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Virtual Reality-Based Interventions and Cognition and Motor Functions of Stroke Patients: A Systematic Review and Meta-Analysis

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ABSTRACT

Aim: The aim of this study was to assess the effect of Virtual Reality-Based Interventions on Cognition and motor functions of Stroke Patients.

Methods: Cochrane Library, Web of Science, and PubMed. The search terms "stroke," "virtual reality," and "rehabilitation" were used. Clinical trials and observational studies investigating the use of any virtual reality (VR) system in the rehabilitation of patients who had acute, subacute, or chronic strokes were included. The meta-analysis was conducted using Analysis R program. We used the $\chi2$ test and I2 to evaluate heterogeneity. To decrease the impact of study heterogeneity, we used random-effect models to assess the pooled treatment effect.

Results: The VR interventions were associated with significant improvements in stroke patients' cognitive function as assessed by the Montreal Cognitive Assessment Scale (MoCA). Significant improvements in stroke patients' memory function as assessed by the Wechsler Memory Scale-III (WMS-III) were seen. The VR therapies were linked to moderate but statistically significant improvements in cognitive function as assessed by the Korean Mini-mental State Examination (K-MMSE). Also, VR interventions had been associated with significant improvements in mild behavioral impairment as assessed by the MBI in stroke patients.

Conclusion: Virtual reality interventions are effective in improving cognitive function, motor function, daily living activities, and mild behavioral impairments in stroked patients. While VR shows great promise, more studies are needed to address the limitations and optimize VR protocols for consistent and reliable outcomes

Keywords: Virtual reality – VR – Systematic – Stroke – Cognition – Motor - Meta-analysis

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1. INTRODUCTION

Over 17 million individuals worldwide suffer from strokes each year, which is the leading cause of death and disability (1). Even though stroke mortality and incidence have decreased in high-income countries due to improvements in medical technology and treatments, patients still experience long-term neurological impairments, such as cognitive, behavioral, language, functional, and mobility difficulties (2).

Stroke rehabilitation is an intricate procedure that maximizes recovery and minimizes functional impairments by improving neuronal regeneration and optimizing healing of damaged neural tissue (3). Combining physical, occupational, speech, and cognitive psychology treatment is the cornerstone of stroke recovery, necessitating multidisciplinary involvement (4, 5). Goal-oriented, task-specific training, an adequate duration and intensity of the intervention, and the use of biofeedback are all necessary for stroke rehabilitation to be successful (6, 7). Costs, time restrictions, and maintaining patient motivation and engagement might all render this difficult (8).

Theoretically, virtual reality (VR) may overcome over these restrictions, especially the financial and time restrictions. According to Stasieńko and Sarzyńska-Długosz, virtual reality (VR) is described as "a computer rendered, 3-dimensional, real-time, interactive experience of artificial reality containing items, characters, and events existing only in the memory of a computer" (9)

The user may engage with the virtual environment via a variety of methods and get visual feedback on a head-mounted device, computer display, or screen of any type (10). An environment is the platform that is used to interact with virtual reality; it can be immersive, semi-immersive, or non-immersive (11). Immersion environments offer a high level of realism and involvement by enclosing the subject in a virtual world. Head-mounted devices can be used to perform this (12). Between a highly immersive and a non-immersive setting, a semi-immersive setting has a certain degree of realism and immersion. High-resolution displays and technology for computers are used to observe the virtual world in a non-immersive setting where subjects are completely responsive to the actual one (13).

Immersion, imagination, and engagement are key ideas in VR use (14). Immersion is the degree to which a user feels as though they are in a virtual setting as opposed to the actual one (15). Semi-immersive or non-immersive virtual reality is now affordable and accessible for application in healthcare settings because to the quick growth and advancement of video game technology (16). Like the Nintendo Wii and PlayStation gaming platforms, these commercial gaming systems mimic real-life scenarios, demand whole body motions that are similar to those in the real world, and promote intense, repeated hand movements (17). Because they improve user involvement, participation, and enjoyment, immersive environments are considered better (18).

Over the past 20 years, there has been an exponential increase in the number of articles discussing virtual reality and rehabilitation after stroke. Despite the fact that this topic has been the subject of multiple systematic studies, it is challenging to make firm conclusions due to varying techniques and outcomes. According to a Cochrane systematic review, VR had no significant impact on upper extremity function when compared to traditional therapy (19). On the other hand, several systematic reviews found that VR was more effective than conventional therapies for restoring function in the upper extremities (20, 21). Similar conflicting results have been found in reviews studying VR effects on movement and balance (1, 22-24). Rehabilitation clinicians find it difficult to provide evidence-based therapy and make well-informed therapeutic judgments due to the availability of contradictory data from systematic reviews. The aim of this study was to assess the effect of Virtual Reality-Based Interventions on Cognition and motor functions of Stroke Patients.

2. METHODS

This systematic review with meta-analysis was firstly conducted because of that crucial need for a collaborative review for the motor functions and cognitive behaviors overview of stroke patients and how VR can enhance or control these functions.

Inclusion criteria

Clinical trials and observational studies investigating the use of any VR system in the rehabilitation of patients who had acute, subacute, or chronic strokes were included in the search strategy.

Criteria for Exclusion

Reviews, studies that did not report on the outcome of interest, or studies that were conducted on animals were all excluded. Additionally, case reports and case series were not included.

Methods of Search

We searched the Cochrane Library, Web of Science, and PubMed. The search terms "stroke," "virtual reality," and "rehabilitation" were used.

Reviews of Data

The retrieved abstracts were evaluated for eligibility by two separate reviewers based on their relevance. Discussions were held to resolve disagreements until an agreement was achieved.

Measures of Outcome

Improvement in MOCA, a measure of motor impairment, was the primary outcome. Improvement in motor function represented one of the secondary outcomes. The meta-analysis was conducted using Analysis R program. We used the $\chi 2$ test and I^2 to evaluate heterogeneity. To decrease the impact of study heterogeneity, we used random-effect models to assess the pooled treatment effect. Publication bias was assessed by funnel plot for outcomes containing more than 5 studies. Sensitivity analysis was performed to overcome high heterogeneity.

Risk of bias assessment

The quality assessment of the included studies was performed by Cochrane risk-of-bias tool for randomized controlled trials (ROB 2) and Cochrane Reviews for non-randomized studies tool (ROB-I).

3. RESULTS

This review search strategies identified 2336 records in total. Duplicates identified were 176, 1300 records were excluded by screening title and abstract. The remaining 860 records were retrieved in full text for eligibility assessment. After careful review, 22 studies were found eligible for the review (**Figure 1**).

