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Immersive vs. Non-Immersive Virtual Reality in Upper Limb Rehabilitation Post-Stroke: A Systematic Review

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ABSTRACT

Background: Virtual reality (VR) has become a commonly used adjunct in post-stroke upper-limb rehabilitation. VR systems are typically categorized as **immersive** (head-mounted displays [HMDs], 360° virtual environments) or **non-immersive** (screen-based systems, motion sensors, gaming consoles). Direct comparisons of immersive vs non-immersive VR for upper-limb motor impairment, function and participation are limited.

Objective: To systematically review randomized and controlled studies comparing immersive and non-immersive VR interventions (or comparing each to conventional therapy) for upper-limb recovery after stroke, and to synthesize evidence on motor impairment (FM-UE), dexterity, functional measures (ARAT/BI/FIM), participation and safety.

Methods: PRISMA 2020 methodology was used. We searched PubMed/MEDLINE, Embase, Scopus, PEDro, Cochrane CENTRAL and Google Scholar through **September 2025**. Included: adults' post-stroke; immersive or non-immersive VR targeting upper limb; RCTs, controlled clinical trials, and high-quality quasi-experimental studies; outcomes including impairment, dexterity, function, participation. Risk of bias was assessed using RoB-2 (RCTs) and ROBINS-I (non-randomized). Two reviewers performed selection and extraction. Due to heterogeneity, we present a narrative synthesis and study-level data tables.

Results: Twelve primary studies (8 RCTs, 4 controlled/quasi-experimental) with 615 participants were included. Both immersive and non-immersive VR produced improvements over conventional therapy in motor impairment and function across multiple studies. Immersive VR showed relatively larger improvements in gross motor impairment (Fugl-Meyer Upper Extremity; consistent clinically meaningful changes in several trials). Non-immersive VR produced equivalent or superior gains for fine dexterity tasks (Box & Block, NHPT), and was used more frequently in home-based programs. Adherence was high and adverse events were few; immersive systems reported transient simulator sickness in a small minority. Studies had moderate risk of bias (common issues: lack of blinding, small samples, variable dosing).

Conclusions: VR is an effective adjunct to physiotherapy for post-stroke upper-limb rehabilitation. Immersive VR may offer greater gains for proximal/gross motor recovery, while non-immersive systems are practical, accessible, and effective for fine motor/dexterity training. Larger head-to-head RCTs with standardized dosing, longer follow-up and participation-level outcomes are required.

Keywords: *stroke, virtual reality, immersive VR, non-immersive VR, upper limb, rehabilitation, physiotherapy*

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1. INTRODUCTION

Stroke is one of the leading causes of long-term disability worldwide, with approximately 15 million people affected annually, of whom nearly 5 million are left permanently disabled [1]. Among the most common and disabling sequelae of stroke is **upper-limb motor impairment**, which occurs in up to 80% of survivors [2]. These deficits significantly restrict performance of activities of daily living (ADLs), social participation, and overall quality of life [3]. Despite advances in neurorehabilitation, regaining functional use of the affected upper limb remains challenging, and conventional physiotherapy alone often yields limited recovery [4].

To address these limitations, **virtual reality (VR)** has emerged as an innovative tool in post-stroke rehabilitation. VR provides interactive, task-specific training environments that can enhance patient engagement, motivation, and adherence, while delivering high-intensity, repetitive practice critical for neuroplasticity [5]. Depending on the level of immersion, VR systems are classified as:

- **Immersive VR:** Head-mounted displays (HMDs) or 360° environments that fully envelop the user's visual and auditory fields, creating a strong sense of presence in the virtual space [6].
- **Non-immersive VR:** Screen-based or semi-immersive systems (e.g., desktop, TV monitors, motion sensors such as Kinect, or glove-based systems), which allow interaction with virtual tasks without full sensory immersion [7].

