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VIRTUAL REALITY-BASED REHABILITATION FOR STROKE RECOVERY: A SYSTEMATIC REVIEW OF RANDOMIZED CONTROLLED TRIALS

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ABSTRACT
Background: Stroke may also affect motor abilities, balance and cognitive abilities, and is a major cause of disability in the world. Virtual reality (VR) is a new approach to rehabilitation providing attractive therapeutic environments, which are interactive, task-focused, and can significantly enhance the recovery.
Objective: The intent of this project is to review extensively literature on the topic of virtual reality (VR) rehabilitation and its impact on motor, balance, cognitive, and psychosocial outcomes in stroke patients.
Methods: We followed the PRISMA criteria when we performed our systematic review of RCTs. Studies were included from the year 2022–2026. Studies assessing VR based interventions in stroke rehabilitation were selected. Data were extracted and synthesized narratively Due to methodological, intervention and outcome measurement inconsistencies among all the studies. The PEDro scale was used to evaluate the quality of the methods, and the Cochrane Risk of Bias 2 tool was used to evaluate the risk of bias.
Results: The upper limb motor function was significantly improved with VR-based therapy as shown by all of the research that were considered. balance, gait, cognitive performance, and psychological outcomes. Immersive and combined VR interventions showed greater improvements in some studies; however, several trials reported comparable outcomes between VR and conventional therapy. VR interventions also enhanced patient engagement, motivation, and adherence to rehabilitation. The methodological quality on the whole, was moderate to high and the risk of bias was low-moderate.
Conclusion: Virtual reality (VR) is a promising tool for stroke patients' rehabilitation. particularly as an adjunct to conventional therapy. While it consistently improves multiple functional outcomes, its superiority over traditional rehabilitation remains inconclusive. Further testing with standard methods and prospective follow up would be needed for it to be fully utilized in the clinic.

INTRODUCTION
Stroke is one of the major causes of disability and death in the world because of the long-term effects. resulting from a vascular insult to the brain such as ischemia or haemorrhage. It commonly leads to impairments in motor, sensory, cognitive, and functional abilities, significantly affecting an individual's independence and quality of life. Stroke survivors (about 80 percent) have motor deficits (weakness, lack of coordination, balance and gait difficulties) that restrict their activities of daily living activities [1].
Rehabilitation has been a pillar in stroke management as it is used to restore functionality, facilitate neuroplasticity and increase patient independence. Traditional methods of rehabilitation like physiotherapy, task-oriented training and vestibular rehabilitation have been proven to be effective in enhancing functional outcomes. Nevertheless, such methods have been linked to such shortcomings as decreased patient motivation, no interactions and the inadequate intensity or repetition needed to achieve maximum motor recovery [1,2].
One of the new and promising techniques of neuro rehabilitation is virtual rehabilitation. With the help of a virtual reality (VR) system, patients are then able to do workouts with interactive and multimodal feedback on a repetition of a given task. It enhances the use of improvement, motivation and compliance of the patients to the treatment and encourages motor learning and neuroplasticity. Recent randomized controlled trials have shown that VR-based interventions have the capacity to enhance upper limb functionality, balance, gait and cognitive behavior of stroke survivors [310].
As an example, VR interventions have demonstrated considerable balance and gait outcomes improvements relative to traditional therapy in stroke patients with subacute stroke [1]. Likewise, experiments of immersive and non-immersive VR systems have shown that there are higher upper extremity functioning, motor control, and functional independence in stroke survivors [4 9]. Moreover, VR-based therapies were also linked to increased patient satisfaction and compliance as they are interactive and engaging [6,8].
Although these are promising results, there are still a number of gaps in the literature. There is considerable heterogeneity in study designs, types of VR systems used (immersive versus non-immersive), intervention protocols, duration of therapy, and outcome measures. Also, there is no consensus available on the best treatment method for

stroke survivors, either in terms of traditional therapy or VR therapy, particularly with respect to the acute, subacute and chronic phases of recovery. Although individual randomized controlled trials have reported positive outcomes, the variability in methodologies makes it difficult to draw definitive conclusions regarding the effectiveness of VR interventions [7–16].

In order to assess the benefits of VR for rehabilitation in the clinic, a meta-analysis of good quality research studies will need to target randomized controlled trials.

