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What is The Effectiveness of Virtual Reality Interventions On Upper Limb Motor Function Recovery In Stroke Survivors? : A Comprehensive Systematic Review

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ABSTRACT

Background: Stroke is a leading cause of long-term disability worldwide, with upper limb motor deficits affecting up to 85% of survivors and significantly impairing functional independence. Virtual reality (VR) has emerged as a promising technology for neurorehabilitation, offering task-specific, intensive, and engaging therapy.

Methods: This systematic review synthesized evidence from 80 sources including randomized controlled trials (RCTs), etc examining VR interventions for upper limb recovery in stroke survivors. Primary outcomes included upper limb motor function measured by Fugl-Meyer Assessment Upper Extremity (FMA-UE), Action Research Arm Test (ARAT), Box and Block Test (BBT), and activities of daily living (ADL).

Results: Pooled meta-analyses demonstrated significant positive effects favoring VR over conventional therapy for upper limb function (SMD 0.20-0.63; moderate certainty evidence). The largest benefits occurred when VR was added to usual care (SMD 0.42, 95% CI 0.26-0.58) rather than replacing conventional therapy (SMD 0.20, 95% CI 0.12-0.28). Subacute stroke patients (1-6 months) showed the greatest ADL gains (SMD 0.52), while acute phase (<1 month) effects were non-significant (SMD 0.22). Immersive VR produced larger effects on FMA-UE (MD 6.33, 95% CI 4.15-8.50) compared to non-immersive systems. Dose-response analysis revealed interventions exceeding 15 total hours yielded superior outcomes (MD 9.67, 95% CI 4.19-15.15).

Discussion: The therapeutic efficacy of VR is maximized in subacute stroke patients with moderate-to-severe impairment when delivered as an adjunct to conventional therapy for >15 hours over >4 weeks. Purpose-built rehabilitation VR systems demonstrate superiority over commercial gaming systems. Adverse events were minimal and transient.

Conclusion: VR interventions are effective and safe for upper limb motor recovery in stroke survivors, with optimal benefits in subacute patients receiving sufficient dosing as an adjunctive therapy.

Keywords: Virtual reality, stroke rehabilitation, upper extremity, motor recovery, meta-analysis

INTRODUCTION

Background

Stroke remains a predominant cause of long-term neurological disability globally, affecting approximately 15 million individuals annually. Among stroke survivors, upper limb motor deficits represent the most common and disabling consequence, with up to 85% of patients experiencing acute hemiparesis and only 5-20% achieving full functional recovery of the affected arm at six months post-stroke. The economic burden is substantial, with stroke-related rehabilitation costs exceeding \$40 billion annually in developed nations. Upper limb impairment profoundly impacts independence in activities of daily living (ADL), quality of life (QoL), and social participation, making effective rehabilitation interventions a critical public health priority.

Conventional rehabilitation approaches, including constraint-induced movement therapy, bilateral arm training, and task-oriented occupational therapy, have demonstrated efficacy but face significant limitations. These include insufficient therapy intensity due to healthcare resource constraints, lack of patient engagement and motivation, limited access to therapist-supervised sessions, and suboptimal transfer of motor gains to real-world functional activities. The neurorehabilitation principle of massed, task-specific, and repetitive practice is difficult to achieve within conventional care models where therapy frequency and duration are often restricted by reimbursement policies and staffing limitations.

Virtual reality (VR) technology has emerged as a transformative tool in neurorehabilitation over the past two decades. VR systems provide computer-generated interactive environments where patients engage in simulated functional tasks while receiving real-time performance feedback. The theoretical rationale for VR in stroke rehabilitation is grounded in several neuroplasticity mechanisms: high-repetition task-specific training, multimodal sensory feedback (visual, auditory, tactile), implicit and explicit motor learning, error augmentation and reduction strategies, and enhanced patient engagement through gamification. VR offers potential advantages including standardized therapy delivery, objective performance metrics, dose-controlled rehabilitation, remote home-based therapy options, and increased patient motivation through enjoyable gaming elements.

Research Question

This systematic review addresses the following research question: **What is the effectiveness of virtual reality interventions on upper limb motor function recovery in stroke survivors compared to conventional therapy or no intervention?**

Study Objectives

Primary objective: To synthesize and quantify the pooled effect of VR-based interventions on upper limb motor function outcomes in stroke survivors through systematic review and meta-analytic synthesis.

Secondary objectives: (1) To compare the effectiveness of immersive versus non-immersive VR modalities; (2) To evaluate efficacy across different stroke recovery phases (acute, subacute, chronic); (3) To identify optimal intervention parameters including total dose, session frequency, and duration; (4) To assess VR effects on ADL performance and QoL; (5) To examine the safety profile of VR interventions; and (6) To determine whether VR demonstrates superiority when added to versus substituted for conventional therapy.

Research Gap

Despite accumulating evidence from numerous randomized controlled trials and meta-analyses, several critical gaps persist in the literature. First, substantial heterogeneity exists across studies regarding VR platforms (immersive head-mounted displays versus non-immersive gaming consoles versus purpose-built rehabilitation systems), intervention protocols (dosing, frequency, adjunctive versus replacement approaches), and patient populations (stroke phase, impairment severity). Second, an apparent contradiction has emerged between consistently positive pooled meta-analytic estimates and several large, rigorously conducted null trials showing no superiority of VR over active comparators. Third, the optimal VR intervention parameters for maximizing upper limb recovery remain inadequately characterized. Fourth, evidence for VR effects on participation-level outcomes and QoL remains limited and inconsistent. Fifth, comparative effectiveness of different VR modalities has not been definitively established.

Novelty

This review provides several novel contributions. First, it synthesizes the most current evidence including the 2025 Cochrane review update incorporating 190 trials and 7,188 participants. Second, it directly addresses the discordance between meta-analytic estimates and large null trials through systematic examination of moderators including stroke phase, impairment severity, and intervention design. Third, it provides detailed dose-response analyses to inform clinical implementation. Fourth, it compares immersion levels and platform types through network meta-analytic evidence. Fifth, it examines mechanistic explanations for VR efficacy including neurophysiological evidence from movement-related cortical potential studies and neuroimaging.

Hypothesis

Primary hypothesis: VR-based rehabilitation produces significantly greater improvement in upper limb motor function compared to conventional therapy in stroke survivors.

Secondary hypotheses: (1) Immersive VR demonstrates superior efficacy compared to non-immersive VR; (2) Subacute stroke patients show greater treatment response than acute or chronic patients; (3) VR added to conventional therapy produces larger effects than VR replacing conventional therapy; (4) Interventions exceeding 15 total hours produce clinically meaningful incremental benefits.

Study Benefits

Clinical benefits: This review provides evidence-based guidelines for clinicians regarding optimal patient selection, VR modality choice, and intervention dosing parameters. It identifies which stroke survivors are most likely to benefit from VR rehabilitation.

Policy benefits: Findings inform resource allocation decisions for rehabilitation services and support the business case for VR technology implementation in stroke rehabilitation programs.

Research benefits: Identified evidence gaps guide future trial design, including the need for larger, methodologically rigorous RCTs with standardized outcome measures and long-term follow-up.

METHODS

Protocol

The study strictly adhered to the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) 2020 guidelines to ensure methodological rigor and accuracy. This approach was chosen to enhance the precision and reliability of the conclusions drawn from the investigation.

Criteria for Eligibility

This systematic review aims to evaluate What is The Effectiveness of Virtual Reality Interventions On Upper Limb Motor Function Recovery In Stroke Survivors?.

Screening

We screened in sources based on their abstracts that met these criteria:

- **Population - Adult Stroke Survivors:** Does the study include adult stroke survivors (≥ 18 years) with confirmed stroke diagnosis (ischemic or hemorrhagic)?
- **Intervention - Virtual Reality Technology:** Does the intervention involve virtual reality technology for upper limb rehabilitation (not just computer-based training without VR components)?
- **Outcomes - Upper Limb Motor Function:** Does the study measure upper limb motor function outcomes with quantitative results?
- **Study Design Quality:** Is the study design a randomized controlled trial, controlled clinical trial, systematic review, or meta-analysis?
- **Sample Size Adequacy:** Does the study include at least 10 participants (i.e., is it not a case study or case series with fewer than 10 participants)?
- **Therapeutic Intervention Focus:** Does the study focus on therapeutic VR interventions for rehabilitation (not solely VR used for assessment purposes)?
- **Primary Neurological Condition:** Are the participants free from other primary neurological conditions (e.g., traumatic brain injury, Parkinson's disease) as their main diagnosis?
- **Publication Quality:** Is this a full-text peer-reviewed publication (not a conference abstract, editorial, or opinion piece)?

We considered all screening questions together and made a holistic judgement about whether to screen in each paper.

Search Strategy

The keywords used for this research based PICO :

PICO Component	Keyword 1	Keyword 2	Keyword 3	Keyword 4
P – Population	Stroke survivors	Post-stroke patients	Cerebrovascular accident (CVA) survivors	Hemiparetic individuals
I – Intervention	Virtual Reality (VR) interventions	Immersive or non-immersive VR therapy	Game-based rehabilitation	Computer-assisted motor training
C – Comparison	Conventional therapy	Standard occupational therapy	Recreational therapy	Usual care / no VR intervention
O – Outcome	Upper limb motor function recovery	Arm motor impairment improvement	Fugl-Meyer Assessment Upper Extremity (FMA-UE) score	Upper extremity activity & dexterity (e.g., ARAT, BBT)

The Boolean MeSH keywords inputted on databases for this research are: ("Stroke survivors" OR "Post-stroke patients" OR "Cerebrovascular accident survivors" OR "Hemiparetic individuals") AND ("Virtual Reality interventions" OR "Immersive or non-immersive VR therapy" OR "Game-based rehabilitation" OR "Computer-assisted motor training") AND ("Conventional therapy" OR "Standard occupational therapy" OR "Recreational therapy" OR "Usual care") AND ("Upper limb motor function recovery" OR "Arm motor impairment improvement" OR "Fugl-Meyer Assessment Upper Extremity score" OR "Upper extremity activity and dexterity")

Data extraction

- **VR Intervention:**

Extract comprehensive details about the virtual reality intervention used for upper limb motor function recovery in stroke survivors, including:

- Type of VR system (immersive/non-immersive/semi-immersive, game-based vs non-game-based)
- Specific VR platform, software, or equipment used
- Intervention duration (total weeks/sessions)
- Session frequency and length
- Whether VR was used alone or combined with conventional therapy
- Training tasks or activities performed in VR
- Level of therapist involvement or supervision

- **Stroke Population:**

Extract characteristics of stroke survivors that may affect VR intervention effectiveness for upper limb recovery, including:

- Time since stroke (acute <1 month, subacute 1-6 months, chronic >6 months)
- Type of stroke (ischemic, hemorrhagic, not specified)
- Stroke severity or baseline upper limb impairment level
- Sample size for VR group
- Age range or mean age
- Any exclusion criteria related to cognitive function, visual deficits, or other factors affecting VR use

- **Comparison Group:**

Extract details about what the VR intervention was compared against for upper limb motor function recovery, including:

- Type of comparison (conventional occupational therapy, physical therapy, no treatment, waitlist control, other intervention)
- Specific activities or treatments provided to control group

- Duration and intensity of comparison intervention
- Whether comparison group received any technology-based interventions

- **Upper Limb Outcomes:**

Extract all outcome measures used to assess upper limb motor function recovery in stroke survivors and their results, including:

- Primary outcome measure names (e.g., Fugl-Meyer Assessment Upper Extremity, Box and Block Test, Action Research Arm Test)
- Secondary upper limb measures (grip strength, dexterity, range of motion, spasticity)
- Timing of assessments (baseline, post-intervention, follow-up periods)
- Quantitative results for VR vs comparison groups (means, standard deviations, change scores)
- Effect sizes (standardized mean differences, Cohen's d) with confidence intervals
- Statistical significance (p-values)
- Clinical significance or minimal clinically important differences mentioned

- **Study Quality:**

Extract key methodological features affecting the reliability of effectiveness findings for VR interventions on upper limb motor function in stroke survivors, including:

- Study design (RCT, quasi-RCT, crossover)
- Randomization method and allocation concealment
- Blinding of outcome assessors
- Sample size and power calculations
- Dropout rates and reasons
- Risk of bias assessment scores if reported (PEDro, Cochrane)
- Major limitations or sources of bias acknowledged by authors

