Research Article

Impact of Immersive Virtual Reality-Based Rehabilitation on Postural Balance, Functional Independence, Intervention Characteristics, and Clinical Outcomes Following Stroke: A Scoping Review

Padmanabhan Suresh Babu Roshan[1], Ajay Kumar[2], Abhilash PV[3], Madhuripu P[4], M. Premkumar[5]

[1] PhD Research Scholar, Srinivas University, Mangalore, and Associate Professor, Laxmi Memorial College of Physiotherapy, Mangalore, Karnataka, India. roshan0388@gmail.com; ORCID 0009-0006-8234-692X.
[2] Professor, Institute of Physiotherapy, Srinivas University, Mangalore, India. drajay@srinivasuniversity.edu.in; ORCID 0000-0002-0633-1471.
[3] PhD Research Scholar, Srinivas University, Mangalore, and Professor, Laxmi Memorial College of Physiotherapy, Mangalore, Karnataka, India. pvabhilashiyc@gmail.com; ORCID 0009-0005-5712-8464.
[4] Associate Professor, Institute of Physiotherapy, Srinivas University, Mangaluru, Karnataka, India. madhuripu@gmail.com; ORCID 0000-0002-7639-4697.
[5] Professor and Head, Institute of Physiotherapy, Srinivas University, City Campus, Pandeshwar, Mangaluru, Karnataka 575001, India. ORCID 0000-0001-6182-2014.
***Corresponding author**: Dr. M. Premkumar, premkumar.ipt@srinivasuniversity.edu.in; 80pk2009@gmail.com;*

Abstract

Background: Immersive virtual reality (IVR) is increasingly used in stroke rehabilitation, yet evidence on postural balance and functional independence is fragmented across mixed virtual reality (VR) modalities.
Objective: To map the evidence on VR-based rehabilitation after stroke, distinguishing immersive from non-immersive systems, with emphasis on balance, functional independence, intervention characteristics and outcomes.
Methods: A scoping review followed Joanna Briggs Institute guidance and PRISMA-ScR reporting. Seven databases, Google Scholar and reference lists were searched from January 2020 to November 2026. Two reviewers independently screened records and charted data.
Results: Of 2,230 records identified, 1,555 were screened after duplicate removal, 132 were assessed in full text and 12 systematic reviews and meta-analyses were included. Pooled estimates indicated small-to-moderate benefits for balance (Berg Balance Scale mean difference 1.35; standardised effect 0.31), gait and daily function, but most reviews combined immersive, semi-immersive, non-immersive or robot-assisted VR. The single review restricted to IVR (34 randomised trials) reported benefits for upper-limb impairment and selected gait parameters, but inconsistent effects on balance, functional performance and quality of life, with low to very low certainty. Evidence specific to middle cerebral artery stroke and dose–response was scarce, and follow-up and safety reporting were inconsistent.
Conclusions: IVR is a promising adjunct to conventional physiotherapy, but its independent contribution to balance and independence is unproven. Trials with defined immersion levels, standardised reporting, extended follow-up and stroke-subtype characterisation are needed.

Keywords: stroke; immersive virtual reality; postural balance; functional independence; neurological rehabilitation; scoping review

1. Introduction

Stroke is a leading cause of acquired neurological disability worldwide. The Global Burden of Disease 2021 analysis estimated 93.8 million people living with stroke, 11.9 million new events and 7.3 million stroke-related deaths, with a substantial share of the burden in low- and middle-income countries (GBD 2021 Stroke Risk Factors Collaborators, 2024). Survivors frequently experience persistent impairments of motor function, postural stability, mobility and independence in activities of daily living (ADL), increasing demands on health systems and caregivers. Middle cerebral artery (MCA) infarction is an important subtype because cortical and subcortical involvement may produce contralateral hemiparesis, altered tone, sensory and visuospatial disturbance and reduced trunk stability. These impairments contribute to asymmetrical weight-bearing, impaired postural adjustment and falls risk, affecting sitting, standing, transfers, gait and stair negotiation. Contemporary guidelines emphasise repetitive, task-specific and functionally relevant practice (Intercollegiate Stroke Working Party, 2023).

The subacute phase offers an opportunity for experience-dependent neuroplasticity and cortical reorganisation, and motor-learning principles favour intensive, task-oriented practice with multisensory and augmented feedback. Conventional physiotherapy, including trunk stabilisation, weight-shifting, balance retraining and gait training, remains fundamental, but its effect depends on treatment intensity, engagement, adherence and therapist availability. Randomised trials in acute and inpatient settings have explored VR-supported training (Lin et al., 2020; Sheehy et al., 2020), although benefits over conventional rehabilitation have not been uniform across functional domains.

