Effectiveness of VR-based cognitive training and games on cognitive rehabilitation in patients with MCI：A Systematic Review and Meta-Analysis

Peiming Yuan, Dianhui Peng, Jiaxi Chen, Bin Liu, Chunxia Lu

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Abstract

Background: Mild Cognitive Impairment (MCI), characterized by cognitive decline exceeding age-related norms without significant functional impairment, represents a critical prodromal stage for dementia. Given the limited efficacy of pharmacological interventions and the escalating global burden of aging populations, effective non-pharmacological strategies are urgently needed. Virtual Reality (VR), offering immersive and interactive environments, shows promise for cognitive rehabilitation in MCI, but evidence regarding its efficacy remains inconsistent due to heterogeneity in intervention types (training vs. gaming) and technical parameters, particularly immersion level.

Objective: This systematic review and meta-analysis synthesized evidence from randomized controlled trials (RCTs) to evaluate the efficacy of VR-based cognitive training and gaming interventions on cognitive function in older adults with MCI and to investigate the moderating role of immersion level.

Methods: We systematically searched four electronic databases (PubMed, Web of Science, Embase, Scopus) from inception to July 20, 2025, for RCTs investigating VR interventions (cognitive training or games) in individuals aged ? 55 years diagnosed with MCI. Two independent reviewers performed study selection, data extraction (including intervention characteristics, implementation details, and behavior change techniques), and risk-of-bias assessment using the Cochrane Risk of Bias tool (RevMan 5.4.1). Standardized mean differences ((Hedges's g) with 95% confidence intervals (CI) were pooled using random-effects models in Stata 18.0. Heterogeneity was quantified using I^2. Publication bias was assessed via funnel plots and Egger's test. Pre-specified meta-regression explored immersion level as a potential moderator.

Results: Of the 1,411 articles retrieved in total, 11 studies were included in the analysis. VR demonstrated a statistically significant improvement in the efficacy of cognitive rehabilitation among patients with MCI (Hedges's g = 0.6, 95% CI: 0.29 to 0.90, $p < 0.05$). Specifically, VR-based games (Hedges's g = 0.68, 95% CI: 0.12 to 1.24, $p = 0.02$) showed greater advantages in improving cognitive impairments compared to VR-based cognitive training (Hedges's g = 0.52, 95% CI: 0.15 to 0.89, $p = 0.05$). The immersive level of VR interventions emerged as a significant moderator of heterogeneity across the included studies.

Conclusions: VR-based interventions, including cognitive training and games, effectively improve cognitive function in MCI patients, with VR games showing a trend toward greater efficacy. Critical to these outcomes is VR immersion level, highlighting the need to optimize sensory integration (e.g., multi-modal feedback) while balancing individual tolerance. Moderate heterogeneity across studies underscores the importance of standardized protocols for intervention design and immersion assessment. These findings support VR as a valuable non-pharmacological tool for MCI cognitive rehabilitation, with future research needed to refine personalized approaches and enhance generalizability.

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Effectiveness of VR-based cognitive training and games on cognitive rehabilitation in patients with MCI：A Systematic Review and Meta-Analysis

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Background: Mild Cognitive Impairment (MCI), characterized by cognitive decline exceeding age-related norms without significant functional impairment, represents a critical prodromal stage for dementia. Given the limited efficacy of pharmacological interventions and the escalating global burden of aging populations, effective non-pharmacological strategies are urgently needed. Virtual Reality (VR), offering immersive and interactive environments, shows promise for cognitive rehabilitation in MCI, but evidence regarding its efficacy remains inconsistent due to heterogeneity in intervention types (training vs. gaming) and technical parameters, particularly immersion level.

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Results: Of the 1,411 articles retrieved in total, 11 studies were included in the analysis. VR demonstrated a statistically significant improvement in the efficacy of cognitive rehabilitation among patients with MCI (Hedges's g = 0.6, 95% *CI*: 0.29 to 0.90, $p < 0.05$). Specifically, VR-based games (Hedges's g = 0.68, 95% *CI*: 0.12 to 1.24, $p = 0.02$) showed greater advantages in improving cognitive impairments compared to VR-based cognitive training (Hedges's g = 0.52, 95% *CI*: 0.15 to 0.89, $p = 0.05$). The immersive level of VR interventions emerged as a significant moderator of heterogeneity across the included studies.

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Keywords: Virtual reality; Mild cognitive impairment; Cognitive rehabilitation; Games; Meta-analysis

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1 Introduction

Mild cognitive impairment (MCI), defined as a level of cognitive ability that is lower than would be expected for their age and educational level, occurring between normal aging and dementia(Petersen, 2016). Individuals diagnosed with MCI are at a significantly higher risk of progressing to dementia, with a mean annual conversion rate of approximately 10%, compared to the annual incidence of 1–2% in the general population(Meng et al., 2022; Petersen et al., 2018). Treatments can be implemented to slow down the advancement of dementia during the preclinical phase(Anderson, 2019), making the identification of effective therapeutic strategies to delay or prevent the progression to dementia of utmost importance.