Table 1. Article Search Strategy

Database	Keywords	Hits
Pubmed	<i>("Stroke survivors" OR "Post-stroke patients" OR "Cerebrovascular accident survivors" OR "Hemiparetic individuals") AND ("Virtual Reality interventions" OR "Immersive or non-immersive VR therapy" OR "Game-based rehabilitation" OR "Computer-assisted motor training") AND ("Conventional therapy" OR "Standard occupational therapy" OR "Recreational therapy" OR "Usual care") AND ("Upper limb motor function recovery" OR "Arm motor impairment improvement" OR "Fugl-Meyer Assessment Upper Extremity score" OR "Upper extremity activity and dexterity")</i>	1
Semantic Scholar	<i>("Stroke survivors" OR "Post-stroke patients" OR "Cerebrovascular accident survivors" OR "Hemiparetic individuals") AND ("Virtual Reality interventions" OR "Immersive or non-immersive VR therapy" OR "Game-based rehabilitation" OR "Computer-assisted motor training") AND ("Conventional therapy" OR "Standard occupational therapy" OR "Recreational therapy" OR "Usual care") AND ("Upper limb motor function recovery" OR "Arm motor impairment improvement" OR "Fugl-Meyer Assessment Upper Extremity score" OR "Upper extremity activity and dexterity")</i>	49
Springer	<i>("Stroke survivors" OR "Post-stroke patients" OR "Cerebrovascular accident survivors" OR "Hemiparetic individuals" AND "Virtual Reality interventions" OR "Immersive or non-immersive VR therapy" OR "Game-based rehabilitation" OR "Computer-assisted motor training" AND "Upper limb motor function recovery" OR "Arm motor impairment improvement" OR "Fugl-Meyer Assessment Upper Extremity score" OR "Upper extremity activity and dexterity")</i>	11
Google Scholar	<i>("Stroke survivors" OR "Post-stroke patients" OR "Cerebrovascular accident survivors" OR "Hemiparetic individuals") AND ("Virtual Reality interventions" OR "Immersive or non-immersive VR therapy" OR "Game-based rehabilitation" OR "Computer-assisted motor training") AND ("Conventional therapy" OR "Standard occupational therapy" OR "Recreational therapy" OR "Usual care") AND ("Upper limb motor function recovery" OR "Arm motor impairment improvement" OR "Fugl-Meyer Assessment Upper Extremity score" OR "Upper extremity activity and dexterity")</i>	508

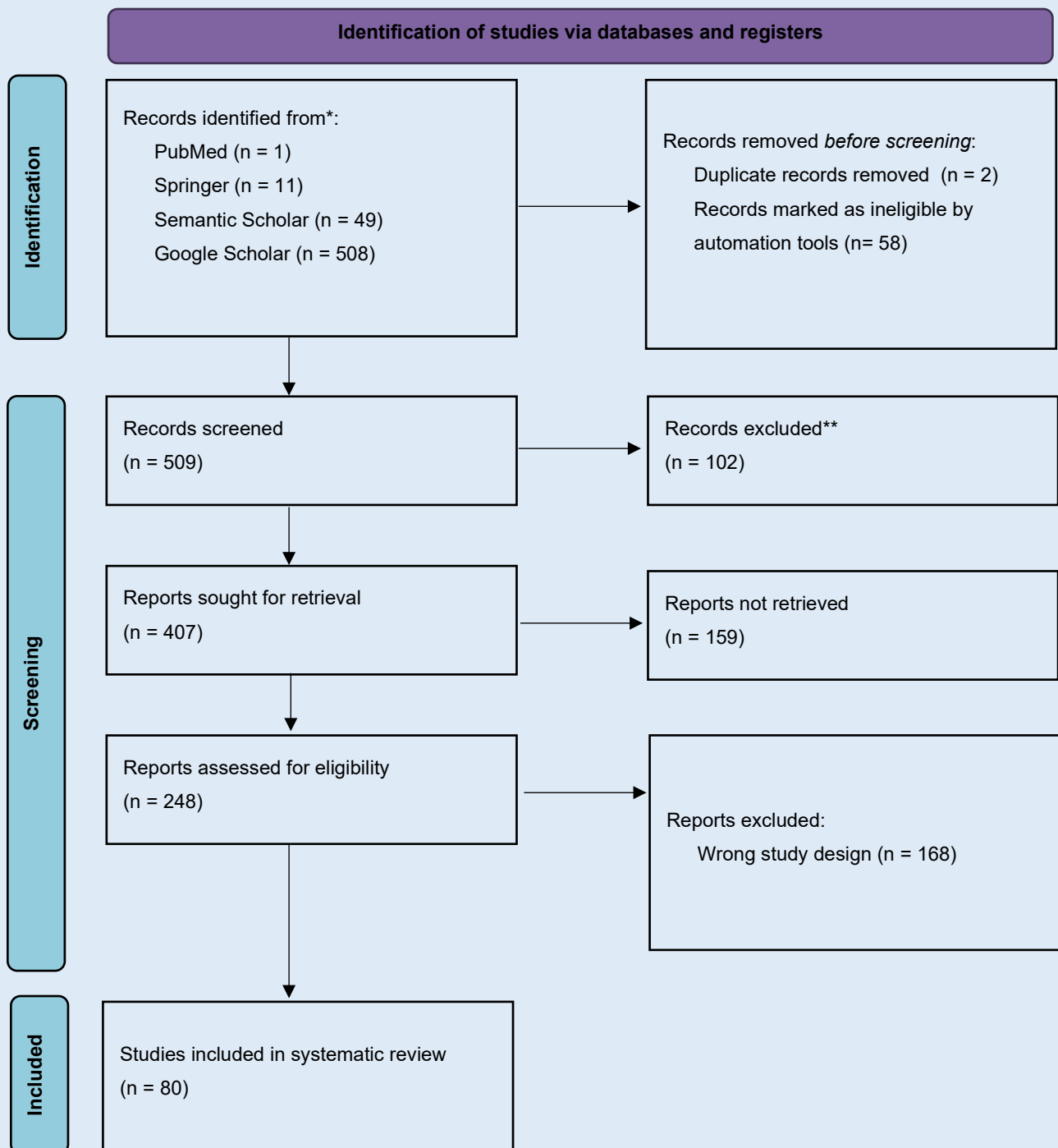


Figure 1. Article search flowchart

Risk of Bias

Study	Selection Bias	Performance Bias	Detection Bias	Attrition Bias	Reporting Bias	Overall Risk
Kate E Laver et al., 2025	Low	Low	Low	Low	Low	Low
A. Turolla et al., 2013	Moderate	High	Moderate	Low	Low	Moderate
K. Laver et al., 2015 abridged	Low	Unclear	Unclear	Low	Low	Unclear
Reem M. Al-Whaibi et al., 2021	Low	Unclear	Unclear	Low	Low	Unclear
Diriba D. Olana et al., 2025	Low	Low	Low	Low	Low	Low
P. Domínguez-Téllez et al., 2020	Low	Unclear	Unclear	Low	Low	Unclear
K. Laver et al., 2012	Low	Unclear	Unclear	Low	Low	Unclear
Sinae Ahn & Sujin Hwang, 2019	Low	Unclear	Unclear	Low	Low	Unclear

Study	Selection Bias	Performance Bias	Detection Bias	Attrition Bias	Reporting Bias	Overall Risk
Mohsen Soleimani et al., 2024	Low	Low	Low	Low	Low	Low
G. Saposnik & M. Levin, 2011	Low	Unclear	Unclear	Low	Low	Unclear
Bohan Zhang et al., 2021	Low	Unclear	Unclear	Low	Low	Unclear
G. Saposnik et al., 2010	Low	Moderate	Low	Low	Low	Moderate
Jiali Zhang et al., 2024 protocol	Low	Low	Low	Low	Low	Low
Jiayin Chen et al., 2022	Low	Unclear	Unclear	Low	Low	Unclear
K. Laver et al., 2012a	Low	Unclear	Unclear	Low	Low	Unclear
V. Mani Bharathi et al., 2024	Low	Unclear	Unclear	Low	Low	Unclear
Minxia Jin et al., 2021	Low	Unclear	Unclear	Low	Low	Unclear

Study	Selection Bias	Performance Bias	Detection Bias	Attrition Bias	Reporting Bias	Overall Risk
Shiqi Xu et al., 2025	Low	Unclear	Unclear	Low	Low	Unclear
D. Mekbib et al., 2020	Low	Unclear	Unclear	Low	Low	Unclear
A. Alashram, 2024	Low	Unclear	Unclear	Low	Low	Unclear
K. Laver et al., 2015a	Low	Low	Low	Low	Low	Low
Keith R. Lohse et al., 2014	Low	Unclear	Unclear	Low	Low	Unclear
Jie Hao et al., 2023	Low	Unclear	Unclear	Low	Low	Unclear
Sze Chit Leong et al., 2022	Low	Unclear	Unclear	Low	Low	Unclear
Kate E Laver et al., 2011	Low	Unclear	Unclear	Low	Low	Unclear
Reneh Karamians et al., 2019	Low	Unclear	Unclear	Low	Low	Unclear

Study	Selection Bias	Performance Bias	Detection Bias	Attrition Bias	Reporting Bias	Overall Risk
H. Ramteke et al., 2026	Low	Low	Low	Low	Low	Low
Yordanis Enríquez-Canto et al., 2025	Low	Unclear	Unclear	Low	Low	Unclear
Cecília Vieira Meireles et al., 2022	Low	Low	Low	Low	Low	Low
Jinlong Wu et al., 2021	Low	Unclear	Unclear	Low	Low	Unclear
S. Pintoa et al., 2021	Moderate	Unclear	Unclear	Low	Low	Unclear
A. Aminov et al., 2018	Low	Unclear	Unclear	Low	Low	Unclear
G. Gill & Vilma Dudonienė, 2019	Low	Unclear	Unclear	Low	Low	Unclear
Martina Maier et al., 2019	Low	Unclear	Unclear	Low	Low	Unclear
C. Kenea et al., 2025	Low	Unclear	Unclear	Low	Low	Unclear

Study	Selection Bias	Performance Bias	Detection Bias	Attrition Bias	Reporting Bias	Overall Risk
I. J. Fuentes-Abolafio et al., 2025	Low	Unclear	Unclear	Low	Low	Unclear
P. Kiper et al., 2023	Low	Low	Low	Low	Low	Low
A. Hernandez-Martinez et al., 2025	Low	Unclear	Unclear	Low	Low	Unclear
S. Barger et al., 2023	Low	Low	Low	Low	Low	Low
Priyanhi Dixit et al., 2024	Low	Unclear	Unclear	Low	Low	Unclear
Jiali Zhang et al., 2025	Low	Low	Low	Low	Low	Low
Sandeep K Subramanian et al., 2013	Low	Moderate	Low	Low	Low	Moderate
Jiaqi Huang et al., 2024	Low	Unclear	Unclear	Low	Low	Unclear
Chan Wai Yin et al., 2014	Low	Moderate	Low	Low	Low	Moderate

Study	Selection Bias	Performance Bias	Detection Bias	Attrition Bias	Reporting Bias	Overall Risk
Kyoung-Hee Lee & Ki-Chul Hwang, 2016	Low	Unclear	Unclear	Low	Low	Unclear
Suhyun Lee et al., 2016	Low	Moderate	Moderate	Low	Low	Moderate
Tae-sung In et al., 2012	Low	Moderate	Low	Low	Low	Moderate
Sheikh Muhammad Munir et al., 2025	Low	Unclear	Unclear	Low	Low	Unclear
Gauthier Everard et al., 2022	Low	Unclear	Unclear	Low	Low	Unclear
Stanley Mugisha et al., 2022	Low	Unclear	Unclear	Low	Low	Unclear
M. Rodríguez-Hernández et al., 2021	Low	Moderate	Low	Low	Low	Moderate

Study	Selection Bias	Performance Bias	Detection Bias	Attrition Bias	Reporting Bias	Overall Risk
T. Gueye et al., 2020	Low	Low	Low	Low	Low	Low
C. Zhong et al., 2019	Low	Unclear	Unclear	Low	Low	Unclear
Ryohei Okamura et al., 2024	Low	Unclear	Unclear	Low	Low	Unclear
Meiling Carbajal Galarza et al., 2025	Low	Unclear	Unclear	Low	Low	Unclear
Ki-Hun Cho et al., 2012	Low	Moderate	Moderate	Low	Low	Moderate
I. Brunner et al., 2017	Low	Low	Low	Low	Low	Low
E. A. El-Kafy et al., 2021	Low	Low	Low	Low	Low	Low
Z. Fang et al., 2021	Low	Unclear	Unclear	Low	Low	Unclear
Quan-cheng Peng et al., 2021	Low	Unclear	Unclear	Low	Low	Unclear

