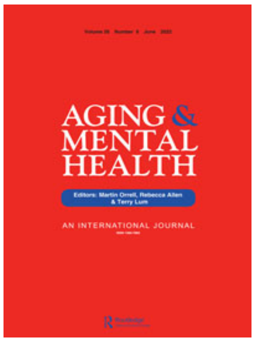

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REVIEW

The effect of virtual reality on executive function in older adults with mild cognitive impairment: a systematic review and meta-analysis

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ABSTRACT

Objectives: This review aimed to summarize the currently available premium evidence to determine the effect of virtual reality (VR) on executive function (EF) in older adults with mild cognitive impairment (MCI), and to detect what level of immersive VR would be the most beneficial.
Method: Five electronic databases, namely, PubMed, Embase, PsycINFO, CINAHL, and Cochrane Library were searched. Our research team screened the studies and extracted data according to our inclusion criteria. The methodological quality of each study was rated using the PEDro scale. When three or more studies reported the same outcome, a meta-analysis was conducted using Review Manager 5.4.1.
Results: Finally, 14 randomized controlled trials with a total of 518 participants were included. VR training had an overall positive effect on cognitive flexibility, global cognitive function, attention, and short-term memory compared to the control groups. Additionally, semi-immersive VR was more effective in improving cognitive flexibility compared to the other two types of VR. The application of non-immersive level of VR had a significant effect on global cognitive function, attention, short-term memory, and cognitive flexibility.
Conclusion: VR may be effective in improving EF in older adults with MCI. However, the level of immersive VR that would be the most beneficial on EF still needs to be investigated with a greater number of well-designed studies.

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KEYWORDS
Virtual reality; executive function; mild cognitive impairment; cognitive functioning

Introduction

Dementia is considered to be a syndrome rather than a particular disease. It is mainly characterized by cognitive decline, and has a significant adverse impact on independent daily functional activities (Gale et al., 2018). It is estimated that by 2030, the number of people with dementia worldwide will reach 78 million (World Health Organization, 2021), which will place a heavy burden on global public health. The risk of acquiring dementia rises as an individual becomes older, especially once beyond the age of 53 (Tisher & Salardini, 2019). Mild cognitive impairment (MCI), a transitional stage of cognitive impairment lying between normally aging individuals and people with dementia (Tangalos & Petersen, 2018), may evolve into dementia within three years, with an incidence of up to 46% (Pal et al., 2018). As MCI is a progressive disease, early detection and treatment are necessary to slow down the progression of dementia (Knopman & Petersen, 2014).

Executive function (EF), a complex process involving multiple skills like working memory (WM), inhibition control, and cognitive flexibility (Blair, 2017; Diamond, 2013), plays an important role in our functional independence. The inhibition control, which is commonly evaluated by Stroop task test (Meier et al., 2020), allows subjects to set priorities and resist impulsive actions or responses; WM refers to information reprocessing, and is commonly measured by a digit span test (Diamond, 2013); cognitive flexibility typically involves set-shifting or task switching measured by the Wisconsin Card Sorting Inspired Task (WCST) (Dajani & Uddin, 2015). The diverse skills mentioned above are highly interrelated. People with executive dysfunction will have problems with planning, problem-solving, organization, and their information processing speed. One study has reported that executive dysfunction becomes more pronounced with normal aging as it progresses to MCI (Kirova et al., 2015). A cross-sectional trial concluded that individuals at an early stage of MCI showed poorer performance regarding EF than their healthy counterparts (Seo et al., 2016). Moreover, early dementia can be characterized by the poor performance of WM (Kirova et al., 2015). In that case, the decline in EF may lead to a decline in cognitive function in older people with MCI (Kirova et al., 2015).

Virtual reality (VR) - a computer simulation of a real or imagined three-dimensional (3-D) environment, which allows users to have the same experiences they would get in a similar real situation (D'Cunha et al., 2019), has stimulated the interest of researchers and clinicians since its first use in 1994 (Diaz-Perez & Florez-Lozano, 2018). Compared to traditional pen-and-paper training, it is symbolized as a systematic and controllable intervention that makes use of data visualization and provides immediate feedback based on the participants' performance (Charles et al., 2020). VR is usually categorized into three types according to the form of connection with the physical world, including non-immersive, semi-immersive, and full-immersive VR (An & Park, 2018; Thapa et al., 2020). The VR system consisting of a

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modern 3-D head-mounted display and wireless hand controllers is considered to be full-immersive VR (Strong, 2020); semi-immersive VR comprises a high performance graphics computing system which includes a large screen monitor, a large screen projector system and multiple television projection systems, such as the BTS Nirvana interaction system (Maggio et al., 2018); non-immersive VR refers to a virtual environment delivered via a standard computer monitor or television and controlled by operating the mouse or keyboard (Strong, 2020).

