Systematic Review / Meta-analysis

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The efficacy of virtual reality-based rehabilitation in improving motor function in patients with stroke: a systematic review and meta-analysis

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Background: Stroke is a major cause of adult disability, prompting the exploration of innovative rehabilitation methods. Virtual rehabilitation (VR), leveraging technological advances, has gained popularity as a treatment for stroke recovery.

Methodology: The authors conducted a systematic review and meta-analysis of randomized controlled trials (RCTs) published in English within the last decade, adhering to the PRISMA guidelines. The authors searched databases such as Medline/PubMed, and the Cochrane Library using specific search keywords and Medical Subject Headings (MeSH). The methodological quality was assessed using the PEDro scale, focusing on RCTs involving adult stroke patients undergoing VR rehabilitation, with outcomes related to motor function and quality of life.

Results: The authors included 15 studies in our meta-analysis. VR rehabilitation offers several advantages over traditional therapy, such as enhanced feedback and increased patient motivation. Engaging VR environments helps improve focus during treatment, potentially boosting recovery from post-stroke impairments. VR therapies significantly benefit motor function, which can improve activities of daily living and overall quality of life.

Conclusion: VR has demonstrated efficacy in improving motor function and quality of life for stroke survivors. Future research should explore patient variability and refine intervention methods. Incorporating VR into rehabilitation programs could optimize stroke recovery outcomes.

Keywords: exposure therapy, motor function, physical therapy, stroke, virtual rehabilitation

Introduction

Brain damage resulting from acute events like strokes often leads to disability and death[1,2]. Stroke is the primary cause of impairment and the second most common cause of death worldwide[3,4]. Even though physical therapy with aerobic exercise is believed to be the best approach to motor rehabilitation after a stroke, 15–30% of those who suffer from stroke are permanently disabled. Globally, it was the third leading cause of death and disability in 2019. Approximately 12.2 million new strokes are observed every year, with 25% of people aged over 25 years having a chance of stroke in their lifetime[4]. More than 50% of survivors have a disability in the form of reduced mobility following a stroke[5]. Numerous deficiencies have been noted, such as exhaustion, lassitude, fluctuations in mood, loss of sensory perception, deconditioning of the heart, nervousness, clumsiness, disorganized motions, inadequate equilibrium, and difficulties with walking[6]. In the case of a stroke, these deficits may impact the patient's ability to perform functional tasks[7,8].

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Despite advancements in stroke care within clinical settings, which have greatly reduced the number of stroke-related mortality cases, stroke is the world's leading cause of death and disability[5,9,10]. Concurrently, there is a discernible increase in the proportion of individuals with neurological abnormalities who experience substantial disability[11]. Although aerobic activities along with physical training are the gold standard for post-stroke motor rehabilitation, 15–30% of stroke patients experience lifelong impairment and only a few patients reported an improvement of their upper limbs (UL) function[12,13]. This significantly affects individuals' ability to perform daily tasks independently and engage socially[14].

It has been predicted that several motor rehabilitation programs utilizing motor learning frameworks will assist stroke victims in regaining the functional use of a damaged limb[3,15,16]. This is achieved by neural plasticity, which modifies the morphology and function of the nervous system[17]. International stroke rehabilitation research has recently focused on interventions for post-stroke motor and cognitive impairment, depression, and decreased functional independence. Novel therapies, such as virtual reality (VR), repetitive transcranial magnetic stimulation (RTMS), and robotic assistive therapies, have been demonstrated as potential future therapies[18–20]. Consequently, it has been demonstrated that enhanced neuronal plasticity has an important role in the rehabilitation of damaged limbs[21,22]. Recent research has led to the development of several stroke rehabilitation regimens aimed at improving post-stroke limb function, with evidence from the clinical trials of neuroplasticity-induced brain remodeling[16,23–26].

The effectiveness of motor function improvement is examined and confirmed by several meta-analyses[27,28]. It is challenging to determine which program is better or which ones should be used consistently during rehabilitation, though, because of the intricacy of stroke recovery and the variations in the methods of research[23–26].

It has been suggested that general exercises and a task-based approach with appropriate intensity be incorporated into stroke rehabilitation programs[29,30]. In stroke patients, passive stimulation techniques that use stimuli such as proprioception for movement of the body and visual input are employed to restore lost motor as well as sensory function[30]. These comprise a variety of electrical stimulation methods, including thermal stimulation (TS)[31,32], periodic pneumatic compression[28,33], neuromuscular stimulation, cutaneous electrical stimulation, transcutaneous electrical nerve stimulation (TENS), and peripheral stimulation with magnets[28].

For stroke patients with severe disability, conventional therapies (CT) such as physical or occupational therapy are frequently used to improve their upper extremity motor function recovery[34,35]. Nevertheless, the results of this traditional strategy frequently rely on the skill and expertise of the medical staff, and it is frequently time-consuming with a low compliance rate. It has been shown, although, that the training incorporated into conventional therapy is still insufficient to result in a motor improvement of the damaged limb based on brain plasticity[22].

The previously mentioned drawbacks prompted scientists to create and evaluate additional novel approaches, like virtual rehabilitation[21,34], that would be more effective in helping stroke victims achieve functional recovery of their affected limbs.

Acknowledged as a cutting-edge approach, computer-simulated environment-based virtual rehabilitation enables users to engage in an array of situations and exercises within the designated virtual environment[22], sometimes at higher levels of intensity than that found in traditional rehabilitation regimens for post-stroke patients[36]. This method has emerged as a viable option for stroke patients undergoing rehabilitation of motor function who have UL impairments[34]. Stroke survivors can engage in a goal-oriented program through virtual rehabilitation that supports and strengthens their functional limitations, activity restrictions, and limitations on their capacity to contribute to society[37]. Additionally, real-time visual feedback for motions is provided by virtual rehabilitation, which also boosts patient engagement in enjoyable rehabilitation programs[38].

HIGHLIGHTS

- Stroke is a leading cause of adult disability, driving the exploration of novel rehabilitation methods. Virtual rehabilitation (VR) leverages technological advancements to offer innovative solutions for stroke recovery.
- This study presents a comprehensive systematic review and meta-analysis of randomized controlled trials (RCTs) published in the last decade.
- VR rehabilitation offers distinct advantages over traditional therapy, including enhanced feedback mechanisms and increased patient motivation. Engaging VR environments facilitate focused treatment sessions, potentially accelerating recovery from post-stroke impairments.
- Enhanced motor function can translate into improved activities of daily living and overall quality of life for stroke survivors.
- VR-based rehabilitation emerges as a promising intervention for stroke recovery, with demonstrated efficacy in enhancing motor function and quality of life.

Although several VR interventions have been used with stroke survivors, the effectiveness of virtual rehabilitation interventions has not yet been significantly supported by high-quality research. VR-based therapy usually includes moving and acting within a virtual setting. Patients can use computer simulations to enhance their motor abilities by recognizing objects, following paths, and carrying out routine tasks in three-dimensional virtual environments (Fig. 1)[39]. VR technology in rehabilitation offers several benefits over previous rehabilitation techniques. Initially, it enables users to experience risky or unfeasible circumstances in real-world settings safely and efficiently. Second, patients do not have to worry about pressure, as they can work out at their own speed and skill level in a virtual setting. Third, virtual reality technology can assist patients in gaining self-assurance in handling challenging real-world circumstances. Significant alterations in healthcare provision, including rehabilitation services, have been observed due to the COVID-19 pandemic[40].

