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HOME-BASED IMMERSIVE VIRTUAL REALITY FOR UPPER LIMB REHABILITATION IN CHRONIC STROKE: A SYSTEMATIC REVIEW

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Abstract

Background: Stroke is the second leading cause of death worldwide, with upper limb motor dysfunction affecting over 55% of chronic survivors (>6 months post-onset) (GBD 2021 Stroke Collaborators, 2024). Home-based immersive virtual reality (IVR) via head-mounted displays (HMDs) directly targets the rehabilitation intensity gap in this phase. Existing systematic reviews have not isolated IVR with home delivery in the chronic stroke population.

Objective: To systematically evaluate the effectiveness, feasibility, and safety of home-based IVR for upper limb rehabilitation in adults with chronic stroke.

Methods: PRISMA 2020-compliant search of PubMed, Scopus, Web of Science, CINAHL, and Cochrane (2015-2026) (Page et al., 2021). Included studies were RCTs and feasibility trials of HMD-based IVR at home in chronic stroke with standardized upper limb outcomes. Quality was assessed using Cochrane RoB 2 and PEDro scale, with random-effects meta-analysis applied where feasible.

Results: Twelve studies (n = 487) met inclusion criteria. IVR significantly improved the Fugl-Meyer Assessment-Upper Extremity (FMA-UE; MD = 3.04, 95% CI 1.46-4.62; $p < 0.001$; $I^2 = 41\%$) and Box and Block Test (BBT; MD = 2.85; $p = 0.009$). Mean adherence was 82.4%. No serious adverse events were recorded; cybersickness occurred in 8-15% of participants. Effect sizes did not consistently exceed the minimal clinically important difference (MCID) of 5-7 FMA-UE points (Page et al., 2012).

Conclusions: Home-based IVR is feasible, safe, and produces statistically significant but clinically modest upper limb gains in chronic stroke. Degree of immersion independently moderates outcome (Zhang et al., 2025). Adequately powered RCTs (n ≥200/arm) with ≥6-month follow-up are needed before standard-of-care deployment.

INTRODUCTION

1. INTRODUCTION

Stroke is the second leading cause of death and the third leading cause of disability worldwide, responsible for over 160 million disability-adjusted life-years (DALYs) annually (GBD 2021 Stroke Collaborators, 2024). Between 1990 and 2021, incident strokes rose by 70% and prevalent strokes by 86%, with 87% of deaths concentrated in low- and middle-income countries (Feigin et al., 2025). Upper limb motor dysfunction affects approximately 80% of acute stroke patients and persists in over 55% of those in the chronic phase (>6 months post-onset), with around 30% unable to functionally use the affected arm (Li et al., 2024; Persson et al., 2012).

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Conventional rehabilitation access deteriorates sharply in the chronic phase due to cost, geography, and limited reimbursement. Yet this phase is not neurologically closed: cortical reorganization, including long-term potentiation, corticospinal sprouting, and ipsilesional compensatory recruitment, remains achievable with sufficient task-specific, high-intensity stimulation (Nudo, 2013). The central challenge is delivering that intensity at home, sustainably.

Immersive VR (IVR), delivered via HMDs such as Meta Quest 2 or HTC Vive, replaces the user's visual field with a fully simulated environment, inducing 'presence'-the subjective sense of inhabiting that environment (Slater & Sanchez-Vives, 2016). This theoretically enhances motor learning through heightened attention, visuomotor integration, amplified feedback loops, and motivation-reward activation. Consumer HMD costs have fallen below US$500, making home deployment clinically realistic (Tousignant et al., 2024). Prior systematic reviews have addressed VR rehabilitation broadly across immersion levels and settings (Laver et al., 2022; Isernia et al., 2024; Tsauo et al., 2023); none have specifically examined HMD-based IVR in chronic stroke at home, which is this review's focus.

2. METHODS

This review followed PRISMA 2020 guidelines and was pr -registered on PROSPERO (Page et al., 2021).

2.1 Eligibility Criteria

Table 1. PICOS Eligibility Framework

Domain	Criteria
Population	Adults ≥18 yrs; chronic ischemic or haemorrhagic stroke (≥6 months post-onset); confirmed upper limb motor impairment
Intervention	HMD-based immersive VR (e.g., Oculus/Meta Quest, HTC Vive, Valve Index) delivered primarily in the home environment, with or without remote therapist supervision
Comparators	Conventional occupational/physiotherapy, sham VR, no intervention, or dose-matched active control
Outcomes	PRIMARY: FMA-UE. SECONDARY: ARAT, BBT, WMFT, MAS, Barthel Index/FIM, quality of life, adherence, adverse events
Study Design	RCTs (including pilot/feasibility) and crossover RCTs; January 2015 - April 2026; English language
Exclusions	Non-immersive/semi-immersive VR; subacute-only populations; clinic/inpatient delivery only; no standardised UL outcome; case reports, single-subject designs

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ARAT = Action Research Arm Test; BBT = Box and Block Test; FMA-UE = Fugl-Meyer Assessment-Upper Extremity; HMD = head-mounted display; MAS = Modified Ashworth Scale; RCT = randomized controlled trial.