Virtual reality (VR) provides computer-generated environments in which users interact through visual, auditory and sensory feedback. Systems are classed as non-immersive, semi-immersive or fully immersive according to sensory engagement. Immersive VR (IVR), typically delivered through head-mounted displays (HMDs) and

motion tracking, offers a greater sense of presence and supports goal-directed repetition, graded difficulty and real-time feedback. Its contribution must be distinguished from that of screen-based gaming.

Systematic reviews suggest that VR may benefit selected outcomes. Zhang et al. (2021) reported benefits for limb motor function, balance, gait, cognition and daily function; Garay-Sánchez et al. (2021) emphasised separating immersive from non-immersive VR when examining static and dynamic balance; and Wu et al. (2021) found improvements in upper-limb function and balance, with variable protocols. Fang et al. (2022) examined VR combined with conventional rehabilitation, and Leong et al. (2022) evaluated virtual, augmented and mixed reality for motor recovery and ADL. Hao et al. (2023) found VR comparable with conventional rehabilitation in early-stage stroke, Shen et al. (2023) reported improvements in balance, walking and Modified Barthel Index scores across 14 trials, and Zhang et al. (2023) supported VR and robot-assisted interventions for balance, gait and daily function. Recent trials have compared vestibular rehabilitation with VR (Sana et al., 2023), combined VR with robot-assisted gait training (Akıncı et al., 2023), examined subacute IVR with brain functional connectivity (Huang et al., 2024), tested touch-controller-based fully immersive balance training (Kwak et al., 2024) and evaluated VR-assisted gait adaptation training (Wang et al., 2024). In the last, walking speed and obstacle avoidance improved, but Barthel Index changes did not differ between groups, suggesting that motor and balance gains do not automatically translate into independence.

Important limitations persist. VR technology, dosage, progression and concurrent therapy vary widely; stroke populations are rarely differentiated by lesion location, severity or vascular territory, so evidence specific to subacute MCA stroke is limited; and many reviews combine immersive and non-immersive interventions (Hao et al., 2024; Khan et al., 2024; Laver et al., 2025). Evidence on sustained benefit, adherence, cybersickness and feasibility is also limited. The Cochrane review by Laver et al. (2025; 190 trials, 7,188 participants) reported moderate- to low-certainty benefits for upper-limb function, balance and activity limitation, but uncertainty for mobility, participation and quality of life, and Zhang et al. (2025) reported small-to-moderate improvements in motor function, daily function and balance. Islam et al. (2026), focusing on IVR (34 trials, 1,200 participants), found inconsistent results for functional performance, balance and quality of life, with low to very low certainty. A scoping review is therefore warranted to map the breadth of evidence, describe technologies and intervention characteristics, identify outcome measures and highlight gaps. This review aimed to map the evidence on VR-based rehabilitation, with attention to immersive systems, for postural balance and functional independence after stroke; to describe technology, dosage, integration with conventional physiotherapy, assessment instruments and outcomes; and to identify evidence on subacute stroke, MCA involvement and the sustainability of improvement at follow-up.

2. Methods

2.1 Design and framework

A scoping review was conducted following the Joanna Briggs Institute (JBI) methodology (Peters et al., 2020; Aromataris et al., 2024) and reported according to the PRISMA extension for scoping reviews (PRISMA-ScR) (Tricco et al., 2018). The protocol was developed before screening and deposited in the Open Science Framework; deviations were documented. Ethical approval was not required for synthesis of published literature.

2.2 Review questions

Questions were framed using the Population–Concept–Context (PCC) framework: adults with stroke (population); VR-based rehabilitation, distinguishing immersive systems (concept); and neurological rehabilitation across recovery stages (context). The primary question was: what is the available evidence on VR-based rehabilitation, particularly immersive VR, for improving postural balance and functional independence after stroke? Secondary questions addressed technology and immersion level; frequency, duration, intensity and progression; outcome measures; reported outcomes and follow-up; and gaps concerning subacute stroke and MCA involvement.

2.3 Eligibility criteria

Eligible reports were systematic reviews and meta-analyses (including network meta-analyses, umbrella reviews and meta-reviews) of VR-based rehabilitation in adults (≥18 years) with ischaemic or haemorrhagic stroke at any recovery stage. VR could be delivered alone or alongside conventional physiotherapy, balance or gait training or functional task practice, and reviews were required to report at least one outcome of balance, functional independence, gait, mobility, ADL, motor recovery, feasibility or safety. Immersive (HMD-based), semi-immersive and non-immersive systems were classified as reported by each review. Primary studies, study protocols, scoping and narrative reviews, editorials, commentaries, non-stroke populations and non-VR interventions were excluded; primary trials were used only to contextualise findings. Information on MCA stroke and the subacute phase was sought separately.