Over the past several years, trials have investigated the effect of VR on EF, but inconsistent findings have been reported. Positive statistically significant differences on EF between a VR group and a control group have been reported in some trials (Liao et al., 2019; J. S. Park et al., 2020; Thapa et al., 2020), whereas no significant differences were reported in other studies (Maggio et al., 2018; Mrakic-Sposta et al., 2018). Additionally, as all the articles mentioned above only focus on the overview of EF rather than detailed descriptions of the effect of VR on each domain of EF, like WM, inhibition control, and cognitive flexibility. Consequently, a precise description of the effect of VR on EF in older adults with MCI has not been established. Furthermore, a deeper immersion leads to a greater presence of a virtual environment (Strong, 2020), which may attract the participants' attention and result in more interaction with the VR training programs contributing to a better training result. However, so far, there has been no evidence that proves the effect different immersive levels have on improving EF. Therefore, this review aimed to systematically determine the effect of VR on EF in older adults with MCI, and to detect what level of immersive VR would have the greatest effect on EF in older adults with MCI.

Methods

Database searches and keywords search strategy

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement guidelines used extensively in health care interventions (Liberati et al., 2009) in November 2020. Five electronic databases, namely, PubMed, Cochrane Library, PsycINFO, CINAHL and Embase, were searched using the terms 'virtual reality', 'executive function', and 'mild cognitive impairment', combined with Boolean characters 'AND' and 'OR'. The details of the keywords search strategy are presented in **Appendix 1**. Additionally, a backward search was conducted by looking up the reference lists of eligible studies.

Study eligibility

Inclusion criteria

- Participants: Older adults (>65 years old) diagnosed with MCI by neurological examinations or neuropsychological assessments;
- Intervention: VR;
- Control group: inactive controls included educational programs or no intervention; active controls included traditional rehabilitation or any other type of physical exercise without a VR component;
- Outcome measurements:
- Primary outcomes: we included global EF and individual domains of EF with representative psychometric tasks used to assess them.
- (1) global EF: assessed by a Frontal Assessment Battery (FAB) (Hurtado-Pomares et al., 2018); (2) WM: assessed by digit span test-backward (DST-B) (Diamond, 2013) or an N-back test (Owen et al., 2005); (3) inhibition control: assessed by a Stroop task (MacLeod, 1991) or a go/no-go task (Cragg & Nation, 2008); (4) cognitive flexibility: assessed by a Wisconsin Card Sorting Test (WCST) or a Trail Making Test-B(TMT-B) (Arnett & Labovitz, 1995).
- Secondary outcomes: as EF is a component of cognitive function that involves attention and memory, we have also included them in the analysis.
- (1) global cognitive function: assessed by the MMSE or MoCA; (2) attention: assessed by a Trail Making Test-A (TMT-A) (Bossers et al., 2012); (3) memory: assessed by a digit span test-forward (DST-F) (Diamond, 2013);
- Study design: only randomized controlled trials (RCT) were included in our review, given that the evidence based on an RCT is considered to be of the highest quality and have the lowest risk of bias (Bhide et al., 2018);
- Publication date: from January 1, 2010 to November 30, 2020;

Exclusion criteria

- Participants: healthy older adults, individuals with schizophrenia or depression;
- Intervention: VR used for assessment; VR used for the control group;
- Outcome measurement: no specific assessment of EF;

Study design: studies other than RCT, such as reviews, case–control studies, and case reports.

Data extraction and quality assessment

The author (YD) screened the title, abstract, and full-text of each paper according to the inclusion criteria, and extracted the following information: the first author's last name, publication year, the contents of the treatment, and the EF assessment tools used. All of the information was confirmed by the second author (LX). If any controversy arose, the third author was consulted. All of the extracted data are presented in Table 1. The methodological quality of each study was assessed using the Physiotherapy Evidence Database (PEDro) scale (Cashin & McAuley, 2020), resulting in a score ranging from 1 to 10. The research team then reviewed each item of the PEDro scale with reference to the PEDro official website to perform a scrutinized rating of each paper, with a higher rating indicating a better methodological quality (low quality: 1–3; fair quality: 4–5; good quality: 6–8; excellent quality: 9–10).