The term "home-based VR" describes the use of virtual reality technology in patients' rehabilitation in settings they are accustomed to, such as their own homes. Because treatment and exercise can be done remotely, patients no longer need to go often to hospitals or rehabilitation facilities. With the help of doctors and therapists, patients can receive their rehabilitation remotely, in the privacy and security of their own homes[41–43]. Promising results of VR therapy has been noted as the improvement of motor function, balance, and the ability to perform necessary daily tasks for patients with musculoskeletal and neurological disorders. For multiple sclerosis, severe brain damage, and stroke, it is a helpful therapeutic substitute[44–46].

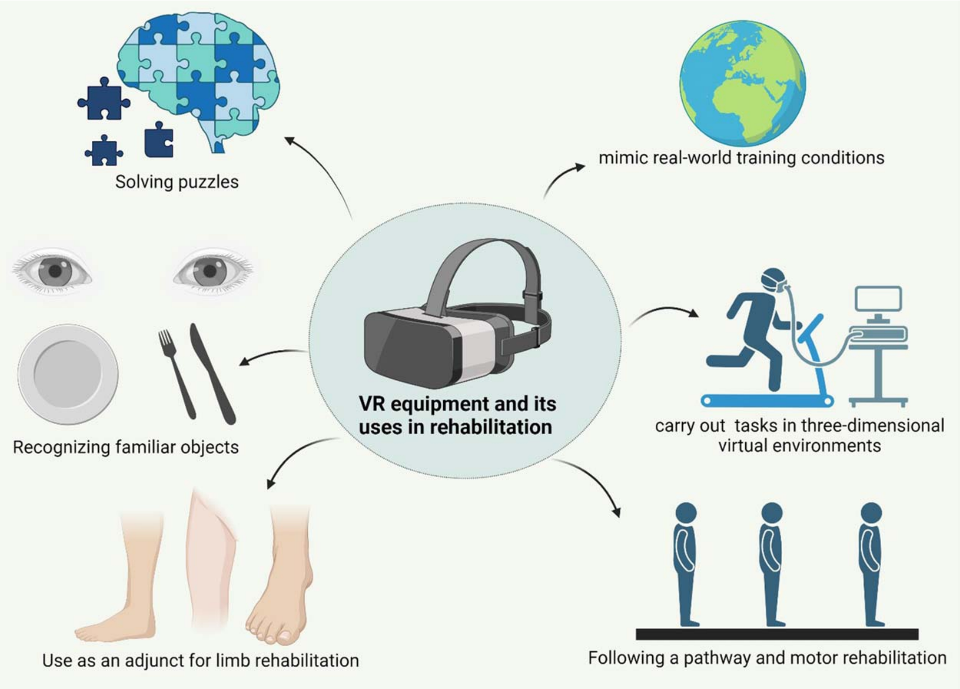


Figure 1. The different uses of virtual reality in the rehabilitation of stroke patients. VR, virtual rehabilitation.

Methodology

Study searching and selection

The "Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)" criteria were followed in the conduct and reporting of this study. Medline/PubMed, and the Cochrane Library were the databases used in the literature search. The following search phrases were used: "physical therapy modalities," "exposure therapy" "virtual rehabilitation," and "stroke." Medical Subject Heading (MeSH) descriptors were employed in the search strategy formation.

Types of records were determined by study design framework, contrasts, outcomes, interventions, and participants. Any patient with a persistent stroke that impacted their upper limbs was eligible to participate. The key result of interest was the treatment's efficacy, with VR-based therapy serving as the intervention and traditional therapy serving as a comparison. The baseline values were compared to the most recent follow-up point, and a positive change was considered an indicator of effectiveness. In cases when many outcomes are recorded, the most pertinent result to other studies or the primary outcome is used when assessing a study's efficacy in maintaining homogeneity.

Inclusion criteria

The subsequent inclusion standards were determined: (i) publications released between 2012 and 2022 to gather up-to-date and relevant research; (ii) The use of the English language; (iii) Randomized controlled trials (RCTs); (iv) adult stroke patients (age > 18 years); (v) a VR game-based intervention that simulates virtual environments through the use of personal computers, electronic devices for video games and smartphone apps (vi) outcomes of motor function and quality of life assessed.

Exclusion criteria

A thorough verification procedure was used to ensure the papers in this systematic review fulfilled the eligibility requirements. Exclusions from this study included records or non-full texts about animal populations, non-randomized trials, and other research designs, including cohort, cross-sectional, case-control, and case studies. Those studies that did not disclose the data individually and merged participants with stroke in addition to those with other diseases were eliminated.

Each article that was part of this analysis had information available about the kind of treatment, the number of participants, the frequency of visits, the length of each session, the overall duration of therapy, the measuring instrument, and the outcome measures.

Evaluation of the bias risk

The methodological quality of the RCTs included in the meta-analysis was evaluated using the PEDro scale[47]. Eleven items in all address the topics of performance, attribution bases, information, detection, and selection[48].

We utilized Cochrane's updated quality assessment instrument (ROB-II) for randomized controlled trials[49]. Their internal validity must be critically assessed, which is made simpler by using ROB-II. This method aids in the transparent and uniform evaluation of bias, which enables researchers to make more informed decisions about which papers to include and which to omit from systematic reviews and meta-analyses[49].

Statistical analyses

A meta-analysis was performed to assess the degree of effect changes between the control and intervention groups (IG) before and following treatments. The effectiveness of VR-based