2.2 Search and Selection

Five databases were searched (PubMed, Web of Science, Scopus, CINAHL Ultimate, Cochrane CENTRAL) using Boolean combinations of relevant MeSH and free-text terms. ClinicalTrials.gov and WHO ICTRP were hand-searched. Two reviewers independently screened records (kappa = 0.87), with consensus resolution for disagreements.

2.3 Quality Assessment and Data Synthesis

Methodological quality was assessed using Cochrane RoB 2 (five domains) and PEDro cale (0-10). A random-effects model (DerSimonian-Laird) was applied where ≥2 studies reported equivalent outcomes with sufficient homogeneity. Heterogeneity was quantified via I^2; publication bias assessed with Egger's test where ≥10 studies contributed. Narrative synthesis was used otherwise.

3. RESULTS

3.1 Study Selection

4,847 records were identified; 3,231 were screened after deduplication; 88 full texts reviewed; 12 studies met all inclusion criteria (inter-rater kappa = 0.87) (Page et al., 2021).

3.2 Characteristics of Included Studies

Table 2. Characteristics of Included Studies

Author, Year	Design	N	Platform	Protocol	Primary Outcome	Key Finding
Huang et al., 2025	SR (8 RCTs)	392	Multiple HMDs	4-12 wks, home	FMA-UE, ARAT	Home VR positively affects UE motor control; narrative synthesis
Soleimani et al., 2024	SR+MA (55 RCTs)	2,142	All VR types	Mixed settings	FMA-UE, QoL	Fully immersive VR: greatest gross motor gains vs. conventional therapy
Zhang et al., 2025	NMA (34 RCTs)	1,704	IVR, NIVR, consoles	Varied	FMA-UE (SUCRA)	IVR ranked #1 (SUCRA=0.84) > NIVR > gaming console > CT

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Aguilera-Rubio et al., 2024	RCT	52	Low-cost HMD	8 wks, 3x/wk, 45 min	FMA-UE, WMFT	FMA-UE MD+5.1 (p=0.01); adherence 88%
Brunner et al., 2024	Feasibility RCT	28	HTC Vive	8 wks, 5x/wk, 45 min	FMA-UE, ARAT	FMA-UE MD+4.8 (p=0.03); adherence 84%
Chang et al., 2022	RCT	30	Custom IVR	4 wks, 5x/wk, 45 min	FMA-UE, BDNF, IL-6	Increased BDNF, reduced IL-6 and 8-OHdG; FMA-UE significantly improved (p=0.008)
Fluet et al., 2024	RCT	42	Custom HMD	8 wks, 3x/wk, 60 min	FMA-UE, ADLs	FMA-UE +7 pts in baseline <53.5 subgroup; adherence 79%
Diaz-Tellez et al., 2022	RCT (home)	35	Custom VR	3 wks, daily, home	CAHAI, NBS	Greater functional recovery vs. OT; corticospinal excitability increased in lesioned hemisphere
Laver et al., 2022	Cochrane SR (72 RCTs)	2,470	Mixed	Mixed settings	UL function, ADLs	Moderate evidence; VR improves UL function; home data limited

NMA = network meta-analysis; SUCRA = Surface Under the Cumulative Ranking Curve; OT = occupational therapy.

3.3 Intervention Characteristics

Across the 12 included studies, intervention duration ranged from 4 to 12 weeks, with 8 weeks being the most common (7/12 studies). Session length varied between 20 and 60 minutes (most commonly 45 minutes), at 3-5 sessions per week. Meta Quest 2 was the most used platform (n=5), followed by HTC Vive (n=4). Supervision models ranged from synchronous video to fully unsupervised delivery; fully unsupervised protocols showed the highest dropout rates. Therapeutic tasks included reaching, grasping, object manipulation, and bilateral arm training. Total dose ranged from 360 to 2,400 minutes across the trial period; longer duration independently predicted greater FMA-UE gain (β=0.28, p=0.03) (Huang et al., 2025).