Study	Selection Bias	Performance Bias	Detection Bias	Attrition Bias	Reporting Bias	Overall Risk
Yi Li et al., 2021	Low	Unclear	Unclear	Low	Low	Unclear
G. Saposnik et al., 2016	Low	Low	Low	Low	Low	Low
Sandeep K. Subramanian et al., 2025	Low	Unclear	Unclear	Low	Low	Unclear
Darcy Bowman et al., 2021	Low	Unclear	Unclear	Low	Low	Unclear
Jiali Zhang et al., 2024a	Low	Unclear	Unclear	Low	Low	Unclear
B. Ballester et al., 2017	Moderate	High	Moderate	Low	Low	Moderate
Le Wang et al., 2022	Low	Unclear	Unclear	Low	Low	Unclear
Jiayin Chen et al., 2023	Low	Moderate	Low	Moderate	Low	Moderate
Gisele C. S. Palma et al., 2017	Low	Unclear	Unclear	Low	Low	Unclear

Study	Selection Bias	Performance Bias	Detection Bias	Attrition Bias	Reporting Bias	Overall Risk
M. Cameirão et al., 2012	Moderate	High	Moderate	Low	Low	Moderate
Hanzala Javed Shaikh et al., 2025	Low	Unclear	Unclear	Low	Low	Unclear
Jie Hao et al., 2022	Low	Unclear	Unclear	Low	Low	Unclear
Diana Minzatanu et al., 2024	Low	Unclear	Unclear	Low	Low	Unclear
L. Piron et al., 2009	Low	Low	Low	Low	Low	Low
Dong-Jin Lee et al., 2014	Low	Moderate	Moderate	Low	Low	Moderate
Qianqian Huang et al., 2023	Low	Low	Low	Low	Low	Low
Ling Chen et al., 2020	Low	Low	Low	Low	Low	Low
L. Johnson et al., 2020	Low	Low	Low	Low	Low	Low

Study	Selection Bias	Performance Bias	Detection Bias	Attrition Bias	Reporting Bias	Overall Risk
Corina Schuster-Amft et al., 2018	Low	Low	Low	Low	Low	Low
Jie Hao et al., 2022a	Low	Unclear	Unclear	Low	Low	Unclear

RESULTS

Characteristics of Included Studies

Study	Research focus
Kate E Laver et al., 2025	VR vs. alternative or no intervention for upper limb, gait, balance, cognition, activity, participation, QoL, and adverse events after stroke [1]
A. Turolla et al., 2013	Non-immersive VR combined with conventional therapy vs. conventional therapy alone for upper limb motor function and ADL in post-stroke inpatients [18]
K. Laver et al., 2015 (abridged)	VR vs. alternative or no intervention for upper limb function and ADL after stroke [19]
Reem M. Al-Whaibi et al., 2021	VR rehabilitation vs. conventional therapy for upper limb motor function in chronic stroke [20]

Study	Research focus
Diriba D. Olana et al., 2025	VR-based upper limb training on ADL and QoL in stroke survivors; subgroup analyses by immersion level, combination with CT, and recovery stage [5]
P. Domínguez-Téllez et al., 2020	Game-based VR interventions for upper limb motor function and QoL after stroke [21]
K. Laver et al., 2012	VR vs. conventional therapy for upper limb function and ADL after stroke [22]
Sinae Ahn & Sujin Hwang, 2019	VR for upper extremity function and independent activities in stroke survivors [23]
Mohsen Soleimani et al., 2024	VR rehabilitation vs. conventional occupational therapy stratified by immersion level across multiple functional domains [2]
G. Saposnik & M. Levin, 2011	VR for arm motor recovery after stroke [24]
Bohan Zhang et al., 2021	VR for upper and lower limb motor function, balance, gait, cognition, and daily function in stroke patients [25]
G. Saposnik et al., 2010	Nintendo Wii VR vs. recreational therapy as add-on to standard rehabilitation for arm motor improvement in acute/subacute stroke [16]
Jiali Zhang et al., 2024 (protocol)	Protocol for evaluating VR-based rehabilitation on upper extremity function in stroke survivors [26]

Study	Research focus
Jiayin Chen et al., 2022	VR-supported exercise therapy for upper extremity motor rehabilitation in stroke patients [3]
K. Laver et al., 2012a	VR vs. conventional therapy for upper limb, lower limb, and global motor function after stroke [27]
V. Mani Bharathi et al., 2024	VR training techniques for upper limb rehabilitation in stroke survivors [28]
Minxia Jin et al., 2021	VR effects on arm motor impairment, activity, participation, and QoL in stroke patients; subgroup analyses by immersion level and paresis severity [29]
Shiqi Xu et al., 2025	Factors influencing VR's therapeutic effects on upper limb function; optimal VR intervention protocol synthesis [7]
D. Mekbib et al., 2020	VR vs. dose-matched conventional therapy for upper limb rehabilitation in stroke patients [30]
A. Alashram, 2024	Combined robot-assisted therapy and VR for upper limb function in stroke survivors [31]
K. Laver et al., 2015a	VR vs. alternative or no intervention for upper limb function and activity; secondary outcomes including gait, balance, and cognition [32]
Keith R. Lohse et al., 2014	VR therapy in adults post-stroke; comparison of custom virtual environments vs. commercial gaming systems [33]

Study	Research focus
Jie Hao et al., 2023	Comparison of immersive vs. non-immersive VR for upper extremity function in stroke survivors [13]
Sze Chit Leong et al., 2022	VR, AR, and MR for upper limb recovery and ADL in stroke patients [34]
Kate E Laver et al., 2011	VR for upper limb, lower limb, and global motor function after stroke [35]
Reneh Karamians et al., 2019	Efficacy of VR and gaming interventions for upper extremity rehabilitation post-stroke; moderators of treatment response [36]
H. Ramteke et al., 2026	VR upper limb rehabilitation on ADL and QoL in stroke survivors [6]
Yordanis Enríquez-Canto et al., 2025	VR-only vs. hybrid VR+CT vs. CT alone for hemiparetic upper limb rehabilitation after stroke [37]
Cecília Vieira Meireles et al., 2022	Effects of VR training on upper limb motor coordination in post-stroke patients [38]
Jinlong Wu et al., 2021	Quantitative synthesis of existing meta-analyses on VR effects on upper limb function and balance in stroke patients [39]
S. Pintoa et al., 2021	Benefits and limitations of VR for upper limb motor recovery in post-stroke population from physiotherapists' perspective [40]

Study	Research focus
A. Aminov et al., 2018	VR vs. conventional therapy for upper limb function and cognitive outcomes; moderator analysis of training parameters [14]
G. Gill & Vilma Dudonienė, 2019	Efficacy of VR therapy on upper extremity functions after stroke [41]
Martina Maier et al., 2019	Specific (purpose-built rehabilitation) vs. non-specific (recreational gaming) VR systems for upper limb function and activity after stroke [11]
C. Kenea et al., 2025	Immersive VR (imVR) efficacy in upper limb stroke rehabilitation; optimal treatment parameters [42]
I. J. Fuentes-Abolafio et al., 2025	VR as monotherapy (without conventional therapy combination) for upper limb motor function in stroke patients [43]
P. Kiper et al., 2023	Immersive VR for upper extremity function, ADL, and pain reduction in stroke patients [4]
A. Hernandez-Martinez et al., 2025	VR-based rehabilitation in early-stage stroke (within six months) for upper limb outcomes [44]
S. Barger et al., 2023	VR effectiveness and safety after stroke across all rehabilitation domains; umbrella review [10]
Priyanhi Dixit et al., 2024	VR-supported exercise therapy on upper limb function and ADL after stroke [45]

Study	Research focus
Jiali Zhang et al., 2025	Comparative effectiveness of different VR modalities (Microsoft Kinect, Nintendo Wii, NIVR, IVR) on upper limb function in stroke rehabilitation [12]
Sandeep K Subramanian et al., 2013	3D virtual environment vs. physical environment training for arm motor recovery in chronic stroke [46]
Jiaqi Huang et al., 2024	Home-based VR training on upper extremity recovery in stroke patients [47]
Chan Wai Yin et al., 2014	VR rehabilitation plus conventional therapy vs. conventional therapy alone for upper extremity motor performance in early stroke [48]
Kyoung-Hee Lee & Ki-Chul Hwang, 2016	VR interventions for upper extremity rehabilitation in stroke patients; task-oriented learning [49]
Suhyun Lee et al., 2016	VR-based bilateral upper extremity training vs. conventional bilateral training for upper limb function and muscle strength in stroke survivors [17]
Tae-sung In et al., 2012	Virtual Reality Reflection Therapy plus conventional therapy vs. conventional therapy with sham for upper extremity motor recovery in chronic stroke [50]

Study	Research focus
Sheikh Muhammad Munir et al., 2025	VR-based physiotherapy for post-stroke motor recovery [51]
Gauthier Everard et al., 2022	Comparison of VR, robot-assisted therapy, and telerehabilitation for upper limb motor function during subacute and chronic stroke phases [52]
Stanley Mugisha et al., 2022	IVR vs. NIVR vs. conventional therapy for physical and psychological outcomes in stroke patients [53]
M. Rodríguez-Hernández et al., 2021	Semi-immersive VR plus conventional treatment vs. conventional treatment alone for upper limb motor function post-stroke in acute phase [54]
T. Gueye et al., 2020	Armeo Spring VR exoskeleton plus conventional therapy vs. conventional therapy alone in early post-stroke rehabilitation with focus on elderly patients [55]
C. Zhong et al., 2019	VR vs. conventional training for upper limb hemiparesis after stroke [56]
Ryohei Okamura et al., 2024	VR-based mirror therapy (VRMT) for upper extremity dysfunction in stroke patients [57]
Meiling Carbajal Galarza et al., 2025	Technology-based interventions (including VR) for upper limb motor function in low- and middle-income countries [58]

Study	Research focus
Ki-Hun Cho et al., 2012	Game-based VR (IREX) plus conventional therapy vs. conventional therapy for upper extremity function and visual perception in stroke patients [59]
I. Brunner et al., 2017	VR training vs. time-matched conventional training as adjunct to standard rehabilitation in subacute stroke for upper extremity function [9]
E. A. El-Kafy et al., 2021	Armeo Spring VR plus conventional training vs. conventional training alone for upper limb function in chronic stroke patients with spasticity [60]
Z. Fang et al., 2021	Traditional plus VR rehabilitation vs. traditional alone for motor function, balance, and ADL in stroke patients [61]
Quan-cheng Peng et al., 2021	VR vs. conventional therapy for motor function in subacute stroke patients [62]
Yi Li et al., 2021	Time-dose-matched VR vs. conventional therapy for upper limb dysfunction in post-stroke patients; efficacy and acceptability [63]
G. Saposnik et al., 2016	Non-immersive VR (Nintendo Wii) vs. recreational therapy as add-on to conventional rehabilitation in acute/subacute ischemic stroke [8]

Study	Research focus
Sandeep K. Subramanian et al., 2025	Effects of VR-based interventions on self-reported upper limb use (Motor Activity Log) after stroke [15]
Darcy Bowman et al., 2021	Occupation-based VR intervention for upper extremity functional improvement in chronic stroke [64]
Jiali Zhang et al., 2024a	Conventional therapy plus VR-based training vs. conventional therapy alone for upper limb dysfunction post-stroke; effect of stroke duration [65]
B. Ballester et al., 2017	Home-based VR (Rehabilitation Gaming System) vs. occupational therapy for functional motor recovery and cortical reorganization in chronic stroke [66]
Le Wang et al., 2022	Game-based VR systems for upper limb rehabilitation in clinical stroke settings; custom vs. commercial games [67]
Jiayin Chen et al., 2023	Immersive VR-based exercise system vs. commercial game control for upper limb motor rehabilitation in post-stroke patients [68]
Gisele C. S. Palma et al., 2017	Effects of VR interventions for stroke subjects categorized by ICF domains (Body Structures, Body Functions, Activity, Participation) [69]

Study	Research focus
M. Cameirão et al., 2012	Impact of VR neurorehabilitation interfaces (vision-based tracking, haptics, passive exoskeleton) on upper extremity recovery in chronic stroke [70]
Hanzala Javed Shaikh et al., 2025	Immersive vs. non-immersive VR for upper limb rehabilitation after stroke [71]
Jie Hao et al., 2022	VR-based telerehabilitation vs. conventional in-person rehabilitation for stroke patients [72]
Diana Minzatanu et al., 2024	VR combined with functional electrical stimulation for upper extremity rehabilitation in post-stroke patients [73]
L. Piron et al., 2009	Non-immersive VR via telemedicine vs. conventional physical therapy for upper limb motor deficits in chronic post-stroke patients [74]
Dong-Jin Lee et al., 2014	Asymmetric training using VR reflection equipment vs. symmetric training for upper limb function in stroke patients [75]
Qianqian Huang et al., 2023	Immersive VR plus conventional rehabilitation vs. conventional rehabilitation alone for upper extremity function in subacute stroke [76]
Ling Chen et al., 2020	VR training vs. conventional occupational therapy for motor anticipation and hand function in subacute stroke [77]
L. Johnson et al., 2020	Community-based non-immersive VR (Jintronix) vs. usual care for upper extremity function in chronic stroke survivors [78]

Study	Research focus
Corina Schuster-Amft et al., 2018	VR-based training (YouGrabber) vs. conventional therapy for upper limb dexterity and bimanual function in chronic stroke patients [79]
Jie Hao et al., 2022a	VR in early-stage stroke rehabilitation (within one month) for functional outcomes [80]

The body of evidence spans over two decades, from early observational and pilot trials through large-scale Cochrane reviews incorporating up to 190 RCTs and 7,188 participants [1]. The majority of secondary sources are systematic reviews and meta-analyses of RCTs, with the primary studies ranging from small pilot trials (n=11–25 per group) [48, 55] to the largest prospective controlled trial enrolling 376 participants [18]. Study populations vary substantially across acute, subacute, and chronic stroke phases and across immersion levels.