The increasing prevalence of MCI, driven by the aging global population, there are few medications or dietary therapy that can improve cognitive function or slow MCI progression, non-pharmacological treatments have received attention(Petersen et al., 2018; Pinto & Subramanyam, 2009). One of the non-pharmacological treatments is the use of VR technology, which is currently employed in the control and treatment of various diseases(Grassini, 2022). It helps the user create a real sense of presence and immersion in the virtual world through multiple sensory stimuli (visual, auditory, tactile, and olfactory) while also functioning by distracting them within that virtual and simulated environment(Laghari et al., 2021; Li et al., 2017).VR technology can manifest in VR-based cognitive training and VR-based games. VR cognitive training integrates VR technology into the training to create an immersive experience for MCI patients(Buele et al., 2024). Using computer-generated simulations, it enhances patients' cognitive function and executive functions through targeted training content and encourages them to actively participate in the training process(J. S. Park et al., 2020). VR-based games, which involve the use of virtual reality technology to create interactive and immersive gaming experiences, achieve targeted improvement of cognitive functions through multisensory stimulation and task interactivity(Amjad et al., 2019). In these games, players are fully immersed in a computer-generated environment that responds to their actions in real-time(Tao et al., 2021). In contrast, VR-based games use VR to provide users with engaging and entertaining experiences, prioritizing narrative, gameplay, and overall enjoyment(Moulaei et al., 2023).

Several trials have investigated the impact of VR on older adults with MCI, but the findings have been inconclusive. For example, studies by Baldimtsi et al(Baldimtsi et al., 2023) and Park et al(J. S. Park et al., 2020) revealed a significant effect of VR on general cognitive abilities. However, the findings from Park et al(J. H. Park et al., 2020) showed that a 12-week, culture-based VR training program did not improve general cognitive abilities and did not show significant differences in scores on the Mini-Mental Status Examination (MMSE). Also, it is challenging to make definitive conclusions about the effectiveness of interventions because of variations VR intervention content (cognitive training or games). In a study conducted by Yang et al (Yang et al., 2022), daily life-based VR training games (making juice, shooting crows, finding the number of fireworks, and memorizing objects in the house) were found to positively affect general cognitive performance. However, in a study by kang et al(Kang et al., 2021), while the VR group participants received multidomain and neuropsychologist-assisted cognitive training, no significant differences in general cognitive performance were observed when compared to other groups or baseline measurements.

To the best of our knowledge, although the use of VR technology to improve cognitive function is increasing(Zhong et al., 2021), the impact of VR-based cognitive training and games on the cognitive rehabilitation of patients with MCI remains controversial(Amjad et al., 2019; J. H. Park et al., 2020). Thus, the validation of the effectiveness of VR-based cognitive training on cognitive rehabilitation has limitations. In view of the dearth of systematic reviews or meta-analyses exploring the influence of VR-based cognitive training and gaming interventions on cognitive rehabilitation in individuals with mild cognitive impairment (MCI). Therefore, this study conducted a meta-analysis to investigate the effects of both interventions on cognitive rehabilitation in this population.

2 Materials and Methods

2.1 Search strategy

Studies were identified by searching web-based databases with support and consultation provided by institutional librarians. Four databases were searched (PubMed, Embase, Web of Science, Scopus) by combining keywords. To include studies reflecting the latest advancements in VR technology and methodologies, the focus was on literature published from January 2013 to December 2025. The year 2013 was chosen to ensure consistency in the technological sophistication and usability standards of VR interventions, as VR technology and its applications in cognitive rehabilitation have rapidly evolved over the past decade. Keywords and search strategies are included: (“Virtual Reality” OR “VR” OR “virtual environment” OR “Virtual Reality Training” OR “virtual game” OR “Game” OR “Gaming” OR “video games”) AND (“Mild Cognitive Impairment” OR “MCI” OR “Cognitive Dysfunction” OR “Cognitive Disorder” OR “Cognitive Impairment” OR “cognitive decline”) AND (“treatment” OR “intervention” OR “rehabilitation” OR “therapy” OR “training”).

2.2 Selection criteria

2.2.1 Inclusion criteria

The inclusion criteria were defined with the PICOS approach: ⅰ) Participants: Studies concerning older adults (aged ≥ 55 years) with a confirmed diagnosis of MCI by neurologic examination or neuropsychological assessment were included; ⅱ) Intervention: VR-based cognitive training and gaming; ⅲ) Controls: Studies with any type of control group were included (inactive controls include educational programs or no intervention; active controls include traditional rehabilitation or any other type of physical activity, physical-cognitive co-training, or video games without VR components); ⅳ) Outcome: Overall cognitive function; ⅴ) Study design: randomized controlled trials (RCTs); ⅵ) Additional：Published in English; full-text available

2.2.2 Exclusion criteria

The exclusion criteria were as follows:

i. No specific identification of cognitive impairment: Studies where VR was not used in the intervention group, or VR was used in the control group, were excluded.
ii. Cognitive impairment caused by other conditions: Studies where cognitive impairment was attributed to other medical conditions, such as stroke, cerebral infarction, traumatic brain injury, or other neurological disorders, were excluded. This ensures that the cognitive impairment under study is specifically related to MCI and not secondary to other health issues.
iii. Materials such as books, book chapters, letters to the editor, and conference abstracts were excluded from the analysis.