2.4 Search strategy

PubMed/MEDLINE, Scopus, Web of Science, Embase, CINAHL, the Cochrane Central Register of Controlled Trials (CENTRAL) and the Physiotherapy Evidence Database (PEDro) were searched from January 2020 to November 2026, supplemented by Google Scholar and reference lists of relevant articles. Strategies combined MeSH or database-specific subject headings with free-text terms for stroke, middle cerebral artery stroke, subacute stroke, immersive and fully immersive virtual reality, head-mounted display, balance, postural control, functional independence, activities of daily living and gait, using Boolean operators and adapted to each database. Reporting followed PRISMA-S (Rethlefsen et al., 2021).

2.5 Selection and data charting

Records were exported to a reference manager and duplicates removed. Two reviewers independently screened titles and abstracts, then full texts, after pilot screening to align application of the criteria; disagreements were resolved by consensus or a third reviewer, and reasons for full-text exclusion were recorded. Two reviewers independently charted data using a piloted Microsoft Excel form capturing: study identification; design and scope; population (age, stroke type, MCA involvement, recovery stage); VR technology and immersion level; intervention frequency, intensity and duration; comparators; balance outcomes (Berg Balance Scale [BBS], Timed Up and Go [TUG], Functional Reach Test [FRT]); functional outcomes (Barthel Index [BI], Modified Barthel Index [MBI], Functional Independence Measure [FIM]); gait and mobility; follow-up; main findings and reported certainty of evidence; and feasibility and safety.

2.6 Appraisal and synthesis

Formal critical appraisal is optional in scoping reviews (Peters et al., 2020) and was not undertaken; the certainty of evidence reported by the included reviews was charted where available. Data were summarised using frequencies and tables and a narrative synthesis organised into four domains: (1) postural balance, (2) functional independence and ADL, (3) gait and mobility, and (4) feasibility, adherence and safety. Follow-up findings and evidence concerning MCA and subacute stroke were mapped separately. No pooled effect was estimated, as the aim was to map rather than quantify effectiveness.

3. Results

3.1 Study selection

The searches identified 2,230 records: 2,058 from the seven databases (PubMed/MEDLINE n = 412, Scopus n = 538, Web of Science n = 386, Embase n = 342, CINAHL n = 188, CENTRAL n = 132, PEDro n = 60) and 172 from other sources (Google Scholar n = 126; reference lists n = 46). After 675 duplicates were removed, 1,555 records were screened and 1,417 excluded. Of 138 full-text reports sought, six could not be retrieved and 132 were assessed; 120 were excluded because they were not systematic reviews or meta-analyses (n = 44), involved non-stroke populations (n = 18), non-VR interventions (n = 21) or ineligible outcomes (n = 16), or for other reasons such as protocols, scoping reviews and commentaries (n = 21). Twelve systematic reviews and meta-analyses were included (Figure 1).