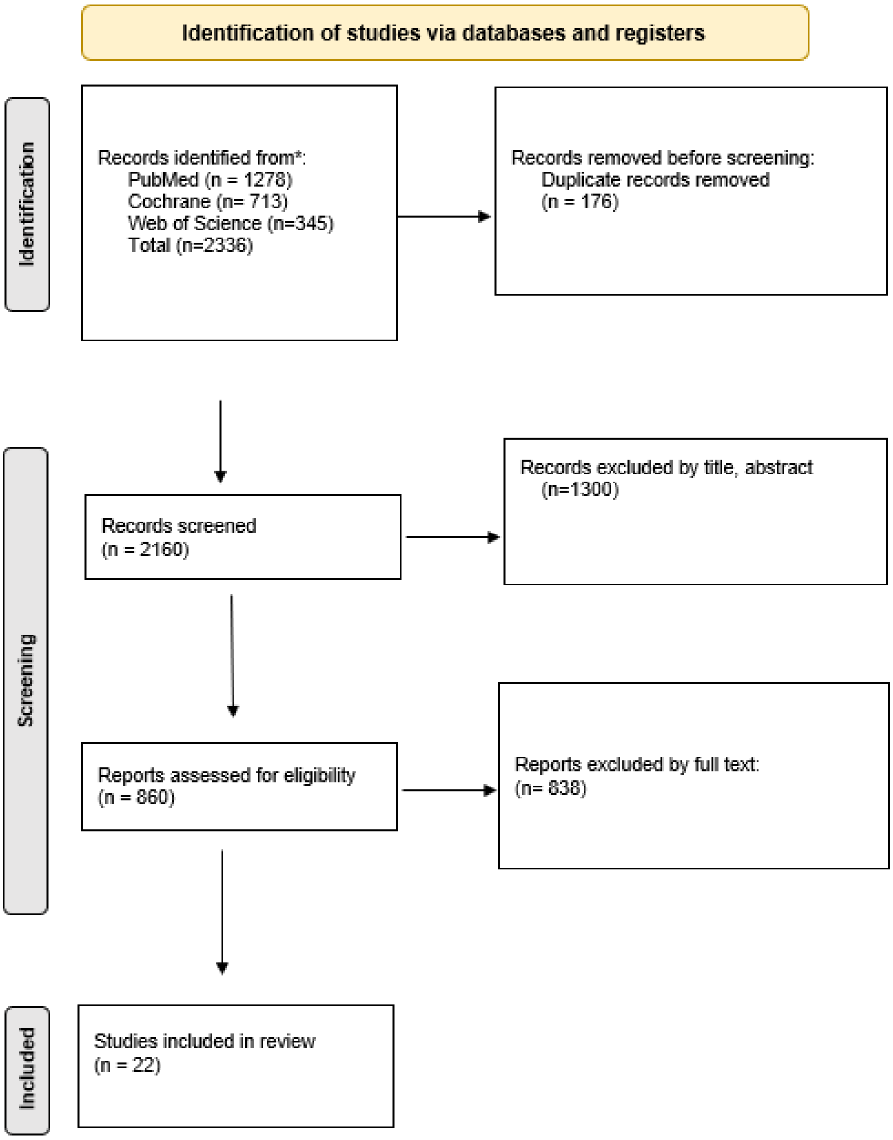

Figure 1. PRISMA 2020 flow diagram for systematic reviews

Characteristics of the included studies

The characteristics of the included studies are summarized in Table 1. A wide range of methodological methods is shown by the investigations' utilization of a variety of designs, such as RCTs, retrospective analyses, pilot studies, and cross-sectional studies. Studies were conducted in a number of countries, including as South Korea, China, Italy, Portugal, the UK, the Netherlands, India, Japan, and Spain, indicates that VR applications for cognitive rehabilitation are of interest for individuals all over the world. Sample sizes range greatly, ranging from 200 in a larger randomized controlled trial to only 10 in certain pilot studies. Numerous VR technology uses in cognitive rehabilitation are demonstrated by the VR interventions, which vary from immersive and non-immersive VR setups to cognitive training and rehabilitation systems (e.g., Reh@Task, VRRS).

Meta-analysis

Table 1: Characteristics of the included studies

First author, year	Country	Study design	Sample Size	Type of virtual reality
Chang-Hyung Lee, 2020 (25)	Republic of Korea	Randomized controlled trial	22	Virtual reality cognitive training
Shi, 2023 (27)	China	Retrospective analysis (Case control)	94	Computer-aided cognitive rehabilitation (CACR) combined with VR technology
Rosaria De Luca, 2018 (32)	Italy	RCT	12	Virtual reality training (VRT) with BTs-Nirvana
Ana L. Faria, 2018 (26)	Portugal	RCT	24	Virtual reality (Reh@Task)
Jorge Oliveira, 2022 (33)	Portugal	Single-arm pre-post intervention study	30	Virtual reality (Systemic Lisbon Battery)
Pedro Gamito, 2014 (34)	Portugal	Randomized controlled trial	17	Virtual reality (HMD vs. desktop screen)
Faria, 2016 (35)	Portugal	Randomized Controlled Trial	18	VR-based intervention (Reh@City)
Chatterjee, 2022 (36)	UK	Double-blind Phase 2b Randomized Control Trial	40	Immersive VR (VIRTUE)
Spreij, 2020 (29)	Netherlands	Cross-sectional study	154	Non-immersive VR (Computer Monitor) and Immersive VR (Head-Mounted Display)
Faria et al., 2020 (37)	Portugal	Randomized Controlled Trial	36	Reh@City v2.0
Chauhan et al., 2024 (38)	India	Randomized Controlled Trial	69	Non-immersive VR

Torrisi et al., 2019 (39)	Italy	Randomized Controlled Trial	40	VR Rehabilitation System (VRRS)
Jonsdottir et al., 2021 (40)	Italy	Pilot Feasibility Study	34	HEAD VR protocol
Park & Ha, 2023 (41)	South Korea	Randomized Controlled Trial	60	Immersive VR
Katz et al., 2005 (31)	Israel	Randomized Controlled Trial	19	Non-immersive VR
Pedro Gamito, 2014 (34)	Portugal	Randomized controlled trial	20	VR-based serious games
Antonio Gangemi, 2023 (42)	Italy	Quasi-randomized clinical trial	30	VRRS (Virtual Reality Rehabilitation System)
Kazuhiro Yasuda, 2017 (43)	Japan	Pilot study (pre-post design)	10	Immersive VR with HMD
Xiao-Ping Cheng, 2024 (44)	China	Randomized controlled trial (protocol)	200	VR (NEVRS301)
Bo Ryun Kim, 2011 (45)	South Korea	Randomized controlled trial	28	VR training and computer-based cognitive rehabilitation
Martina Maier, 2020 (46)	Spain	Randomized controlled pilot trial	30	VR-based cognitive training (RGS system)
Zhilan Liu, 2023 (30)	China	Randomized controlled trial	30	Immersive virtual reality (IVR)

Disease characteristics and study groups

Table 2 provides a summary of the study groups and disease characteristics for all of the included studies. VR interventions are being investigated at various phases of stroke recovery, as seen by the research' coverage of a variety of stroke types, including sub-acute and chronic. Because stroke and cognitive impairment evaluation are complex, a range of diagnostic methods are utilized, including the MMSE, MoCA, and Motricity Index. Numerous outcome measures, including those for motor function (FIM, FM-UE), cognitive function (MoCA, LOTCA), and daily living activities (MBI), demonstrate the thoroughness of the evaluation process for VR interventions. From immersive VR experiences to cognitive training applications (such Reh@Task and VRRS), the VR interventions ranged greatly, demonstrating how adaptable VR technology is in addressing various rehabilitation requirements.

Table 2: Disease characteristics and study groups

First author, year	**Type of stroke**	**Disease assessment (diagnosis)**	**Outcome assessment**	**Intervention**	**Control**
Chang-Hyung Lee, 2020 (25)	Sub-acute stroke	Korean Mini-Mental Status Examination (K-MMSE)	LOTCA, VQ, BDI	Virtual reality cognitive training	Conventional cognitive therapy
Shi, 2023 (27)	Post-stroke cognitive impairment	Mini-Mental State Examination (MMSE)	MMSE, MoCA, P300, BDNF, Cys-C, NSE, MBI	CACR combined with VR technology	Routine rehabilitation training
Rosaria De Luca, 2018 (32)	Chronic stroke	Mini-Mental State Examination (MMSE)	MoCA, FIM, FAB, AM, TMT, TCT, MI	VRT with BTs-Nirvana	Standard cognitive treatment
Ana L. Faria, 2018 (26)	Chronic stroke	Motricity Index (MI)	MoCA, SLC, DC, BT, FM-UE, CAHAI, MAS, BI	Reh@Task (VR cognitive-motor training)	Conventional occupational therapy
Jorge Oliveira, 2022 (33)	Sub-acute stroke	Mini-Mental State Examination (MMSE)	MoCA, FAB, WMS, CTT	Virtual reality cognitive training	None
Pedro Gamito, 2014 (34)	Stroke	Mini Mental Examination Test	WMS-III, RCF, TP	VR training program (HMD or desktop screen)	None
Faria, 2016 (35)	Stroke	Addenbrooke Cognitive Examination (ACE), Trail Making Test A and B, Picture Arrangement from WAIS III, Stroke Impact Scale 3.0	Cognitive and functional assessment	VR-based cognitive rehabilitation	Conventional rehabilitation