Data synthesis

The meta-analysis was performed using Review Manager 5.4.1. The post-training data with the mean and standard deviation (SD) were extracted to conduct the meta-analysis when more than three studies reported the same outcome. For continuous data, the effect size was reported as the mean deviation (MD) or standard mean difference (SMD), with 95% confidence intervals (CI). A P value ≤ 0.05 was considered statistically significant. Furthermore, I^2 was used to measure the statistical heterogeneity. If I^2 was above 50%, the random-effects model was selected; otherwise, the fixed-effects model was selected. In addition, a subgroup analysis was performed to evaluate the effect of the different levels of immersive VR on EF.

Table 1. Characteristics of studies.

Authors, year	VR immersive level	Target domains of VR training	Control group	Sessions	Sample size and age (Mean ± SD)	Executive function assessment scale
Thapa et al., 2020	Full-immersive	VRG: NR	CG: educational program on general health care	VRG: 100mins × 3/ wk × 8wks CG: 30~50 mins × 1/wk × 8wks	VRG: n = 34 72.6 ± 5.4 CG: n = 34 72.7 ± 5.6	TMT-A & B, SDST
Park et al., 2020a	Non-immersive	VRG: attention, memory, problem-solving, executive function	CG: conventional rehabilitation	30 mins × 5/wk × 6wks	VRG: n = 20 75.8 ± 8.5 CG: n = 20 77.2 ± 7.2	TMT-A & B, DST-B & F
Park et al., 2020b	Full-immersive	VRG: attention, processing speed, executive function, Memory	CG: no training	30 mins × 2/wk × 12wks	VRG: n = 10 71.8 ± 6.61 CG: n = 11 69.45 ± 7.45	DST-B & F, Stroop test color, Stroop test word, Word fluency animal
Maier et al., 2020	Non-immersive	VRG: attention, memory, visuo-spatial short-memory, divided attention	CG: active control, 30 individual cognitive tasks	30 mins × 5/wk × 6wks	VRG: n = 19 63.63 ± 6.73 CG: n = 19 67.21 ± 6.45	TMT-A & B, WAIS C, FAB
Liao et al., 2019	Full-immersive	VRG: executive function	CG: combined physical and cognitive training	60 mins × 3/wk × 12wks	VRG: n = 21 75.5 ± 5.2 CG: n = 21 73.1 ± 6.8	TMT-A & B, SCWT-numbers, SCWT-time
Mrakic-Sposta et al., 2018	Semi-immersive	VRG: memory, attention, orientation, executive function	CG: no training	40 ~ 45 mins × 3/wk × 6wks	VRG: n = 5 72.0 ± 5.15 CG: n = 5 74.60 ± 6.43	FAB, TMT-A, VFT
Maggio et al., 2018	Semi-immersive	VRG: attention, spatiotemporal orientation, memory, language, executive function	CG: active group with therapist	60 mins × 3/wk × 6wks	VRG: n = 10 69.9 ± 6.3 CG: n = 10 68.9 ± 10.05	FAB, WEIGL
Monteiro-Junior et al., 2017	Semi-immersive	VRG: decision making, mind flexibility, inhibitory control, working memory	CG: active group the same movements as VRG	30 ~ 45 mins/session × 24 sessions	VRG: n = 10 86 ± 7 CG: n = 9 86 ± 5	DST-F & B, VFT
Faria et al., 2016	Non-immersive	VRG: visuo-spatial orientation, attention, memory and executive functions (problem resolution, reasoning and planning)	CG: conventional cognitive training	20 mins × 12 times distributed from 4 to 6 weeks	VRG: n = 9 58 (48-71) CG: n = 9 53 (50.5-65.5)	TMT-A & B
Tarnanas et al., 2014	Semi-immersive	VRG: memory, attention, executive functions, navigation, spatial orientation and spatial memory	CG1: active control group CG2: non-contact control group	90 mins × 2/wk × 20wks	VRG: n = 39 70.5 ± 4.3 CG1: n = 39 69.7 ± 4.5 CG2: n = 36 70.9 ± 4.4	Stroop-test (color repetition), TMT-B, DST-F & B, Letter fluency
Hughes et al., 2014	Semi-immersive	VRG: NR	CG: healthy aging education program	90 mins × 1/wk × 24wks	VRG: n = 10 78.5 ± 7.1 CG: n = 10 76.2 ± 4.3	Tracking A & B
Kim et al., 2011	Semi-immersive	VRG: NR	CG: computer-assisted (CA) cognitive rehabilitation	VRG: 30mins × 3/wk × 4wks CA: 30mins × 2/wk × 4wks CG: 30mins × 5/wk × 4wks	VRG: n = 15 66.5 ± 11 CG: n = 13 62.0 ± 15.8	TMT-A, TOL, DST-F & B
Optale et al., 2010	Full-immersive	VRG: memory	CG: music therapy	Initial training phase: 30 mins × 3/wk × 12wks Booster training phase: 30 mins × 2/wk × 12wks	VRG: n = 18 78.5 ± 10.9 CG: n = 18 81.9 ± 5.0	PVF, DTPT, CET
Amjad et al., 2019	Semi-immersive	VRG: logic, physical, memory, reflexes, and math	CG: motion and stretching exercise	25 ~ 30 mins × 5/wk × 6wks	VRG = 22 CG = 22 No data about mean age	TMT-A & B