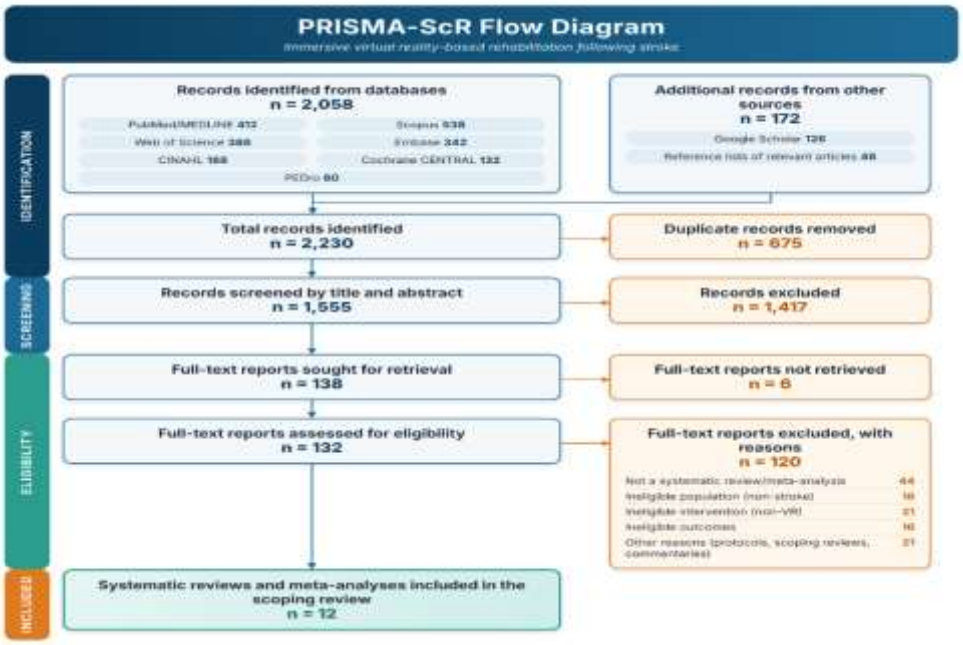


Figure 1. PRISMA-ScR flow diagram of study identification, screening, eligibility and inclusion.

3.2 Characteristics of the included reviews

Table 1 summarises the principal included reviews. They comprised pairwise and network meta-analyses, a Cochrane review, an umbrella review and a meta-review, ranging from 10 primary studies (Garay-Sánchez et al., 2021) to 190 randomised trials (Laver et al., 2025). Only Islam et al. (2026) was restricted to IVR; the remaining reviews addressed VR broadly, pooling immersive, semi-immersive and non-immersive VR, mixed reality or robot-assisted VR, so effects could not be attributed to immersion.

Table 1. Characteristics and main findings of principal systematic reviews and meta-analyses of VR-based stroke rehabilitation

No.	Reference	Design and scope	Main findings	Relevance to immersive VR
1	Garay-Sánchez et al. (2021)	SR/MA; 10 studies (9 pooled)	Immersive and non-immersive VR for static and dynamic balance; seven studies reported significant improvement, three did not.	Supports a balance benefit but pools immersion levels; cannot isolate IVR.
2	Fang et al. (2022)	SR/MA of RCTs	Conventional rehabilitation plus VR improved upper-limb motor outcomes; no significant pooled difference for FIM or BBS.	Motor gains do not necessarily translate into balance or independence gains.
3	Leong et al. (2022)	SR/MA of virtual, augmented and mixed reality	Benefits for selected upper-limb and ADL outcomes; technologies heterogeneous.	Informs functional recovery; mixed-reality scope limits IVR specificity.
4	Shen et al. (2023)	SR/MA; 14 RCTs, 423 participants	BBS MD 1.35; TUG MD −0.81; FRT MD 3.06; 10-m walk MD −1.53; MBI MD 5.26.	Supports balance, mobility and ADL benefits; VR not restricted to immersive systems.
5	Zhang et al. (2023)	Network MA; 52 RCTs, 1,559 participants	Robot-assisted plus VR ranked highest for balance (MD 4.10; 95% CI 0.43–7.67); VR ranked highly for gait velocity and daily function.	Includes robot-assisted and conventional VR; does not isolate HMD-based IVR.
6	Hao et al. (2024)	Umbrella review of SRs	Effectiveness across stroke outcomes; variable study quality and intervention characteristics.	Identifies broad patterns and methodological limitations.
7	Khan et al. (2024)	Meta-review of SRs	Evidence for upper- and lower-limb rehabilitation, gait and balance.	Broad context; no immersive-specific evidence.
8	Laver et al. (2025)	Cochrane SR; 190 RCTs, 7,188 participants	Benefits for selected outcomes; uncertainty for mobility, participation and quality of life.	High-level evidence on VR overall; not restricted to IVR.
9	Zhang et al. (2025)	MA; 27 RCTs, 877 participants	Lower-limb d = 0.41; upper-limb d = 0.25; daily function d = 0.24; balance d = 0.31.	Small-to-moderate effects; not attributable specifically to IVR.
10	Islam et al. (2026)	SR/MA focused on IVR; 34 RCTs	Improved upper-limb motor impairment and selected gait parameters; inconsistent function, balance and quality of life; low to very low certainty.	Most directly relevant; separates impairment-level outcomes from balance and independence.

ADL, activities of daily living; BBS, Berg Balance Scale; CI, confidence interval; d, standardised effect size; FIM, Functional Independence Measure; FRT, Functional Reach Test; HMD, head-mounted display; IVR, immersive virtual reality; MA, meta-analysis; MBI, Modified Barthel Index; MD, mean difference; RCT, randomised controlled trial; SR, systematic review; TUG, Timed Up and Go; VR, virtual reality.