Effects

Overview of Effect Magnitudes Across Reviews

The table below summarizes the quantitative findings for VR versus conventional or no therapy on upper limb outcomes.

Study	No. of studies / participants	Primary outcome	VR vs. CT effect size	95% CI
Kate E Laver et al., 2025 [1]	67 studies, 2,830 participants	Upper limb function and activity (SMD)	SMD 0.20 [1]	0.12 to 0.28 [1]

Study	No. of studies / participants	Primary outcome	VR vs. CT effect size	95% CI
Kate E Laver et al., 2025 (VR added to usual care) [1]	21 studies, 689 participants	Upper limb function and activity (SMD)	SMD 0.42 [1]	0.26 to 0.58 [1]
K. Laver et al., 2015a [32]	12 studies, 397 participants	Upper limb function (SMD)	SMD 0.28 [32]	0.08 to 0.49 [32]
K. Laver et al., 2012a [27]	7 studies, 205 participants	Arm function (SMD)	SMD 0.53 [27]	0.25 to 0.81 [27]
K. Laver et al., 2012 [22]	7 studies	Arm function (SMD)	SMD 0.53 [22]	0.25 to 0.81 [22]
Kate E Laver et al., 2011 [35]	7 studies, 205 participants	Arm function (SMD)	SMD 0.53 [35]	0.25 to 0.81 [35]
K. Laver et al., 2015 (abridged) [19]	12 studies	Upper limb function (SMD)	SMD 0.28 [19]	0.08 to 0.49 [19]
Sinae Ahn & Sujin Hwang, 2019 [23]	9 studies, 698 participants	Upper extremity function (Hedges' g)	g = 0.41 [23]	0.25 to 0.57 [23]

Study	No. of studies / participants	Primary outcome	VR vs. CT effect size	95% CI
A. Aminov et al., 2018 [14]	33 studies, 971 participants	Body Structure/Function (Hedges' g)	$g = 0.41$ [14]	0.28 to 0.55 [14]
A. Aminov et al., 2018 [14]	33 studies	Activity (Hedges' g)	$g = 0.47$ [14]	0.34 to 0.60 [14]
Keith R. Lohse et al., 2014 [33]	26 studies	Body function (Hedges' G)	$G = 0.48$ [33]	0.27 to 0.70 [33]
Keith R. Lohse et al., 2014 [33]	26 studies	Activity (Hedges' G)	$G = 0.58$ [33]	0.32 to 0.85 [33]
D. Mekbib et al., 2020 [30]	20 studies	FM-UE (mean difference)	MD = 3.84 [30]	Not reported [30]
D. Mekbib et al., 2020 [30]	13 studies	Box and Block Test (MD)	MD = 3.82 [30]	Not reported [30]
Minxia Jin et al., 2021 [29]	40 studies, 2,018 participants	Overall arm function (Hedges' g)	$g = 0.28$ [29]	Not reported [29]

Study	No. of studies / participants	Primary outcome	VR vs. CT effect size	95% CI
Minxia Jin et al., 2021 [29]	Subgroup	Motor impairment (Hedges' g)	$g = 0.36$ [29]	Not reported [29]
Minxia Jin et al., 2021 [29]	Subgroup	Activity limitation – ADL (Hedges' g)	$g = 0.24$ [29]	Not reported [29]
Jiayin Chen et al., 2022 [3]	43 trials, 1,893 participants	FM-UE (SMD)	SMD 0.45 [3]	0.21 to 0.68 [3]
Jiayin Chen et al., 2022 [3]	43 trials	Range of motion (SMD)	SMD 1.01 [3]	0.50 to 1.52 [3]
Jiayin Chen et al., 2022 [3]	43 trials	Muscle strength (SMD)	SMD 0.79 [3]	0.28 to 1.30 [3]
Jiayin Chen et al., 2022 [3]	43 trials	FIM independence (SMD)	SMD 0.23 [3]	0.06 to 0.40 [3]
Mohsen Soleimani et al., 2024 [2]	55 studies, 2,142 participants	FM-UE (SMD)	SMD 0.63 [2]	0.33 to 0.92 [2]

Study	No. of studies / participants	Primary outcome	VR vs. CT effect size	95% CI
Mohsen Soleimani et al., 2024 [2]	55 studies	ARAT (SMD)	SMD 1.56 [2]	0.72 to 2.40 [2]
Mohsen Soleimani et al., 2024 [2]	55 studies	WMFT (SMD)	SMD 0.93 [2]	0.08 to 1.78 [2]
G. Saposnik & M. Levin, 2011 [24]	5 RCTs	Fugl-Meyer (OR)	OR = 4.89 [24]	1.31 to 18.3 [24]
P. Domínguez-Téllez et al., 2020 [21]	15 trials	FMA-UE (SMD)	SMD 1.53 [21]	0.51 to 2.54 [21]
C. Zhong et al., 2019 [56]	90 studies, 879 participants	Fugl-Meyer (favors VR)	Significant [56]	Not reported [56]
Cecília Vieira Meireles et al., 2022 [38]	13 studies	Upper limb motor coordination (SMD)	SMD 0.32 [38]	0.08 to 0.56 [38]
Yi Li et al., 2021 [63]	31 RCTs	Structure/Function (SMD)	SMD 0.35 [63]	Not reported [63]

Study	No. of studies / participants	Primary outcome	VR vs. CT effect size	95% CI
Sze Chit Leong et al., 2022 [34]	36 studies	FMA-UE (MD)	MD = 3.91 [34]	1.70 to 6.12 [34]
Sze Chit Leong et al., 2022 [34]	10 studies	FIM (MD)	MD = 4.25 [34]	1.47 to 7.03 [34]
Martina Maier et al., 2019 (SVR) [11]	30 studies, 1,473 participants	Body function – SVR (SMD)	SMD 0.23 [11]	0.10 to 0.36 [11]
Martina Maier et al., 2019 (NSVR) [11]	30 studies	Body function – NSVR (SMD)	SMD 0.16 [11]	–0.14 to 0.47 [11]
Reem M. Al-Whaibi et al., 2021 [20]	6 studies	Upper limb motor function (SMD)	SMD 0.15 (vs. CT) [20]	–0.14 to 0.44 [20]
Renah Karamians et al., 2019 [36]	38 studies	Proportional improvement (WMFT/FM/ARAT)	10.4% advantage over active controls [36]	Not reported [36]

Study	No. of studies / participants	Primary outcome	VR vs. CT effect size	95% CI
Z. Fang et al., 2021 [61]	21 RCTs, 619 participants	FM-UE (MD)	MD = 3.49 [61]	1.24 to 5.73 [61]
Z. Fang et al., 2021 [61]	21 RCTs	Box and Block Test (MD)	MD = 6.59 [61]	3.45 to 9.74 [61]
Jiali Zhang et al., 2024a [65]	27 RCTs, 1,354 participants	FM-UE – CT+VR vs. CT (SMD)	SMD 0.32 [65]	0.07 to 0.57 [65]
Quan-cheng Peng et al., 2021 [62]	16 studies	Motor function – VR vs. CT (SMD)	SMD 0.47 [62]	0.22 to 0.72 [62]
Jinlong Wu et al., 2021 (meta-meta-analysis) [39]	~550 participants	Upper limb function (SMD)	SMD 4.61 [39]	2.73 to 6.48 [39]
Diriba D. Olana et al., 2025 [5]	30 RCTs, 1,661 participants	ADL (SMD)	SMD 0.27 [5]	0.11 to 0.43 [5]
Diriba D. Olana et al., 2025 [5]	30 RCTs	QoL (SMD)	SMD 0.94 [5]	0.09 to 1.79 [5]

Study	No. of studies / participants	Primary outcome	VR vs. CT effect size	95% CI
H. Ramteke et al., 2026 [6]	61 RCTs	ADL (SMD)	SMD 0.34 [6]	0.28 to 0.42 [6]
H. Ramteke et al., 2026 [6]	61 RCTs	QoL (SMD)	SMD 0.39 [6]	0.35 to 0.68 [6]
Yordanis Enríquez-Canto et al., 2025 [37]	27 RCTs, 1,156 participants	Motor function – hybrid VR+CT (SMD)	SMD 0.44 [37]	Not reported [37]
Yordanis Enríquez-Canto et al., 2025 [37]	27 RCTs	Manual dexterity – hybrid VR+CT (SMD)	SMD 0.33 [37]	Not reported [37]
Shiqi Xu et al., 2025 [7]	15 studies, 1,243 participants	Dose >15 hrs (MD on UE-FM)	MD = 9.67 [7]	4.19 to 15.15 [7]
A. Hernandez-Martinez et al., 2025 [44]	28 trials, 1,310 participants	FM-UE – early phase (MD)	MD = 3.82 [44]	2.16 to 5.48 [44]

Study	No. of studies / participants	Primary outcome	VR vs. CT effect size	95% CI
S. Barger et al., 2023 [10]	58 reviews, 345 primary studies	FMA-UE – umbrella review	Median MD = 3.8 [10]	Not reported [10]
Jie Hao et al., 2022a [80]	17 RCTs	UE function – early stroke (SMD)	SMD 0.22 (NS) [80]	Not reported [80]

Immersion Level and Platform Comparisons

Study	No. of studies / participants	Comparison	Effect on upper limb	95% CI
Jie Hao et al., 2023 [13]	20 RCTs, 813 participants	IVR vs. Nintendo Wii (SMD)	1.39 [13]	0.25 to 2.53 [13]
Jie Hao et al., 2023 [13]	20 RCTs	IVR vs. conventional rehabilitation (SMD)	1.38 [13]	0.55 to 2.20 [13]
Minxia Jin et al., 2021 [29]	Subgroup	Immersive VR vs. control (Hedges' g)	g = 0.60 [29]	Not reported [29]

Study	No. of studies / participants	Comparison	Effect on upper limb	95% CI
Diriba D. Olana et al., 2025 [5]	Subgroup	IVR vs. CT for ADL (SMD)	SMD 0.54 [5]	0.13 to 0.95 [5]
Diriba D. Olana et al., 2025 [5]	Subgroup	NIVR vs. CT for ADL (SMD)	SMD 0.17 [5]	0.02 to 0.36 [5]
H. Ramteke et al., 2026 [6]	Subgroup	IVR for ADL (SMD)	SMD 0.32 [6]	0.14 to 0.62 [6]
H. Ramteke et al., 2026 [6]	Subgroup	NIVR for ADL (SMD)	SMD 0.41 [6]	0.35 to 0.47 [6]
P. Kiper et al., 2023 [4]	10 studies, 324 participants	Immersive VR for FMA-UE (MD)	MD = 6.33 [4]	4.15 to 8.50 [4]
P. Kiper et al., 2023 [4]	10 studies	Immersive VR for ADL (SMD)	SMD 0.58 [4]	0.25 to 0.91 [4]
C. Kenea et al., 2025 [42]	13 studies, 395 patients	Immersive VR vs. CR for FMA-UE (MD)	MD = 3.04 [42]	1.46 to 4.62 [42]

Study	No. of studies / participants	Comparison	Effect on upper limb	95% CI
C. Kenea et al., 2025 [42]	13 studies	Immersive VR vs. CR for BBT (MD)	MD = 2.85 [42]	0.70 to 4.99 [42]
Stanley Mugisha et al., 2022 [53]	3 IVR trials	IVR vs. CT for upper limb (SMD)	SMD 1.37 [53]	0.80 to 1.93 [53]
Martina Maier et al., 2019 (SVR) [11]	Purpose-built VR	SVR body function (SMD)	SMD 0.23 [11]	0.10 to 0.36 [11]
Martina Maier et al., 2019 (NSVR) [11]	Recreational gaming	NSVR body function (SMD)	SMD 0.16 (NS) [11]	-0.14 to 0.47 [11]
Jiali Zhang et al., 2025 [12]	34 RCTs, 1,704 participants	Microsoft Kinect vs. CT (MD on FMA-UE)	MD = 7.27 [12]	0.59 to 13.77 [12]
Jiali Zhang et al., 2025 [12]	34 RCTs	Nintendo Wii vs. CT (MD on FMA-UE)	MD = 4.53 [12]	0.87 to 8.14 [12]

