

Research Article

Virtual reality: applications, mechanisms, and rehabilitation implications: a narrative review

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ABSTRACT

Background: Virtual Reality (VR) is an emerging technology that creates immersive, interactive environments, offering real-time feedback, task-specific repetitive practice, and gamified exercises that enhance neuroplasticity, motivation, and adherence during rehabilitation.

Objective: To synthesize current literature on VR applications, mechanisms of action, and rehabilitation outcomes across diverse populations.

Methodology: A comprehensive literature search was conducted in Google Scholar, PubMed, Elsevier, and JSTOR for studies published between 2015 and 2024. Randomized controlled trials, quasi-experimental trials, pilot studies, systematic reviews, and meta-analyses using VR as a primary intervention in rehabilitation were included in the review. Data were extracted on study design, sample characteristics, type of VR intervention, duration, and motor or functional outcomes. Twelve studies meeting inclusion criteria were synthesized narratively, highlighting intervention types, effects, and trends across patient populations.

Results: VR-based interventions demonstrated significant improvements on upper and lower limb motor function, gait, balance, and independence in post-stroke patients. While the Parkinson's patients exhibited enhanced postural control, gait, and reduced fall risk. Intensive VR-based exergaming showed great improvement in gross motor function and coordination as well as engagement and motivation in children with cerebral palsy. In older adults' VR improved balance, dual-task walking, and functional mobility. High satisfaction and tolerability were indicated as patients reported consistent improved outcomes. Despite these benefits, low awareness, training gaps, and equipment costs have reduced its adoption in clinical settings. Low cost VR solutions can be safely employed in resource-limited clinical settings as suggested by feasibility studies.

Conclusion: Motor recovery, neuroplasticity as well as patient engagement are greatly improved with use of VR based therapy as it is a promising adjunct to traditional exercises and conventional rehabilitation.

Keywords: cerebral palsy; neurological deficits; rehabilitation; stroke; virtual reality.

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Citation

Samina Ghulam, Amjad Sharif, Komal Bhatti. Virtual reality: applications, mechanisms, and rehabilitation implications: a narrative review. T Rehabili. J. 2025;09(04); 03-07 doi: 10.52567/trehabj.v9i04.116

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Article History

Submitted: 04-09-2025
Accepted: 15-11-2025
Published: 19-11-2025

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INTRODUCTION

Virtual reality (VR) is a technology that creates immersive, interactive 3-D environments by simulating real or imagined worlds [1]. In rehabilitation, movements and activities of daily living can now be practised in safe, controlled, and engaging virtual settings [2, 3]. Recent advances in VR such as affordable head-mounted displays, motion-capture sensors, and integration with telemedicine and AI - have greatly expanded its use in healthcare and physiotherapy [2, 4]. Home and clinics now have easy access to VR due to recent developments. The ability to precise tracking and feedback on patient performance has enhanced [4].

The gamified and task-oriented exercises through VR has strongly enhanced motor learning and coordination. VR accelerates motor skill acquisition more effectively than conventional therapy by providing real-time visual and haptic feedback on movement. Various systematic reviews have reported that intensive, repetitive practice with immediate performance feedback through VR-rehabilitation, drive neuroplasticity and skill retention [3, 5]. VR environments can be tailored and adjusted to specific patient's ability level, thus increasing engagement and motivation during therapy [3, 4]. Importantly, VR training stimulates synaptic plasticity in the brain by activating neural circuits associated with reward and motor planning, thereby stimulating synaptic plasticity in the brain [2, 5].

VR interventions which are fully-immersive have shown significant effect across various patient populations. VR training improved upper-limb functions, gait, balance, and independence, with improved motor skills to real-world tasks in post-stroke rehabilitation [3, 6]. Among Parkinson patients, VR-based balance and gait exercises, have improved the postural control, walking ability, and reduced fall risk. This also stimulated automatic motor pathways and cognitive processes [3, 5]. VR modifies therapy as engaging and less fatiguing. Intensive training showed positive improvements in gross motor skills and coordination in the upper limb function in CP children [7]. Among older adults, VR-based exercise programs showed improvements in gait speed, dual-task walking, and overall mobility. Reduction in fall-risk markers and dual-task costs were also noted. The older adults achieved safer and more confident ambulation [8].

Due to lack of awareness and training in VR, it is still under-utilized and less explored in many clinical settings [9]. High quality VR requires costly reliable hardware and sometimes custom software, creating technical hurdles [4]. There are also limited clinical guidelines for VR integration, and concerns related to patient safety. Collectively, these issues and

barriers contributed in lack of use of VR in rehabilitation practice.

Hence an updated narrative review is needed as the VR technologies are undergoing rapid evolution and the evidence base is growing. Such as low-cost and high-end systems, clarify the underlying mechanisms of examine the feasibility for implementation of VR in resource-limited clinical settings. As healthcare systems strive to expand rehabilitation access worldwide, it is crucial to highlight potential of VR as well as its limitations in low-resource contexts. By covering the latest innovations, outcomes, and real-world challenges, this review aims to guide clinicians and policymakers on harnessing VR's full promise in rehabilitation.