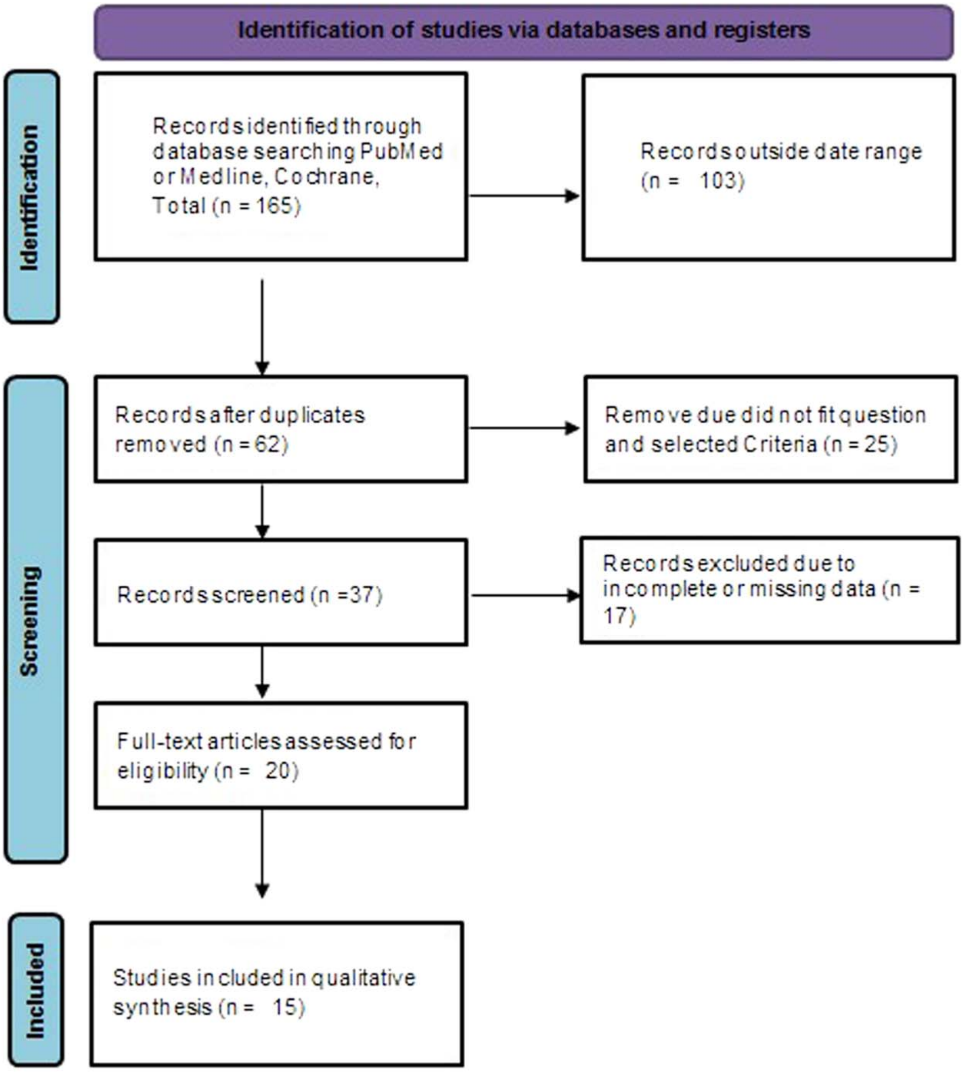


Figure 2. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram.

techniques was examined in the meta-analysis using the SPSS version 23 software. We performed subgroup analyses to minimize heterogeneity. To lessen the effects of study heterogeneity, a random-effects model was used to assess the pooled treatment effect of the various trials that were integrated[50]. Hedges'g, and the effect size (ES), Egger regression was used to measure publication bias, and Q statistics and I^2 tests were used to evaluate heterogeneity. The trim-and-fill technique was utilized to incorporate absent studies, and meta-regression was employed to investigate the impact of time elapsed since the previous stroke on the efficacy of virtual reality.

Results

Overall, 165 articles were captured with the previously mentioned combination of keywords in the database searches, as shown in Figure 2. One hundred three articles underwent screening for eligibility check; after that, duplicates were removed. There were 20 articles in the review overall after the selection procedure; 15 of those were used in the meta-analysis of the statistical analysis. Figure 2 shows the whole selection process for each of the relevant operations. Table 1 displays the final score as well as the distinct features of each study (Appendix). Most of the studies that were selected for analysis showed excellent methodological quality (Table 2).

Risk of bias

Table 2 and Figure 3 presents the RCTs that were included and their study quality. Three studies showed a high risk of bias, five had minor concerns, and nine had a low overall risk of bias. One of them had a low risk of bias while the other had a substantial risk of bias for non-randomized trials. The risk of bias in sequence generation, allocation concealment, outcome assessor blinding, selective outcome reporting, and other sources of bias was low in all of the studies (Saposnik *et al.*,[51], Kong *et al.*,[52], Choi *et al.*,[53], Taveggia *et al.*,[56], Subramanian *et al.*,[60], Sheehy *et al.*,[59], Rand *et al.*,[64], Lee *et al.*,[70], Shin *et al.*[69]). The therapist and participant blinding in all trials (Brunner *et al.*[54], Rubio *et al.*,[57]; Kwon *et al.*[62]; Sin *et al.*[63], Thielbar *et al.*[65], Feng *et al.*[68]) was unclearly biased. There was a significant

Table 1

Presents the primary attributes of the research interventions

Study	Group interventions	VR groups	No. participant	The average age of participants in years/SD	Frequency	Session duration (min/h)	Intervention duration (week)	Outcome measure	Measuring instrument	Results
Saposnik *et al.*[51]	Control group: Recreational activities intervention group: Conventional treatment + virtual rehabilitation along with Nintendo Wii	Commercial games based on Nintendo Wii	Total participants = 121 Control group:62 Instrumental group:59	62 (12.0) 62 (13.0)	5	60 min	2	1. Motor function 2. Quality of life 3. Kinematics parameters	1. WMFT, Box, and Block Test, SIS, dynamometer. 2. SIS, MBI, FIM, and Modified Rankin Scale 3. Kinematic analysis with RPSS	Following the intervention, no statistically significant change was seen between the groups.
Kong *et al.*[52]	Control group: Conventional treatment IG: virtual rehabilitation with Nintendo Wii	Commercial games created on Nintendo Wii	Participants = 68 Control group:35 Intervention group:33	55.8 (11.5) 58.1 (9.1)	4	60	3	1. Motor function 2. Quality of life	1. FMA-UE, ARAT. 2. FIM, SIS	Following the intervention, no statistically significant change was seen between the groups.
Choi *et al.*[53]	Control group: Conventional treatment Intervention group: virtual rehabilitation-based Mobile games	Mobile games using a smartphone and a Tablet or computer	Participants = 24 Control group:12 Intervention group:12	72.1 (9.9) 61.0 (15.2)	5	30	2	1. Motor function 2. Quality of life 3. Depression	1. FMA-UE, Brunnstro¨m, MMT 2. MBI, EQ-5D 3. BDI	There was a noticeable statistical difference between the FMA-UE, Brunnstro¨m, and MMT groups.
Brunner *et al.*[54]	Control group: Conventional treatment Intervention group; Conventional treatment + virtual rehabilitation system + bionic gloves (YouGrabber	Games based on interacting with virtual environments and objects	*N* = 102 CG:52 IG:50	62.0 (—) 62.0 (—)	4	60	4	1. Motor function 2. Quality of life	1. ARAT, Box, and Block Test 2. FIM	Following the intervention, no statistically significant change was seen between the groups.
Shin *et al.*[55]	CG: Conventional treatment Intervention group; virtual rehabilitation with biofeedback bionic gloves (SmartGlove)	Games based on interacting with virtual environments and objects	*N* = 33 CG:14 IG:19	59.8 (13.0) 57.2 (10.3)	3	30	4	1. Motor function 2. Quality of life	1. FMA-UE, JTT, PPT (Purdue pegboard test) 2. SIS	There was a discernible difference between the Fugl-Meyer Assessment for the Upper Extremities, SIS and JTT groups.
Taveggia *et al.*[56]	Control group: Conventional treatment Intervention group: Conventional treatment and virtual rehabilitation system with an exoskeleton (Armeo Spring)	Games based on performing virtual tasks in virtual environments	*N* = 54 CG:27 IG:27	68.0 (13.0) 73.0 (10.0)	5	30	6	1. Motricity 2. Spasticity 3. Pain 4. Quality of life	1. MI 2. Ashworth 3. FIM 4. VAS	Each measure showed a statistically significant difference between the two groups.
Rubio *et al.*,[57]	Conventional treatment + virtual rehabilitation system	Games based on interacting with virtual environments and objects	10	59.50 (± 11.43) years	2	60	8	1. Motor function	1. Action Research Arm Test (ARAT) 2. BBT 3. SF-36	There was a statistically significant variation in the UL motor function (BBT, ARAT, grip strength, and upper extremity muscle strength) in patients.
Mekbib *et al.*,[58]	Conventional treatment Intervention group: virtual rehabilitation system	VR-based limb mirroring therapy	21	57.13 (± 4.45)	4	60	2	UE	Resting-state fMRI and FMA for UL	Exercises involving bilateral and unilateral limb mirroring in a fully immersive virtual setting

Table 1

(Continued)