This systematic review analyzes RCT studies to determine VR as a successful method of rehabilitation for stroke recovery. Our first focus is to observe the results of virtual reality (VR) treatment on functional abilities, gait, balance and motor functions in stroke patients. Secondly, we are interested in comparing and contrasting VR-based rehabilitation with conventional therapy. Thirdly, we wish to look at methodological quality and bias in the studies included.

METHODOLOGY

Study Design

This review was done under the guidance of the CONSORT Statement for Systematic Reviews and Meta-Analyses (PRISMA). The main intent of the evaluation was to determine the effectiveness of VR therapy for stroke recovery by including only randomized controlled trials (RCTs). A structured and comprehensive approach was adopted to identify, screen, and analyse relevant studies.

Eligibility Criteria

The criteria that led us to choose the articles were identified using the PICO framework: population, intervention, comparison and outcome.

Population

covered studies covered rehabilitation programs for adults with a history of stroke, whether it be ischemic or hemorrhagic. Stages of stroke recovery can be acute, subacute and chronic.

Intervention

Studies evaluating virtual reality–based rehabilitation interventions were included. VR interventions could include immersive VR, non-immersive VR, game-based VR rehabilitation systems, or VR combined with conventional physiotherapy.

Comparison

Studies comparing VR interventions with:

- Conventional physiotherapy
- Standard rehabilitation
- Other rehabilitation techniques
- No additional intervention

were included.

Outcomes

All studies were included with any of the following results:

Primary outcomes:

- Motor function recovery
- Upper limb function
- Balance
- Gait performance

Secondary outcomes:

- Daily tasks to complete
- Life quality
- Cognitive outcomes
- Functional independence

Exclusion Criteria

These studies were excluded if they met one of the following:

- Non-randomized studies include observational studies, cohort studies, case reports and case series.
- This includes articles that have been reviewed, evaluations of systems and data studies, editorials or abstracts from conferences.
- Research that has not been limited to stroke, e.g. on groups that may be affected by Parkinson's disease or traumatic brain injury.
- Pediatric populations (<18 years)
- Interventions not involving virtual reality-based rehabilitation
- Studies without relevant functional or clinical outcomes

- Non-English publications or studies without accessible full text

Data Sources and Search Strategy

A proper literature search was conducted to review the available and suitable research. A variety of electronic databases were combed through:

- PubMed
- Scopus
- Web of Science
- Google Scholar

A mix of stroke-related keywords and Medical Subject Headings (MeSH) phrases were used in the search approach. The use of virtual rehabilitation was one of the options that was considered. The following terms were used:

Use of virtual reality for rehabilitation OR randomized controlled trial, in the context of a stroke OR CVA.

Boolean (AND, OR) operators were used to narrow the search. Studies published in English between 2022 and 2026 were the only ones considered.

Study Selection Process

We imported all the records that were found and checked for duplicates. After removing duplicates, the relevance of the titles and abstracts was determined. Next, the full-text articles were assessed based on the inclusion/exclusion criteria that had previously been determined. All 16 RCTs were included in the final analysis.

Data Extraction

Utilizing a standardized data extraction form, pertinent information was retrieved from the studies that were included. The data that was retrieved comprised:

- The year published and the author(s)
- This process will be guided by a research plan which will be determined by research participants.
- Descriptions of the people who participated in the activity.
- The types and duration of the VR intervention.Type and length of VR intervention.
- Utilized outcome metrics
- Crucial results

Quality Assessment

The methods quality of the included research was assessed using the Physiotherapy Evidence Database (PEDro) scale which provides a scale measure of the validity of the research and the statistical reporting. Additionally, the Cochrane Risk of Bias (RoB 2) tool was used to assess possible bias within each study including reporting bias, outcomes assessment, deviations from intended treatment, and non-allocation due to randomisation.

Outcome Measures

The aim of this review was to assess randomized controlled trials that have implemented virtual reality (VR) rehabilitation to examine its effectiveness and examine whether VR enhances motor, functional and cognitive outcomes following stroke.

Primary Outcomes

The most frequently reported primary outcomes included:

- **Motor Function (Upper and Lower Limb):**

Assessed using validated scales such as the Fugl-Meyer Assessment (FMA) and Action Research Arm Test (ARAT) to evaluate motor recovery and coordination.