Chatterjee, 2022 (36)	Stroke	Montreal Cognitive Assessment (MoCA), Cognitive Assessment of Minnesota (CAM)	Cognitive and functional assessment	VR-based cognitive rehabilitation	Sham VR treatment
Spreij, 2020 (29)	Stroke	Montreal Cognitive Assessment (MoCA)	Cognitive and functional assessment	VR-task in virtual supermarket	None
Faria et al., 2020 (37)	Chronic stroke	Montreal Cognitive Assessment (MoCA)	MoCA, TMT A & B, WMS-III Verbal Paired Associates, WAIS-III Digit Symbol Coding, Symbol Search, Digit Span, Vocabulary, PRECIS	Reh@City v2.0 (VR-based intervention)	Task Generator (TG) (paper-and-pencil intervention)
Chauhan et al., 2024 (38)	Stroke (subacute)	NIHSS, ACE III, MOCA	NIHSS, ACE III, MOCA	rTMS + VR	rTMS + Sham VR, Sham rTMS + VR
Torrisi et al., 2019 (39)	Stroke (subacute)	MOCA, FAB, AM, TMT, RAVLT, HRS-A, HRS-D	MOCA, FAB, AM, TMT, RAVLT, HRS-A, HRS-D	VRRS-Evo + Home Tablet	Standard cognitive training
Jonsdottir et al., 2021 (40)	Chronic stroke	2MWT, MoCA	2MWT, MoCA	ClinicHEAD + HomeHEAD	Usual care
Park & Ha, 2023 (41)	Stroke (3-36 months post-stroke)	K-MMSE-2, MVPT-3, K-MBI, SF-12	K-MMSE-2, MVPT-3, K-MBI, SF-12	VR-based cognitive rehabilitation	Conventional and computer-assisted cognitive rehabilitation
Katz et al., 2005 (31)	Right hemisphere stroke with USN	Neuro-imaging (brain CT or MRI), with persistent USN	Standard USN assessments, paper and pencil and ADL checklist; Test on the VR street program; and Actual street crossing videotaped. Testing was performed pre and post intervention	Computer desktop-based Virtual Reality (VR) street crossing training	computer based visual scanning tasks

Pedro Gamito, 2014 (34)	Stroke	Stroke diagnosis confirmed by medical records	Attention and memory functions	VR-based cognitive training	Waiting list control
Antonio Gangemi, 2023 (42)	Ischemic stroke	Chronic phase (≥6 months post-stroke)	EEG (theta, alpha, beta bands)	VR cognitive training	Conventional neuro-rehabilitation
Kazuhiro Yasuda, 2017 (43)	Stroke	Unilateral spatial neglect (USN)	Behavioral Inattention Test (BIT)	VR-based training for near and far space neglect	No control group
Xiao-Ping Cheng, 2024 (44)	Stroke	Post-stroke cognitive impairment (PSCI)	MMSE, MoCA, FAB, CDT, DST, LMT, MBI, fNIRS	tDCS + VR	Sham tDCS + sham VR
Bo Ryun Kim, 2011 (45)	Stroke with cognitive impairment	K-MMSE (Korean version of the Mini-Mental Status Examination)	Computerized neuropsychological test, Tower of London (TOL) test, Korean-Modified Barthel index (K-MBI), Motricity index (MI)	VR group: VR training + computer-based cognitive rehabilitation	Control group: computer-based cognitive rehabilitation only
Martina Maier, 2020 (46)	Chronic stroke with cognitive impairment	Montreal Cognitive Assessment (MoCA)	Neuropsychological test battery, Hamilton Depression Rating Scale (HAM-D), Barthel Index (BI), Fugl-Meyer Assessment for the upper extremity (FM-UE)	ACCT using RGS	Standard cognitive tasks at home
Zhilan Liu, 2023 (30)	Post-stroke cognitive impairment	Montreal Cognitive Assessment (MoCA)	MoCA, TMT-A, DSST, DST, VFT, MBI, self-report questionnaire	IVR-based puzzle game therapy (15 min/day, 6 sessions/week for 6 weeks)	Traditional cognitive training (15 min/day, 6 sessions/week for 6 weeks)

Characteristics of the studies participants

The characteristics of the participants in the included studies are presented in Table 3. From small pilot studies with about 10 respondents to larger trials with up to 94 individuals, the number of participants varies greatly between investigations. The average age of participants was in the older adult range, usually between 40 and 70 years. Most investigations had included male and female participants, but some studies have a larger percentage of men. A verified diagnosis of stroke, particular post-stroke time periods (e.g., 1-6 months, chronic phase), and degrees of cognitive impairment (e.g., MMSE scores) are common inclusion criteria. Participation in other cognitive studies, incapacity to complete necessary activities, and significant comorbidities (such as mental problems or severe aphasia) are common exclusion criteria.

Table 3: Characteristics of the studies participants

First author, year	Number of Participants in each group	Age of participants	Gender	Inclusion criteria	Exclusion criteria
Chang-Hyung Lee, 2020 (25)	11 (experimental), 11 (control)	Mean: 58.18 (experimental), 59.09 (control)	Male: 6 (experimental), 7 (control); Female: 5 (experimental), 4 (control)	Diagnosed with stroke, 1-6 months post-stroke, K-MMSE scores 18-23, stable medical condition	Severe unilateral spatial neglect, unable to maintain independent seating, speech and hearing impairments, illiteracy
Shi, 2023 (27)	49 (observation), 45 (control)	Mean: 64.7	Male: 52, Female: 41	Cognitive impairment after stroke, stable vital signs, MMSE < 27	Other cerebrovascular diseases, previous history of mental illness, significant intellectual impairment prior to stroke, long-term medication affecting mental state
Rosaria De Luca, 2018 (32)	6 (experimental), 6 (control)	Mean: 40	Male: 4 (experimental), 3 (control); Female: 2 (experimental), 3 (control)	Ischemic or hemorrhagic stroke, 3-6 months post-stroke, MMSE 10-23	Severe unilateral spatial neglect, unable to stand independently, severe psychiatric or medical illness
Ana L. Faria, 2018 (26)	12 (VR), 12 (control)	Mean: 57.1 (VR), 68.9 (control)	Male: 4 (VR), 5 (control); Female: 8 (VR), 7 (control)	Chronic stroke (>6 months), motor impairment of upper extremity, cognitive deficit	Visual/auditory deficits, history of psychiatric or neurological disorder, alcohol or drug abuse
Jorge Oliveira, 2022 (33)	30	Mean: 60	Male: 18, Female: 12	1-6 months post-stroke, aged over 18, no visual/auditory deficits, no history of psychiatric or neurological disorder	Dementia, history of alcohol or drug abuse, unable to complete at least 6 sessions
Pedro Gamito, 2014 (34)	9 (desktop VR), 8 (HMD)	Mean: 55 (desktop VR), 45 (HMD)	Male: 58%, Female: 42%	Memory and attention deficits post-stroke, more than 12 years of	More than 6 months post-stroke, language disorders, dementia, psychiatric disorders

				formal education	
Faria, 2016 (35)	9 (VR), 9 (Control)	Not specified	Not specified	No hemi-spatial neglect, capacity to be seated, ability to read and write, minimum cognitive function (MMSE ≥ 15), motivation to participate	Moderate or severe language comprehension deficits
Chatterjee, 2022 (36)	30 (VR), 10 (Control)	Median: 77.5 (VR), 63 (Control)	43% Female (VR), 60% Female (Control)	Aged over 18, unilateral confirmed stroke within 1 day to 3 weeks, cognitive impairment	Bilateral weakness, history of dementia, epilepsy, visual acuity less than 6/60, too ill to participate
Spreij, 2020 (29)	88 (Stroke), 66 (Healthy controls)	Mean: 55.32 (Stroke), 46.24 (Healthy controls)	61.4% Male (Stroke), 42.4% Male (Healthy controls)	Clinically diagnosed with stroke, aged ≥ 18, physically and cognitively able to perform VR tasks	Epilepsy, severe visuo-spatial neglect
Faria et al., 2020 (37)	Reh@City v2.0: 17, TG: 19	Reh@City: 59.1, TG: 65	Reh@City: 5M/9F, TG: 11M/7F	No more than 75 years old; first stroke episode and at least 6 months post-stroke; no hemi-spatial neglect; capacity to be seated; minimum of 2 years of schooling; motivation to participate in the study	Severe depressive symptomatology; undergoing occupational therapy at least 2 months before the study; total score of more than two standard deviations below the mean score for age and education in MoCA