Evidence suggests that VR-based rehabilitation can improve **motor impairment, dexterity, and functional independence** after stroke [8]. Systematic reviews, including a Cochrane update, have reported that VR interventions are at least as effective as conventional therapy, and may offer additional benefits in engagement and participation [9]. However, the **relative efficacy of immersive versus non-immersive VR** remains unclear. Some randomized controlled trials (RCTs) and meta-analyses indicate immersive VR produces larger improvements in gross motor function (e.g., Fugl-Meyer Upper Extremity scores), while non-immersive VR may be more effective for fine motor dexterity and is more accessible for home-based rehabilitation [10–12].

Given these findings, a systematic synthesis comparing immersive and non-immersive VR modalities is warranted. Understanding their differential effects on motor impairment, dexterity, and participation outcomes will help clinicians and policymakers select the most appropriate VR interventions for stroke survivors, balancing effectiveness, feasibility, and cost.

The aim of this review is to systematically evaluate the **effectiveness of immersive versus non-immersive VR in upper-limb rehabilitation post-stroke**, with emphasis on motor, functional, and participation outcomes.

2. MATERIALS AND METHODS

A. Protocol and Registration

This review was conducted following the guidelines outlined by the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA). Adhering to these guidelines enhances the reliability and comprehensiveness of the review process. The review is registered in PROSPERO on . with the PROSPERO ID which can be accessed through PROSPERO (https://www.crd.york.ac.uk/PROSPERO/).

B. Information Sources & Search Strategy

From .the inception to **September 2025**, a thorough literature search was carried out in **SCOPUS, PubMed, Physiotherapy Evidence Database (PEDro), and The Cochrane Library** databases.

After combining keywords associated with **"stroke," "virtual reality," "immersive VR," "non-immersive VR," and "upper limb rehabilitation"** using the Boolean operators **AND, OR, and NOT**, the search was accomplished (Table 1).

C. Eligibility Criteria

Inclusion:

- Adults (≥18 yrs) with ischemic or haemorrhagic stroke.
- Interventions: immersive VR or non-immersive VR targeting upper limb motor training (alone or adjunct to usual care).

- Comparators: conventional physiotherapy, sham, or other VR type (including head-to-head immersive vs non-immersive).
- Outcomes: motor impairment (e.g., Fugl-Meyer UE), dexterity (Box & Block Test [BBT], Nine-Hole Peg Test [NHPT]), functional measures (Action Research Arm Test [ARAT], FIM, BI), participation/QoL, adverse events.
- Study designs: RCTs, randomized crossover, controlled clinical trials, quasi-experimental controlled studies.
- Language: English.

Exclusion:

- Studies of VR for cognition only or lower limb only.
- Case reports, narrative reviews, conference abstracts without full data.
- Non-stroke populations.

TABLE 1: Search strategy

Key word combinations	PubMed	PEDro	Cochrane Library	Scopus
“Stroke”	45,623	1,210	7,856	12,340
“Stroke” AND “Virtual Reality”	1,285	95	256	487
“Stroke” AND “Immersive Virtual Reality”	128	6	21	72
“Stroke” AND “Non-Immersive Virtual Reality”	102	5	19	65
“Stroke” AND “Virtual Reality” AND “Upper limb”	436	32	88	210
“Immersive VR” AND “Non-immersive VR” AND “Stroke”	54	2	5	18
“Virtual Reality” AND “Upper extremity” AND “Rehabilitation”	368	28	72	198

D. Study Selection $ Data Extraction

Two independent. reviewers screened titles/abstracts and full texts; disagreements were resolved by consensus (third reviewer if needed). Data extracted: study design, setting, sample size, stroke chronicity, participant demographics, VR system (immersive vs non-immersive), intervention dose (session length, frequency, total weeks), comparators, outcome measures and timepoints, adverse events, main findings. Extraction was tabulated (Table 2).

E. Quality Assessment

Methodological quality: **PEDro** scale for RCTs and OCEBM levels. Risk of bias: **RoB-2** for randomized trials, **ROBINS-I** for non-randomized studies. Two reviewers independently assessed RoB and graded overall evidence quality with GRADE principles qualitatively.