- **Balance and Postural Control:**

Measured using tools such as the Berg Balance Scale (BBS) and Timed Up and Go (TUG) test, which assess dynamic balance and mobility.

- **Gait Performance:**

Evaluated using the Dynamic Gait Index (DGI), gait speed, and walking endurance tests.

Secondary Outcomes

Secondary outcomes included:

- **Functional Independence:**

Evaluated by tools that include the Functional Independence Measure (FIM) and Barthel Index (BI) to indicate the capacity to do activities of daily living.

- **Cognitive Function:**

Evaluated in selected studies using standardized cognitive assessments.

- **Dizziness and Vestibular Symptoms:**

Measured using the Dizziness Handicap Inventory (DHI) in studies focusing on vestibular rehabilitation and balance impairments.

- **Quality of Life and Psychological Outcomes:**

Some studies assessed patient-reported outcomes such as quality of life and depressive symptoms.

Most of the trials reviewed that met the inclusion criteria had pre and post measurements, but some had follow-up measures to determine if the benefits of the therapy continued. For example, one randomized controlled experiment, which implemented the TUG/DGI/DHI scale, found measure-taking pre- and post-8-week intervention revealed changes in Dizziness, balance, gait, and mobility scores.

Statistical Analysis

The statistical analysis methods varied across the included studies but followed standard approaches for randomized controlled trials.

- Descriptive Statistics:

Baseline characteristics of the participants were summarized as percentages, frequencies, standard deviations and averages.

- Testing for Normality:

In order to determine which of the non parametric or parametric statistical methods would better suit the data and to check for distribution of data, we implemented test such as Shapiro-Wilk test.

- The analysis of groups within a group.

Our analysis included using: to evaluate changes within groups prior to and following the intervention.

✧ In the two cases where the data is normally distributed, the data are tested with T-tests (pairwise T-tests).
✧ Wilcoxon signed-ranked tests are used on non-parametric data.

- Comparative Analysis:
- Comparisons between the two groups were made using:

✧ Labeled t-tests
✧ Comparisons using tests named Mann-Whitney U

- Level of Significance:

In most investigations a P value of < 0.05 was considered to represent statistical significance.

- Reporting the size of an effect:

Several studies reported effect sizes to determine the impact of the intervention.

- Programs Employed:

Common software for statistical analysis used were SPSS.

Ethical Considerations

There was no need to obtain original data or connect with human participants since this systematic review relied on data from already published research. So this means that an official clearance by an ethical committee was not required.