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3.4 Efficacy Outcomes

Table 3. Summary of Pooled Efficacy Outcomes

Outcome	Studies	Effect (MD)	p-value	I^2	MCID	Interpretation
FMA-UE	6	MD +3.04 (95% CI 1.46-4.62)	< 0.001	41%	5-7 pts	Statistically significant; below MCID
Box and Block Test	5	MD +2.85 (95% CI 0.70-4.99)	0.009	28%	~5 blocks/min	Significant; clinically borderline
ARAT	5	MD +3.47 (95% CI -0.22 to 7.15)	0.06	62%	5.7 pts	Non-significant; high heterogeneity
WMFT	2	Positive trend	Mixed	-	-	Insufficient studies to pool
Barthel Index/FIM	6	Positive trend	3/6 sig.	-	-	ADL benefit plausible; not definitive
Quality of Life	4	Positive trend	2/4 sig.	-	-	Emotional and physical domains improved

FMA-UE scored 0-66; MCID 5-7 points for chronic stroke (Page et al., 2012). ARAT scored 0-57; MCID 5.7 points. MD = mean difference.

A 2025 network meta-analysis by Zhang et al. (34 RCTs, n=1,704) confirmed IVR as superior across all VR modalities for upper limb motor recovery (SUCRA = 0.84 vs. NIVR = 0.57 vs. gaming consoles = 0.41 vs. conventional therapy = 0.18), directly supporting the therapeutic value of immersion beyond task repetition alone.

3.5 Adherence, Feasibility, and Safety

Table 4. Adherence, Usability, and Safety Data

Parameter	Finding	Comparator/Context	Clinical Note
Mean Adherence	82.4% (range 71-96%)	Conventional home exercise: 50-65% (Lohse et al., 2014)	Game-like design sustains engagement

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System Usability Scale (SUS)	75-84 / 100	>70 = 'Good'; >85 = 'Excellent'	Older adults rated high usability
Cybersickness	8-15% mild, self-resolving	No withdrawals due to cybersickness	SSQ monitored in 7/12 studies
Dropout Rate	3-19%	Setup difficulty; caregiver unavailability	Dominant-hand hemiparesis: key barrier
Serious Adverse Events	None	Across all 487 participants	Absolute contraindication: photosensitive epilepsy

3.6 Neuroplasticity Evidence

Chang et al. (2022) demonstrated in a 30-patient chronic stroke RCT that IVR-based motor training produced significant reductions in IL-6 (inflammation) and 8-OHdG (oxidative stress), alongside significant increases in BDNF, compared to conventional occupational therapy. This provides molecular evidence that IVR may modulate the neuroinflammatory microenvironment to support synaptic plasticity. Separately, Diaz-Tellez et al. (2022) showed cortical map displacement in the lesioned hemisphere, measured by navigated brain stimulation, that correlated with clinical improvement (CAHAI score), confirming cortical reorganization rather than mere compensation.

3.7 Risk of Bias

Table 5. Risk of Bias Summary (Cochrane RoB 2) and PEDro Scores

Study	D1	D2	D3	D4	D5	Overall	PEDro
Aguilera-Rubio et al., 2024	Low	Some	Low	Low	Low	Low	8/10
Brunner et al., 2024	Low	Some	Low	Some	Low	Some concerns	7/10
Chang et al., 2022	Low	Some	Low	Low	Low	Low	7/10
Diaz-Tellez et al., 2022	Some	Some	Low	Some	Some	Some concerns	6/10
Fluet et al., 2024	Low	Some	Some	Low	Low	Some concerns	6/10
Remaining 7 studies	Mixed	Some	Mixed	Mixed	Mixed	2 High risk	4-7/10

D1-D5: RoB 2 domains. Inherent non-blinding of participants inflates D2 across all VR trials. Outcome assessor blinding achieved in 6/12 studies.

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4. DISCUSSION

This review confirms three things: home-based IVR is feasible and safe, it outperforms non-immersive VR modalities, and its effect sizes-while statistically real-do not yet meet the bar for confident individual clinical benefit.

4.1 Efficacy

Pooled FMA-UE improvement of 3.04 points is statistically significant but falls short of the accepted MCID of 5-7 points for chronic stroke (Page et al., 2012). The network meta-analysis ranking (SUCRA 0.84 for IVR) is reassuring about IVR's relative superiority over other VR modalities (Zhang et al., 2025), but superiority relative to weaker comparators does not establish clinical meaningfulness for the individual patient. Longer duration is the most robust predictor of benefit (β=0.28, p=0.03) (Huang et al., 2025), which likely means 4-week protocols are simply underdosed, consistent with dose-response principles in stroke rehabilitation more broadly (Kwakkel et al., 2004).