2.3 Study selection and data extraction

The article search and selection process were reviewed through the title and abstract of searched articles after the primary database search and, in the full review, two authors finally selected the articles by considering the eligibility criteria. This process was performed using a preferred reporting items for systematic reviews and meta-analysis (PRISMA) flow chart(Moher et al., 2009). Data were extracted by 2 researchers (HY and LZ) and cross-checked by a third researcher (FC). The data extraction form encompassed various fields, including the author, published year, country, study design, sample size (male/female), mean age, intervention in treatment group, intervention in control group, duration of the session and the follow-up period and outcome characteristics was extracted.

2.4 Risk of bias and quality assessment

The quality assessment was conducted using the risk of bias tool from Rev Man 5.4.1 (Higgins et al., 2011). This tool evaluates seven aspects: random sequence generation, allocation concealment, blinding of participants and personnel, blinding of outcome assessment, incomplete outcome data, selective reporting, and other biases. Each aspect was rated by the researchers as high risk (−), low risk (+), or uncertain risk (?). In cases of disagreement on the ratings, a consultation process was implemented to reach a consensus.

2.5 Statistical analysis

The included studies were synthesized and analyzed using Stata version 17.0 software. Statistical heterogeneity, effect size, meta-regression, and publication bias were analyzed. Hedge's g was used to calculate and interpret the effect size. For calculation and analysis of results, mean, standard deviation, and number of subjects were used as values. The heterogeneity was quantitatively determined by I2, where I2 values of < 25, 26–74, and > 75% represented small, moderate, and large levels of heterogeneity, respectively. Fixed-effects models were applied when heterogeneity was graded as small, whereas random-effects models were utilized for moderate or large heterogeneity(Cooper, 2015). Publication bias refers to an error in which research results are published or not published depending on the characteristics or direction of research results. If a distorted sample of studies is included in a meta-analysis, the overall size of the analysis result can be said to be a distorted result(Hwang, 2016). To confirm this tendency, it was reviewed and presented through a funnel plot and Egger's regression test(Duval & Tweedie, 2000). In addition, meta regression was used to assess the sources of heterogeneity in the included studies.

3 Results

3.1 Study Selection

A total of 1,411 papers were identified using the four databases, of which 367 were duplicates. Each of these studies underwent a rigorous and meticulous review, during which inclusion and exclusion criteria were carefully applied. The assessment process involved a thorough examination of the methodologies, results, and relevance to the research focus. After this meticulous screening, 12 articles that met the inclusion criteria were finally selected. The detailed process of this screening is as follows (Figure 1).

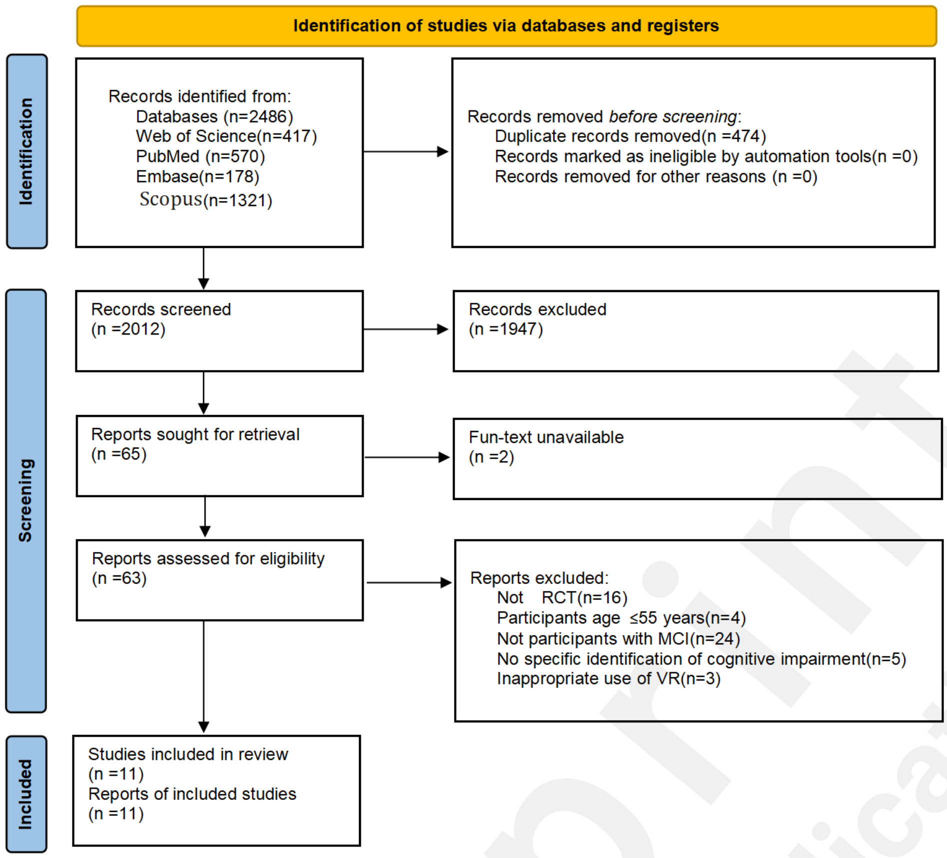


Figure 1. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flow diagram. MCI: mild cognitive impairment; RCT: randomized controlled trial; VR: virtual reality.