Study	Group interventions	VR groups	No. participant	The average age of participants in years/SD	Frequency	Session duration (min/h)	Intervention duration (week)	Outcome measure	Measuring instrument	Results
										have the potential to improve motor performance and cortical reorganization.
Sheehy *et al.*,[59]	Conventional treatment occupational therapy rehabilitative exercise	Games based on interacting with virtual environments, arm and trunk movement	69	64.7 (±16.2)	5	30–45 min	2	UE	Jintronix software and a Kinect 2 three-dimensional motion-tracking camera	As sitting balance results were comparable for both groups, this study does not support the use of VRT-provided sitting balance exercises for the rehabilitation of sitting balance following a stroke. Though this is only the second study to look into virtual reality therapy (VRT) for sitting balance and post-stroke upper extremity function for sitting balance, more research employing more difficult exercises and more intense treatment is needed before definitive findings can be drawn.
Subramanian *et al.*[60]	CG: Similar real therapy Intervention group:: 3D immersive VR (CAREN)	Games based on interacting with virtual environments and object	*N*= 25 CG:13 IG:12	60.0 (11.0) 62.0 (9.7)	3	—	4	1. Motor function 2. Arm use. 3. Kinematcs parameters	1. Fugl-Meyer Assessment for the Upper Extremities, WMFT, RPSS (Reaching Performance Scale for Stroke) 2. MAL–AS 3. Kinematic 3D analysis	No statistically significant difference was found between groups in kinematics, arm motor impairment, activity level, and arm us.
Cho & Jung,[61]	Control group: Conventional treatment Intervention group: immersive VR (IREX)	Games based on interacting with virtual environments and objects	*N*= 29 CG:14 IG:15	63.7 (8.8) 64.0 (7.1)	5	60	4	1. Motor function 2. Visual perception and processing time	1. WMFT 2. MVPT (Motor-free Visual Perception Test)	No statistically significant difference was found between groups on WMFT. A statistically significant difference was found in MVPT between groups.
Kwon *et al.*[62]	Control group: Conventional therapy IG: Conventional therapy + Immersive VR (IREX)	Games based on interacting with virtual environments and objects	*N*= 26 CG:13 IG:13	57.9 (12.3) 57.1 (15.4)	5	30	4	1. Motor function 2. Quality of life	1. Fugl-Meyer Assessment for the Upper Extremities, MFT (Manual Function Test) 2. MBI	Following the intervention, no statistically significant change was seen between the groups.
Sin *et al.*[63]	Control group: Conventional treatment Intervention group: Conventional therapy + semi-immersive VR with Xbox Kinect	Commercial games based on Xbox Kinect	*N*= 35 CG:17 IG:18	75.5 (5.5) 71.7 (9.4)	3	30	6	1. Motor function 2. Manual dexterity	1. Active ROM, Fugl-Meyer Assessment for the Upper Extremities, 2. Box, and Block Test	A statistically significant difference was found between active ROM, FMA-UE and BBT groups.

Rand *et al.*[64]	Control group: Conventional treatment Intervention group: Semi-immersive and non-immersive VR with Xbox Kinect, PlayStation 2&3	Commercial games based on Xbox Kinect, Sony Play Station 2 EyeToy, Sony Play Station 3 Move, and SeeMe VR system	*N*= 29 CG:14 IG:15	62.5 (—) 57.0 (—)	2	60	12	1. Motor function	1. Number of movements, acceleration, and movement intensity	A statistically significant difference was found between groups in the number of intentional movements
Thielbar *et al.*[65]	Control group: Intensive treatment IG: Intensive therapy with mechatronic VR (AVK)	Games based on interacting with a virtual Keypad	*N*= 14 CG:7 IG:7	59.0 (7.0) 54.0 (7.0)	3	—	6	1. Motor function	1. JTT, ARAT, Fugl-Meyer Assessment for the Upper Extremities, finger function	A statistically significant difference was found between the FMA-UE, JTT, and finger function groups.
Zheng *et al.*[66]	CG: RTMS treatment + immersive VR IG: L-F RTMS treatment + immersive VR	Games based on interacting with virtual environments and objects	*N*= 108 CG:53 IG:55	66.2 (13.1) 65.4 (13.5)	6	—	4	1. Motor function 2. Quality of life	1. Fugl-Meyer Assessment for the Upper Extremities, WMFT 2. Modified Barthel Index 3. SF-36	A statistically significant difference was found between the FMA-UE, WMFT, and MBI groups.
Kiper *et al.*[67]	CG: Conventional treatment Intervention group: Conventional treatment + VR feedback gloves	Games based on interacting with virtual environments and object	*N*= 44 CG:21 IG:23	65.5 (14.2) 63.1 (9.5)	5	60	4	1. Motor function 2. Quality of life 3. Kinematic parameters	1. Fugl-Meyer Assessment for the Upper Extremities 2. FIM 3. Kinematic 3D analysis	There was a discernible variation between the groups in terms of FMA-UE, FIM, and kinematics characteristics.
Feng *et al.*[68]	Conventional treatment and physiotherapy + virtual rehabilitation	Games based on interacting with virtual environments and objects	*N*= 28	IG: 67.47 ± 4.79 CG: 66.93 ± 4.64	5	45 min	12	Motor function	1. BBS 2.FGA 3.TUGT	The study's findings suggest that, in comparison to traditional physical treatment, 12 weeks of VR rehabilitation improved the balance and gait of patients receiving physical therapy..
Shin *et al.*[69]	Control group: Conventional treatment Intervention group: Conventional treatment and virtual rehabilitation system	Games based on interacting with virtual environments and objects	*N*= 32 CG:16 IG:16	54.6 (13.4) 53.3 (11.8)	5	60	4	1. Quality of life 2.Depression 3. Motor function	1. HRQOL and SF-36 2. Hamilton 3. Fugl-Meyer Assessment for the Upper Extremities	Following the intervention, no statistically significant change was seen between the groups.
Lee *et al.*[70]	Control group: Conventional treatment Intervention group: Conventional treatment and virtual rehabilitation system	Games based on interacting with virtual environments and objects	*N*= 18 CG:8 IG:10	73.1 (8.9) 69.2 (5.5	3	30	6	1. Motor function	1. JTHFT, BBT, GPT (Grooved pegboard test), dynamometer	There was a statistically significant variation in the UL motor function (JTHFT, BBT, GPT, grip strength, and upper extremity muscle strength) between the groups.

BBS, Berg Balance Scale; BBT, Box and Block Test; CG, control group; FGA, Functional Gait Assessment; FIM, Functional Independence Measure; FMA-UE, Fugl-Meyer Assessment for Upper Extremity; GPT, Grooved Pegboard Test; HRQOL, Health-Related Quality of Life; IG, intervention group; JTHFT, Jebsen-Taylor Hand Function Test; JTT: Jebsen-Taylor Hand Function Test; MBI, Modified Barthel Index; MMT, Manual Muscle Testing; RPSS, Reaching Performance Scale for Stroke; RTMS, repetitive transcranial magnetic stimulation; SIS, Stroke Impact Scale; TUGT, Timed Up and Go Test; UL, upper limb; VAS, Visual Analog Scale; VR, virtual reality; WMFT, Wolf Motor Function Test.

Table 2

Risk of bias ROB 2.