3.3 Postural balance

Balance was the most consistently examined domain. Shen et al. (2023) reported improvements in BBS (MD 1.35), TUG (MD −0.81) and FRT (MD 3.06), and Zhang et al. (2025) found a small effect on balance (d = 0.31). In the network meta-analysis by Zhang et al. (2023), robot-assisted rehabilitation combined with VR ranked highest for balance (MD 4.10). Garay-Sánchez et al. (2021) found significant improvement in seven of ten studies of immersive and non-immersive VR. By contrast, Fang et al. (2022) found no significant pooled difference in BBS, and Islam et al. (2026) judged the effect of IVR on balance inconsistent and not robustly quantifiable. Among primary trials, Kwak et al. (2024) reported significant BBS and TUG improvements after touch-controller-based fully immersive training in chronic stroke.

3.4 Functional independence

Evidence for independence was less consistent. Shen et al. (2023) reported an MBI improvement (MD 5.26) and Zhang et al. (2025) a small effect on daily function (d = 0.24), whereas Fang et al. (2022) found no significant pooled difference in FIM. Leong et al. (2022) reported benefit for selected ADL outcomes, but the Cochrane review identified uncertainty for mobility, participation and quality of life (Laver et al., 2025), and the IVR-specific review described inconsistent functional performance findings (Islam et al., 2026). In a primary trial, Barthel Index changes did not differ between VR-assisted and overground gait training despite gains in walking speed (Wang et al., 2024).

3.5 Gait and mobility

Shen et al. (2023) reported improved 10-metre walking performance (MD −1.53), and Zhang et al. (2023) ranked VR highly for gait velocity. Islam et al. (2026) found small but significant effects on selected gait parameters, consistent with gait improvements after fully immersive training (Kwak et al., 2024) and gains in walking speed and obstacle avoidance after VR-assisted gait adaptation (Wang et al., 2024). Gait measures and reporting were not standardised.

3.6 Intervention characteristics, recovery stage and follow-up

Reviews described wide variation in immersion level, HMD and tracking systems, controllers, session duration, frequency, total intervention period and concurrent conventional therapy. The Cochrane review indicated that VR is often delivered in addition to usual care, increasing overall therapy exposure (Laver et al., 2025). Recovery stage was rarely analysed separately: Huang et al. (2024) investigated subacute stroke, including a 12-week follow-up, whereas Kwak et al. (2024) investigated chronic stroke. No included review provided a distinct synthesis of MCA territory stroke, and longer follow-up (three or six months) was inconsistently reported.

3.7 Feasibility and safety

The Cochrane review reported relatively few and generally mild adverse events in studies that monitored safety (Laver et al., 2025). Reporting of adherence, acceptability, cybersickness, dizziness, visual discomfort, fatigue and attrition remained inconsistent across the literature. The evidence map and research gaps are summarised in Table 2.

Table 2. Evidence map and research gaps in immersive VR rehabilitation after stroke

Evidence domain	Current evidence	Identified research gap
Postural balance	Kwak et al. (2024) evaluated fully immersive balance training; reviews report balance benefits but often pool immersive and non-immersive VR.	Adequately powered trials of clearly defined HMD-based systems with validated balance measures.
Functional independence	Huang et al. (2024) assessed the Barthel Index with upper-limb recovery; reviews report variable ADL findings.	Prespecified BI, MBI or FIM outcomes to test whether motor gains translate into independence.
Gait and mobility	Kwak et al. (2024) examined gait parameters; Shen et al. (2023) and Islam et al. (2026) report walking outcomes.	Standardised gait measures and longer-term assessment of walking capacity.
Recovery stage	Huang et al. (2024) studied subacute stroke; Kwak et al. (2024) studied chronic stroke.	Studies across acute, subacute and chronic stages.
Technology characteristics	HMD-based and other VR platforms are used interchangeably across the literature.	Consistent reporting of headset specification, field of view, tracking, interaction and immersion.

Evidence domain	Current evidence	Identified research gap
Intervention dosage	Duration and frequency vary across studies and reviews.	Dose–response studies of session length, weekly frequency, total exposure and progression.
Follow-up	Huang et al. (2024) included a 12-week follow-up; longer follow-up is inconsistently reported.	Three- and six-month assessments to establish sustainability.
Feasibility and safety	Reviews suggest IVR is a useful adjunct, but adverse-event and acceptability reporting varies.	Standardised reporting of cybersickness, dizziness, fatigue, falls, adherence and tolerance.
MCA territory stroke	No sufficiently clear, separate synthesis of immersive VR outcomes in MCA stroke was identified.	Report vascular territory, lesion location, severity and associated impairments.