3.2 Characteristics of included articles

A total of 11 studies were included, among which 8 were conducted in South Korea, and the remaining 3 were carried out in China, Turkey, and Ecuador. All included studies focused on elderly individuals with mild cognitive impairment (MCI). Regarding interventions for cognitive rehabilitation in MCI patients, 6 studies adopted VR-based cognitive training, such as spatial cognitive training, simulated shopping activities, and virtual kayaking paddling exercises; the other 5 studies utilized VR-based games, including Seek a Song of Our Own, Fireworks Party, and Boxing Trainer. In one of the articles, no intervention was implemented in the control group, while other studies applied interventions such as conventional training or a combination of cognitive training and physical activities. The characteristics of the included articles were presented in Table 1.

Table 1 Characteristics of the included articles.

Author, Year	Country	Study Design	Sample size (M/F)	Age (SD)	Intervention in treatment group	Intervention in control group	Duration of the session and the follow-up period	Outcome
Park et al., 2022(Park, 2022)	Korea	RCT (single-blind)	EG: 28(12/16） CG: 28(11/17)	EG: 71.93±3.11 CG: 72.04±2.42	VR-based training programs (a VR-based spatial cognitive task crafted to enhance spatial memory)	A VR-based spatial cognitive task crafted to enhance spatial memory	56 sessions, 45 min a session, 3 days a week for 8 weeks	WAIS-BDT
Kang et al., 2021(Kang et al., 2021)	Korea	RCT	EG: 23(6/17） CG: 18(6/12)	EG: 75.48 ± 4.67 CG: 73.28 ± 6.96	Undergoing cognitive trainingwith the assistance of a neuropsychologist in a completely immersive VR environment	Usual therapy: pharmacotherapy	Approximately 20–30 min for each session, twice a week, for 1 month	MMSE
Buele et al., 2024(Buele et al., 2024)	Ecuador	RCT (single-blind)	EG: 17(7/10） CG: 17(4/13)	EG：75.14±5.76 CG：77.35±6.75	Individual cognitive training was performed using an immersive VR-based system that simulates a task of searching for ingredients in a kitchen cupboard	The individual cognitive training consisted of a task similar to that of the experimental group, but without the use of VR	6-week intervention (a total of twelve 40-minutes sessions)	MoCA

Table 1 (continued)

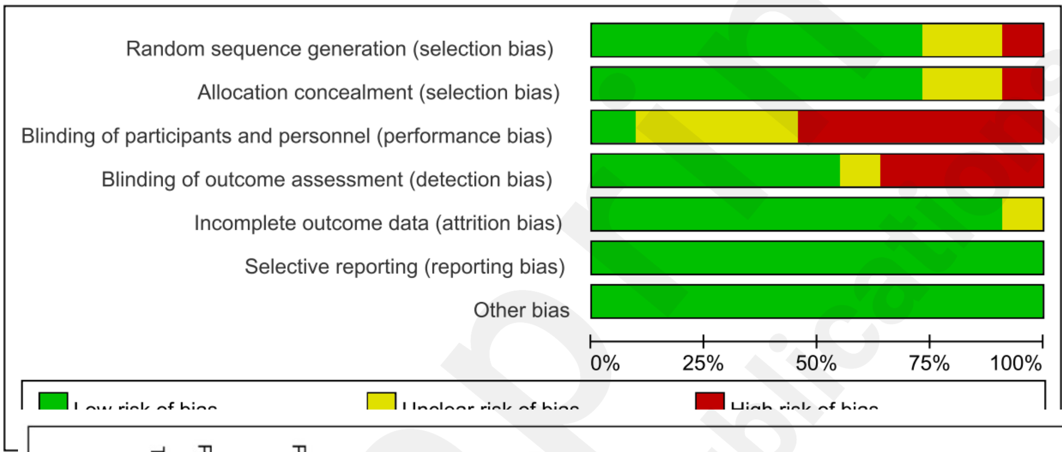
Author, Year	Country	Study Design	Sample size (M/F)	Age (SD)	Intervention in treatment group	Intervention in control group	Duration of the session and the follow-up period	Outcome
Park et al., 2020-1(J. S. Park et al., 2020)	Korea	RCT	EG:18(10/8） CG: 17(7/10)	EG: 75.8 ± 8.5 CG: 77.2 ± 7.2	MOTOCOG®system: performing driving, bathing, cooking, and shopping activities	Tabletop activities: including puzzles, wood blocks, card play, stick construction activity, maze and pencil–paper	30 min per day, 5 days/week, for 6 weeks	MoCA
Choi et al., 2019(Choi & Lee, 2019)	Korea	RCT	EG: 30(5/25) CG: 30(4/26)	EG: 77.27 ± 4.37 CG: 75.37 ± 3.97	Virtual kayak paddling exercise	Home exercises	60 min per day, 22days/week, for 6 weeks	MoCA
Liao et al., 2019(Liao et al., 2020)	China	RCT (single-blind)	EG: 18(7/11) CG: 16(4/12)	EG: 75.5 ± 5.2 CG: 73.1 ± 6.8	VR daily activities; Cognitive tasks: IADL based scenarios (take mass rapid transit, looking for a store, kitchen chef, and convenience store clerk）	Combined Physical (Resistance, aerobic and balance exercises) and Cognitive Training (different tasksin ecological scenarios)	60 min per day, 3days/week, for 12 weeks	MoCA

