled effect sizes in that analysis parallels the consistent between-group differences observed in our included studies, reinforcing the potential for VR to enhance conventional therapy. Our findings regarding the importance of individualized, intensive training programs are consistent with the observations of Khalid et al. (2023), who identified trunk control and hip extensor strength as predictors of gait recovery. Several trials in our review incorporated lower limb strengthening and trunk stability components alongside VR, potentially explaining their positive gait outcomes.

The recommendations from Hornby et al. (2020) in the clinical practice guideline — advocating moderate- to high-intensity walking training or VR-based gait training for individuals more than six months post-stroke — are directly supported by the majority of trials we analyzed. Many VR protocols in our included studies met these intensity recommendations, which may have contributed to their favorable results.

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Laver et al. (2017) emphasized that gait recovery is essential for reducing fall risk and promoting independence. This aligns with secondary outcomes in our review, where improvements in functional ambulation classification, trunk control, and daily activity participation were frequently reported. Selves et al. (2020) highlighted the value of integrating electromechanical devices and VR into rehabilitation for walking recovery. While not all studies in our review used robotic assistance, those that did — particularly VR-augmented robotic gait training — demonstrated notable improvements in dual-task walking performance and mobility, in line with Selves et al.'s conclusions.

CONCLUSION

We conclude that VR-based rehabilitation is effective in improving balance, gait, and functional outcomes in post-stroke populations. While VR appears more beneficial than conventional therapy in most studies, some evidence indicates comparable outcomes when high-intensity conventional programs are provided. Heterogeneity in VR systems, intervention dosages, and outcome measures limits direct comparison in trials.

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