ADL, activities of daily living; BI, Barthel Index; FIM, Functional Independence Measure; HMD, head-mounted display; MBI, Modified Barthel Index; MCA, middle cerebral artery; VR, virtual reality.

4. Discussion

4.1 Principal findings

This scoping review mapped systematic-review evidence on VR-based rehabilitation for postural balance, functional independence and mobility after stroke. Three findings emerged. First, reviews generally reported small-to-moderate benefits for balance, gait and daily function (Shen et al., 2023; Zhang et al., 2025), but only one was restricted to IVR, and its balance and functional findings were inconsistent (Islam et al., 2026). Second, impairment-level outcomes, particularly upper-limb function and selected gait parameters, were more consistently improved than independence, participation and quality of life (Islam et al., 2026; Laver et al., 2025). Third, evidence specific to MCA stroke, dose–response relationships and long-term follow-up was limited (Table 2).

4.2 Balance, independence and the role of immersion

VR-based balance training offers weight shifting, reaching, trunk movement and postural adjustment with continuous visual feedback, which may support sensorimotor integration. The pooled balance effects were modest (Shen et al., 2023),. Improved balance did not necessarily accompany improved independence: no significant pooled FIM or BBS difference was found by Fang et al. (2022), and BI was unchanged between groups in one trial despite gait gains (Wang et al., 2024). This is plausible because ADL performance also depends on cognition, sensory integration, motor control, environmental accessibility and psychological confidence. Balance (BBS, TUG, FRT) and independence (BI, MBI, FIM) should therefore be assessed together rather than inferred from one another.

A second interpretive difficulty is separating immersion from dose. VR is frequently added to usual care and so increases therapy exposure (Laver et al., 2025); apparent benefits may reflect greater repetition, engagement and practice time rather than the immersive technology itself. Because most reviews pooled immersive and non-immersive systems (Garay-Sánchez et al., 2021; Hao et al., 2024; Khan et al., 2024), the independent contribution of immersion cannot yet be established. Dose-matched comparisons are needed.

4.3 Subacute stroke, neuroplasticity and MCA involvement

Interactive virtual environments allow repetitive, goal-directed and progressively challenging practice consistent with motor-learning principles. Huang et al. (2024) linked subacute IVR to upper-limb recovery and changes in functional connectivity, providing a basis for mechanistic hypotheses, which nevertheless require confirmation in larger, balance-focused studies. Generalisation is limited because studies differ in severity, lesion characteristics, treatment duration and outcomes. MCA infarction can produce varied motor, sensory, perceptual and postural deficits, yet no included review separated MCA stroke from mixed populations. Future studies should report vascular territory, lesion location, neurological severity, baseline function and recovery stage.

4.4 Sustainability, feasibility and implementation

Most evidence concerns immediate post-intervention change. The low to very low certainty reported for IVR (Islam et al., 2026) and the single 12-week follow-up identified (Huang et al., 2024) show that maintenance of gains is poorly established; three- and six-month assessments of independence, balance confidence, community mobility and participation are required. Adverse events appear infrequent and mild (Laver et al., 2025), yet systematic reporting is needed. Cybersickness, dizziness, equipment cost, maintenance and therapist training

may restrict implementation, particularly in resource-constrained settings, where much of the stroke burden lies (GBD 2021 Stroke Risk Factors Collaborators, 2024).

4.5 Clinical implications

Current evidence supports IVR as a complementary option within comprehensive rehabilitation, adding opportunities for repetitive, interactive practice of balance, trunk control, weight-shifting and functional tasks. Use should be guided by cognitive status, visual tolerance, functional capacity, goals and equipment availability, while conventional physiotherapy remains essential.

4.6 Strengths and limitations

Strengths include an a priori protocol, adherence to JBI and PRISMA-ScR guidance, a multi-database search and independent duplicate screening and charting. Limitations should be noted. The unit of analysis was the systematic review, so primary IVR trials not yet synthesised may be missed, and overlap of primary trials among reviews was not quantified. Reviews were not formally appraised, differed in quality and definitions of immersion, and findings describe the distribution of evidence rather than effectiveness.

5. Conclusion

Evidence on VR-based stroke rehabilitation is growing and suggests small-to-moderate benefits for balance, gait and daily function, but most of it does not isolate immersive systems, and the effects of IVR on balance, functional independence and sustained recovery are inconsistent and of low certainty. Priority research includes adequately powered, dose-matched randomised trials with clearly specified immersion level, standardised balance and independence outcomes, three- and six-month follow-up, systematic safety reporting and detailed characterisation of subacute and MCA stroke populations.