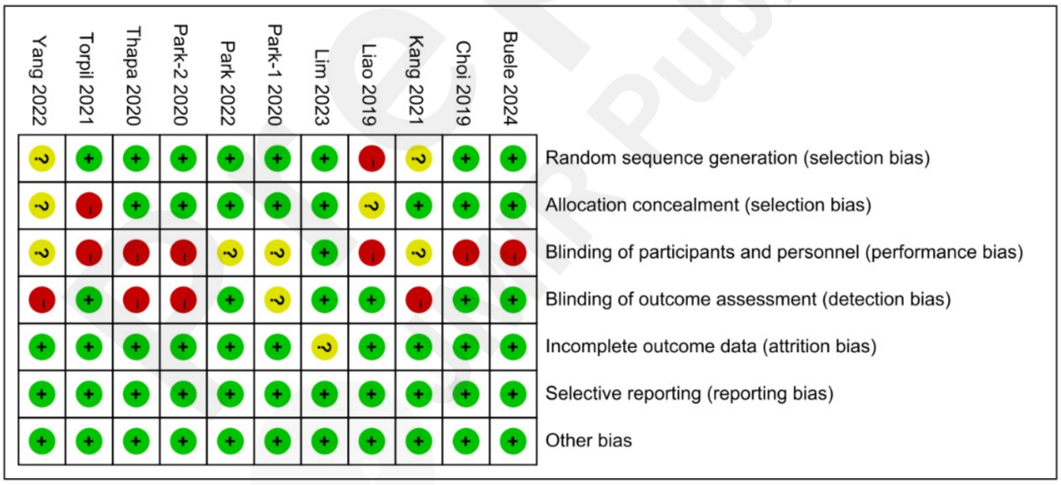
Author，Year	Country	Study Design	Sample size (M/F)	Age (SD)	Intervention in treatment group	Intervention in control group	Duration of the session and the follow-up period	Outcome
Torpil et al., 2021(Torpil et al., 2021)	Turkey	RCT (single-blind)	EG: 30(11/19) CG: 31(14/17)	EG: 70.12±2.57 CG: 70.30±2.73	Four games (Boxing Trainer, Jet Run, Superkick, Air Challenge)	LOTCA-G cognitive domain intervention	45 min per day, 2days/week, for 12 weeks	LOTCA-G
Thapa et al., 2020(Thapa et al., 2020)	Korea	RCT	EG: 34(6/28) CG: 34(10/24)	EG: 72.6 ± 5.4 CG: 72.7 ± 5.6	Four VR training games: juice making, crow shooting,find the fireworks number, memory object at the house	An educational program focusing on overall healthcare	100 min per day, 3days/week, for 8 weeks	MMSE
Lim et al., 2023(Lim et al., 2023)	Korea	RCT (single-blind)	EG: 12(3/9) CG: 12(4/8)	EG: 75.42 ± 5.74 CG: 73.33 ± 17.52	Brain Talk™ home-based Serious game	Performing daily tasks	30 min per day, 3days/week, for 4 weeks	MoCA
Yang et al., 2022(Yang et al., 2022)	Korea	RCT	EG: 33(13/20) CG: 33(6/27)	EG: 72.5 ± 5.0 CG: 72.6± 5.6	Four games encompassing various brain domains, such as attention and working memory	Education seminars on health-related topics (nutrition and exercise tips on prevention of	100 min per day, 3days/week, for 8 weeks	MMSE

						geriatric disease)		
Park et al., 2020-2(J. H. Park et al., 2020)	Korea	RCT	EG: 10(3/7) CG: 11(4/7)	EG: 71.80 ± 6.61 CG: 69.45 ± 7.45	Six VR Game Training Programs (Janggu, Fireworks Party, Fruit Cocktail, Shopping in the Mart, etc.)	Maintain normal daily activities	30 min per day, 2days/week, for 3 months	MMSE

3.3 Assessment of Methodological Quality

The results of quality assessment were as follows: random sequence generation (low: 8, uncertain: 2, high: 1), allocation concealment (low: 8, uncertain: 2, high: 1), blinding of participants and personnel (low: 1, uncertain: 4, high: 6), blinding of outcome assessment (low: 6, uncertain: 1, high: 4), incomplete outcome data (low: 10, uncertain: 1), selective reporting (low: 11), and other biases (low: 11). For other biases, items such as lack of sample size calculations, differences in baseline characteristics, and lack of study protocol registration were assessed as uncertain or high(Babic et al., 2019) (Figure 2).