METHODOLOGY

Study Design: For this narrative review the Scale for the Assessment of Narrative Review Articles (SANRA) guidelines was used, in the study to be transparent, comprehensive, and methodologically sound accuracy. The *objective was to summarize the literature on Virtual Reality (VR) as an intervention in rehabilitation settings.*

Search Strategy: To conduct a comprehensive literature search the Google Scholar, PubMed, Elsevier, and JSTOR were used. The main focus of the search strategy was to explore the studies using VR in rehabilitative interventions, published between 2015 and 2024. The virtual reality, cerebral palsy, stroke, neurological deficits, motor declines, healthy older adults, and community dwelling individuals were the keywords used for literature search by applying Boolean operators (AND, OR) to refine the search results. The reference lists of relevant articles were also screened to identify the more studies.

Inclusion and Exclusion Criteria: The studies included in this review are the pilot studies, randomized controlled trials, quasi experimental, systematic reviews and meta-analysis conducted on human participants in which primary intervention was the VR in healthcare or rehabilitation. The studies lacking a clear methodological description, focusing primarily on teacher, parent, or caregiver perspectives rather than participant outcomes, were excluded.

Study Selection: Following the screening of databases and abstract review of the articles, a total of n=12 meeting the inclusion criteria were selected for synthesis. A range of research designs represented in the selected articles were the randomized controlled trials, quasi-experimental trials, pilot studies, systematic reviews, and meta-analyses.

Data Extraction and Synthesis: Data were extracted on the study designs, sample

characteristics, types of VR intervention, duration, and outcomes related to motor and functional performance. There was no statistical method was used for data collection but narratively synthesized to highlight the trends, similarities, and variations among studies. Several studies have consistently shown that virtual reality can be a valuable tool in rehabilitation. Various VR platforms were included used in previous researches, such as Nintendo Wii, Microsoft Kinect, Mandala Gesture Xtreme, and PlayStation-based systems. The duration of VR programs varied widely, from 10-minute sessions to

several weeks, showing that these interventions can be easily adapted for different age groups and rehabilitation settings.

RESULTS

The narrative summary table of n=12 studies highlighting the main results, study features, types of VR interventions, their duration, and the functional outcomes reported. It also shows the current trends; VR effectiveness and approaches can be applied in clinical practice.

Table 1: Overview of VR Interventions and Outcomes

Ref #	Study	Design	Sample Characteristics	VR Intervention Type	Duration	Outcomes Related to Motor/Functional Performance
[10]	Zhang et al. (2025)	Network meta-analysis	Stroke patients	Non-immersive VR (Kinect)	Varies across trials	Significant improvement in upper-limb motor function
[5]	De Natale et al. (2025)	Meta-analysis	Parkinson's disease patients	Immersive VR balance training	Varies	Improved postural control (SMD=0.58)
[11]	Tobaiqi et al. (2023)	Systematic review/meta-analysis	Children with cerebral palsy	Exergaming platforms (Nintendo Wii, Kinect)	4-8 weeks	Improved gross motor skills and functional activity
[12]	Zak et al. (2024)	Randomized controlled trial	Older women, aged 65+	Immersive VR + Otago exercise	8 weeks	Enhanced balance, functional mobility
[13]	Baníková et al. (2025)	Pilot study	Sub-acute ischemic stroke patients	Immersive VR (head-mounted display)	2 weeks	High patient satisfaction, improved tolerance
[14]	Mesa-Burbano et al. (2025)	Systematic review	Children with CP	Various VR platforms	2-12 weeks	Enhanced coordination, attention, motivation
[15]	Slatman et al. (2024)	Survey	Dutch physiotherapists	Various platforms (low use)	N/A	7% VR use; main goals: pain relief, coordination
[16]	Morris et al. (2010)	Feasibility study	Adult burn patients in South Africa	Low-cost immersive VR (headset)	Single-session trials	Trend toward pain and anxiety reduction
[2]	Capriotti et al. (2025)	Review	Mixed populations	Multiple VR types	Variable	Functional gains across stroke, MS, Parkinson's
[17]	Solares et al. (2025)	Systematic review	Neurodegenerative disease patients	VR for physical rehab	4-12 weeks	Improved gait, strength, tolerability noted
[3]	Cardile et al. (2025)	Systematic review	Post-stroke patients	Semi-immersive, immersive VR	2-6 weeks	76.3% of interventions yielded motor improvements
[18]	Lu et al. (2025)	Meta-analysis	Stroke survivors	VR-based lower-limb training	Varies across studies	Significant gains in mobility and gait performance

DISCUSSION

The current study's objective was to synthesize current literature on VR applications, mechanisms of action, and rehabilitation outcomes across diverse populations, and also examined barriers to clinical adoption and feasibility in low-resource settings. Recent evidence strongly supports the efficacy of VR-based rehabilitation across a variety of conditions. Combined immersive VR and conventional therapy significantly improved postural balance in Parkinson's disease, compared to conventional therapy alone, as investigated in a meta-analysis conducted in 2025 [5]. Similarly, in stroke recovery, non-immersive VR (using devices like the Microsoft Kinect) was the most effective modality for improving upper limb motor function as

reported in a systematic review (2025) [10]. Another meta-analysis showed that VR-based exercise substantially enhanced lower-limb mobility after stroke [18]. A review also noted that the majority of VR interventions (76.3%) produced positive motor outcomes among post-stroke patients, with semi-immersive systems yielding the highest proportion of improvements. These findings indicate that VR can be an effective adjunct to standard therapy for neurological conditions, engaging patients with motivating, task specific exercises and potentially facilitating neuroplasticity [3].