4.2 Neuroplasticity Mechanisms

The molecular evidence from Chang et al. (2022) (increased BDNF, reduced IL-6 and 8-OHdG) and the cortical reorganization data from Diaz-Tellez et al. (2022) (corticospinal excitability shift in lesioned hemisphere) provide biologically plausible mechanistic support for IVR-induced recovery beyond compensation. However, both are single small studies. The specific role of 'presence'-whether immersion independently enhances motor memory encoding beyond high-repetition task practice-has not been experimentally isolated in this population. That is a critical mechanistic gap that confounds IVR vs. non-immersive VR comparisons.

4.3 Practical Realities for Clinical Deployment

Three realities need honest acknowledgment before deployment. First, caregiver dependency is underreported: approximately half of included studies required caregiver assistance for HMD setup, particularly for patients with dominant-hand hemiparesis. This is a systemic implementation barrier. Second, the minimum viable supervision model appears to be asynchronous log review with weekly remote contact-fully unsupervised protocols had the highest dropout and greatest protocol deviations. Third, cost-effectiveness has not been formally analyzed in any included study (Cano-de-la-Cuerda et al., 2024). Consumer HMDs cost under US$500 (Tousignant et al., 2024), but hardware cost alone does not determine cost-effectiveness; that calculation requires therapist time, dropout costs, and long-term health utility data that do not yet exist.

4.4 Limitations of This Review

Four limitations merit disclosure. First, sample sizes are consistently small; no individual study reached the n≈126 required to detect a medium effect (d=0.5) at 80% power (Bernhardt et al., 2017). Second, outcome measure heterogeneity (7 different primary outcomes across 12 studies) limits meta-analytic precision. Third, maximum follow-up was 12 weeks post-intervention, so durability of

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gains is unknown. Fourth, publication bias cannot be excluded; funnel plot asymmetry testing was not possible for most outcomes due to fewer than 10 contributing studies.

5. RESEARCH PRIORITIES

Table 6. Evidence Gaps and Recommended Research Priorities

#	Gap	Recommended Design	Rationale
1	Underpowered trials	RCTs n≥200/arm; 12-month follow-up; pre-specified subgroup by baseline FMA-UE	No existing study reaches medium-effect power threshold (Bernhardt et al., 2017)
2	Supervision dose unknown	3-arm trial: synchronous vs. asynchronous vs. unsupervised home IVR	Unsupervised protocols show higher dropout; minimum effective model undefined
3	Neuroplasticity mechanisms	fMRI/TMS substudies embedded in home IVR RCTs	Existing neuroimaging evidence limited to subacute or clinic settings
4	Outcome heterogeneity	Mandate FMA-UE as primary; ARAT and BBT as secondary; assess at 6 months post-treatment	COMET Initiative stroke rehabilitation core outcome set not yet uniformly adopted
5	No cost-effectiveness data	Health economic analysis embedded in definitive RCTs	HMD cost <US$500 (Tousignant et al., 2024) but full economic case unproven
6	Unrepresentative populations	Include older adults, severe impairment, low-resource settings, non-dominant hand stroke	Current trials skewed toward younger, mildly impaired, well-resourced participants

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6. CONCLUSIONS

Home-based immersive VR is feasible, safe, and produces statistically significant-though clinically modest-upper limb motor improvements in chronic stroke. Fully immersive HMD-based delivery outperforms non-immersive modalities (Zhang et al., 2025); longer duration outperforms shorter protocols (Huang et al., 2025). The biological rationale is sound, with emerging molecular and neuroimaging evidence of genuine cortical reorganization (Chang et al., 2022; Diaz-Tellez et al., 2022). The evidence does not yet justify widespread standard-of-care deployment. The appropriate institutional response is investment in properly powered, long-term definitive trials (Bernhardt et al., 2017). For individual clinicians, judicious use in motivated patients with mild-to-moderate impairment, intact cognition, adequate home support, and rigorous outcome monitoring is defensible-provided patient expectations are calibrated to evidence, not to technology's promise.

Table 7. Clinical Decision Aid: Patient Selection for Home-Based IVR

SUITABLE (Consider)	CAUTION (Assess Case-by-Case)	CONTRAINDICATED
FMA-UE 20-50 (mild-moderate impairment); MMSE ≥24; stable cardiovascular status; caregiver available; ≥6 months post-stroke; no vestibular disorder	FMA-UE <20 (severe impairment); MMSE 18-23; motion sensitivity; no caregiver (dominant hand affected); mild hemispatial neglect; low digital literacy	Photosensitive epilepsy (absolute); MMSE <18; active vestibular pathology; severe hemispatial neglect; medically unstable; upper limb contracture

Criteria synthesized from contraindication data across included studies and VR rehabilitation safety reviews.

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