RESULTS

Study Selection

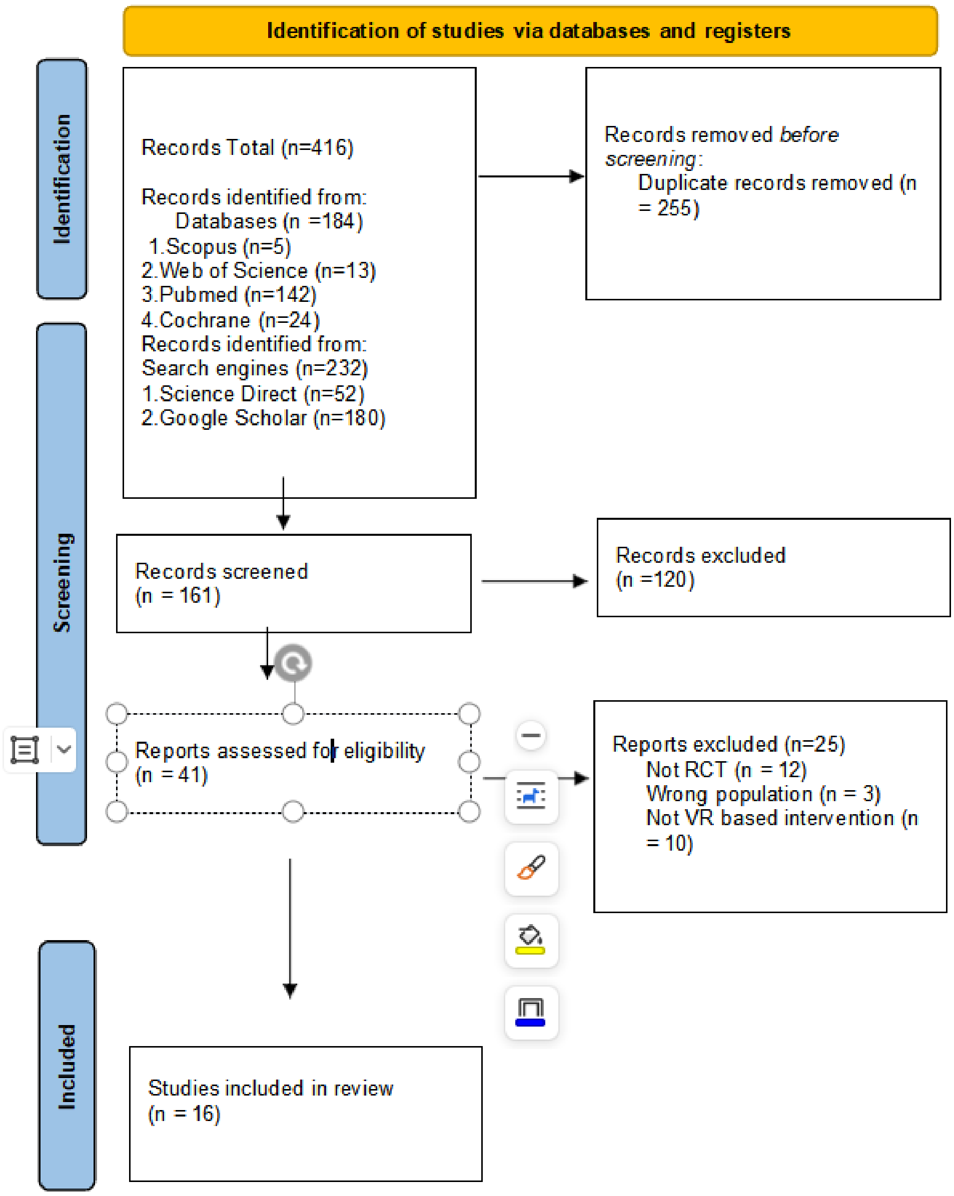
The results of a comprehensive literature search led to the discovery of 416 documents from a wide variety of electronic sources. The 184 studies were identified in the following databases: PubMed (n = 142), Cochrane Library (n = 24), Web of Science (n = 13), and Scopus (n = 5). In addition, search engines (ScienceDirect, n = 52; Google Scholar, n = 180) were also used to locate 232 documents.

[Abstract and Title records] =255 - duplicates = 161. In this stage 120 records were removed as not relevant for the research topic.

A total of 41 full text articles were reviewed in all. The final tally of articles recorded only 25 articles, because these were not randomized controlled trials (12 articles), the wrong population (3 articles) or don't employ VR-based therapies (10 articles).

Finally sixteen randomized controlled studies met the inclusion criteria for this systematic review.

To select studies, the PRISMA 2020 flowchart (Figure 1) has been followed.



PEDro Scale Assessment of Included Studies

The results of methodological quality assessment of the included RCTs using Physiotherapy Evidence Database (PEDro) scale are presented in Table 1.

All of the included studies had high methodological quality with PEDro scores ranging from 7 to 8/10. The higher quality internal validity and good statistical reporting metrics was apparent in most studies (Aguiler-Rubio, 2024; Ase, 2025; Hsu, 2022; and Huang, 2022, 2024), with these being each rated as 8/10. Others, like Chen et al. (2022), Kwak et al. (2024), Peláez-Vélez et al. (2023), and Wan et al. (2025), attained only seven points out of ten, which was in part due to the absence of allocation concealment.

All the studies included confirmed random allocation and baseline comparability, which ensured the first equivalency between groups. For instance, one of the included trials explicitly reported randomization using an envelope-based method, along with blinded outcome assessment, supporting a low risk of selection and detection bias.

One typical disadvantage of rehabilitation trials utilising VR therapies is the lack of blinding of patients and therapists. Sadly this was not realized in any of the investigations. Action and involvement characterize VR treatment, so it is impossible for a blind person to try it. In any case, most studies employed blind validation of the outcomes, to assure the validity of the study and lessen measurement bias.

Additionally, most studies met medium requirements for follow-up rates (>85 %), low absence rates and had adequate comparisons between the groups statistically, and reported point estimates with measurements of variability. Several studies particularly on intention-to-treat analysis, had been dealt with.