Chauhan et al., 2024 (38)	23 in each group	40-70 years	Male: 78.2%-82.6% Female: 17.4%-21.7%	Unilateral hemispheric stroke, 2-9 months post-stroke, motor evoked potentials, active finger movement, MOCA ≥18, NIHSS <15	Neurological/psychiatric disease, bilateral paralysis, severe aphasia, contraindications to TMS/MRI
Torrisi et al., 2019 (39)	20 in each group	55.17 ± 18.37 years	Male: 65% Female: 35%	Subacute stroke (3-6 months), no severe spasticity, no sensory alterations	Severe paresis, psychiatric illness, epilepsy
Jonsdottir et al., 2021 (40)	11 in HH, 23 in UC	55 years (SD 13.7)	Male: 52.9% Female: 47.1%	Chronic stroke, able to stand for 30s	MMSE <20, severe pain, limited range of motion
Park & Ha, 2023 (41)	20 in each group	62.5 years (SD 4.7)	Male: 55% Female: 45%	First-time stroke, K-MMSE-2 score 17-27, able to participate with guardian	Severe aphasia, visuospatial neglect, neurological/psychiatric conditions
Katz et al., 2005 (31)	11 in experimental group, 8 in the control group.	mean age in years = 62.4 +14.0 SD, control: 63.3 +10.8SD	experimental group: 7 men and 4 women, control group: 5 men and 3 women.	Participants who use any type of mobility aid, but have difficulty in crossing streets in a safe or confident manner.	
Pedro Gamito, 2014 (34)	10 (Intervention), 10 (Control)	Mean age: 55 (SD = 13.5)	9 male, 11 female	Stroke patients with cognitive impairments	Previous neurological or psychiatric disorders, substance abuse, uncorrected visual deficiencies
Antonio Gangemi, 2023 (42)	15 (Experimental), 15 (Control)	Mean age: 58.13 (Experimental), 57.33 (Control)	10 male, 5 female (Experimental), 10 male, 5 female (Control)	Chronic ischemic stroke, right hemisphere damage, age 18-75	Psychoactive drugs, neurological disorders other than stroke, severe cognitive-behavioral problems

Kazuhiro Yasuda, 2017 (43)	10 (All in intervention group)	Mean age: 68.1	6 male, 4 female	Stroke patients with USN, right hemisphere damage, age 45-85	Severe cognitive impairment, visual field deficits, inability to reach with right upper extremity
Xiao-Ping Cheng, 2024 (44)	50 (Group A: tDCS + VR), 50 (Group B: tDCS + sham VR), 50 (Group C: sham tDCS + VR), 50 (Group D: sham tDCS + sham VR)	Age 18-70	Not specified	Stroke within 6 months, MMSE score 10-26	Severe illness, metal implants, history of epilepsy, severe aphasia
Bo Ryun Kim, 2011 (45)	VR group: 15, Control group: 13	Mean age: 64.2	11 males, 17 females	Cognitive impairment following stroke, K-MMSE score range 10-24	Severe cognitive impairment, aphasia, poor sitting balance, limited range of motion of the neck, loss of visual acuity
Martina Maier, 2020 (46)	Experimental group: 15, Control group: 15	Mean age: Experimental group: 63.63, Control group: 67.21	Experimental group: 8 females, Control group: 7 females	Cognitive impairment due to first-ever stroke, MoCA < 26, chronic state (more than 6 months after stroke but less than 10 years)	Severe cognitive incapacity, severe impairments like spasticity, communication disabilities, history of severe mental health problems
Zhilan Liu, 2023 (30)	15 in IVR group, 15 in control group	74.16 ± 7.08 years	17 men, 13 women	(1) Stroke diagnosed by Chinese Guidelines for Prevention and Treatment of Cerebrovascular Diseases; (2) Age 60-90, stroke onset ≥6 months; (3) PSCI diagnosis; (4) MoCA 18-26; (5) Fugl-Meyer motor scale >85; (6) Education ≥9 years	(1) Difficult to evaluate or cooperate; (2) Severe hearing/visual impairment, mental disorders, epilepsy; (3) Previous vertigo; (4) Participating in other cognitive function studies

Outcomes of using virtual reality rehabilitation for stroke patients

The results and conclusions of the included studies are presented in Table 4, which offers a comprehensive summary of the efficacy of virtual reality (VR) interventions in stroke rehabilitation

Table 4: outcomes and conclusion

First author, year	Outcomes	Conclusion
Chang-Hyung Lee, 2020	Significant improvements in cognitive function and rehabilitation motivation in experimental group	Virtual reality cognitive training is more effective than conventional therapy for cognitive function and rehabilitation motivation in sub-acute stroke patients
J. Shi, 2023	Significant improvements in cognitive function, P300 amplitude, BDNF levels, and daily living activities in observation group	CACR combined with VR technology is more effective in improving cognitive function and daily living activities in stroke patients
Rosaria De Luca, 2017	Significant improvements in cognitive and motor functions in experimental group	VRT with BTs-Nirvana is effective in improving cognitive and motor functions in chronic stroke patients
Ana L. Faria, 2018	Significant improvements in motor function in VR group	VR cognitive-motor training improves motor outcomes in chronic stroke patients
Jorge Oliveira, 2020	Improvements in global cognition, executive functions, memory, and attention	Virtual reality-based cognitive rehabilitation is effective in improving cognition in stroke patients
Pedro Gamito, 2014	Increased working memory and sustained attention in both groups	VR training is effective for cognitive recovery in stroke patients, with no significant difference between HMD and desktop screen
Faria, 2016	Significant improvements in global cognitive functioning, attention, memory, visuo-spatial abilities, executive functions, emotion, and overall recovery in the VR group	VR-based cognitive rehabilitation has more impact than conventional methods
Chatterjee, 2022	Significant improvements in MoCA scores for severe cognitive impairment group, reduced hospital stay	VR-based cognitive rehabilitation is safe and acceptable, with potential benefits for severe cognitive impairment
Spreij, 2020	High completion rate, enhanced user-experience with HMD, no preference for one interface	VR is feasible in stroke patients, with enhanced user-experience in immersive VR
Faria et al., 2020	Reh@City v2.0 improved general cognitive functioning, visuospatial ability, executive functioning, attention, verbal memory, and processing speed. TG improved orientation, processing speed, and verbal memory.	Reh@City v2.0 showed higher effectiveness in improving cognitive domains and self-perceived cognitive deficits. TG retained fewer cognitive gains for longer. VR-based interventions are more effective than paper-and-pencil tasks.

Chauhan et al., 2024	Improved cognitive function (memory, language), reduced stroke severity	Combined rTMS and VR is effective for cognitive recovery in stroke patients.
Torrisi et al., 2019	Improved cognitive function, attention, memory, language	VR-based telerehabilitation is effective for cognitive recovery in stroke patients.
Jonsdottir et al., 2021	Improved functional mobility, cognitive function	VR-based rehabilitation is feasible and effective for chronic stroke patients.
Park & Ha, 2023	Improved stroke self-efficacy, cognitive function, visual perception, ADL, HRQoL	VR-based cognitive rehabilitation is effective for stroke patients.
Katz et al., 2005	The VR group achieved on the USN measures results that equaled those achieved by the control group treated with conventional visual scanning tasks. They improved more on the VR test and they did better on some measures of the real street crossing	Despite several limitations in this study the present results support the effectiveness of the VR street program in the treatment of participants with USN, and further development of the program.
Pedro Gamito, 2015	Significant improvements in attention and memory in the intervention group	VR-based cognitive training is effective for neuropsychological rehabilitation in stroke patients
Antonio Gangemi, 2023	Increased alpha and beta band power in the experimental group	VR cognitive training enhances neuroplasticity in chronic stroke patients
Kazuhiro Yasuda, 2017	Improvement in far space neglect, no significant change in near space neglect	Immersive VR is effective for far space neglect in stroke patients
Xiao-Ping Cheng, 2024	Cognitive function, speech ability, daily living skills	tDCS combined with VR may enhance cognitive function in PSCI patients
Bo Ryun Kim, 2011	Significant improvement in K-MMSE, visual and auditory CPT, forward DST, forward and backward VST, visual and verbal learning tests, TOL, K-MBI, and MI scores in VR group	VR training combined with computer-based cognitive rehabilitation may be beneficial for treating cognitive impairment in stroke patients
Martina Maier, 2020	Improvement in attention, spatial awareness, and generalized cognitive functioning in experimental group	ACCT positively influences attention and spatial awareness, as well as depressive mood in chronic stroke patients
Zhilan Liu, 2023	Improved DSST scores in IVR group (Z=2.203, p=0.028); No significant differences in MoCA, TMT-A, MBI, DST, VFT; Most patients satisfied with IVR equipment and training content; Mild adverse reactions reported	IVR-based puzzle games improve executive function and visual-spatial attention in elderly stroke patients; Feasible and safe for cognitive rehabilitation

Improvements in Cognitive Function: Multiple studies documented significant improvements in cognitive function as assessed by tools such as the Mini-Mental State Examination (MMSE), Montreal Cognitive Assessment (MoCA), and other cognitive assessments. Chang-Hyung Lee (2020) (25) revealed that VR cognitive training improved cognitive function and rehabilitation motivation in sub-acute stroke patients more than conventional therapy.

Improvements in Motor Function: A number of studies pointed to improvements in motor function. After VR cognitive-motor training, chronic stroke patients showed significant improvements in their motor function, according to Ana Faria (2018) (26).