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3.4 Meta-Analysis Results

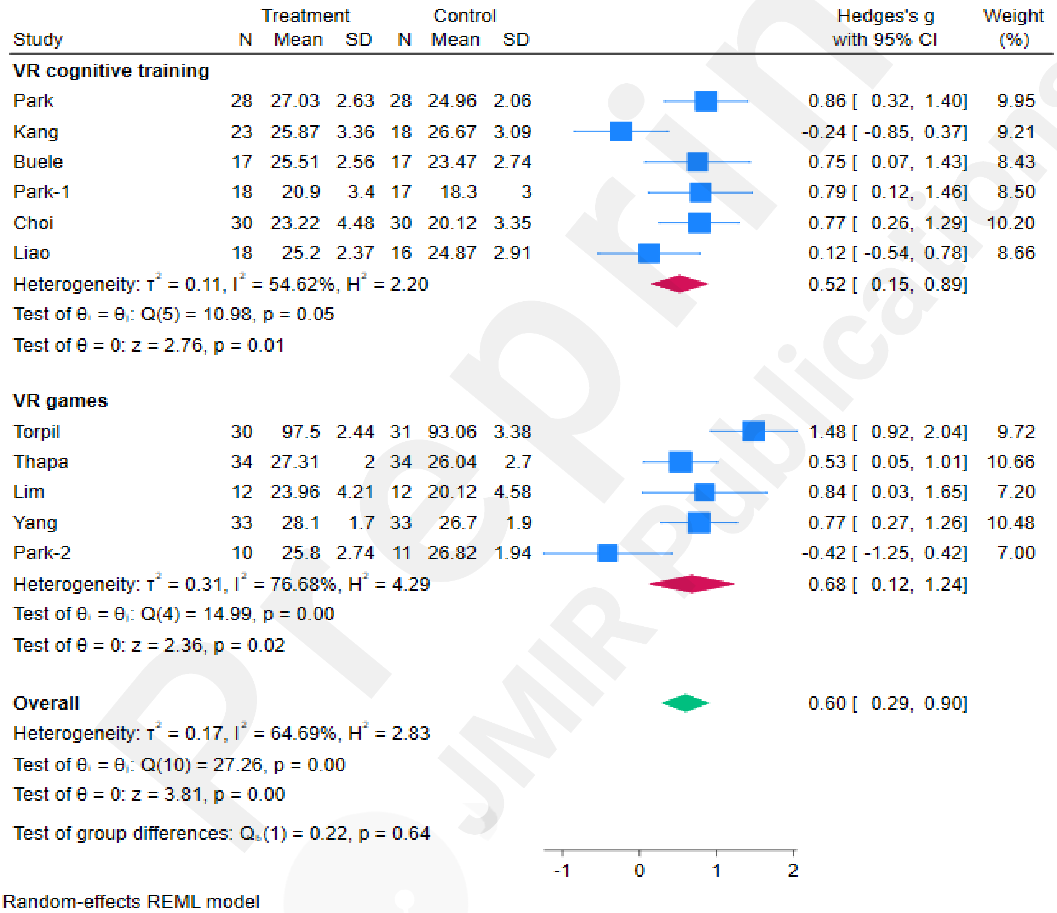
3.4.1 The effect size on cognitive rehabilitation

A total of 11 studies involving 500 MCI patients reported on the effects of VR technology based interventions on cognitive rehabilitation at postintervention time points (range 4~12 weeks) compared with conventional control conditions [Fig. 3 (Buele et al., 2024; Choi & Lee, 2019; Kang et al., 2021; Liao et al., 2020; Lim et al., 2023; Park, 2022; J. H. Park et al., 2020; J. S. Park et al., 2020; Thapa et al., 2020;

Torpil et al., 2021; Yang et al., 2022)].

The I² between the included studies was >50%, thus a random-effects model was employed to assess the effect size. The research indicates that VR-based therapy has a significant positive impact on cognitive rehabilitation in individuals with MCI (Hedges's g= 0.6, 95% *CI* 0.29 to 0.90, $p < 0.05$). The highest and lowest effect sizes were related to the study of Torpil(Torpil et al., 2021) and Liao(Liao et al., 2020), respectively (Fig. 3).

Based on Cohen's d standardized effect size, this effect size is medium(Fox et al., 2014). Also, VR games (Hedges's g = 0.68, 95% *CI*: 0.12 to 1.24, $p = 0.02$) have been demonstrated to improve cognitive disorders more effectively than cognitive training