Overall, the included studies demonstrated acceptable methodological rigor, with consistent strengths in randomization, outcome measurement, and statistical reporting. The primary limitation across studies was the lack of blinding of participants and therapists, which should be considered when interpreting the results

Table 1: PEDro Quality Assessment of Included Studies

Study	1	2	3	4	5	6	7	8	9	10	11	Score (/10)	Quality
Aguilera-Rubio 2024	✓	✓	✓	✓	✗	✗	✓	✓	✓	✓	✓	8/10	Good
Ase 2025	✓	✓	✓	✓	✗	✗	✓	✓	✓	✓	✓	8/10	Good
Chen 2022	✓	✓	✗	✓	✗	✗	✓	✓	✓	✓	✓	7/10	Good
Hsu 2022	✓	✓	✓	✓	✗	✗	✓	✓	✓	✓	✓	8/10	Good
Huang 2022	✓	✓	✓	✓	✗	✗	✓	✓	✓	✓	✓	8/10	Good
Huang 2024	✓	✓	✓	✓	✗	✗	✓	✓	✓	✓	✓	8/10	Good
Janavičiūtė 2025	✓	✓	✓	✓	✗	✗	✓	✓	✓	✓	✓	8/10	Good
Jo 2024	✓	✓	✓	✓	✗	✗	✓	✓	✓	✓	✓	8/10	Good
Kiper 2022	✓	✓	✓	✓	✗	✗	✓	✓	✓	✓	✓	8/10	Good
Kwak 2024	✓	✓	✗	✓	✗	✗	✓	✓	✓	✓	✓	7/10	Good
Liu 2025	✓	✓	✓	✓	✗	✗	✓	✓	✓	✓	✓	8/10	Good
Patel 2025	✓	✓	✓	✓	✗	✗	✓	✓	✓	✓	✓	8/10	Good
Peláez-Vélez 2023	✓	✓	✗	✓	✗	✗	✓	✓	✓	✓	✓	7/10	Good
Sana 2023	✓	✓	✓	✓	✗	✗	✓	✓	✓	✓	✓	8/10	Good
Sylaja 2026	✓	✓	✓	✓	✗	✗	✓	✓	✓	✓	✓	8/10	Good
Wan 2025	✓	✓	✗	✓	✗	✗	✓	✓	✓	✓	✓	7/10	Good

Study Characteristics

The analysis comprises 16 Randomised Controlled Trials (RCTs). The studies comprised sample sizes ranging from 14 to 132 participants, involving both subacute and chronic stroke populations. The interventions primarily included immersive, non-immersive, and home-based virtual reality systems, often combined with conventional physiotherapy or task-oriented training. There were several OUTCOMES, such as motor function, balance, gait, ADLs and quality of life. With regard to motor function, balance and functional outcomes, most of the studies reported mildly successful VR-based rehabilitation. However, several trials found VR to be comparable rather than superior to conventional therapy. Additionally, VR interventions demonstrated benefits in cognitive function, neuroplasticity, and psychological outcomes such as depression.

Table 2. Study Characteristics

Author (Year)	Study Design	Sample	Intervention	Comparison	Outcome Measures	Key Findings
Aguilera-Rubio et al., 2024	RCT	36 (chronic stroke)	Low-cost VR + conventional therapy	Conventional therapy	Grip strength, ARAT, BBT, DASH	Improved motor function and adherence
Peláez-Vélez et al., 2023	Pilot RCT	24	VR + physiotherapy	Physiotherapy	Motricity Index, Balance scales	Improved balance and motor outcomes
Sana et al., 2023	RCT	34 (subacute)	VR therapy	Vestibular rehab	TUG, DGI, DHI	Better balance & gait
Kwak et al., 2023	Pilot RCT	36	Fully immersive VR	Conventional therapy	BBS, TUG	Improved gait and balance
Sylaja et al., 2026	RCT	60	Non-immersive VR	Physiotherapy	FMA, WMFT, BI	Comparable to conventional therapy
Patel et al., 2025	RCT	100	VR + robotics	Usual care	ARAT, UEFMA	No long-term superiority
Ase et al., 2025	RCT	14	Home-based VR	Home rehab	FMA-UE, MAL	Improved upper limb function
Jo et al.,	RCT	45	360° VR	MT, control	FMA-UE,	Superior