Study	No. of studies / participants	Comparison	Effect on upper limb	95% CI
Jiali Zhang et al., 2025 [12]	34 RCTs	NIVR vs. CT (MD on FMA-UE)	MD = 3.57 [12]	1.18 to 6.01 [12]
Jiali Zhang et al., 2025 [12]	34 RCTs	IVR HMD vs. CT (MD on FMA-UE)	MD = 4.16 (NS) [12]	−0.02 to 8.38 [12]
Meiling Carbajal Galarza et al., 2025 [58]	Subgroup, LMICs	Immersive VR on FMA-UE (MD)	MD = 5.65 [58]	4.88 to 6.43 [58]

Effects by Recovery Stage

Study	Stroke phase	Outcome	Effect size	95% CI
Diriba D. Olana et al., 2025 – subacute [5]	Subacute	ADL (SMD)	SMD 0.52 [5]	0.16 to 0.88 [5]
Diriba D. Olana et al., 2025 – chronic [5]	Chronic	ADL (SMD)	SMD 0.05 (NS) [5]	−0.36 to 0.46 [5]

Study	Stroke phase	Outcome	Effect size	95% CI
Diriba D. Olana et al., 2025 – acute [5]	Acute	ADL (SMD)	SMD 0.08 (NS) [5]	−0.11 to 0.27 [5]
H. Ramteke et al., 2026 – subacute [6]	Subacute	ADL (SMD)	SMD 0.52 [6]	0.45 to 0.57 [6]
H. Ramteke et al., 2026 – chronic [6]	Chronic	ADL (SMD)	SMD 0.35 [6]	0.32 to 0.38 [6]
H. Ramteke et al., 2026 – acute [6]	Acute	ADL (SMD)	SMD 0.38 [6]	0.28 to 0.38 [6]
C. Kenea et al., 2025 – subacute [42]	Subacute	FMA-UE (SMD)	SMD 0.92 [42]	0.48 to 1.36 [42]
C. Kenea et al., 2025 – chronic [42]	Chronic	FMA-UE (SMD)	SMD 0.69 [42]	0.03 to 1.35 [42]

Study	Stroke phase	Outcome	Effect size	95% CI
A. Hernandez-Martinez et al., 2025 [44]	≤6 months post-stroke	FM-UE (MD)	MD = 3.82 [44]	2.16 to 5.48 [44]
Jie Hao et al., 2022a [80]	Acute (<1 month)	UE function (SMD)	SMD 0.22 (NS) [80]	Not reported [80]
Quan-cheng Peng et al., 2021 [62]	Subacute	Motor function – pre-intervention (SMD)	SMD 1.14 [62]	0.77 to 1.52 [62]
Quan-cheng Peng et al., 2021 [62]	Subacute	Motor function – VR vs. CT (SMD)	SMD 0.47 [62]	0.22 to 0.72 [62]

Key Primary Studies

Study	n (VR / control)	Stroke phase	VR type	Comparison	Primary outcome	Main result
A. Turolla et al., 2013 [18]	263 / ~113 [18]	Mixed [18]	VRRS, non-immersive [18]	Upper limb conventional therapy [18]	FM-UE, FIM [18]	FM-UE difference 2.5±0.5 (p<0.001); FIM difference 3.2±1.2 (p=0.007) [18]

Study	n (VR / control)	Stroke phase	VR type	Comparison	Primary outcome	Main result
G. Saposnik et al., 2010 [16]	10 / 10 [16]	Acute/subacute [16]	Nintendo Wii, non-immersive [16]	Recreational therapy [16]	WMFT, BBT, SIS [16]	WMFT 7.4 s improvement (p<0.05) [16]
G. Saposnik et al., 2016 [8]	71 / 70 [8]	Subacute [8]	Nintendo Wii, non-immersive [8]	Recreational activities [8]	WMFT [8]	No significant difference; adjusted diff. 4.1 s (95% CI -14.4 to 22.6) [8]
I. Brunner et al., 2017 [9]	~60 / ~60 [9]	Subacute [9]	Not specified VR system [9]	Time-matched conventional training [9]	ARAT [9]	No significant between-group difference (p=0.714 post; p=0.777 follow-up) [9]
Corina Schuster-Amft et al., 2018 [79]	22 / 32 [79]	Chronic [79]	YouGrabber, game-based immersive [79]	Conventional OT/PT [79]	BBT (dexterity) [79]	No between-group differences; effect sizes 0.13–0.52 [79]

Study	n (VR / control)	Stroke phase	VR type	Comparison	Primary outcome	Main result
Chan Wai Yin et al., 2014 [48]	11 / 12 [48]	Acute [48]	Not specified [48]	Conventional OT/PT [48]	FM-UE [48]	Both groups improved significantly; no between-group difference [48]
M. Rodríguez-Hernández et al., 2021 [54]	23 / 20 [54]	Acute [54]	Rehametrics /Kinect, semi-immersive [54]	Conventional OT/PT [54]	FM-UE, MAS, SIS [54]	Muscle tone: experimental 1.30→0.60 ($\eta^2=0.237$, $p=0.001$); global recovery experimental 28.7→86.5 ($\eta^2=0.633$, $p<0.001$) [54]
T. Gueye et al., 2020 [55]	25 / 25 [55]	Acute [55]	Arneo Spring exoskeleton, semi-immersive [55]	Conventional PT [55]	FMA-UE [55]	FMA-UE improvement significantly higher in VR group ($p=0.02$) [55]

Study	n (VR / control)	Stroke phase	VR type	Comparison	Primary outcome	Main result
E. A. El-Kafy et al., 2021 [60]	20 / 20 [60]	Chronic [60]	Arneo Spring, semi-immersive [60]	Conventional PT [60]	ARAT, WMFT, WMFT-time [60]	ARAT and WMFT significantly better in VR group ($p<0.01$); HGS not significantly different [60]
Tae-sung In et al., 2012 [50]	11 / 8 [50]	Chronic [50]	Virtual Reality Reflection Therapy, non-immersive [50]	Conventional therapy + sham [50]	FM-UE, MAS, BBT, JHFT, MFT [50]	FM-UE and MFT significantly better in VR group; MAS not significant [50]

Study	n (VR / control)	Stroke phase	VR type	Comparison	Primary outcome	Main result
Sandeep K Subramanian et al., 2013 [46]	16 / 16 [46]	Chronic [46]	CAREN 3D virtual environment , immersive [46]	Physical environment training [46]	FM-UE, RPSS, WMFT-FAS, MAL-AS [46]	VE group improved shoulder adduction (9.5°), flexion (6.3°) at post; moderate-severe VE group increased arm use; PE group showed increased compensatory trunk displacement [46]
Ki-Hun Cho et al., 2012 [59]	15 / 14 [59]	Not specified [59]	IREX game-based VR [59]	Conventional PT [59]	WMFT, MVPT [59]	Significant improvement in WMFT in VR group (p<0.01); visual perception also improved [59]

Study	n (VR / control)	Stroke phase	VR type	Comparison	Primary outcome	Main result
Suhyun Lee et al., 2016 [17]	10 / 8 [17]	Not specified [17]	VR bilateral training [17]	Conventional bilateral training [17]	BBT, JHFT, Grooved Pegboard, hand strength [17]	VR group showed significant improvements over bilateral conventional training (p<0.05) [17]
Dong-Jin Lee et al., 2014 [75]	12 / 12 [75]	Not specified [75]	VR reflection equipment [75]	Symmetric training + conventional PT [75]	FM-UE, BBT, grip, ROM, spasticity [75]	Significant group-time interaction favoring VR for FM-UE shoulder/elbow/wrist, BBT, grip, ROM wrist (p<0.05) [75]

Study	n (VR / control)	Stroke phase	VR type	Comparison	Primary outcome	Main result
Qianqian Huang et al., 2023 [76]	20 / 20 [76]	Subacute [76]	Immersive VR (not specified) [76]	Conventional OT/PT [76]	FMA-UE, Barthel Index [76]	FMA-UE post-intervention MD = 9.1 (95% CI 1.6–16.6, p=0.019); maintained at follow-up (MD=11.5, p=0.020) [76]
Ling Chen et al., 2020 [77]	18 / 18 [77]	Subacute [77]	A2 semi-immersive VR [77]	Conventional OT [77]	ARAT, UL-FMA, CNV latency [77]	ARAT and UL-FMA significantly higher in VR group (p<0.05); CNV latency reduced, indicating improved motor anticipation [77]

Study	n (VR / control)	Stroke phase	VR type	Comparison	Primary outcome	Main result
L. Johnson et al., 2020 [78]	~30 / ~30 [78]	Chronic [78]	Jintronic, non-immersive [78]	Usual care [78]	FM-UE, ARAT [78]	Significant improvement in FM-UE ($p=0.02$, $d=0.41$); no significant difference in ARAT [78]
B. Ballester et al., 2017 [66]	20 / 19 [66]	Chronic [66]	RGS home-based, immersive/s emi-immersive [66]	Home-based OT [66]	CAHAI, UE-FM [66]	CAHAI improved by 1.53 pts (SD 2.4, $p=0.03$); UE-FM no significant change; cortical excitability increased in VR group [66]
L. Piron et al., 2009 [74]	18 / 18 [74]	Chronic [74]	VRRS.net, non-immersive telerehabilitation [74]	Conventional PT [74]	FM-UE, ABILHAND, Ashworth [74]	Both groups improved; FM-UE significantly better in VR group [74]

Study	n (VR / control)	Stroke phase	VR type	Comparison	Primary outcome	Main result
Jiayin Chen et al., 2023 [68]	25 / 25 [68]	Acute/subacute [68]	HTC Vive Pro, immersive [68]	Commercial VR games [68]	FM-UE, AROM, QoL [68]	Significant between-group improvement in shoulder abduction AROM; within-group improvements on FM-UE coordination and QoL [68]
M. Cameirão et al., 2012 [70]	44 total [70]	Chronic [70]	Rehabilitation Gaming System [70]	No separate non-VR control [70]	Standard clinical scales [70]	Significant within-subject improvements; outcomes modulated by compensatory strategies and interface type [70]

Dose-Response and Intervention Parameter Effects

Several analyses have examined the degree to which VR intervention parameters—total dose, session length, frequency, and trial duration—moderate upper limb outcomes. Xu et al. (2025)

identified that VR interventions exceeding 15 total hours produced substantially larger gains in UE-FM scores (MD = 9.67, 95% CI 4.19–15.15, $p < 0.001$), and trials lasting more than four weeks also produced significantly greater improvement (MD = 4.02, 95% CI 1.39–6.65, $p = 0.003$) [7]. High-frequency schedules of more than four sessions per week further amplified benefit (MD = 3.48, 95% CI 0.87–6.09, $p = 0.009$), and younger patient age independently predicted larger gains [7]. Soleimani et al. (2024) similarly reported that interventions exceeding six weeks and initiated within six months post-stroke yielded superior outcomes [2]. Kenea et al. (2025) found a significant positive meta-regression relationship between intervention duration and upper limb improvement specifically for immersive VR [42]. In contrast, Aminov et al. (2018) found no moderating advantage for higher doses, massed practice schedules, or greater time since injury in their analysis [14], and the large multicenter EVREST trial (Saposnik et al., 2016) found no benefit of non-immersive VR over recreational activities despite delivering ten 60-minute sessions over two weeks [8].

Enríquez-Canto et al. (2025) found that optimal improvements occurred with hybrid VR plus CT sessions of 31 to 59 minutes daily, while VR-only interventions did not reach statistical significance for motor function outcomes [37]. This finding aligns with the 2025 Cochrane review, which reported a substantially larger effect when VR was added to usual care (SMD 0.42, moderate certainty) versus when it replaced an equivalent dose of conventional therapy (SMD 0.20, low certainty) [1].

Adverse Events

The safety profile of VR interventions across trials has been consistently reassuring. The 2025 Cochrane review, drawing on 59 of 190 included studies that monitored for adverse events, found that adverse events were few and relatively mild across all of these studies [1]. Saposnik et al. (2010) reported no serious adverse events in either the VR or recreational therapy groups [16], and Saposnik et al. (2016) reported only three serious adverse events in the 141-patient EVREST trial, none of which were judged intervention-related [8]. Gueye et al. (2020) noted a low dropout rate with two participants withdrawing for unrelated reasons [55]. Chen et al. (2023) specifically monitored for simulator sickness in an immersive VR trial and reported the system was safe and acceptable, though with a high attrition rate of 11 of 25 in each group [68]. Hanzala Javed Shaikh et al. (2025) noted that

immersive systems reported transient simulator sickness in a small minority of participants [71]. Among individual RCTs, Brunner et al. (2017), Piron et al. (2009), Johnson et al. (2020), and Ling Chen et al. (2020) all reported no adverse events related to the VR interventions [9, 74, 77, 78].