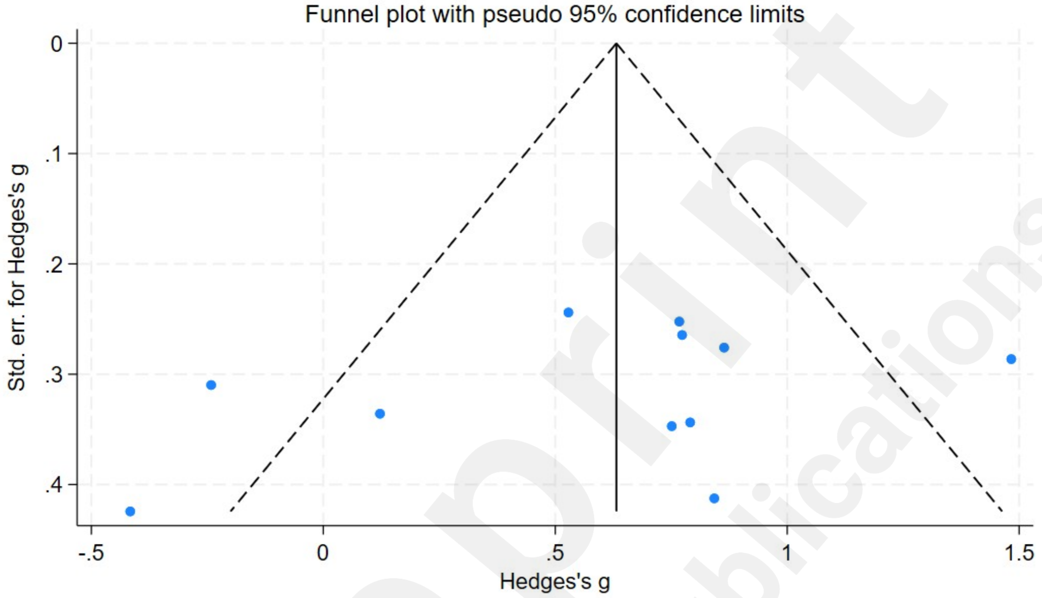
(Hedges's g = 0.52, 95% CI: 0.15 to 0.89, $p = 0.05$).

Figure 3. The forest map shows the efficacy of VR-based cognitive training and games on cognition in MCI patients.

3.4.2 Publication bias

The funnel plot (Fig. 4) illustrates the absence of publication bias in the studies. Moreover, the result of the Egger's regression test was (t = -1.07, p = 0.31). This shows there is no publication bias.

Figure 4. Publication bias of the included articles.



3.4.3 Meta-regression analysis

The effect sizes obtained from the random effects model were not found to be statistically significant for duration of intervention, blind implementation, type of VR intervention and result measure characteristics.(p > 0.05) (Table 2). This means that these variables have little effect on the results of cognitive rehabilitation studies in MCI patients through virtual reality. However, the effect size of VR immersion level obtained from the random effects model (coefficient β =0.834 > 0, 95% *CI*: 0.212 to 1.485, P < 0.05) is statistically significant and positively correlated with the effect size —— that is, the effect size increases by 0.834 on average for each unit increase in VR immersion level (e.g., from "low" to "medium", "medium" to "high") (Table 2).

Table 2. Effect sizes for separate meta-analyses on moderator variables

Covariates	Coefficient	Standard error	95% *CI*	*p*
Duration of intervention	−0.446	0.212	(−0.992, 0.099)	0.089
Blind implementation	0.891	0.392	(−0.118, 1.900)	0.072
Immersive level	0.834	0.242	(0.211, 1.457)	0.018

Type of VR intervention	0.361	0.216	(−0.193, 0.915)	0.154
Result measure characteristics	0.075	0.127	(−0.251, 0.401)	0.581

4 Discussion

The present systematic review and meta-analysis specifically focuses on the efficacy of VR-based cognitive training and games in patients with MCI, providing targeted insights into this critical transitional stage between normal aging and dementia. The findings indicate that both VR-based cognitive training and games exert significant positive effects on cognitive rehabilitation in MCI patients, with a medium overall effect size (Hedges's g = 0.60, $p < 0.05$). Subgroup analysis further reveals that VR games (Hedges's g = 0.68) yield a slightly larger effect size than VR cognitive training (Hedges's g = 0.52), though the difference is not statistically significant (p = 0.64). Additionally, meta-regression identifies VR immersion level as a key moderator of intervention efficacy, highlighting its potential role in optimizing therapeutic outcomes.

The positive effect of VR intervention on cognitive rehabilitation in MCI patients may be attributed to the unique pathophysiological characteristics of MCI(Petersen & Negash, 2008). Unlike advanced dementia, MCI patients retain partial cognitive plasticity and daily functional abilities, making them more responsive to targeted cognitive stimulation(Petersen et al., 1999). Virtual reality technology creates a simulated environment that closely resembles real-life scenarios through multi-sensory integration (visual, auditory, and tactile feedback) and real-time interactive tasks(Baus & Bouchard, 2014; Moreno et al., 2019). This environment activates neural networks associated with memory, attention, and executive functions, thereby enhancing cognitive functions in patients with MCI. As our findings suggest, which lend support to the potential mechanisms underlying the efficacy of VR interventions in patients with MCI, accumulating evidence from a range of studies(Lee et al., 2018; Maeng et al., 2021; Zhao et al., 2020; Zhu et al., 2022) has also indicated that VR-based cognitive training and games can enhance cognitive abilities in individuals with MCI. Notably, the applicability of VR interventions extends beyond MCI, as shown in related research: Yang et al.'s study(Yang et al., 2014) revealed the potential benefits of virtual reality training for enhancing cognitive performance in brain tumor patients, and Kim et al.'s study (Kim et al., 2011) illustrated that virtual reality training combined with computer-based cognitive rehabilitation therapy offers additional benefits for cognitive impairment in stroke patients. These findings collectively highlight the broader efficacy of VR-based interventions in targeting cognitive dysfunction across diverse patient populations, with MCI patients, due to their retained cognitive plasticity, standing to gain particular advantages.