Reference T	Randomization process	Deviations from intended interventions	Missing outcome data	Measurement of the outcome	Selection of the reported result	Overall bias
Saposnik *et al.*, (2016)[51]	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Kong *et al.*, (2016)[52]	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Choi *et al.*, (2016)[53]	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Brunner *et al.*, (2017)[54]	Some concerns	Low risk	Low risk	Low risk	Some concerns	Some concerns
Shin *et al.*, (2016)[55]	Some concerns	Low risk	High risk	Low risk	Low risk	High risk
Taveggia *et al.*, (2016)[56]	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Rubio *et al.*, (2022)[57]	Some concerns	Low risk	Low risk	Low risk	Some concerns	Some concerns
Mekbib *et al.*, (2020)[58]	Some concerns	Low risk	High risk	Low risk	Low risk	High risk
Sheehy *et al.*, (2020)[59]	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Subramanian *et al.*, (2013)[60]	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Cho & Jung, (2012)[61]	Some concerns	Low risk	Low risk	Low risk	Some concerns	Some concerns
Kwon *et al.*, (2012)[62]	Some concerns	Low risk	Low risk	Low risk	Some concerns	Some concerns
Sin *et al.*, (2013)[63]	Some concerns	Low risk	High risk	Low risk	Low risk	High risk
Rand *et al.*, (2014)[64]	Some concerns	Low risk	High risk	Low risk	Low risk	High risk
Thielbar *et al.*, (2014)[65]	Some concerns	Low risk	High risk	Low risk	Low risk	High risk
Zheng *et al.*, (2014)[66]	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Kiper *et al.*, (2014)[67]	Some concerns	Low risk	Low risk	Low risk	Some concerns	Some concerns
Feng *et al.*, (2019)[68]	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Shin *et al.*, (2015)[69]	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Lee *et al.*, (2016)[70]	Some concerns	Low risk	Low risk	Low risk	Some concerns	Some concerns

chance of bias in five studies (Zheng *et al.*,[66], Shin *et al.*,[55], Mekbib *et al.*,[58], Cho & Jung,[61], Kiper *et al.*,[67]) based on inadequate outcome data.

Viability of virtual rehabilitation treatment

Sixteen articles evaluating the viability of virtual reality treatment (pre-intervention versus post-mediation) were retrieved for the analysis. There was a notable improvement in subacute stroke patients receiving VR treatment as compared to their pre-intervention score. The analysis revealed that the post-stroke period (days) had no discernible impact on the therapeutic outcomes.

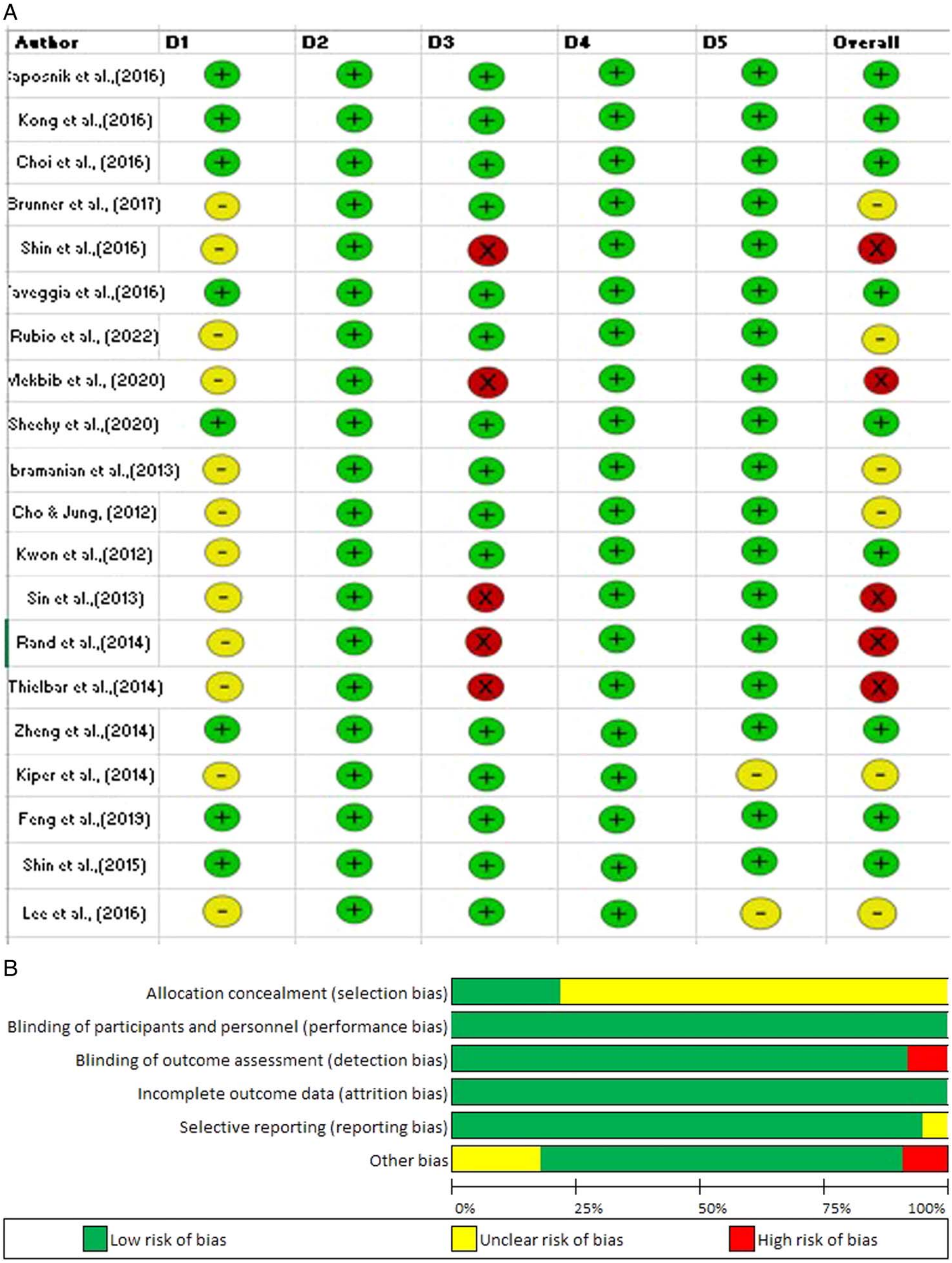
Key characteristics of various groups assembled for the meta-analysis are displayed in Table 3. These groups were formed considering the physical results examined in the investigations. As a result, two categories were created: quality of life and UL motor function. Furthermore, various subgroups were formed based on the instrument employed to quantify the outcomes. The quality of life group and the UL motor function group were subdivided into two subgroups.

Graphical representation of the main outcome

In the above figure, data are taken based on the frequency and intensity of exercise to determine how quickly the injured upper extremity recovers. Study evidence indicates that paretic extremities training has to be task-specific, repeated, and motivating. To help individuals in rehabilitation, motor training should also be customized for each person. Thus, physical exercises which improve sitting balance, and carry out daily tasks like holding utensils, turning knobs or locks, using a phone or computer, and writing are physical outcomes that are strongly related to the quality of life after a stroke (Fig. 4). The study's findings show that effect sizes varied significantly amongst research, with an I-squared value of 0.97 indicating a high degree of heterogeneity. Large and significant physical outcomes of the groups on motor functioning were found by main outcome analyses utilizing a random-effects model ($g = 1.23$; 95% CI = 0.30–2.76; $P = 0.011$; and $I^2 = 97\%$).