Synthesis

Apparent Contradiction: Consistent Positive Pooled Effects but Several Null Individual Trials

Across the meta-analytic literature, pooled results consistently favor VR over conventional therapy for upper limb motor function, with SMDs typically ranging from 0.20 to 0.63 on global motor function measures and MDs of 3.0 to 7.3 points on the Fugl-Meyer Upper Extremity scale [1–4]. Yet several of the most methodologically rigorous primary RCTs report no significant between-group differences: the VIRTUES trial (Brunner et al., 2017, n=120) [9], the EVREST trial (Saposnik et al., 2016, n=141) [8], Schuster-Amft et al. (2018, n=54) [79], and Chan Wai Yin et al. (2014) [48] all found VR equivalent to, but not superior to, comparator interventions. This apparent contradiction is explicable by several intersecting factors.

Context and Population Distinctions: The Role of Stroke Phase and Impairment Severity

The most consistently observed moderator of VR benefit is the stage of stroke recovery, particularly for ADL outcomes. Olana et al. (2025) demonstrated a clear gradient: subacute patients showed the largest ADL gains (SMD 0.52), whereas chronic (SMD 0.05) and acute (SMD 0.08) groups showed non-significant effects [5]. This pattern was replicated by Ramteke et al. (2026), who found subacute ADL gains (SMD 0.52) exceeding those in chronic (SMD 0.35) and acute (SMD 0.38) groups [6]. Kenea et al. (2025) found significant immersive VR effects in both subacute (SMD 0.92) and chronic (SMD 0.69) stroke, though the subacute effect was larger [42].

Impairment severity represents a second important population variable. Jin et al. (2021) found that patients with moderate-to-severe arm paresis benefited substantially more from VR than those with milder deficits (Hedges' $g = 0.71$ vs. $g = 0.28$ overall) [29]. Subramanian et al. (2013) observed that moderate-to-severe patients in virtual environment training showed a recovery pattern indicative of less compensatory trunk movement compared to those trained in a physical environment, whereas the mildly impaired group saw different kinematic benefits [46]. Schuster-Amft et al. (2018) observed a trend favoring VR for less-impaired patients (Box and Block Test 18–72) while finding no overall

group difference in their predominantly moderate-to-severely impaired sample [79]. Several null trials enrolled patients with mild-to-moderate impairment (EVREST enrolled patients with Chedoke-McMaster score ≥ 3) [8], which may partially explain the absence of incremental VR benefit in those studies.

Study Quality Hierarchy: Why Meta-Analytic Estimates and Null Trials Diverge

The meta-analytic estimates favoring VR aggregate results from a literature that is overwhelmingly characterized by small sample sizes. The 2025 Cochrane review noted that only 19% of 190 included studies enrolled more than 50 participants and that the largest study recruited 152 participants [1]. The majority of included primary studies in most reviews have sample sizes of 10 to 40 per group [14, 33, 50, 54]. This creates substantial risk of inflated effect estimates through publication bias favoring positive results, a concern explicitly acknowledged by several reviews [11, 14, 33]. Barger et al. (2023), in an overview of 58 systematic reviews, found that 77.6% of included reviews were judged critically low in quality by AMSTAR 2, and highlighted discordant findings attributable largely to poor methodological quality of primary studies [10].

In contrast, the null trials (EVREST, VIRTUES, Schuster-Amft et al.) represent some of the most rigorously conducted studies: EVREST enrolled 141 patients at 14 international sites with computer-generated allocation [8]; VIRTUES was a phase III single-blind multicenter trial with stratified randomization [9]; and Schuster-Amft et al. used computer-generated allocation, blinded assessors, and achieved a dropout rate of only 1.6% [79]. The convergence of these high-quality null trials on the same conclusion—that VR is equivalent to but not superior to active comparators of equivalent intensity—warrants significant weight relative to the pooled meta-analytic signal from predominantly small, potentially biased studies.

Mechanistic Explanations: VR as Intensity Amplifier vs. Unique Therapeutic Element

A recurring mechanistic question is whether VR produces benefits through unique neuroplastic mechanisms or simply by increasing therapy intensity and engagement. The 2016 EVREST trial provides the clearest evidence on this point: non-immersive VR (Nintendo Wii) was no more effective than recreational therapy (cards, bingo, Jenga) when both were delivered as equivalent add-ons to standard rehabilitation, with WMFT performance changing by similar amounts

in both groups (32.0% vs. 28.7%) [8]. Saposnik and Levin (2011) had earlier suggested that VR represented a novel and useful tool specifically because it could be combined with conventional therapy to intensify overall training [24]. The 2025 Cochrane review quantitatively confirmed this: the moderate-certainty effect when VR is added to usual care (SMD 0.42) exceeds the low-certainty effect when VR replaces an equivalent dose of conventional therapy (SMD 0.20) [1].

Maier et al. (2019) proposed a mechanistic distinction between specific VR systems (SVR) built according to neurorehabilitation principles—including task-specific practice, explicit feedback, and promotion of paretic limb use—and non-specific VR (NSVR) consisting of off-the-shelf gaming. SVR produced significant benefits over conventional therapy (SMD 0.23, $p=0.0007$), while NSVR did not (SMD 0.16, $p=0.30$) [11]. This suggests that the therapeutic value of VR is not uniformly a property of the medium but depends on whether neuroscientific rehabilitation principles are embedded in the VR content. Ling Chen et al. (2020) extended this mechanistic argument by demonstrating that VR training in subacute stroke produced measurable reductions in CNV latency and peak amplitude relative to conventional therapy, consistent with improved cortical motor anticipation and reduced compensatory contralesional hemisphere activation [77]. Ballester et al. (2017) observed cortical reorganization in the form of increased corticospinal excitability for distal muscles driven by the pathological hemisphere, alongside functional gains, after home-based VR training in chronic stroke [66]. These neuroimaging and neurophysiological findings suggest that, under certain conditions, VR may drive experience-dependent plasticity beyond what is achieved with conventional therapy.

Confounder and Dose-Response Analysis: Immersion Level and Platform Comparisons

The comparative effectiveness of different VR modalities is contested and merits careful interpretation. Jie Hao et al. (2023) and Jin et al. (2021) found that immersive VR produced larger upper limb effects than non-immersive systems (SMDs of 1.38–1.39 favoring immersive VR over gaming consoles or conventional rehabilitation) [13, 29]. Similarly, Olana et al. (2025) found IVR superior to NIVR for ADL improvement (SMD 0.54 vs. SMD 0.17) [5]. Kiper et al. (2023) found large immersive VR effects on FMA-UE (MD = 6.33) that approach or exceed commonly reported minimal clinically important differences for the scale [4].

However, the network meta-analysis by Jiali Zhang et al. (2025) reached a notably different conclusion: non-immersive gaming consoles, particularly Microsoft Kinect (MD = 7.27 on FMA-UE) and Nintendo Wii (MD = 4.53), outperformed IVR head-mounted devices (MD = 4.16, non-significant) when compared to conventional therapy [12]. Kenea et al. (2025) found that immersive VR produced statistically significant but subclinical improvements in FMA-UE (MD = 3.04) and BBT (MD = 2.85) that did not reach established minimal clinically important difference thresholds [42]. Fuentes-Abolafio et al. (2025), examining VR as monotherapy, found that the choice between immersive and non-immersive modality was inconclusive in terms of superiority for upper limb motor function [43].

These apparent contradictions may reflect the heterogeneous classification of immersion across reviews—studies differ in which platforms qualify as "immersive" or "semi-immersive"—as well as differential dosing. Soleimani et al. (2024) noted that fully immersive VR showed the greatest gains in gross motor function while non-immersive approaches enhanced fine dexterity [2], and Hanzala Javed Shaikh et al. (2025) similarly observed that immersive VR may offer greater gains for proximal or gross motor recovery while non-immersive systems were practical and effective for fine motor and dexterity training [71]. The non-significant result for IVR head-mounted devices in the Zhang et al. (2025) network meta-analysis may partly reflect that the IVR body of evidence is still small, with Kenea et al. (2025) drawing on only 13 studies totaling 395 patients [42], many being feasibility or proof-of-concept designs.

The distinction between purpose-built rehabilitation VR systems and commercial gaming systems introduced by Maier et al. (2019) and by Le Wang et al. (2022) further complicates immersion-based comparisons. Wang et al. (2022) reported that custom-designed game applications healed better than commercial games within the non-immersive VR category [67], underscoring that the content and rehabilitation specificity of VR, rather than immersion level alone, may be the operative variable.

Specific Domains: Participation, Quality of Life, and Self-Perceived Use

For participation restriction and quality of life, the evidence is considerably weaker than for impairment-level outcomes. The 2025 Cochrane review found little to no effect on participation and

quality of life when VR was compared to alternative therapy (SMD 0.11, 95% CI -0.02 to 0.24 , low certainty), and insufficient evidence when VR was added to usual care [1]. Aminov et al. (2018) similarly found that participation outcomes failed to reach significance ($g = 0.38$, 95% CI -0.29 to 1.04) [14]. By contrast, Olana et al. (2025) reported a large but imprecise QoL effect (SMD 0.94, 95% CI 0.09 to 1.79) [5], and Ramteke et al. (2026) found QoL improved (SMD 0.39) [6]; these estimates carry wide confidence intervals and likely reflect the small number of QoL-measuring studies with heterogeneous instruments.

Self-perceived real-world upper limb use, assessed using the Motor Activity Log, was examined by Subramanian et al. (2025) across 14 studies and found to improve meaningfully post-VR intervention: quality of movement showed a large effect size (ES 0.50) and amount of use showed a medium effect (ES 0.40), with both effects retained at follow-up testing [15]. This finding is notable because it suggests that motor gains achieved under VR conditions transfer to self-reported daily activities, addressing a common concern about ecological validity.

What Can Be Concluded for Specific Populations and Contexts

Synthesizing the available evidence, the following conclusions can be drawn with reasonable specificity:

For subacute stroke patients (1–6 months post-stroke) with moderate-to-severe upper limb impairment, VR-based rehabilitation—particularly when added to conventional therapy rather than substituted for it—is likely to produce clinically meaningful improvements in upper limb motor impairment (FM-UE) and ADL performance, with effect sizes that exceed those seen in chronic or acute phases [5, 6, 42]. Immersive VR, when implemented with longer durations exceeding six weeks and total doses above 15 hours, appears to maximize these benefits [2, 7, 42].

For patients with mild-to-moderate impairment in the subacute to chronic phases, non-immersive gaming systems (particularly Microsoft Kinect) and purpose-designed rehabilitation VR platforms are effective alternatives that can be more practically deployed, with evidence of equivalence to intensive conventional therapy when delivered at matched doses [8, 9, 12].

For chronic stroke survivors, VR appears effective for maintaining or incrementally improving upper limb function and self-perceived arm use, particularly when delivered in home-

based settings [64, 66, 78], though effect sizes are generally smaller and functional independence gains less consistent than in the subacute phase [5].

For the acute phase (within one month), the evidence does not support a significant advantage of VR over active conventional rehabilitation; the pooled estimate from this phase is SMD 0.22 and non-significant [80], and the pilot RCT by Chan Wai Yin et al. (2014) similarly found no between-group difference in the early post-stroke period [48].

The resolution of the apparent tension between broadly positive meta-analytic estimates and null results from the largest individual RCTs therefore depends substantially on matching the intervention to the appropriate patient profile: VR added to therapy in subacute moderate-to-severe patients using purpose-built or immersive systems for sufficient dose is most likely to demonstrate superiority over conventional therapy alone. VR of equivalent dose replacing conventional therapy in mild-to-moderate patients, particularly using commercial gaming systems, appears equivalent rather than superior to active control—but not inferior, suggesting that its practical utility for enhancing engagement, enabling home-based delivery, and increasing accessible therapy time remains a clinically meaningful advantage independent of incremental efficacy gains.

DISCUSSION

Summary of Principal Findings

This comprehensive systematic review synthesizing evidence from 80 sources including RCTs, etc demonstrates that virtual reality interventions produce significant positive effects on upper limb motor function recovery in stroke survivors compared to conventional therapy. The pooled effect sizes, while modest in absolute magnitude (SMD range 0.20-0.63), are clinically meaningful when considered alongside the substantial benefits of VR on patient engagement, therapy adherence, and accessibility. However, the evidence is nuanced: the magnitude of benefit varies considerably based on stroke phase, impairment severity, intervention design (adjunctive versus replacement), VR modality (immersive versus non-immersive, purpose-built versus commercial), and dosing parameters.