2024			mirror therapy		BBT	outcomes
Hsu et al., 2022	RCT	54	VR mirror therapy	MT, OT	FMA-UE, MAL	Limited superiority
Huang et al., 2022	RCT	30	Immersive VR	OT	FMA-UE, biomarkers	Improved neuroplasticity
Liu et al., 2023	RCT	64	VR + TOCT	VR alone	FMA-UE, BI	Better combined outcomes
Wan et al., 2025	RCT	38	BCI + VR	Conventional	BBS, TUG	Improved balance
Kiper et al., 2022	RCT	60	Immersive VR	Autogenic training	Depression scales	Improved mood
Chen et al., 2022	RCT	36	VR training	Conventional	FMA, ARAT	Improved motor anticipation
Huang et al., 2024	RCT	40	Immersive VR	Conventional	FMA-UE, BI	Improved UE recovery
Janavičiūtė-Pužauskė et al., 2025	RCT	132	VR cognitive training	Conventional	Cognitive tests	Improved cognition

SYNTHESIS OF RESULTS

Motor Function Outcomes

Most of the included studies measured motor control recovery in the upper limbs using standardized assessments: the Fugl-Meyer Assessment (FMA-UE), the Action Research Arm Test (ARAT) and the Box and Block Test (BBT). In many studies,VR-based treatment was shown to be statistically significant in improving motor function. For instance, immersive VR and combined VR-based therapies demonstrated superior improvements in upper limb function compared to conventional therapy in some studies [7,12]. Similarly, home-based VR interventions and VR combined with task-oriented training showed enhanced motor recovery and functional use of the affected limb [3,12].

Additionally, VR-based mirror therapy and motor control training were found to improve sensorimotor function and neuroplasticity-related outcomes [5,6]. Improvements in motor anticipation and cortical activation patterns were also observed following VR interventions, indicating potential neural-level benefits [4]. However, despite these positive findings, several studies reported no statistically significant superiority of VR over conventional rehabilitation, suggesting comparable effectiveness between interventions [13,15].

Balance and Gait Outcomes

Numerous instruments have been developed to assess gait and balance in large number of research, including the Dynamic Gait Index (DGI), Timed Up and Go (TUG) test and Berg Balance Scale (BBS). Recent studies indicate virtual reality (VR) therapy can improve gait function and balance. For example, VR interventions were found to be more effective than vestibular rehabilitation therapy in improving balance and gait, although vestibular therapy showed better outcomes for dizziness [1].

VR-based interventions that are fully immersive and a training that is based on the dual task also led to the significant improvement in postural control, gait parameters, and mobility [11,16]. The results of this study indicate that VR space, This can provide stroke patients with motor relearning and balance control as a tool of multimodal feedback and task specific training.

Activities of Daily Living and Quality of Life

Some of the measures included Barthel Index (BI), Stroke Impact Scale (SIS) and Short-Form 36 which were employed in several studies which evaluated functional independence and quality of life. VR rehabilitation was found to be better in terms of activity of daily living and quality of life but, in most cases, these were as good as those attained with standard therapy [12,15].

Although VR interventions improved functional outcomes, it has been demonstrated that the incremental value of VR interventions over standard rehabilitation is still relatively low in certain instances, especially in situations where standard therapy is already well-structured and intensive.

Cognitive and Psychological Outcomes

In addition to motor recovery, there were studies that investigated cognitive and psychological outcome of VR-based rehabilitation. VR interventions were found to have a positive impact on cognitive abilities, such as attention, memory, and executive functioning [8]. Moreover, immersive VR therapy greatly decreased the level of depressive symptoms and enhanced the psychological well-being amongst stroke patients [10].

In addition, dual-task and brain-computer interface systems based on VR were also demonstrated to improve attention and cognitive processing as well as motor improvements, which suggests the possibility of VR to be a multidimensional rehabilitation tool [16].

Neuroplasticity and Physiological Outcomes

Very little research has been done to investigate the effects of variations in physiological and neuroplastic alterations in connection with VRT therapy. VR-based motor control training led to improvements in biomarkers of inflammation, oxidative stress and neuroplasticity [6]. Moreover, neuroimaging research revealed that VR rehabilitation had the potential to bring about alterations in brain functional connectivity that related to motor recovery [7].