References

1. Akıncı, M., Burak, M., Yaşar, E., & Kılıç, R. T. (2023). The effects of robot-assisted gait training and virtual reality on balance and gait in stroke survivors: A randomized controlled trial. *Gait & Posture, 103*, 215–222. https://doi.org/10.1016/j.gaitpost.2023.05.013

2. Aromataris, E., Lockwood, C., Porritt, K., Pilla, B., & Jordan, Z. (Eds.). (2024). *JBI manual for evidence synthesis*. JBI. https://doi.org/10.46658/JBIMES-24-01

3. Fang, Z., Wu, T., Lv, M., Chen, M., Zeng, Z., Qian, J., Chen, W., Jiang, S., & Zhang, J. (2022). Effect of traditional plus virtual reality rehabilitation on prognosis of stroke survivors: A systematic review and meta-analysis of randomized controlled trials. *American Journal of Physical Medicine & Rehabilitation, 101*(3), 217–228. https://doi.org/10.1097/PHM.0000000000001775

4. Garay-Sánchez, A., Suarez-Serrano, C., Ferrando-Margelí, M., Jimenez-Rejano, J. J., & Marcén-Román, Y. (2021). Effects of immersive and non-immersive virtual reality on the static and dynamic balance of stroke patients: A systematic review and meta-analysis. *Journal of Clinical Medicine, 10*(19), 4473. https://doi.org/10.3390/jcm10194473

5. GBD 2021 Stroke Risk Factors Collaborators. (2024). Global, regional, and national burden of stroke and its risk factors, 1990–2021: A systematic analysis for the Global Burden of Disease Study 2021. *The Lancet Neurology, 23*(10), 973–1003. https://doi.org/10.1016/S1474-4422(24)00369-7

6. Hao, J., Yao, Z., Harp, K., Gwon, Y., Chen, Z., & Siu, K.-C. (2023). Effects of virtual reality in the early-stage stroke rehabilitation: A systematic review and meta-analysis of randomized controlled trials. *Physiotherapy Theory and Practice, 39*(12), 2569–2588. https://doi.org/10.1080/09593985.2022.2094302

7. Hao, J., Crum, G., & Siu, K.-C. (2024). Effects of virtual reality on stroke rehabilitation: An umbrella review of systematic reviews. *Health Science Reports, 7*(9), e70082. https://doi.org/10.1002/hsr2.70082

8. Huang, Q., Jiang, X., Jin, Y., Wu, B., Vigotsky, A. D., Fan, L., Gu, P., Tu, W., Huang, L., & Jiang, S. (2024). Immersive virtual reality-based rehabilitation for subacute stroke: A randomized controlled trial. *Journal of Neurology, 271*(3), 1256–1266. https://doi.org/10.1007/s00415-023-12060-y

9. Intercollegiate Stroke Working Party. (2023). *National clinical guideline for stroke for the United Kingdom and Ireland*. Royal College of Physicians. https://www.strokeguideline.org

10. Islam, D., Marklund, I., von Euler, M., & Jaensson, M. (2026). Effects of immersive virtual reality on limb motor function, balance, gait and quality of life after stroke: A systematic review and meta-analysis. *PLOS ONE, 21*(7), e0351114. https://doi.org/10.1371/journal.pone.0351114

11. Khan, A., Imam, Y. Z., Muneer, M., Al Jerdi, S., & Gill, S. K. (2024). Virtual reality in stroke recovery: A meta-review of systematic reviews. *Bioelectronic Medicine, 10*, 23. https://doi.org/10.1186/s42234-024-00150-9

12. Kwak, H.-D., Chung, E., & Lee, B.-H. (2024). The effect of balance training using touch controller-based fully immersive virtual reality devices on balance and walking ability in patients with stroke: A pilot randomized controlled trial. *Medicine, 103*(27), e38578. https://doi.org/10.1097/MD.0000000000038578