Daily Living Activities: According to certain studies, VR therapies enhanced daily living activities (27), suggesting that VR can have a beneficial effect on patients' daily activities.

Comparative Effectiveness: A lot of studies compare VR interventions with conventional approaches or control groups. For example, Faria et al. (2020) (28) found that VR-based therapies improved cognitive domains more effectively than paper-and-pencil tasks.

Safety and Feasibility: A number of studies, such as Spreij (2020) (29), highlighted the safety and viability of VR therapies, pointing to improved user experiences and high completion rates.

Particular VR Applications: The table lists a number of particular VR applications like VR-based puzzle games (30) and VR street crossing instruction (31), illustrating how adaptable VR technology is in addressing varied rehabilitation requirements.

Meta-analysis

Figure 2 shows that VR interventions are linked to significant improvements in stroke patients' cognitive function as assessed by the MoCA. The forest plot graphically illustrates the benefits of virtual reality across multiple studies, and the pooled effect size validates the overall benefit. When evaluating the results, it is essential to take into account contextual aspects including the type of VR intervention and patient characteristics, as highlighted by the significant heterogeneity.

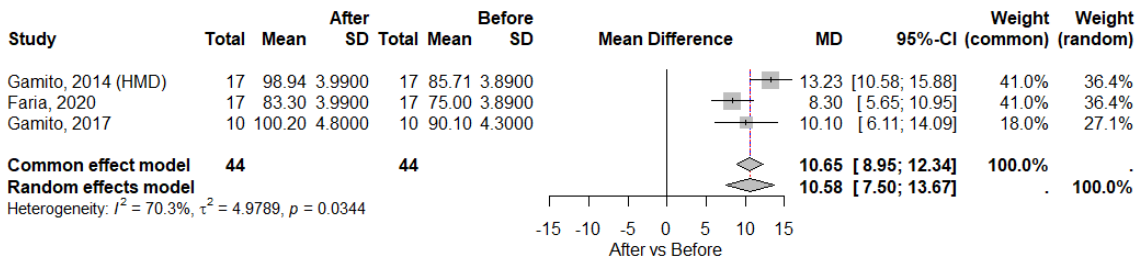

Figure 2a: Montreal Cognitive Assessment Scale (MOCA) improvement after virtual reality interventions in stroke patients

The inclusion of Chatterjee, 2022 (Sham VR) and Shi, 2023 does not significantly alter the original findings, as the sensitivity analysis shows (Figure 2b). When these studies have been removed, the heterogeneity is significantly decreased and the pooled effect size is still statistically significant, suggesting consistent and trustworthy findings across the remaining investigations. The results of this investigation support the use of virtual reality (VR) in stroke rehabilitation programs and reinforce the effectiveness of VR therapies in enhancing cognitive function in stroke patients.

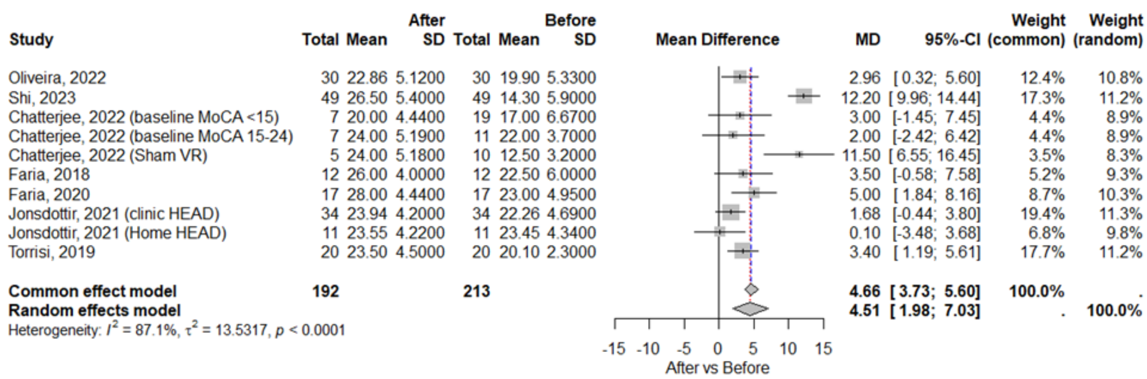

Figure 2b: Montreal Cognitive Assessment Scale (MOCA) improvement after virtual reality interventions in stroke patients (After sensitivity analysis)

Strong evidence that VR interventions are linked to significant improvements in stroke patients' memory function as assessed by the WMS-III is shown in Figure 3. The pooled effect size validates the overall benefit, and the forest plot graphically illustrates the benefits of VR across several trials. The moderate heterogeneity, however, emphasizes how crucial it is to take into account contextual elements when interpreting the results, such as the type of VR intervention and patient characteristics. These results support the use of virtual reality (VR) in stroke rehabilitation programs, but they also point to the need for additional investigations to improve VR procedures and guarantee reliable results.

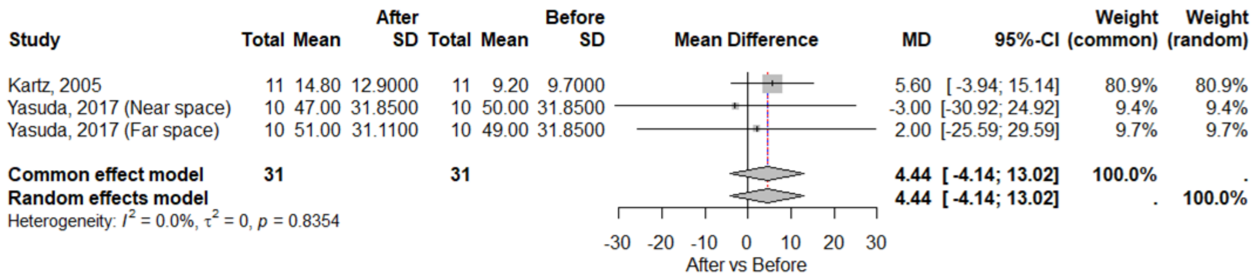

Figure 3: Wechsler Memory Scale-III (WMS III) improvement after virtual reality interventions in stroke patients

According to the Star Cancellation Test, VR interventions did not significantly improve unilateral spatial neglect (USN) as assessed by star cancellation (Figure 4). The low heterogeneity indicates consistent but limited effects across studies, and the pooled effect size is small and not statistically significant. These results indicated that other strategies should be taken into consideration as VR might not be the best strategy for treating USN in stroke patients.

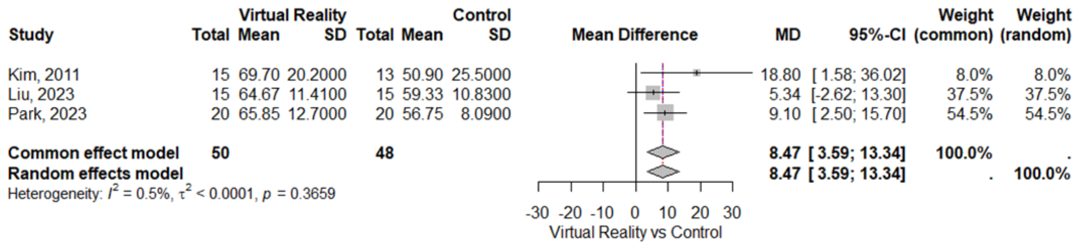

Figure 4: Star Cancellation improvement after virtual reality interventions in stroke patients

When compared to control groups in stroke patients, Figure 5 shows that VR therapies are linked to moderate but statistically significant improvements in cognitive function as assessed by the K-MMSE. The forest plot illustrates the inconsistent results from several research, with some revealing substantial improvements and others revealing insignificant improvement. The significant heterogeneity emphasizes how crucial it is to take into account contextual factors, such as the type of VR intervention and patient characteristics, when interpreting the results, even though the pooled effect size supports the overall benefit of VR treatments.