Our findings demonstrate that, compared with VR-based cognitive training, VR-based games hold greater advantages in cognitive rehabilitation, and their superiority in effect size may stem from their inherent dual nature of “entertainment-therapy”. By incorporating narrative-driven tasks, reward mechanisms, and dynamic difficulty adjustments (e.g., Superkick, Air Challenge, Fireworks Party), these games sustain patient engagement and motivation, addressing the common issue of poor adherence in traditional cognitive training(J. H. Park et al., 2020; Torpil et al., 2021). Muñoz et al.(Muñoz et al., 2022)conducted a study demonstrating that the gamified design of VR game-based tasks, which integrates motor and cognitive stimulation, significantly enhances user engagement and promotes the maintenance of cognitive functions. Yanguas et al.’s study(Rodrigo-Yanguas et al., 2021) similarly exhibited cognitive function improvement through the utilization of VR-based games. In contrast, VR cognitive training, which often focuses on structured tasks (e.g., spatial memory training, simulated shopping), may have more targeted effects but lacks the intrinsic motivational pull of games—though this difference was not statistically significant in our analysis, possibly due to the small sample size of included studies.

A notable finding emerging from this meta-regression is that the level of VR immersion—ranging from low-cost head-mounted displays to fully immersive systems—significantly moderates intervention efficacy (β = 0.834, p < 0.05). Higher immersion likely strengthens the sense of "presence" in the virtual environment, reducing distractions from the physical surroundings and deepening cognitive engagement. Soh et al.’s research (Soh et al., 2021)further corroborated the interference-shielding effect of immersion in remote virtual rehabilitation. By synchronizing visual, auditory, and tactile feedback, virtual reality constructs a self-consistent virtual ecosystem, which enables participants’ perceptual systems to prioritize the processing of information from the virtual environment, thereby mitigating distractions from the physical surroundings. Moreover, Torpil et al.’s study(Torpil et al., 2021), which used a high-immersion VR system, reported the largest effect size, suggesting that immersive experiences may better activate hippocampal and prefrontal cortex regions critical for memory and executive function in MCI patients. This observation underscores the critical role of both hardware and software design in VR-based interventions. Future investigations should place priority on refining immersive experiences—for instance, by incorporating haptic feedback and 360° visual rendering techniques—to optimize the effectiveness of cognitive stimulation, while safeguarding the safety and comfort of elderly individuals with mild cognitive impairment.

Notably, the moderate heterogeneity observed in the study (I^2 = 64.69%) underscores the necessity of developing standardized intervention protocols. The findings of Moulaei et al. (Moulaei et al., 2023)further emphasize the importance of considering specific design elements—such as the immersive characteristics of virtual reality environments—for achieving positive outcomes. Additionally, factors including treatment duration, frequency, and task difficulty should be individually adjusted based on patients' baseline cognitive functions and physical conditions. Research by Samarasinghe et al.(Samarasinghe et al., 2017), which focuses on the design of virtual reality games for patients with Alzheimer’s disease, highlights the significance of customizing interventions to meet the unique cognitive needs of patients. Collectively, these findings reinforce the critical role of deliberate design in maximizing the effectiveness of virtual reality interventions in the field of cognitive health, thereby optimizing potential benefits.

5 Limitations

This study has several limitations. First, the included studies are geographically skewed, with 8 of 11 conducted in South Korea, potentially limiting the generalizability of findings to other cultural contexts. Second, the definition of “VR immersion level” varied across studies, making it challenging to directly compare hardware efficacy. Third, none of the selected articles were double-blind, and therefore possible bias may exist.

6 Conclusions

This systematic review and meta-analysis included 11 RCTs with the aim of evaluating the effectiveness of VR-based cognitive training and games in improving cognitive function among patients with MCI. The results demonstrated that the patients’ cognitive function exhibited a significant improvement with statistical significance. Notably, the level of immersion constitutes a key factor in optimizing outcomes. Optimizing the immersive experience requires not only technological upgrades but also balancing the depth of immersion with individual adaptability, thereby more effectively facilitating deep emotional engagement and further strengthening the consolidation of cognitive gains. These findings highlight the potential of virtual reality as a valuable tool in cognitive rehabilitation strategies, laying a foundation for designing targeted, engaging, and effective VR interventions, as well as providing more comprehensive insights into the therapeutic application of enhancing cognition in clinical settings.

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Declarations

Consent to publish

Informed consent was obtained from all individual participants included in the study. All authors agree with the release of this study.

Conflicts of interest

The authors declare no conflict of interest. The authors have no relevant financial or non-financial interests to disclose.

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Supplementary Files