These results confirm the hypothesis that VR-based rehabilitation can help to reorganize the neural system and improve recovery over the functional improvement.

Overall Effectiveness of VR-Based Rehabilitation

VR appears to be a safe, viable and useful intervention to improve motor, balance, cognitive and quality of life outcomes of stroke patients. A number of studies have reported huge returns in the treatment groups, but inconclusive some studies show VR to be better than traditional treatment.

Virtual reality can be superior to conventional rehabilitation therapies, or can be used alongside them, and it has added advantages of higher patient engagement, motivation and compliance to therapy.

Risk of Bias within Studies

Cochrane Risk of Bias 2 (RoB 2) was used to evaluate the risk of bias. The majority of the studies that were considered had a minimal risk of bias. This was particularly the case for outcome measurement, missing data and randomization. One of the common problems across rehabilitation studies about VR therapies was the lack of blinding and participant staff members in some studies leading to some challenges. There are also some studies with potential measurement errors and poorly defined randomisation methods. Despite these limitations, some trials selected were dependable due to their moderate to high methodological quality.

Table 3. Risk of Bias Assessment through Cochrane ROB 2

Study (Author, Year)	Randomization Process	Deviations from Intended Interventions	Missing Outcome Data	Measurement of Outcome	Selection of Reported Result	Overall Risk of Bias
Sana et al., 2023	Low	Some concerns	Low	Low	Low	Low
Aguilera-Rubio et al., 2024	Low	Some concerns	Low	Low	Low	Low
Ase et al., 2025	Low	Some concerns	Low	Low	Low	Low
Chen et al., 2022	Low	Some concerns	Low	Low	Low	Low
Hsu et al., 2022	Low	Some concerns	Low	Some concerns	Low	Some concerns
Huang et al., 2022	Low	Some concerns	Low	Low	Low	Low
Huang et al., 2024	Low	Some concerns	Low	Low	Low	Low
Janavičiūtė-Pužauskė et al., 2025	Low	Some concerns	Low	Low	Low	Low
Jo et al., 2024	Low	Some concerns	Low	Low	Low	Low
Kiper et al., 2022	Low	Some concerns	Low	Some concerns	Low	Some concerns
Kwak et al., 2024	Some concerns	Some concerns	Low	Low	Low	Some concerns
Liu et al., 2025	Low	Some concerns	Low	Low	Low	Low
Patel et al., 2025	Low	Some concerns	Low	Low	Low	Low
Peláez-Vélez et al., 2023	Some concerns	Some concerns	Low	Low	Low	Some concerns

Sylaja et al., 2026	Low	Some concerns	Low	Low	Low	Low
Wan et al., 2025	Some concerns	Some concerns	Low	Low	Low	Some concerns

DISCUSSION

This systematic review was designed to investigate whether stroke patients could learn to recover faster with the use of virtual reality (VR)-based rehabilitation as revealed by sixteen randomized controlled trials. The results demonstrate that virtual reality interventions are able to improve stroke patients' balance and this can be applied to their gait, cognitive function, psychological function and motor function of the upper limbs. Many of the trials for both motor recovery and postural control demonstrated significance improvement among group participants. However, results from the included studies do not consistently show that virtual reality (VR) is better to traditional rehabilitation methods.

The improvements in upper limb motor function observed in this review are consistent with several studies reporting significant gains in Fugl-Meyer Assessment (FMA-UE), Action Research Arm Test (ARAT), and Box and Block Test (BBT) scores following VR-based interventions [2–7,9,12–15]. For instance, immersive VR and combined interventions such as VR with task-oriented circuit training demonstrated enhanced motor recovery compared to standard rehabilitation approaches [7,12]. Similarly, home-based VR interventions and low-cost VR systems were shown to improve functional use of the affected limb and patient adherence to therapy [2,3]. However, some studies reported comparable outcomes between VR and conventional therapy, suggesting that VR may not always provide superior motor benefits [13,15].

Balance and gait outcomes were also positively influenced by VR-based rehabilitation. Several studies reported significant improvements in balance measures such as the Berg Balance Scale (BBS) and mobility outcomes such as the Timed Up and Go (TUG) test [1,11,14–16]. In particular, immersive VR and dual-task VR-based interventions demonstrated superior improvements in postural control and gait performance compared to control interventions [11,16]. Furthermore, VR was found to be more effective than vestibular rehabilitation therapy in improving balance and gait, although vestibular therapy showed greater benefits for dizziness [1]. This results show a potential added value of using virtual reality (VR) to enhance motor relearning in a task-specific, multimodal training context.