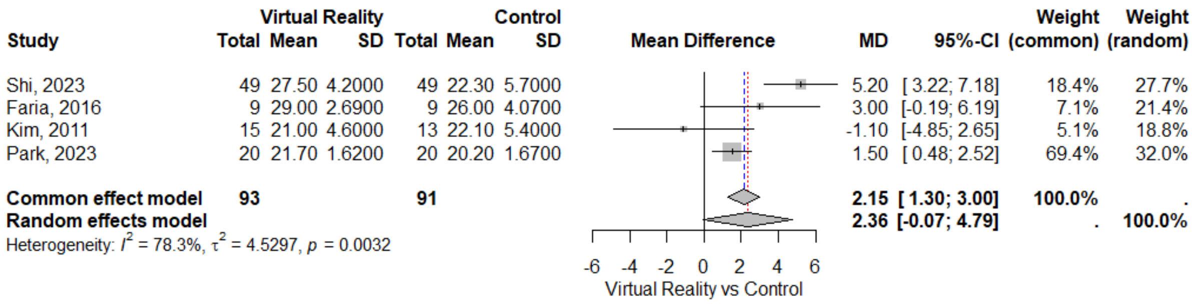

Figure 5: Korean Mini-mental State Examination (K-MMSE) difference between virtual reality and controls

In contrast to control groups, Figure 6 demonstrates that VR interventions have been associated with significant improvements in mild behavioral impairment as assessed by the MBI in stroke patients. The pooled effect size validates the overall benefit, while the forest plot graphically illustrates the benefits of VR across multiple studies. The minimal heterogeneity highlights the findings' consistency across studies, indicating that VR interventions are an effective option for addressing behavioral impairment in stroke patients.

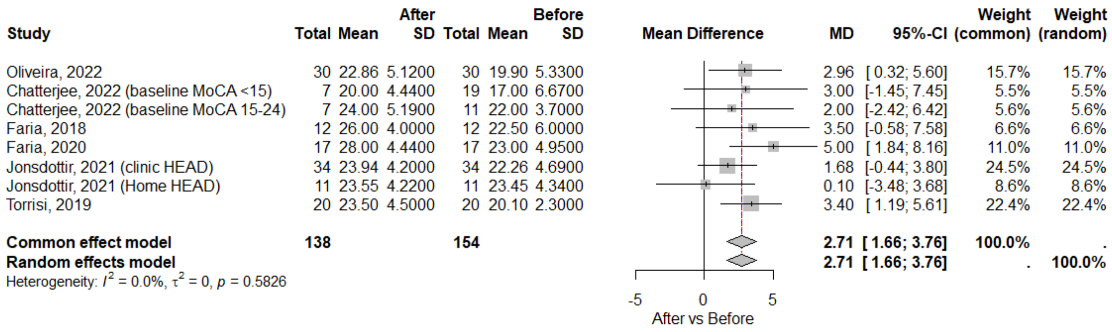

Figure 6: Mild Behavioral Impairment difference between virtual reality and controls

When compared to control groups in stroke patients, Figure 7 demonstrates that VR interventions have been linked to significant improvements in cognitive function as assessed by the MoCA. The pooled effect size validates the overall benefit, and the forest plot graphically illustrates the benefits of VR across several trials. The moderate variability, however, emphasizes how crucial it is to take into account specific factors when interpreting the results, such as the type of VR intervention and patient characteristics.

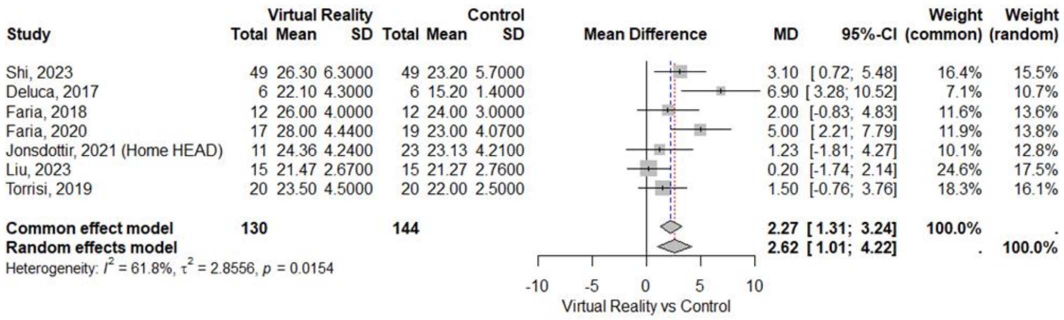

Figure 7: Montreal Cognitive Assessment Scale (MOCA) difference between virtual reality interventions and controls in stroke patients

Publication bias

According to Figure 8 and 9, the meta-analysis of research on how VR interventions affect stroke patients' cognitive function as determined by the MoCA shows no evidence of publication bias. The findings are reliable and strong, according to the relatively symmetrical funnel plot, and the meta-analysis is not significantly impacted by the selective reporting of positive findings.

Publication bias

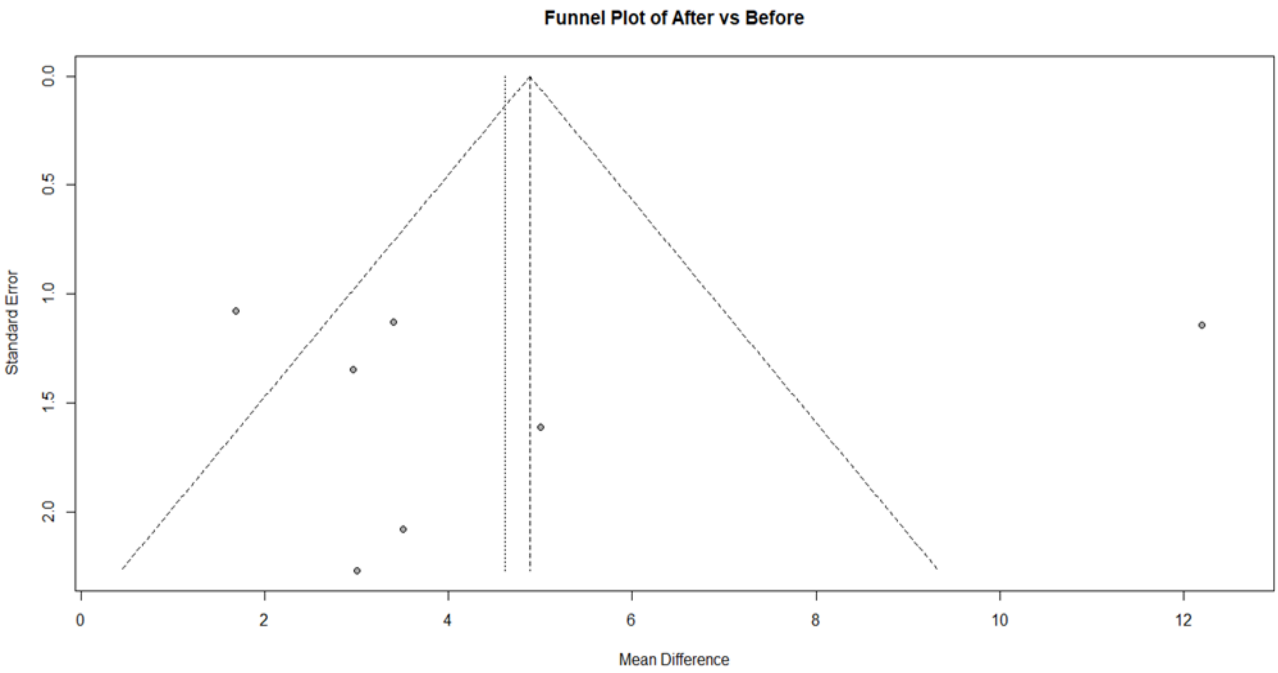

Figure 8: Funnel plot for publication bias assessment of the included studies in Montreal Cognitive Assessment Scale (MOCA) outcome after virtual reality