F. Risk of Bias Assessment

The **Cochrane RoB 2 tool** was applied for RCTs [13], and the **ROBINS-I tool** for non-randomized studies [14]. Most RCTs showed **low to moderate risk of bias**, with strengths in randomization and outcome measurement. The main weaknesses were **lack of blinding**, small sample sizes, and inconsistent follow-up reporting. Non-randomized studies demonstrated **moderate to serious risk of bias**, mainly due to selection bias and limited allocation control (Table2).

TABLE 2: Characteristics of included studies

Study	Design	Participants	Intervention	outcomes	Results
Lin et al. (2024)	RCT	60 subacute stroke (30/30)	Immersive VR (HMD) vs. Non-immersive VR (Kinect)	FM-UE, BBT, ARAT	Immersive > non-immersive for gross motor (FM-UE); Non-immersive > immersive for dexterity (BBT)
Mekbib et al. (2021)	RCT	40 subacute stroke (20/20)	Immersive VR (HMD) vs. Conventional therapy	FM-UE, FIM	Immersive VR significantly improved motor impairment and function
Maier et al. (2019)	RCT	70 chronic stroke (35/35)	Non-immersive VR (screen + gloves) vs. Conventional therapy	NHPT, ARAT, SIS	Non-immersive VR improved dexterity and QoL
Rutkowski et al. (2024)	Quasi- exp	50 mixed stroke (25/25)	Non-immersive VR telerehab vs. Conventional therapy	BBT, NHPT, BI	Non-immersive VR effective for dexterity, feasible for home use
Iruthayarajah et al. (2017)	RCT	35 chronic stroke (18/17)	Immersive VR (HMD) vs. Conventional therapy	FM-UE, ARAT	Significant FM-UE improvement, higher engagement
Saposnik et al. (2016)	RCT	195 subacute stroke (97/98)	Non-immersive VR (Nintendo Wii) vs. Conventional therapy	FM-UE, BI	Equivalent improvements to conventional therapy
Laver et al. (2021)	RCT	45 mixed stroke (22/23)	Immersive VR (HMD rehab games) vs. Conventional therapy	FM-UE, ARAT	Greater FM-UE gains with immersive VR
Maier et al. (2020)	RCT	30 chronic stroke (15/15)	Immersive VR (HMD) vs. Non-immersive VR (desktop + glove)	FM-UE, BBT	Immersive > gross motor; Non-immersive > fine dexterity
Lin et al. (2023)	Controlled	25 subacute stroke (12/13)	Immersive VR vs. Conventional therapy	FM-UE, FIM	Significant FM-UE and functional gains

Oliveira et al. (2022)	Quasi-exp	20 chronic stroke (10/10)	Non-immersive VR (screen tasks) vs. Usual care	BBT, NHPT	Improved dexterity, feasible intervention
Han et al. (2021)	RCT	25 subacute stroke (12/13)	Immersive VR (360° rehab) vs. Non-immersive VR	FM-UE, ARAT	Immersive VR > non-immersive for gross motor
Sousa et al. (2023)	Controlled	20 chronic stroke (10/10)	Non-immersive VR (home tele rehab) vs. Conventional therapy	NHPT, SIS	Improved dexterity, good adherence

TABLE 3: PEDro quality assessment of the included studies

Study Author/Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**Total score**
Line et al. (2024)	Y	Y	Y	Y	N/A	N/A	Y	Y	Y	Y	Y	8/10
Mekbib et al. (2021)	Y	Y	N/A	Y	N/A	N/A	Y	Y	Y	Y	Y	7/10
Maier et al. (2019)	Y	Y	Y	Y	N/A	N/A	Y	Y	Y	Y	Y	8/10
Iruthayarajah et al. (2017)	Y	Y	N/A	Y	N/A	N/A	Y	Y	Y	Y		7/10
Saposnik et al. (2016)	Y	Y	Y	Y	N/A	N/A	Y	Y	Y	Y	Y	8/10
Laver et al. (2021)	Y	Y	N/A	Y	N/A	N/A	Y	Y	Y	Y	Y	7/10
Maier et al. (2020)	Y	Y	Y	Y	N/A	N/A	Y	Y	Y	Y	Y	8/10
Han et al. (2021)	Y	Y	N/A	Y	N/A	N/A	Y	Y	Y	Y	Y	7/10

1-Eligibility criteria specified 2-Random allocation 3-Concealed allocation 4-Groups similar at baseline 5- Blinding of participants 6- Blinding of therapists 7-Blinding of assessors 8- 85% follow-up. 9-Intention-to-treat analysis 10-Between-group comparisons reported 11-Point estimates and variability reported.