Chance of predisposition

The results of VR interventions highlight that a mobile game-based VR rehabilitation program is both feasible and effective in supporting the recovery of the upper limb following an ischemic stroke. Moreover, stroke survivors who underwent additional virtual reality training using an Xbox Kinect demonstrated a significant improvement in upper extremity function (Fig. 5). The study shows strong heterogeneity in effect sizes across trials, as evidenced by a low homogeneity test P value and a high I^2 value of 0.97. The main outcomes of the forest plot indicated that there's a non-significant result was found for VR-based intervention in stroke patients of ($g = 0.59$; 95% CI = 1.01–2.19; $P = 0.047$; $I^2 = 97\%$). The variability-causing elements do not add up to a statistically significant overall effect, as indicated by the non-statistically significant overall



Author	D1	D2	D3	D4	D5	Overall
aposnik et al.,(2016)	+	+	+	+	+	+
Kong et al.,(2016)	+	+	+	+	+	+
Choi et al., (2016)	+	+	+	+	+	+
Brunner et al., (2017)	-	+	+	+	+	-
Shin et al.,(2016)	-	+	X	+	+	X
aveggia et al.,(2016)	+	+	+	+	+	+
Rubio et al., (2022)	-	+	+	+	+	-
lekbib et al., (2020)	-	+	X	+	+	X
Sheehy et al.,(2020)	+	+	+	+	+	+
bramanian et al.,(2013)	-	+	+	+	+	-
Cho & Jung, (2012)	-	+	+	+	+	-
Kwon et al.,(2012)	-	+	+	+	+	+
Sin et al.,(2013)	-	+	X	+	+	X
Rand et al.,(2014)	-	+	X	+	+	X
Thielbar et al.,(2014)	-	+	X	+	+	X
Zheng et al.,(2014)	+	+	+	+	+	+
Kiper et al., (2014)	-	+	+	+	-	-
Feng et al.,(2019)	+	+	+	+	+	+
Shin et al.,(2015)	+	+	+	+	+	+
Lee et al., (2016)	-	+	+	+	-	-

Figure 3. (A) Selected studies are used to assess the risk of bias, (B) the graph and summary's bias risk.

Table 3

Included research groups/subgroups in the meta-analysis.

G	Studies	Outcome	Measuring strategy
1	Saposnik *et al.*,[51], Rubio *et al.*,[57], Mekbib *et al.*,[58] Sheehy *et al.*,[59] Kwon *et al.*,[62] Sin *et al.*,[63] Thielbar *et al.*,[65] Kiper *et al.*,[67] Lee *et al.*,[70] Shin *et al.*,[55] Kong *et al.*,[52] Brunner *et al.*,[54]	Motor functioning	Fugl-Meyer Assessment for Upper Extremity (FMA-UE), Box and Block Test (BBT)
2	Kwon *et al.*,[62] , Zheng *et al.*,[66] Feng *et al.*,[68] Saposnik *et al.*,[51] Kiper *et al.*,[67] Kong *et al.*,[52] Taveggia *et al.*,[56] Brunner *et al.*,[54]	Standard of life	Barthel Scale, Functional Independence Measure (FIM)

effect size ($P = 0.47$). Understanding the results better may require more investigation of the origins of heterogeneity.

Quality of life

The study's high I^2 value of 0.99 indicates significant variation in impact sizes across studies (Fig. 6). There is substantial heterogeneity, as indicated by the low *P* value obtained from the homogeneity test. The results do not, however, appear to support a statistically significant overall effect, as indicated by the overall effect size test's lack of statistical significance. To understand the cause of heterogeneity, more research needs to be conducted.

Treatment impacts of the post-stroke

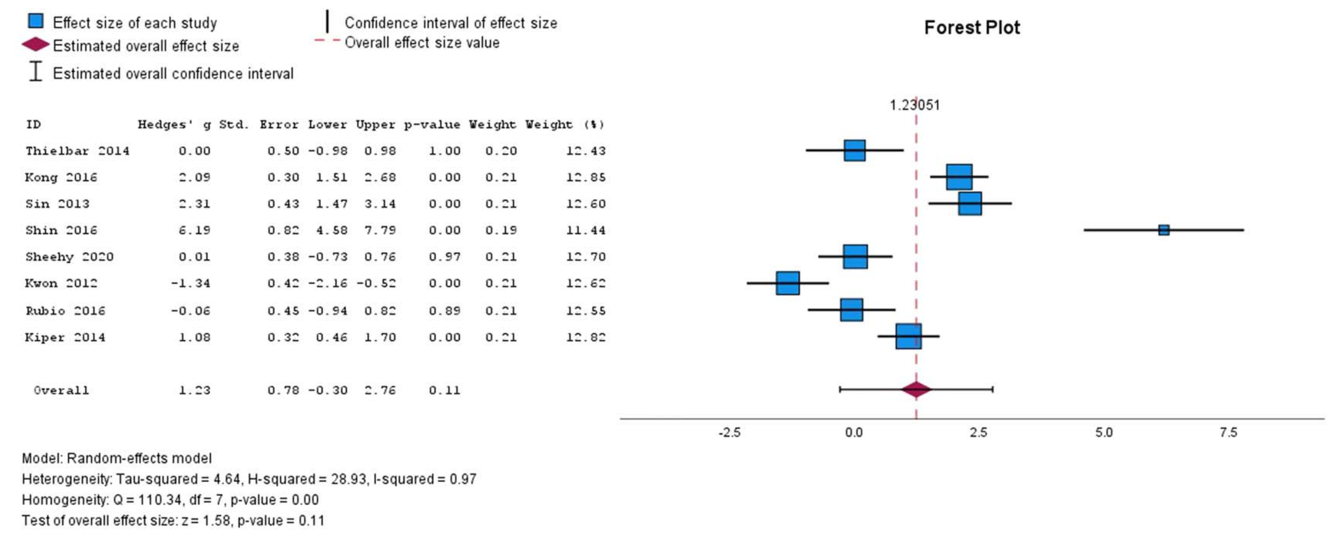
The study's high I^2 value of 0.94 indicates substantial variation in impact sizes across studies (Fig. 7). Significant heterogeneity is present, as indicated by the low *P* value obtained from the homogeneity test. Nevertheless, the overall effect size test yields no statistically significant results, indicating that the data do not indicate a significant overall effect. To comprehend the underlying causes of heterogeneity, additional research is required.

Discussion

The primary goal of this meta-analysis and systematic review of RCTs was to examine the impact of different VR modalities on post-stroke physical capacities and living standards. Virtual rehabilitation systems are a promising technique for physical intervention because they have several advantages over traditional therapies. These benefits include the potential to utilize games to directly offer feedback to patients and increase participant motivation; moreover, they are affordable, easy to use, and compatible with a variety of systems[71].

Moreover, virtual reality therapy administered at home may help stroke patients recover[72]. Regarding the particular technology employed in the several experiments that produced positive outcomes, all these technologies have certain things in common, like allowing individuals to use games to engage with virtual surroundings; based on the degree of immersion applied, subjects behave in manners that are similar to reality. In this approach, the user's attention is enhanced as the involvement increases and subjects have less interaction with the outer surroundings. Considering that attention disorders are the most common cognitive condition following a stroke, it is crucial to recognize their detrimental effects[73].