Note: VRG: Virtual reality group; CG: control group; mins: minutes; wk: week; wks: weeks; MMSE: Mini-Mental State Examination; MoCA: Montreal Cognitive Assessment; aMCI: amnestic Mild cognitive impairment; TMT-A & B: Trail Making Test A &B; SDST: Symbol digit substitution test; DST-F & B: Digit span test-forward & backward; WAIS C: WAIS Digit Symbol Coding; SCWT-numbers: Stroop Color and Word Test-numbers; SCWT-time: Stroop Color and Word Test-time; VFT: Verbal fluency test; WEIGL: Weigl test; CAMCI Total: Computerized Assessment of Mild Cognitive Impairment; PVF: Phonemic verbal fluency; DTP: Dual Task Performance Test; CET: Cognitive Estimation Test; NS: Not significant; NR: Not reported.

Results

Study selection

The initial search yielded a total of 180 records. After removing the duplicates, 143 articles were left for screening according to titles and abstracts. Of them, 25 articles were selected. After a further screening of the 25 articles, two of the studies were excluded because the full-text was inaccessible (Jprn, 2017; Park et al., 2018), while remaining nine studies (Appel et al., 2019; Hsieh et al., 2018; Jacoby et al., 2013; Liao et al., 2020; Maggio et al., 2020; Man et al., 2013; Mirelman et al., 2013; Mirza & Yaqoob, 2018; Zając-Lamparska et al., 2019) were excluded for not meeting the inclusion criteria. The detailed screening information is shown in Figure 1. Finally, 14 RCTs were found to be eligible for inclusion in this review.

Quality assessment (PEDro)

The PEDro scores for the included 14 RCTs ranged from four to eight. Seven studies (Amjad et al., 2019; Faria et al., 2016; Hughes et al., 2014; Maier et al., 2020; Monteiro-Junior et al., 2017; Mrakic-Sposta et al., 2018; J. H. Park et al., 2020) had a moderate methodological quality and seven studies (Kim et al., 2011; Liao et al., 2019; Maggio et al., 2018; Optale et al., 2010; J. S. Park et al., 2020; Tarnanas et al., 2014; Thapa et al., 2020) were of good quality. Overall, the methodological quality of these studies was ranked from moderate to good, as presented in Table 2.

Characteristics of the included studies

The included 14 studies contain a total of 518 participants. Among the studies, there was a considerable difference in sample size, ranging from 10 to 114, with 37 being the average sample size. The total duration of the training was from four to 60 h. Except for one study (Amjad et al., 2019) that did not report information on age, the mean age of all the participants in the other 13 studies was 74.7 years old. More detailed information about the characteristics of the included studies is shown in Table 3.