Along with motor results, VR-based rehabilitation showed positive results on the cognitive and psychological levels. Cognitive functions like attention, memory and executive functioning were positively influenced by VR interventions especially when cognitive training paradigms were implemented with the help of VR environments [8]. In addition, VR therapy (immersive) had a significant beneficial effect on depressive symptoms and psychological well-being of stroke patients [10]. The results indicate that virtual reality could be employed to offer a holistic rehabilitation method which also covers the mental health of patients.

Various processes might have contributed to the success of the VR-based therapy. The training programs in Virtual Reality systems are challenging, repetitive, and task-oriented pointing out to the concept of neuroplasticity and relearning. The interactive and immersive experience of virtual reality also increases the motivation, engagement and adherence to treatment by patients; which are essential elements affecting the outcomes of rehabilitation. This mechanism is supported by neurophysiological evidence of the studies included over the years, which show that biomarkers of neuroplasticity have been improved and changes in brain functional connectivity have occurred in VR interventions [6,7]. Moreover, VR training was also found to enhance the motor anticipation and cortical activation patterns and, therefore, improved neural processing [4].

Although these were positive results, there was evidence of inconsistent findings with studies. Several trials reported no statistically significant differences between VR and conventional therapy [13,15]. These discrepancies may be attributed to heterogeneity in study design, variations in intervention duration and intensity, differences in VR systems (immersive vs non-immersive), and the use of VR as an adjunct rather than a standalone intervention. Additionally, small sample sizes and methodological limitations may have influenced the results.

Particularly clinically, Virtual Reality (VR) rehabilitation offers numerous benefits compared to more traditional approaches. Because of its ability to deliver customized, engaging, and activity-oriented training, both in-clinic and at-home rehabilitation can be greatly helped by its ability to do so. Another issue with long-term stroke therapy is patient motivation and adherence; VR may help with both of these issues.

There are a myriad of factors working in this review's favor. There were no non-randomized controlled trials included ensuring a higher level of evidence. The review followed PRISMA guidelines and provided a comprehensive synthesis of multiple outcome domains, including motor, cognitive, and psychological effects. However, some limitations are noted. A meta-analysis was not conducted because there was significant heterogeneity in interventions, measures of outcome, and populations studied. It was also likely to be a performance bias as it was not feasible to blind participants and therapists in most of the studies. Due to the small sample size of some studies, the results might not be generalizable.

Future studies should focus on standardization of VR intervention techniques and on large-scale and high-quality randomized controlled trials. More research is needed to determine the optimal VR dose, time, and type of therapy with stroke patients to determine long-term benefits.

To sum up, VR-based rehabilitation is an innovative and promising method of stroke rehabilitation. Although it is evident that it is effective in enhancing various functional areas, it is not clear whether it is the best among other conventional therapy. Consequently, VR should be implemented as a supplement to the conventional rehabilitation and has extra advantages in the involvement, motivation, and functional restoration.

CONCLUSION

VR based interventions (VRBI) represent an emergent and effective strategy to improve motor capacity, balance and cognitive ability and psychosocial outcomes in stroke patients. This review indicates that VR interventions are effective in enhancing group functionality in diverse functional domains. Nevertheless, the results of the efficiency of virtual reality as the sphere of rehabilitation are not yet conclusive.

Apparently, VR would work best in combination with the effectiveness of conventional rehab programs compared to VR programs as an independent entity due to its capacity to augment patient engagement, motivational, and treatment intensity. Furthermore, the combination of immersive and task-based VR solutions can additionally streamline the results of the rehabilitation process through neuroplasticity and relearning of the motor skills.

It has a potential of increased expectations of the results but it is difficult to generalise the outcomes due to variation in study design, study intervention and outcome measure. Naturally, to comprehend how VR may be better utilized in stroke rehabilitation, we should possess more high-quality randomized controlled studies that would use standard methods and have longer-term follow-up.

To sum up, VR-based rehabilitation is a novel and useful instrument in the neurorehabilitation domain, and it may be used to supplement a standard treatment and should be offered to an overall functional recovery of stroke patients.

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