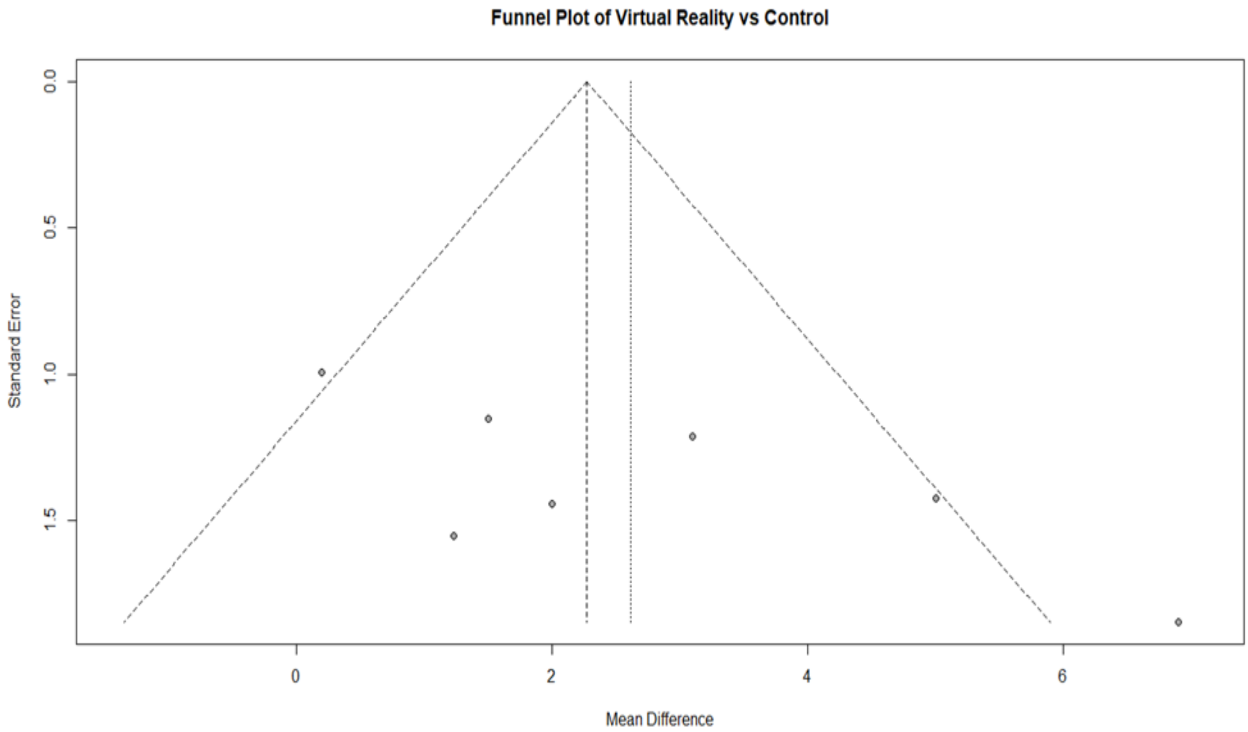

Figure 9: Funnel plot for publication bias asses bias assessment of the included studies in Montreal Cognitive Assessment Scale (MOCA) outcome difference between virtual reality and control

Quality assessment of the included studies

In terms of quality evaluation of non-randomized trials, the studies appear to be of acceptable quality, with the majority of biases classified as low risk. Specific areas, such as "Bias due to confounding," provide an occasional high risk (Figure 10, 11). However, in randomized controlled trials, many studies show low risks in key areas such as attrition bias and reporting bias, consequently confirming the general reliability of the data. High risks in the performance and selection bias categories underline the importance of enhanced allocation concealment and participant/personnel blinding in these studies (Figure 12, 13).