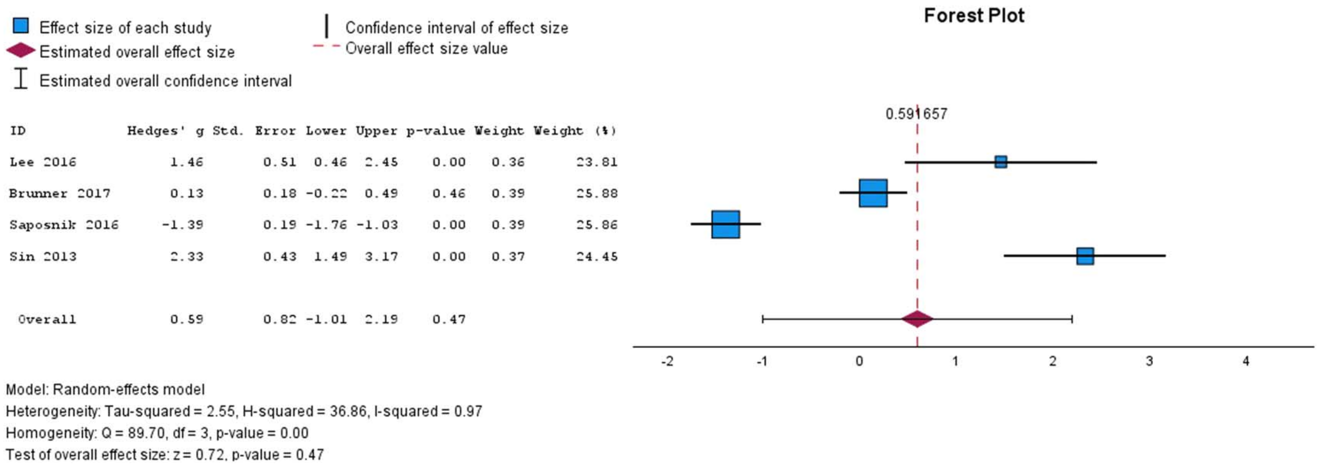
As a result, the application of immersive virtual reality systems, facilitating complete focus on the tasks, may offer significant benefits for deficit rehabilitation. The statistical analysis conducted for this evaluation showed that virtual rehabilitation intervention had a beneficial impact on motor function, particularly in the entire FMA-UE. Findings are under the evaluation of Laver *et al.*[74]; researchers suggested that virtual reality therapies are comparable to traditional therapy to enhance activities of daily living (ADL) and UL motor performance following a stroke. It would be interesting to examine the precise elements of therapy that enable the achievement of these beneficial outcomes. Thus, intensive therapy, stimulating therapy using exercise games, motor learning stimulation, along beneficial interaction between



ID	Hedges' g	Std. Error	Lower	Upper	p-value	Weight	Weight (%)
Thielbar 2014	0.00	0.50	-0.98	0.98	1.00	0.20	12.43
Kong 2016	2.09	0.30	1.51	2.68	0.00	0.21	12.85
Sin 2013	2.31	0.43	1.47	3.14	0.00	0.21	12.60
Shin 2016	6.19	0.82	4.58	7.79	0.00	0.19	11.44
Sheehy 2020	0.01	0.38	-0.73	0.76	0.97	0.21	12.70
Kwon 2012	-1.34	0.42	-2.16	-0.52	0.00	0.21	12.62
Rubio 2016	-0.06	0.45	-0.94	0.82	0.89	0.21	12.55
Kiper 2014	1.08	0.32	0.46	1.70	0.00	0.21	12.82
Overall	1.23	0.78	-0.30	2.76	0.11		

Model: Random-effects model
Heterogeneity: Tau-squared = 4.64, H-squared = 28.93, I-squared = 0.97
Homogeneity: Q = 110.34, df = 7, p-value = 0.00
Test of overall effect size: z = 1.58, p-value = 0.11

Figure 4. Showing the analyzed physical outcomes of the groups.



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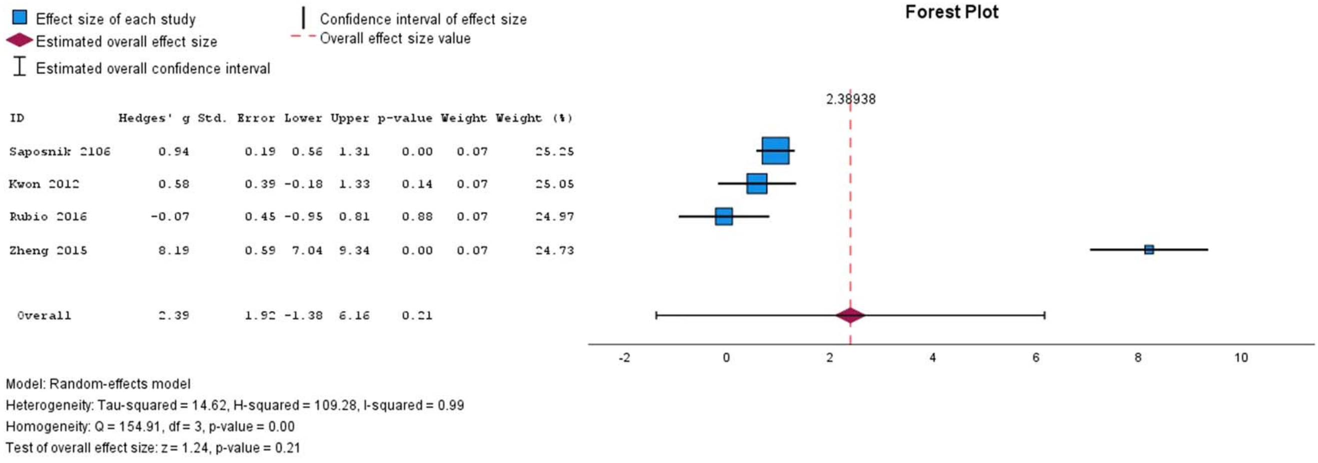
ID            Hedges' g Std. Error Lower Upper p-value Weight Weight (%)
Lee 2016          1.46       0.51  0.46  2.45   0.00   0.36      23.81
Brunner 2017      0.13       0.18 -0.22  0.49   0.46   0.39      25.88
Saposnik 2016    -1.39       0.19 -1.76 -1.03   0.00   0.39      25.86
Sin 2013          2.33       0.43  1.49  3.17   0.00   0.37      24.45

 Overall          0.59       0.82 -1.01  2.19   0.47
```

```
Model: Random-effects model
Heterogeneity: Tau-squared = 2.55, H-squared = 36.86, I-squared = 0.97
Homogeneity: Q = 89.70, df = 3, p-value = 0.00
Test of overall effect size: z = 0.72, p-value = 0.47
```

Figure 5. Showing the virtual reality interventions in stroke patients.

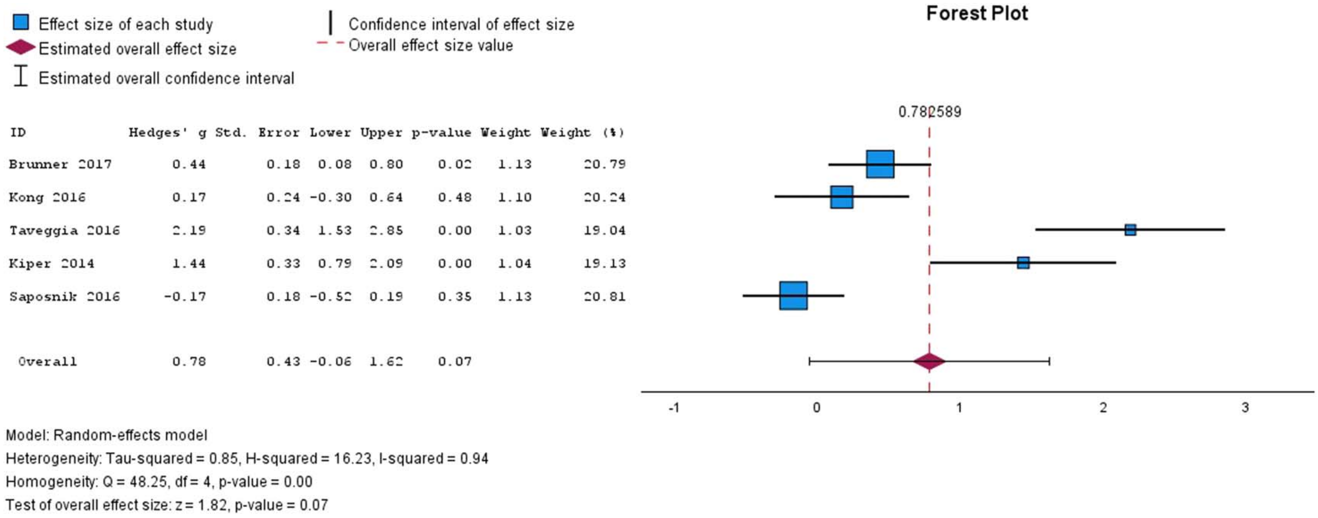