13. Laver, K. E., Lange, B., George, S., Deutsch, J. E., Saposnik, G., Chapman, M., & Crotty, M. (2025). Virtual reality for stroke rehabilitation. *Cochrane Database of Systematic Reviews, 2025*(6), CD008349. https://doi.org/10.1002/14651858.CD008349.pub5
14. Leong, S. C., Tang, Y. M., Toh, F. M., & Fong, K. N. K. (2022). Examining the effectiveness of virtual, augmented, and mixed reality (VAMR) therapy for upper limb recovery and activities of daily living in stroke patients: A systematic review and meta-analysis. *Journal of NeuroEngineering and Rehabilitation, 19*, 93. https://doi.org/10.1186/s12984-022-01071-x
15. Lin, R.-C., Chiang, S.-L., Heitkemper, M. M., Weng, S.-M., Lin, C.-F., Yang, F.-C., & Lin, C.-H. (2020). Effectiveness of early rehabilitation combined with virtual reality training on muscle strength, mood state, and functional status in patients with acute stroke: A randomized controlled trial. *Worldviews on Evidence-Based Nursing, 17*(2), 158–167. https://doi.org/10.1111/wvn.12429
16. Peters, M. D. J., Marnie, C., Tricco, A. C., Pollock, D., Munn, Z., Alexander, L., McInerney, P., Godfrey, C. M., & Khalil, H. (2020). Updated methodological guidance for the conduct of scoping reviews. *JBI Evidence Synthesis, 18*(10), 2119–2126. https://doi.org/10.11124/JBIES-20-00167
17. Rethlefsen, M. L., Kirtley, S., Waffenschmidt, S., Ayala, A. P., Moher, D., Page, M. J., & Koffel, J. B. (2021). PRISMA-S: An extension to the PRISMA statement for reporting literature searches in systematic reviews. *Systematic Reviews, 10*, 39. https://doi.org/10.1186/s13643-020-01542-z
18. Sana, V., Ghous, M., Kashif, M., Albalwi, A., Muneer, R., & Zia, M. (2023). Effects of vestibular rehabilitation therapy versus virtual reality on balance, dizziness, and gait in patients with subacute stroke: A randomized controlled trial. *Medicine, 102*(24), e33203. https://doi.org/10.1097/MD.0000000000033203
19. Shen, J., Gu, X., Yao, Y., Li, L., Shi, M., Li, H., Sun, Y., Bai, H., Li, Y., & Fu, J. (2023). Effects of virtual reality-based exercise on balance in patients with stroke: A systematic review and meta-analysis. *American Journal of Physical Medicine & Rehabilitation, 102*(4), 316–322. https://doi.org/10.1097/PHM.0000000000002096
20. Sheehy, L., Taillon-Hobson, A., Sveistrup, H., Bilodeau, M., Yang, C., & Finestone, H. (2020). Sitting balance exercise performed using virtual reality training on a stroke rehabilitation inpatient service: A randomized controlled study. *PM&R, 12*(8), 754–765. https://doi.org/10.1002/pmrj.12331
21. Tricco, A. C., Lillie, E., Zarin, W., O'Brien, K. K., Colquhoun, H., Levac, D., … Straus, S. E. (2018). PRISMA extension for scoping reviews (PRISMA-ScR): Checklist and explanation. *Annals of Internal Medicine, 169*(7), 467–473. https://doi.org/10.7326/M18-0850
22. Wang, X., Qiu, J., Zhou, Y., Liu, W., Zhang, S., Gong, Y., Jiang, W., Fang, L., Ji, C., Yao, X., Wang, W., Xu, S., Lu, Z., & Ding, Y. (2024). Effects of virtual reality-assisted and overground gait adaptation training on balance and walking ability in stroke patients: A randomized controlled trial. *American Journal of Physical Medicine & Rehabilitation, 103*(6), 480–487. https://doi.org/10.1097/PHM.0000000000002374
23. Wu, J., Zeng, A., Chen, Z., Wei, Y., Huang, K., Chen, J., & Ren, Z. (2021). Effects of virtual reality training on upper limb function and balance in stroke patients: Systematic review and meta-meta-analysis. *Journal of Medical Internet Research, 23*(10), e31051. https://doi.org/10.2196/31051
24. Zhang, B., Li, D., Liu, Y., Wang, J., & Xiao, Q. (2021). Virtual reality for limb motor function, balance, gait, cognition and daily function of stroke patients: A systematic review and meta-analysis. *Journal of Advanced Nursing, 77*(8), 3255–3273. https://doi.org/10.1111/jan.14800
25. Zhang, B., Wong, K. P., Kang, R., Fu, S., Qin, J., & Xiao, Q. (2023). Efficacy of robot-assisted and virtual reality interventions on balance, gait, and daily function in patients with stroke: A systematic review and network meta-analysis. *Archives of Physical Medicine and Rehabilitation, 104*(10), 1711–1719. https://doi.org/10.1016/j.apmr.2023.04.005
26. Zhang, W., Lyu, S., & Zhang, S. (2025). Virtual reality technology for upper and lower limb motor function, daily function, and balance in stroke patients: A meta-analysis of randomized controlled trials. *PeerJ, 13*, e20402. https://doi.org/10.7717/peerj.20402