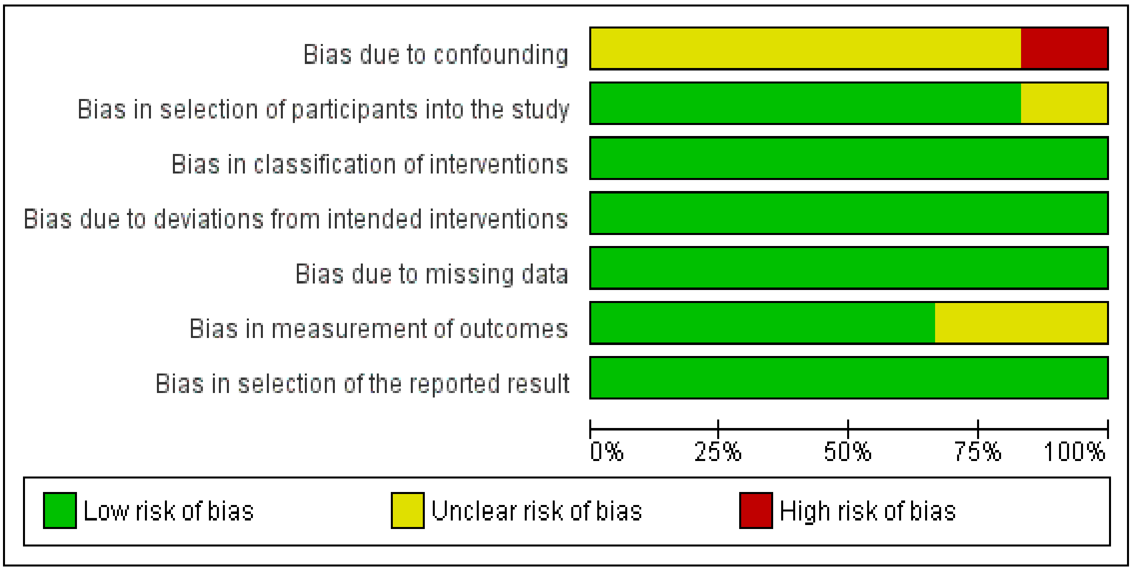

Figure 10: Risk of bias graph of non-randomized trials

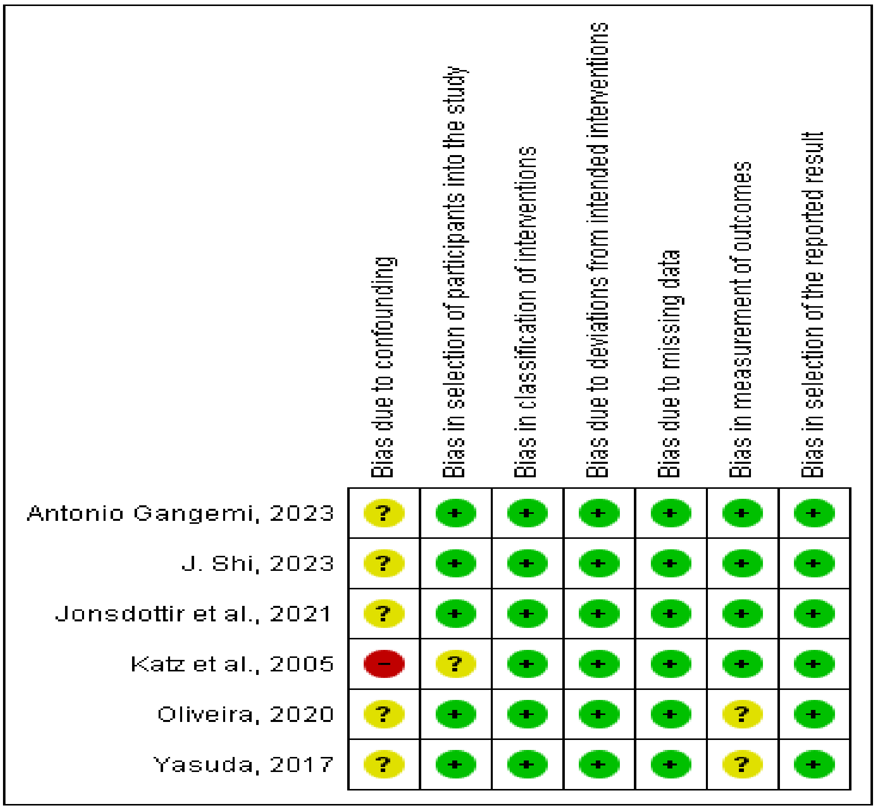

Figure 11: Risk of bias summary of non-randomized trials

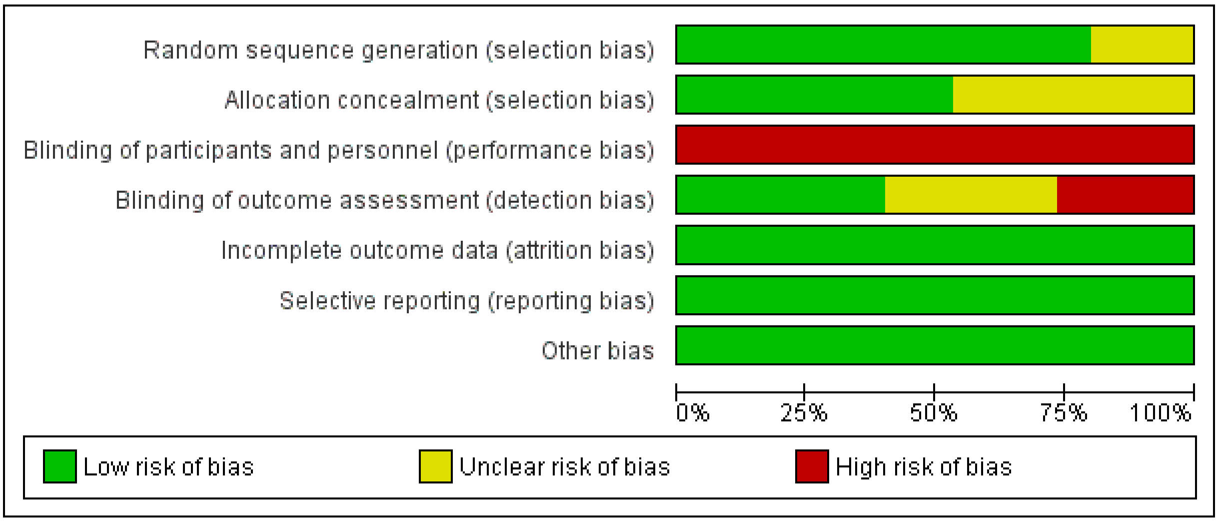

Figure 12: Risk of bias graph of randomized controlled trials

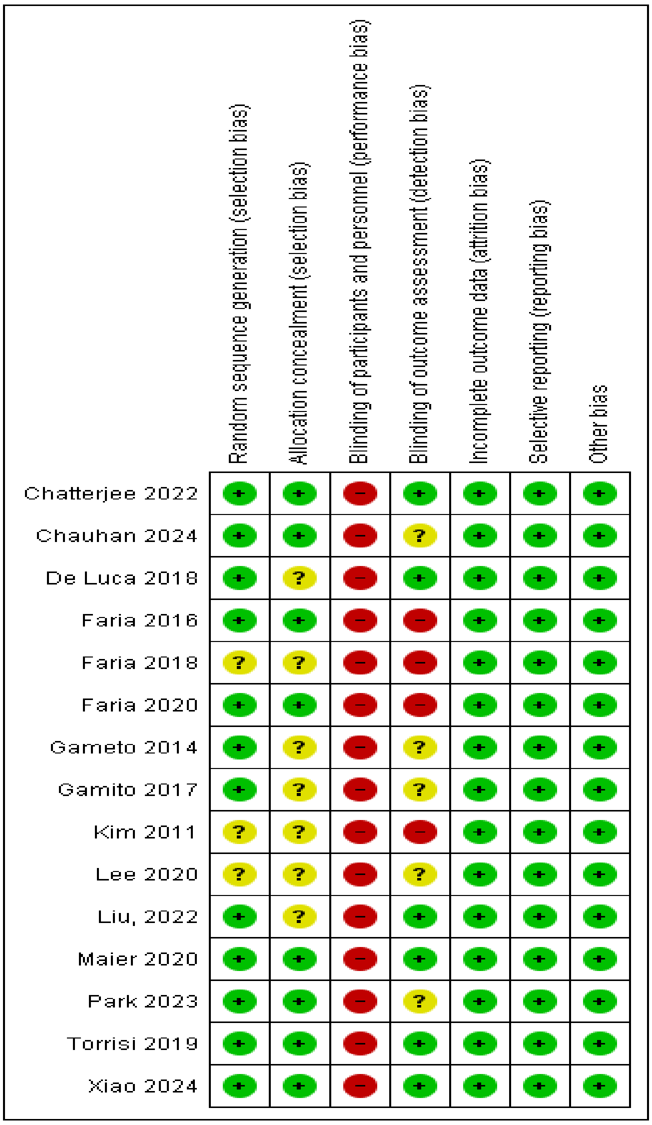

Figure 13: Risk of bias summary of randomized controlled trials

4. DISCUSSION

Virtual reality (VR) therapies have been demonstrated to significantly enhance cognitive function in stroke patients, according to the Montreal Cognitive Assessment (MoCA). These benefits are supported by the current meta-analysis, which shows their efficacy and consistency across several studies. These results provide support to the implementation of virtual reality technology in rehabilitation programs, which may improve patients' quality of life and accelerate recovery.

The systematic review and meta-analysis conducted by Gao et al. (2021) had similar results. The study assessed the impact of VR-based training in conjunction with conventional therapy on post-chronic stroke cognition, motor function, mood, and activities of daily living (ADL) (47). The findings demonstrated that VR-based training had a significant impact on general cognition as well as attention and execution. Although research indicates that virtual reality therapy improve cognitive function in stroke patients, other studies have shown conflicting results. The impact of VR-based training in conjunction with conventional rehabilitation on mood, motor function, cognition, and activities of daily living (ADL) following a chronic stroke was assessed by a systematic review and meta-analysis (47). The results for global cognition were not statistically significant, despite their finding that they discovered notable gains in attention/execution and overall cognition. Furthermore, for motor function and ADLs, VR-based therapies did not demonstrate advantage over conventional rehabilitation. Rose Sin Yi et al. (2024) investigated how VR-based cognitive therapies affected stroke patients' ADL and cognitive function. They found no significant impacts on language, visuospatial ability, or ADL, but moderate-to-large effects on memory, executive function, and global cognitive function (48).

According to the results of the current study, VR interventions significantly improved stroke patients' memory function as measured by the Wechsler Memory Scale-Third Edition (WMS-III). The overall benefit across several studies is confirmed by the pooled effect size and forest plot visualization, indicating that VR therapies are effective in enhancing stroke patients' memory function. In their study on VR's impact on stroke rehabilitation, Khan et al. (2024) emphasized VR's advantages for recovery of the upper and lower limbs, gait, and balance in addition to its favorable effects on cognition (49). The beneficial effects of VR in stroke patients' cognitive rehabilitation was assessed by Pužauskė et al. in 2023. The findings showed improvements in memory, executive function, visual-spatial skills, and gait, among other cognitive processes. However, the study emphasized the necessity of more randomized clinical studies to confirm these results and generate stronger evidence (50).

VR modalities may have a beneficial effect on stroke patients' cognitive recovery, as evidenced by the discovery that VR therapies are associated with mild but statistically significant improvements in cognitive function as measured by the Korean Mini-Mental State Examination (K-MMSE). This was in line with the results of another study that investigated how well VR training affected people with dementia and mild cognitive impairment in terms of their quality of life, daily living activities, and global and domain-specific cognition. The findings indicated that VR training had moderate significant improvements on MCI patients' overall cognition, attention, memory, motor function, and construction. The impact of VR training on global cognition was shown to be significantly moderated by immersion and training modality. Results demonstrated moderate to significant gains in global cognition, memory, and executive function in individuals with dementia following VR training (51).

Regarding the Modified Barthel Index (MBI), the results of this study showed that virtual reality (VR) therapies are beneficial in alleviating moderate behavioral impairment in stroke patients. The limited heterogeneity indicates the validity and reliability of these findings, and the pooled effect size and forest plot indicate consistent benefits across several investigations. Consistent with these findings, a prior systematic review and meta-analysis aimed to ascertain how virtual reality (VR) rehabilitation training affected the cognitive function and activities of daily living (ADL) of individuals suffering from poststroke cognitive impairment (PSCI) demonstrated that MMSE, MoCA, LOTCA, RBMT-II, BI, MBI, and FIM scores may all be increased by VR training (52).

Among the study's limitations are participant characteristics and sample size variation. While moderate heterogeneity suggests variability caused by variations in the type of VR intervention, its duration, intensity, and patient characteristics, heterogeneity in certain data demonstrates inconsistency. The range of VR applications might result in variations in the interventions' efficacy, and comparative effectiveness could not take into consideration all possible confounding variables.

5. CONCLUSION

Reviewing virtual reality (VR) interventions for stroke rehabilitation has revealed significant advantages in a variety of areas. Virtual reality has been associated with improvements in stroke patients' everyday life activities, motor function, cognitive function, and mild behavioral impairments. VR cognitive training can be effective than traditional therapy at improving cognitive function and rehabilitation motivation, according to studies las assessed by MMSE and MoCA. For chronic stroke patients, VR-based cognitive-motor training has also demonstrated significant improvements in motor function. Additionally, VR interventions can improve everyday living tasks, which may have a wider effect on patients' quality of life and functional independence. VR interventions have been shown to be both safe and effective, with high success rates and user satisfaction.

K-MMSE: Korean Mini-mental State Examination; MOCA: Montreal Cognitive Assessment Scale; LOTCA: Loewenstein Occupational Therapy Cognitive Assessment; K-MBI: Korean mild behavioral impairment; VRT: Visual Recognition Test; MVPT-3: Motor-free Visual Perception Test-3; TMT: Trail Making Test; DST: Digit Span Test; WMS-III: Wechsler Memory Scale-III; SIS: Stroke Impact Scale; TOL: Tower of London Test; VST: Visual Span Test; NIHSS: National Institutes of Health Stroke Scale; BDI: Beck Depression Inventory.

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