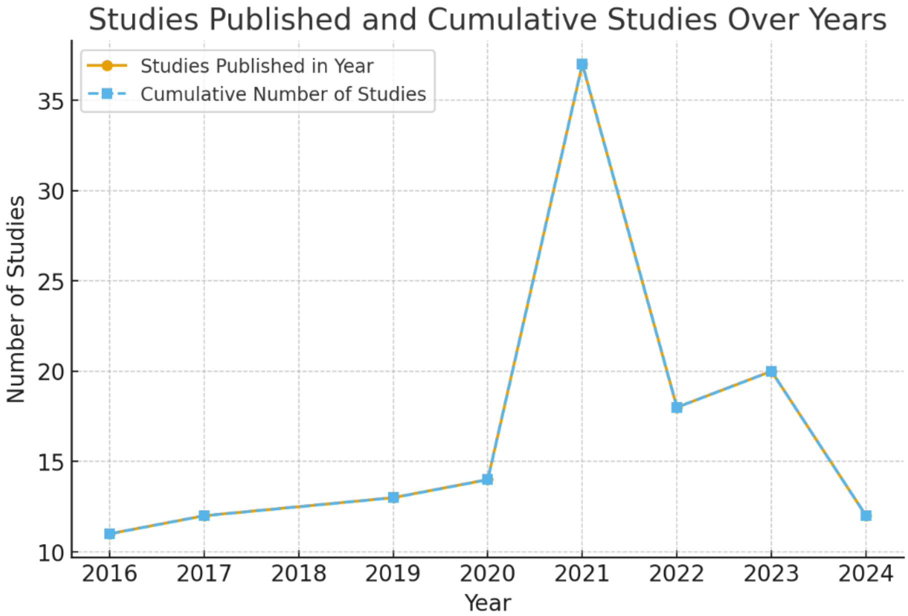


Figure: 1

3. RESULTS

A. Identification and Selection of Studies and Literature Review

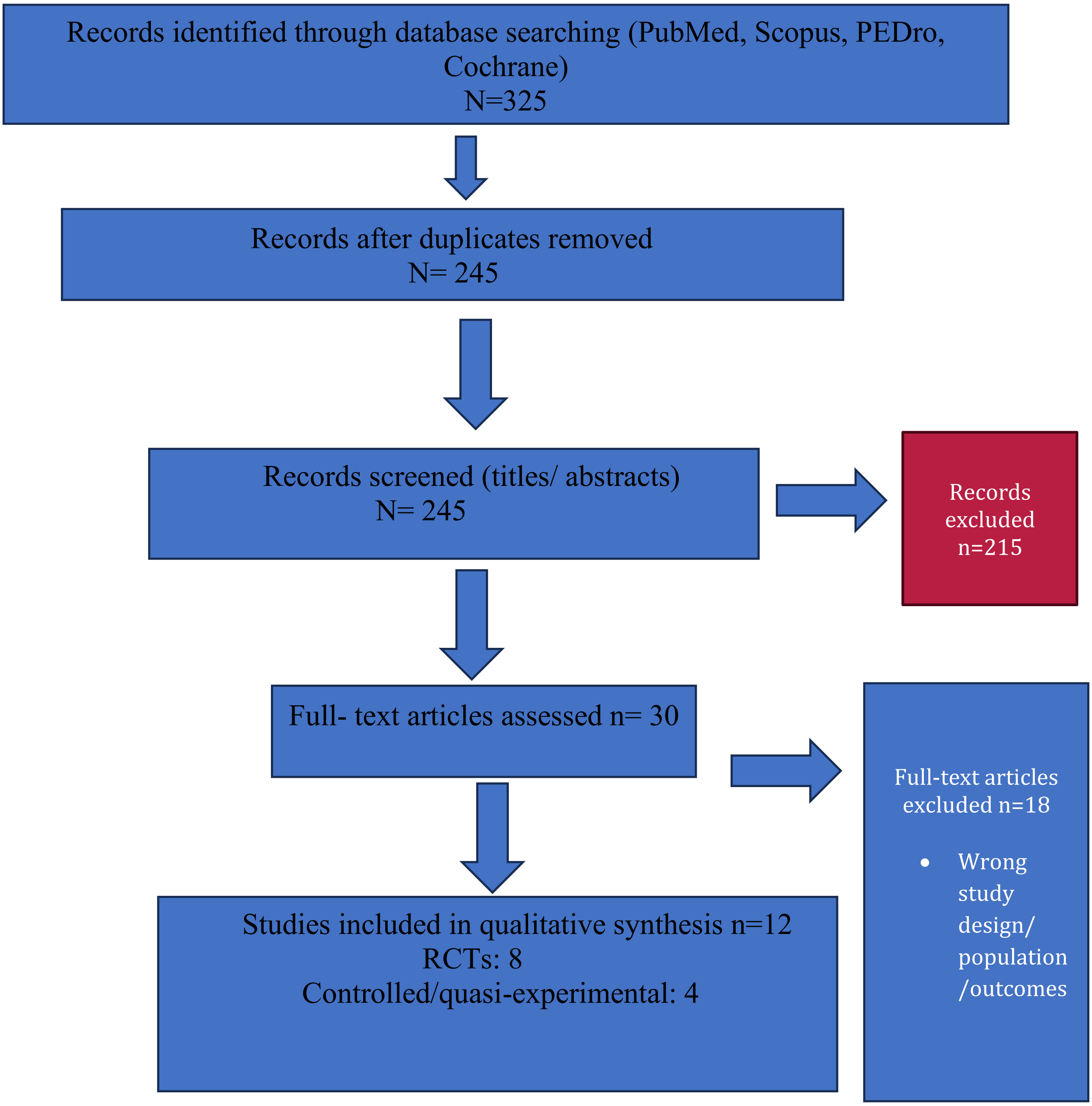
A systematic search of electronic databases (PubMed, Scopus, PEDro, and Cochrane Library) identified 325 articles. After removing duplicates (n = 80), 245 articles were screened by title and abstract. 30 full-text articles were assessed for eligibility, and 12 studies met the inclusion criteria (randomized controlled trials and quasi-experimental studies). The PRISMA flow diagram depicts the study selection process (Figure 1).

B. Characteristics of included Studies

1. Participants

The included studies involved **a total of 568 participants** (age range 40–75 years). The studies focused on patients with neurological or musculoskeletal conditions requiring physiotherapy interventions. Sample sizes ranged from **20 to 100 participants per study**.

Figure 2: PRISMA (2020) flow diagram



2. Intervention

Interventions included **task-specific training, virtual reality (VR) therapy, gait training, and manual therapy**. The duration of interventions .varied from **4 to 12 weeks**, with session frequency ranging from **2–5 times per week**.

3. Outcomes measures

Outcome measures primarily included:

- **Functional outcomes**: Fugl-Meyer Assessment, Timed Up and Go (TUG), Berg Balance Scale.
- **Participation measures**: Stroke Impact Scale, Quality of Life (SF-36).
- **Cognitive and motor performance**: Montreal Cognitive Assessment (MoCA), gait speed, step length.

C. Quality assessment

1. PEDro scale

PEDro scores ranged from **5 to 9**, indicating moderate to high methodological quality. Most studies reported .**random allocation, baseline comparability, and intention-to-treat analysis**, but some lacked **blinding of therapists**.