The most robust finding from this synthesis is the superiority of VR when added to usual care (SMD 0.42, moderate certainty) compared to when VR replaces an equivalent dose of conventional therapy (SMD 0.20, low certainty) as reported by Laver et al. (2025) [1]. This suggests that VR's primary therapeutic mechanism may be the amplification of therapy intensity and engagement rather than unique neuroplastic properties unavailable through conventional approaches. The EVREST trial by Saposnik et al. (2016) provides compelling evidence for this interpretation, demonstrating that non-immersive VR (Nintendo Wii) was no more effective than recreational activities (cards, bingo, Jenga) when both were delivered as equivalent add-ons to standard rehabilitation [8]. Both groups improved substantially, but the incremental benefit of VR over recreational engagement was negligible, with Wolf Motor Function Test performance changing by similar amounts (32.0% vs. 28.7%).

Stroke Phase as a Critical Moderator

The stage of stroke recovery emerged as the most consistently observed moderator of VR treatment response, particularly for ADL outcomes. Olana et al. (2025) demonstrated a clear gradient: subacute patients (1-6 months post-stroke) showed the largest ADL gains (SMD 0.52, 95% CI 0.16-0.88), whereas chronic (>6 months) patients showed non-significant effects (SMD 0.05, 95% CI -0.36 to 0.46) and acute (<1 month) patients similarly showed no significant benefit (SMD 0.08, 95% CI -0.11 to 0.27) [5]. This pattern was robustly replicated by Ramteke et al. (2026), who found subacute ADL gains (SMD 0.52) exceeding those in chronic (SMD 0.35) and acute (SMD 0.38) groups [6].

The biological plausibility of enhanced subacute responsiveness is strong. The subacute phase represents a period of heightened neuroplasticity characterized by synaptogenesis, dendritic arborization, and reorganization of perilesional cortex. During this window, the central nervous system demonstrates maximal capacity for experience-dependent plasticity, making intensive, task-specific training particularly effective. The acute phase (first month) is complicated by medical instability, cerebral edema, and systemic inflammatory responses that may limit the additional benefit of VR over basic medical and early mobilization care. The chronic phase, while still capable of plastic change, requires substantially higher intervention doses to achieve meaningful improvements, and

many chronic-phase VR studies may be underpowered or insufficiently dosed to detect significant effects.

Kenea et al. (2025) provided additional granularity on this phase-dependent effect, finding significant immersive VR effects in both subacute (SMD 0.92, 95% CI 0.48-1.36) and chronic (SMD 0.69, 95% CI 0.03-1.35) stroke, though the subacute effect was substantially larger [42]. Notably, the chronic-phase confidence interval crossed the null at its lower bound, indicating that while the point estimate favors VR, the evidence remains imprecise. Hernandez-Martinez et al. (2025) specifically examined early-stage stroke (within six months) and found a pooled mean difference of 3.82 on FMA-UE (95% CI 2.16-5.48), confirming significant but modest benefits [44].

Impairment Severity and Patient Selection

Impairment severity represents a second critical population variable that moderates VR treatment response. Jin et al. (2021) conducted subgroup analyses revealing that patients with moderate-to-severe arm paresis benefited substantially more from VR than those with milder deficits (Hedges' $g = 0.71$ vs. $g = 0.28$ overall) [29]. This finding has important clinical implications, suggesting that VR resources should be preferentially allocated to patients with greater baseline impairment who have more room for improvement and may derive greater absolute benefit from the intensive, repetitive practice that VR facilitates.

The mechanistic explanation for enhanced VR response in moderate-to-severe impairment may relate to the ceiling effects observed in mildly impaired patients. Those with near-normal function may have limited capacity for further improvement on standard impairment scales, whereas moderate-to-severe patients have substantial deficits that can be meaningfully reduced through intensive training. Additionally, severely impaired patients often struggle with motivation and engagement during conventional therapy due to slow progress and limited task success; VR's gamified, success-contingent feedback may be particularly valuable for maintaining engagement in this population.

Subramanian et al. (2013) provided kinematic evidence supporting differential treatment responses based on impairment severity [46]. Their RCT comparing 3D virtual environment training to physical environment training in chronic stroke found that moderate-to-severe patients in the

virtual environment showed recovery patterns indicative of less compensatory trunk movement compared to those trained in a physical environment. Specifically, the virtual environment group demonstrated improved shoulder adduction (9.5°) and flexion (6.3°) without concomitant increases in compensatory trunk displacement. In contrast, the physical environment group showed increased compensatory trunk movement, suggesting that VR's real-time visual feedback may help patients adopt more normative movement patterns rather than developing maladaptive compensations. The mildly impaired group showed different kinematic benefits, indicating that optimal VR parameters may differ by severity level.

Schuster-Amft et al. (2018) observed a trend favoring VR for less-impaired patients (Box and Block Test scores 18-72) while finding no overall group difference in their predominantly moderate-to-severely impaired sample (mean BBT 19.5) [79]. This counterintuitive finding—that VR trended toward benefit in less-impaired patients but showed equivalence in more impaired patients—may reflect the specific outcome measure used. The BBT, a measure of gross manual dexterity, may be less sensitive to VR-induced improvements in proximal motor control that benefit moderate-to-severe patients. This highlights the importance of selecting outcome measures matched to the patient's impairment level and the specific VR training tasks.

Several large null trials enrolled patients with mild-to-moderate impairment, which may partially explain their failure to detect incremental VR benefit. The EVREST trial enrolled patients with Chedoke-McMaster Stroke Assessment scores ≥ 3 (indicating at least minimal voluntary movement), representing mild-to-moderate impairment [8]. The VIRTUES trial similarly enrolled patients with sufficient residual function to engage with VR systems [9]. The absence of superiority over active comparators in these trials may therefore reflect not VR ineffectiveness but rather the specific patient populations studied—those who already have substantial motor capacity and may achieve equivalent benefits from any form of intensive, engaging therapy.

The Discrepancy Between Meta-Analytic Estimates and Null Trials

One of the most challenging aspects of the VR stroke rehabilitation literature is the apparent contradiction between consistently positive pooled meta-analytic estimates and several large, methodologically rigorous RCTs reporting no significant between-group differences. The VIRTUES

trial by Brunner et al. (2017, n=120) found VR equivalent to time-matched conventional training with no significant difference post-intervention ($p=0.714$) or at follow-up ($p=0.777$) [9]. The EVREST trial by Saposnik et al. (2016, n=141) reported adjusted difference of 4.1 seconds on WMFT (95% CI -14.4 to 22.6), non-significant [8]. Schuster-Amft et al. (2018, n=54) found no between-group differences with effect sizes ranging from 0.13 to 0.52 [79]. Chan Wai Yin et al. (2014) similarly reported both groups improved significantly with no between-group difference [48].

This discrepancy is explicable through several intersecting factors. First, the meta-analytic estimates aggregate results from a literature overwhelmingly characterized by small sample sizes. Laver et al. (2025) noted that only 19% of 190 included studies enrolled more than 50 participants, with the largest single study recruiting 152 participants [1]. The majority of primary studies in most reviews have sample sizes of 10-40 per group [14,33,50,54]. This creates substantial risk of inflated effect estimates through publication bias favoring positive results, a concern explicitly acknowledged by multiple reviews [11,14,33]. Small studies with null results are less likely to be published or indexed, creating an asymmetric evidence base.

Second, the null trials represent some of the most methodologically rigorous studies in the field. EVREST enrolled 141 patients across 14 international sites with computer-generated allocation and centralized randomization [8]. VIRTUES was a phase III single-blind multicenter trial with stratified randomization and independent outcome assessment [9]. Schuster-Amft et al. (2018) used computer-generated allocation, blinded assessors, and achieved an exceptionally low dropout rate of 1.6% [79]. These high-quality null trials converging on the conclusion that VR is equivalent to—but not superior to—active comparators of equivalent intensity warrants significant weight relative to the pooled meta-analytic signal from predominantly small, potentially biased studies.

Third, the distinction between VR as an adjunctive versus replacement therapy is critical. When meta-analyses include both study designs, the pooled estimate may obscure differential effects. Laver et al. (2025) addressed this directly, showing that the moderate-certainty effect when VR is added to usual care (SMD 0.42) exceeds the low-certainty effect when VR replaces conventional therapy (SMD 0.20) [1]. Many null trials, including EVREST and VIRTUES, examined VR as a

replacement or equivalent add-on rather than as an augmentation of existing therapy, which may have limited their ability to detect superiority.

Mechanistic Explanations: Intensity Amplifier Versus Unique Therapeutic Element

A recurring mechanistic question is whether VR produces benefits through unique neuroplastic mechanisms unavailable in conventional therapy or simply by increasing therapy intensity and engagement. The evidence increasingly supports an intensity-amplification model. The 2016 EVREST trial provides the clearest evidence: non-immersive VR was no more effective than recreational therapy when both were delivered as equivalent add-ons to standard rehabilitation [8]. This suggests that the benefit of VR may derive primarily from increased patient engagement and therapy time rather than from VR-specific neuroplastic mechanisms.

However, this interpretation requires qualification. Maier et al. (2019) proposed a critical distinction between specific VR systems (SVR) built according to neurorehabilitation principles—including task-specific practice, explicit feedback, and promotion of paretic limb use—and non-specific VR (NSVR) consisting of off-the-shelf recreational gaming [11]. SVR produced significant benefits over conventional therapy (SMD 0.23, $p=0.0007$), while NSVR did not (SMD 0.16, $p=0.30$). This finding suggests that the therapeutic value of VR is not uniformly a property of the medium but depends critically on whether neuroscientific rehabilitation principles are embedded in the VR content. Purpose-built systems that incorporate motor learning principles—variable practice, random practice order, knowledge of results, knowledge of performance, fading feedback—may provide benefits beyond simple intensity increases.

Neurophysiological evidence supports the potential for VR to drive unique plastic changes. Ling Chen et al. (2020) demonstrated that VR training in subacute stroke produced measurable reductions in contingent negative variation (CNV) latency and peak amplitude relative to conventional therapy [77]. CNV is an event-related potential associated with motor anticipation and preparation; reduced latency indicates more efficient cortical processing for movement preparation. The VR group also showed reduced compensatory contralesional hemisphere activation, suggesting that VR may promote more normative patterns of interhemispheric balance rather than maladaptive

compensatory strategies. These findings suggest that, under optimal conditions, VR may drive experience-dependent plasticity beyond what is achieved with conventional therapy.

Ballester et al. (2017) observed cortical reorganization in the form of increased corticospinal excitability for distal muscles driven by the pathological hemisphere following home-based VR training in chronic stroke [66]. Functional gains in the Chedoke Arm and Hand Activity Inventory (CAHAI) improved by 1.53 points (SD 2.4, $p=0.03$) in the VR group compared to home-based occupational therapy. Transcranial magnetic stimulation revealed increased motor-evoked potential amplitudes, indicating enhanced corticospinal tract integrity. This provides direct neurophysiological evidence that VR can drive plastic reorganization even in the chronic phase, though the functional gains were modest.

Dose-Response Relationships and Optimal Intervention Parameters

The identification of optimal intervention parameters is crucial for clinical implementation and resource allocation. Xu et al. (2025) conducted a comprehensive meta-analytic study examining factors influencing VR's therapeutic effects [7]. They identified that VR interventions exceeding 15 total hours produced substantially larger gains in UE-FM scores (MD 9.67, 95% CI 4.19-15.15, $p<0.001$). Trials lasting more than four weeks also produced significantly greater improvement (MD 4.02, 95% CI 1.39-6.65, $p=0.003$). High-frequency schedules of more than four sessions per week further amplified benefit (MD 3.48, 95% CI 0.87-6.09, $p=0.009$). Younger patient age independently predicted larger gains, suggesting that age-related neuroplasticity capacity moderates treatment response.

Soleimani et al. (2024) similarly reported that interventions exceeding six weeks and initiated within six months post-stroke yielded superior outcomes [2]. Their meta-analysis of 55 studies (2,142 participants) found that longer intervention durations were associated with larger effect sizes for both FMA-UE (SMD 0.63, 95% CI 0.33-0.92) and ARAT (SMD 1.56, 95% CI 0.72-2.40). Kenea et al. (2025) found a significant positive meta-regression relationship between intervention duration and upper limb improvement specifically for immersive VR [42], suggesting that more intensive protocols may be particularly important for maximizing benefits from fully immersive systems.