```
ID            Hedges' g Std. Error Lower Upper p-value Weight Weight (%)
Saposnik 2106     0.94       0.19  0.56  1.31   0.00   0.07      25.25
Kwon 2012         0.58       0.39 -0.18  1.33   0.14   0.07      25.05
Rubio 2016       -0.07       0.45 -0.95  0.81   0.88   0.07      24.97
Zheng 2015        8.19       0.59  7.04  9.34   0.00   0.07      24.73

 Overall          2.39       1.92 -1.38  6.16   0.21
```

```
Model: Random-effects model
Heterogeneity: Tau-squared = 14.62, H-squared = 109.28, I-squared = 0.99
Homogeneity: Q = 154.91, df = 3, p-value = 0.00
Test of overall effect size: z = 1.24, p-value = 0.21
```

Figure 6. Assessment of quality of life by using MBI and FIM.



```
ID            Hedges' g Std. Error Lower Upper p-value Weight Weight (%)
Brunner 2017      0.44       0.18  0.08  0.80   0.02   1.13      20.79
Kong 2016         0.17       0.24 -0.30  0.64   0.48   1.10      20.24
Taveggia 2016     2.19       0.34  1.53  2.85   0.00   1.03      19.04
Kiper 2014        1.44       0.33  0.79  2.09   0.00   1.04      19.13
Saposnik 2016    -0.17       0.18 -0.52  0.19   0.35   1.13      20.81

 Overall          0.78       0.43 -0.06  1.62   0.07
```

```
Model: Random-effects model
Heterogeneity: Tau-squared = 0.85, H-squared = 16.23, I-squared = 0.94
Homogeneity: Q = 48.25, df = 4, p-value = 0.00
Test of overall effect size: z = 1.82, p-value = 0.07
```

Figure 7. Treatment impacts of the post-stroke term between experiment and control groups.

the reaction and the stimuli are four components of VR therapy that may cooperate to guarantee success[75].

The results regarding quality of life illustrate the possible advantages of virtual rehabilitation interventions after a stroke. As per The International System of Classification of Health, Disability and Functioning (ICF)[76], limitations on participation may arise from activity restrictions that are impacted by impairment in terms of both physical structural and functional levels. However, these three areas are not usually directly related to one another[77]. There is a suggestion that the development in UL function that this analysis has uncovered may enhance ADL participation, which in turn may enhance quality of life. Considering that there is a recognized association between the two instruments, it is also possible that the improvements observed in the FIM scale, and the FMA-UE scales are related. Researchers were encouraged to indicate which ICF scale domains they expected to improve with the intervention, in keeping with the research direction suggested by Lohse *et al.*[78].

Finally, Pietrzak *et al.*[79] stated that to simplify the use of the services for virtual interventions and treatment facilities, emphasis should be placed on the necessity of integrating VR-based video games into stroke rehabilitation. Additionally, by modifying the length, intensity, and difficulty level of the VR games, as well as by offering various forms of feedback and encouraging reinforcement, therapists may develop customized games based on the medical characteristics of the patients[72].

Limitations

While the outcomes presented in this review are valuable, it should be noted that it has certain limitations. One limitation concerned the large range of VR treatments, each of which is categorized under one word or term. Moreover, a separate analysis of acute and chronic strokes was not conducted. Some studies[53,60,69] did not offer data gathered before or after the intervention, so they were excluded from the meta-analysis. An additional limitation was the use of various measurement tools. Due to this, it was not possible to compare the research statistically.

Also, while the PRISMA guidelines were followed, restricting the search to a limited number of databases and only articles published in English, which might miss relevant studies, especially those in other languages or other studies that contain negative findings. This could tilt the results towards positive outcomes. Furthermore, the limited focus on measuring improvement outcomes of motor function and quality of life overlooks other aspects that could be assessed such as cost-effectiveness and long-term sustainability. The patient's experience is also a factor that should be assessed. The limitations affect the ability to form a holistic evaluation of VR therapy's potential.

Conclusion

The outcomes suggest that virtual rehabilitation could be useful for enhancing the quality of life following a stroke and motor functioning. By using video games developed for virtual reality platforms, this study can be useful in clinical treatment. It can also serve as a foundation for the development of further research on the topic and offer valuable feedback for future interventions for improvements in methodology. Data with larger sample sizes and more consistency regarding the kind of instrument used, length of treatment sessions, and the effect of the intervention strategy will be needed for clinical research. Determining which specific therapeutic components are more crucial to a successful outcome will also be crucial.

Ethical approval

Ethical approval was not required for this review.

Consent

Informed consent was not required for this review.

Source of funding

No funding obtained.

Author contribution

P.P.: conceptualization, methodology, validation, writing—original draft preparation, writing—review and editing. K.K.C.: methodology, validation, writing—original draft preparation, writing—review and editing. P.B.: conceptualization, writing—original draft preparation, writing—review and editing. E.G.: validation, writing—original draft preparation, writing—review and editing. M.O.A.: methodology, writing—original draft preparation, writing—review and editing. P.I.: writing—original draft preparation, writing—review and editing, data curation. A.S.A.: writing—original draft preparation, writing—review and editing. A.D.: writing—original draft preparation, writing—review and editing. Y.T.: writing—original draft preparation, writing—review and editing. M.D.M.M.: writing—original draft preparation, writing—review and editing. M.M.R.: writing—original draft preparation, writing—review and editing. S.M.: writing—original draft preparation, writing—review and editing. H.B.: writing—original draft preparation, writing—review and editing. G.S.: writing—original draft preparation, writing—review and editing. H.J.: writing—original draft preparation, writing—review and editing. S.G.: writing—original draft preparation, writing—review and editing, validation, supervision. O.A.H.: writing—original draft preparation, writing—review and editing.

Conflicts of interest disclosure

All authors do not have any conflict of interest.

Research registration unique identifying number (UIN)

1. Name of the registry: PROSPERO.
2. Unique identifying number or registration ID: CRD420 24542963.
3. Hyperlink to your specific registration (must be publicly accessible and will be checked): https://www.crd.york.ac.uk/prospero/display_record.php?RecordID=542963.

Guarantor

Srikanth Gadam.

Data availability statement

The data that support the findings of this study are available in the supplementary material of this article.

Provenance and peer review

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