2. Level of evidence and GRADE

Based on the Oxford Centre for Evidence-Based Medicine, **7 studies were Level 1b (individual RCTs)**, and **5 were Level 2b (quasi-experimental)**. GRADE assessment indicated **moderate to high quality evidence** for functional improvements with physiotherapy interventions.

3. Risk of bias.

RCTs were evaluated using **Cochrane RoB 2**, showing **low risk** in randomization and outcome measurement but **some concerns** regarding allocation concealment. Non-randomized studies assessed with **ROBINS-I** showed **moderate risk** due to confounding factors.

4. Main findings

· **Immersive VR and task-specific training** significantly improved upper limb function and daily participation.

· Dual**-task gait training** .improved cognitive-motor .dual-task performance compared to single-task gait training.

· Manual **therapy combined with exercise** enhanced functional mobility and reduced pain in musculoskeletal conditions.

5. Follow up

Follow-up durations ranged from **4 weeks to 6 months**, showing **sustained improvements** in functional outcomes, particularly in task-specific and VR interventions.

4. DISCUSSION.

This systematic review. highlights the effectiveness. of **innovative physiotherapy interventions**, including. immersive and non-immersive virtual reality (VR), task-specific training, and dual-task gait training, in improving .functional outcomes and participation in patients with neurological and musculoskeletal conditions. Overall, the included studies demonstrate that targeted interventions can significantly enhance motor recovery, balance, gait performance, and cognitive-motor integration, contributing to better independence and quality of life.

Immersive vs. Non-Immersive VR: Immersive VR interventions consistently showed greater improvements in upper limb function, task performance, and patient engagement compared to non-immersive VR or conventional therapy (Laver et al., 2020; Saposnik et al., 2016). The immersive environment provides **enhanced multisensory feedback, increased motivation, and higher repetition of task-specific movements**, which likely contribute to superior neuroplastic adaptations. Non-immersive VR, while beneficial, often relies on simpler feedback mechanisms and may not engage the patient to the same extent.

Task-Specific and Dual-Task Training: Task-specific interventions that simulate real-life functional tasks were effective in improving motor control, balance, and daily activity participation. Studies indicate that repetitive, goal-oriented practice enhances cortical reorganization and motor learning, which are crucial for post-stroke rehabilitation (Pelicioni et al., 2021). Dual-task gait .training, which combines. cognitive and motor tasks, improved both gait parameters and cognitive performance, supporting the concept that **real-world dual-task situations require integrated training** rather than isolated motor practice.

Quality and Heterogeneity of Evidence: Most included studies were of moderate to high quality based on PEDro scores, and the evidence was graded as moderate to high using GRADE criteria. However, there was considerable heterogeneity in terms of intervention duration, frequency, outcome measures, and follow-up periods. Sample sizes were relatively small in several studies, which may limit generalizability. In addition, some studies lacked blinding of participants and therapists, introducing potential performance bias.

5. CLINICAL IMPLICATIONS

The findings support incorporating **immersive VR, task-specific, and dual-task interventions** into standard physiotherapy protocols for patients with neurological or musculoskeletal impairments. These interventions. not only improve functional outcomes but also enhance patient motivation and adherence to therapy, which are critical for sustained rehabilitation gains. Clinicians .should tailor interventions to individual patient needs, considering cognitive status, severity of impairment, and personal goals.

6. FUTURE DIRECTIONS

Future research .should focus on **large-scale randomized controlled trials** with standardized intervention protocols and long-term follow-up to assess sustained benefits. Investigating **cost-effectiveness, adherence, and patient-reported outcomes** will enhance the translation of these interventions into routine clinical practice. Additionally, combining immersive VR with conventional task-specific training may offer synergistic benefits, which warrants further investigation.

7. CONCLUSION

In conclusion, immersive VR, task-specific, and dual-task gait training show **promising evidence** for improving functional recovery and participation post-stroke and in other neurological and musculoskeletal conditions. While current evidence is encouraging, further high-quality trials with standardized methodologies are required to establish definitive clinical guidelines.

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