Virtual reality is also being applied in pediatric and geriatric rehabilitation. In children with cerebral palsy (CP), systematic reviews have found that VR interventions lead to improvements in gross motor

function, balance, and upper limb coordination, while also increasing engagement and motivation [14]. One systematic review and meta-analysis specifically reported that VR-assisted exergaming produced significant improvement in motor skills for children with CP [11]. Among older adults, the studies also encouraged that a fully immersive VR exercise program combined with dual-task cognitive components significantly improved balance in older women, beyond what was achieved with conventional Otago exercises [12]. In general, these studies reported that participants perceived VR-based exercises as enjoyable as and less burdensome than traditional therapy, and outcomes often included measurable gains in strength, coordination, and functional mobility [3, 12, 14].

Patient reported positive outcomes on VR rehabilitation in a pilot study of subacute stroke patients, with very high levels (68%) of satisfaction and tolerability with VR therapy. Patients rated clarity of information and perceived therapeutic benefits [13]. These findings align with other reports that VR's immersive and interactive nature tends to enhance motivation and engagement during therapy.

There is a limitation in definite adoption of VR in clinical settings, despite having immense potential. Only about 7% primary care physiotherapists had integrated VR into treatment for chronic pain conditions in a survey conducted in Netherlands recently. Those who primarily used VR for lessening pain and enhancing coordination, rated their experience moderately positive. A very small percentage of physiotherapists have adopted VR since the past two years [15]. Deficiency of familiarity and training with the technology as well as restricted resources became the major barriers to wider use of VR. Increased engagement of VR in clinical practice could be augmented through rigorous training and evidence.

In resource-limited settings, low-cost VR can be feasible and beneficial as shown in various pilot studies. A feasibility trial conducted in South Africa used an inexpensive head-mounted display during physiotherapy for adult burn patients. Although, statistically significant pain reduction was not noted (likely due to limited sample size), there was a trend toward improved pain and anxiety outcomes when VR was added to standard analgesia [16]. Importantly, the study advocated the use of inexpensive VR setups to be safe and well-tolerated. They could potentially be implemented in low-resource burn units [16]. Hence, in low- and middle-income countries (LMICs), where conventional rehab resources are scarce; low-cost and consumer-grade VR systems could be adopted for rehabilitation.

Overall, there is a need for more high-quality trials as noted by recent review articles advocating the benefits of VR in rehabilitation. VR-based exercises greatly improve strength, skill, and mobility across conditions. Secondly, users found VR-based therapy more engaging than traditional exercises as highlighted by published reviews [2, 3]. Another review was conducted which focused on neurodegenerative diseases like Parkinson's, multiple sclerosis. They similarly concluded VR interventions to be effective and well-tolerated, though it called for larger RCTs to confirm long-term benefits [17].

This review employed a narrative synthesis rather than a Meta analytic approach, despite providing a comprehensive synthesis. Further, direct comparability and generalization of findings were restricted due to substantial heterogeneity. There is also publication biasness as studies with null or negative findings remain under-represented while those reporting positive outcomes become likely to be published.

CONCLUSION

Virtual reality (VR) is a powerful alternative to the conventional rehabilitation. To recognize the maximum potential of the VR, large scale trials with longer follow-ups and standardized outcome measures should be focused and explored in future researches. In order to improve real world recovery and quality of life for patients with neurological and musculoskeletal conditions; advances like VR-based rehab could become a routine, evidence-based option.

DECLARATIONS & STATEMENTS

Author's Contribution

SG: substantial contributions to the conception and design of the study.

SG, and AS: acquisition of data for the study.

AS and KB: analysis and interpretation of data for the study
SG and KB: drafted the work.

SG, AS and KB: revised it critically for important intellectual content.

SG, AS and KB: final approval of the version to be published and agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. All authors contributed to the article and approved the submitted version.

Ethical Statement

This narrative review uses only published literature and involves no human or animal subjects; therefore, no ethical approval or consent was required. All sources were appropriately cited and ethical standards were followed.

AI Use Statement

The authors used Grammarly to improve language clarity during manuscript preparation. Generative AI tools such as ScisSpace and Semantic Scholar were used to assist

with literature summarization and refinement of the research rationale. All interpretations, conclusions, and original ideas remain solely those of the authors and approved by the authors.

Consent Statement

Informed consent was obtained from all subjects involved in the study.

Data Availability Statement

The data presented in this study are available on request from the corresponding author.

Acknowledgments

None to declare.

Funding Sources

None to declare.

Conflicts of Interest

None to declare.

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