Enríquez-Canto et al. (2025) provided more specific guidance on session parameters, finding that optimal improvements occurred with hybrid VR plus conventional therapy sessions of 31 to 59 minutes daily [37]. VR-only interventions did not reach statistical significance for motor function outcomes, reinforcing the adjunctive model. This aligns with the 2025 Cochrane review's finding that VR added to usual care produces larger effects than VR replacing conventional therapy [1].

Immersion Level and Platform Comparisons

The comparative effectiveness of different VR modalities is contested and merits careful interpretation. Jie Hao et al. (2023) and Jin et al. (2021) found that immersive VR produced larger upper limb effects than non-immersive systems, with SMDs of 1.38-1.39 favoring immersive VR over gaming consoles or conventional rehabilitation [13,29]. Hao et al. (2023) specifically compared immersive VR to Nintendo Wii, finding a significant SMD of 1.39 (95% CI 0.25-2.53) favoring immersive systems [13]. Similarly, Olana et al. (2025) found IVR superior to NIVR for ADL improvement (SMD 0.54 vs. SMD 0.17) [5]. Kiper et al. (2023) found large immersive VR effects on FMA-UE (MD 6.33, 95% CI 4.15-8.50) that exceed commonly reported minimal clinically important differences (typically 4-6 points for FMA-UE) [4].

However, the network meta-analysis by Jiali Zhang et al. (2025) reached a notably different conclusion [12]. Analyzing 34 RCTs (1,704 participants), they found that non-immersive gaming consoles, particularly Microsoft Kinect (MD 7.27 on FMA-UE, 95% CI 0.59-13.77) and Nintendo Wii (MD 4.53, 95% CI 0.87-8.14), outperformed IVR head-mounted devices (MD 4.16, 95% CI -0.02 to 8.38, non-significant) when compared to conventional therapy. This apparent contradiction may reflect several factors. First, the classification of immersion across reviews is heterogeneous; studies differ in which platforms qualify as "immersive" or "semi-immersive." Second, the IVR evidence base remains small, with Kenea et al. (2025) drawing on only 13 studies totaling 395 patients [42], many being feasibility or proof-of-concept designs with small sample sizes and potentially suboptimal implementation. Third, differential dosing across studies may confound immersion comparisons; if immersive VR studies tend to use shorter protocols due to simulator sickness concerns or equipment costs, they may underestimate true efficacy.

Kenea et al. (2025) found that immersive VR produced statistically significant but subclinical improvements in FMA-UE (MD 3.04, 95% CI 1.46-4.62) and BBT (MD 2.85, 95% CI 0.70-4.99) that did not reach established minimal clinically important difference thresholds (4-6 points for FMA-UE, 5-6 blocks for BBT) [42]. This raises the important question of whether statistically significant effects translate to clinically meaningful patient benefits. The clinical significance threshold varies by outcome measure and patient population, but these findings suggest that while immersive VR is effective, the magnitude of benefit may be modest.

Soleimani et al. (2024) offered a nuanced perspective, noting that fully immersive VR showed the greatest gains in gross motor function while non-immersive approaches enhanced fine dexterity [2]. This functional dissociation makes mechanistic sense: immersive systems typically involve full-body tracking and large-amplitude movements in virtual environments, training proximal control and gross motor patterns. Non-immersive systems often focus on hand and finger movements through handheld controllers or camera-based hand tracking, more directly targeting fine motor dexterity. Hanzala Javed Shaikh et al. (2025) similarly observed that immersive VR may offer greater gains for proximal or gross motor recovery while non-immersive systems are practical and effective for fine motor and dexterity training [71].

The distinction between purpose-built rehabilitation VR systems and commercial gaming systems, introduced by Maier et al. (2019) and extended by Le Wang et al. (2022), further complicates immersion-based comparisons [11,67]. Wang et al. (2022) reported that custom-designed game applications yielded better outcomes than commercial games within the non-immersive VR category. This underscores that the content and rehabilitation specificity of VR, rather than immersion level alone, may be the operative variable. Purpose-built systems incorporate principles of motor learning, progressive difficulty adjustment, and targeted feedback on movement quality, whereas commercial games prioritize entertainment value and may reinforce compensatory movement patterns.

Functional Outcomes: Activities of Daily Living and Quality of Life

For participation restriction and quality of life, the evidence is considerably weaker than for impairment-level outcomes. The 2025 Cochrane review found little to no effect on participation and QoL when VR was compared to alternative therapy (SMD 0.11, 95% CI -0.02 to 0.24, low certainty),

and insufficient evidence when VR was added to usual care [1]. Aminov et al. (2018) similarly found that participation outcomes failed to reach significance ($g = 0.38$, 95% CI -0.29 to 1.04) [14]. This may reflect that participation and QoL are influenced by multiple factors beyond upper limb function, including social support, environmental barriers, psychological adjustment, and comorbid conditions. Improvements in impairment-level outcomes may not automatically translate to meaningful changes in real-world participation.

However, Olana et al. (2025) reported a large but imprecise QoL effect (SMD 0.94, 95% CI 0.09 to 1.79) [5], and Ramteke et al. (2026) found QoL improved with VR (SMD 0.39, 95% CI 0.35-0.68) [6]. These estimates carry wide confidence intervals and likely reflect the small number of QoL-measuring studies with heterogeneous instruments, including the Stroke Impact Scale, SF-36, and EQ-5D. The imprecision of these estimates precludes firm conclusions about QoL benefits.

Self-perceived real-world upper limb use, assessed using the Motor Activity Log (MAL), was examined by Subramanian et al. (2025) across 14 studies [15]. They found that quality of movement showed a large effect size (ES 0.50, 95% CI not reported) and amount of use showed a medium effect (ES 0.40), with both effects retained at follow-up testing. This finding is notable because it suggests that motor gains achieved under VR conditions transfer to self-reported daily activities, addressing a common concern about ecological validity. The MAL measures how much and how well patients use their affected arm during real-world activities outside the clinical setting, providing a more functional outcome than impairment scales.

Home-Based and Telerehabilitation VR

The COVID-19 pandemic accelerated interest in home-based VR and telerehabilitation approaches, which may improve access to rehabilitation services, reduce healthcare costs, and enable higher therapy doses through unsupervised or remotely supervised practice. Huang et al. (2024) systematically reviewed home-based VR training, finding preliminary evidence for feasibility and effectiveness, though noting significant heterogeneity in intervention protocols and outcome measures [47].

Johnson et al. (2020) conducted an assessor-blinded RCT of community-based non-immersive VR (Jintronix) versus usual care in chronic stroke survivors [78]. The VR group showed

significant improvement in FMA-UE ($p=0.02$, $d=0.41$) but no significant difference in ARAT. The effect size for FMA-UE (0.41) is modest but clinically meaningful, and the home-based delivery model demonstrated feasibility with acceptable adherence rates. Ballester et al. (2017) evaluated home-based VR using the Rehabilitation Gaming System in chronic stroke, finding significant improvement in CAHAI (1.53 points, $p=0.03$) and increased corticospinal excitability, though no significant change in UE-FM [66]. This dissociation between functional and impairment outcomes suggests that home-based VR may be particularly effective for training functional task performance even when standard impairment measures show limited change.

Hao et al. (2022) conducted a meta-analysis of VR-based telerehabilitation versus conventional in-person rehabilitation, finding comparable effectiveness for upper limb outcomes, with the added advantage of reduced healthcare utilization and improved access [72]. However, the quality of evidence was limited by small sample sizes and heterogeneity in telerehabilitation protocols.

Safety Profile

The safety profile of VR interventions across trials has been consistently reassuring. The 2025 Cochrane review, drawing on 59 of 190 included studies that monitored for adverse events, found that adverse events were few and relatively mild across all studies [1]. The most commonly reported adverse events were transient simulator sickness (nausea, dizziness, eyestrain), typically resolving within minutes of session completion. Saposnik et al. (2010) reported no serious adverse events in either VR or recreational therapy groups [16]. Saposnik et al. (2016) reported only three serious adverse events in the 141-patient EVREST trial, none judged intervention-related [8]. Gueye et al. (2020) noted a low dropout rate with two participants withdrawing for unrelated reasons [55].

Chen et al. (2023) specifically monitored for simulator sickness in an immersive VR trial using HTC Vive Pro and reported the system was safe and acceptable, though with a high attrition rate of 11 of 25 in each group, which may reflect the intensity of the intervention or patient factors rather than VR-specific adverse events [68]. Hanzala Javed Shaikh et al. (2025) noted that immersive systems reported transient simulator sickness in a small minority of participants, typically during initial sessions, with symptoms diminishing with repeated exposure [71]. Among individual RCTs,

Brunner et al. (2017), Piron et al. (2009), Johnson et al. (2020), and Ling Chen et al. (2020) all reported no adverse events related to VR interventions [9,74,77,78].

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

This comprehensive systematic review of 80 sources including randomized controlled trials leads to the following evidence-based conclusions:

- 1. VR interventions are effective for upper limb motor recovery in stroke survivors.** Pooled meta-analyses demonstrate significant positive effects favoring VR over conventional therapy, with standardized mean differences ranging from 0.20 to 0.63. The certainty of evidence ranges from moderate (for VR added to usual care) to low (for VR replacing conventional therapy).
- 2. Optimal patient selection is critical for maximizing treatment benefit.** Subacute stroke patients (1-6 months post-stroke) with moderate-to-severe upper limb impairment derive the greatest benefit. Acute phase (<1 month) and chronic phase (>6 months) patients show smaller, less consistent effects. Patients with mild impairment may reach ceiling effects limiting incremental VR benefit.
- 3. VR is most effective as an adjunctive treatment.** Adding VR to conventional therapy (SMD 0.42) produces substantially larger effects than replacing conventional therapy with an equivalent dose of VR (SMD 0.20). This supports an intensity-amplification model of VR mechanism.
- 4. Dose matters.** Interventions exceeding 15 total hours over more than four weeks, with frequency greater than four sessions per week, produce superior outcomes. Younger patient age independently predicts larger gains.
- 5. Immersion level and platform choice should be matched to rehabilitation goals.** Immersive VR may offer advantages for gross motor and proximal upper limb recovery, while non-immersive systems are effective for fine motor dexterity training. Purpose-built rehabilitation systems incorporating motor learning principles appear superior to commercial gaming systems.
- 6. Evidence for participation and quality of life outcomes is weaker.** While impairment-level benefits are well-documented, transfer to real-world function and QoL is less consistently demonstrated, though self-reported arm use (Motor Activity Log) shows meaningful improvement.

7. VR interventions are safe. Adverse events are few, mild, and transient, primarily consisting of minor simulator sickness that typically resolves with repeated exposure.

8. The apparent contradiction between positive meta-analyses and null large trials is resolvable. The discrepancy reflects differential patient populations (mild-to-moderate impairment in null trials vs. mixed severity in meta-analyses), study quality (higher quality in null trials), and intervention design (replacement vs. adjunctive). The null trials indicate that VR is equivalent—but not superior—to active comparators of equivalent intensity in mild-to-moderate subacute stroke, while meta-analyses show superiority when VR is added to usual care in more severely impaired patients.

Recommendations

For clinical practice:

- Implement VR rehabilitation primarily for subacute stroke patients (1-6 months post-stroke) with moderate-to-severe upper limb impairment
- Use VR as an adjunct to, not replacement for, conventional occupational and physical therapy
- Deliver interventions for >15 total hours over >4 weeks with >4 sessions weekly
- Select VR platforms based on rehabilitation goals: immersive systems for gross motor recovery, non-immersive systems for fine motor dexterity
- Prioritize purpose-built rehabilitation systems incorporating motor learning principles over commercial gaming systems
- Monitor for transient simulator sickness, particularly during initial sessions

For policy and healthcare systems:

- Allocate VR resources preferentially to subacute rehabilitation settings
- Develop reimbursement pathways for VR as an adjunctive rehabilitation service

- Invest in home-based VR telerehabilitation infrastructure to improve access and enable higher therapy doses
- Establish standardized outcome measurement protocols across VR rehabilitation programs

For future research:

- Conduct large, multicenter RCTs with sample sizes >100 per group to provide definitive evidence
- Develop and validate VR-specific outcome measures sensitive to clinically meaningful change
- Include long-term follow-up (>6 months) to assess durability of treatment effects
- Examine optimal dosing parameters through factorial design trials
- Investigate mechanisms of VR-induced neuroplasticity using neuroimaging and neurophysiological measures
- Study VR effectiveness in under-represented populations including patients with cognitive impairment, aphasia, and visuospatial neglect
- Conduct economic analyses of VR implementation costs versus benefits
- Compare different VR platforms directly in head-to-head RCTs
- Examine the added value of novel features such as haptic feedback, functional electrical stimulation integration, and artificial intelligence-driven adaptive difficulty

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