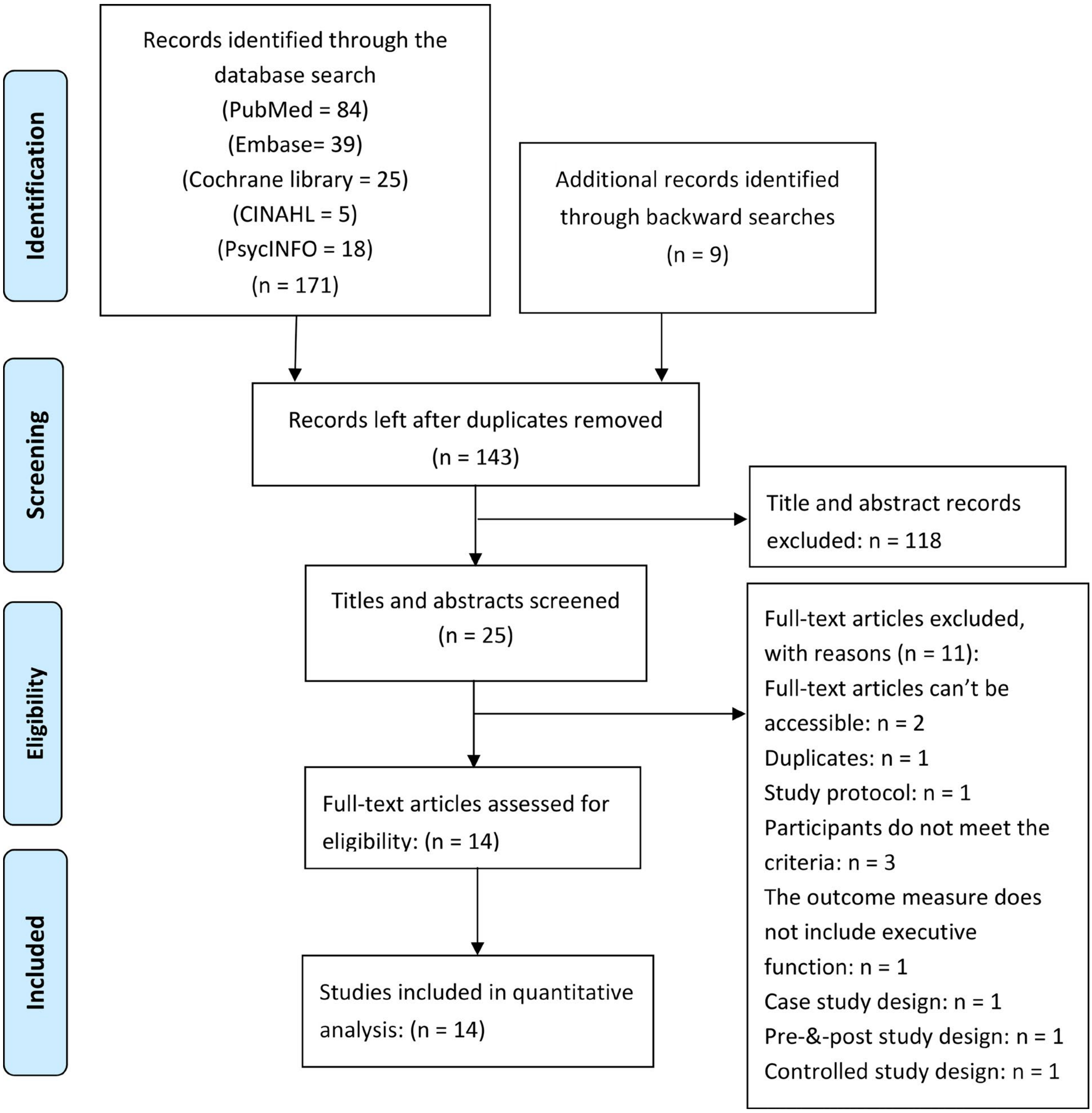

Figure 1. PRISMA flow diagram.

Table 2. PEDro score of included studies.

Included studies	Eligibility criteria	Random allocation	Concealed allocation	Group similar at baseline	Blinded subjects	Blinded therapist	Blinded assessors	Less than 15% dropouts	Intention to treat analysis	Between-group comparisons	Point measures and variability	PEDro scores
Thapa et al., 2020	√	√	×	√	×	×	×	√	√	√	√	6
Park et al., 2020 a	√	√	√	√	×	×	×	√	×	√	√	6
Park et al., 2020 b	√	√	×	√	×	×	×	√	×	√	√	5
Maier et al., 2020	√	√	×	√	×	×	√	×	×	√	√	5
Liao et al., 2019	√	√	√	√	×	×	√	×	×	√	√	6
Mrakic-Sposta et al., 2018	√	√	×	√	×	×	×	×	×	√	√	4
Maggio et al., 2018	√	√	×	√	×	√	√	√	√	√	√	8
Monteiro-Junior et al., 2017	√	√	×	×	×	×	×	√	×	√	√	4
Faria et al., 2016	√	√	×	√	×	×	×	√	×	√	√	5
Tarnanas et al., 2014	√	√	×	√	×	√	√	√	×	×	√	6
Hughes et al., 2014	√	√	×	√	×	×	×	√	×	√	√	5
Kim et al., 2011	√	√	×	√	×	×	×	√	√	√	√	6
Optale et al., 2010	√	√	×	√	×	×	×	√	√	√	√	6
Amjad et al., 2019	√	√	×	√	×	×	×	√	×	√	√	5

Table 3. Summarized characteristics of included studies.

Characteristics	Trials n (%)	References
Sample size		
≤20	5 (36)	(Faria et al., 2016; Hughes et al., 2014; Maggio et al., 2018; Monteiro-Junior et al., 2017; Mrakic-Sposta et al., 2018)
20 < *n* < 40	4 (29)	(Kim et al., 2011; Maier et al., 2020; Optale et al., 2010; J. H. Park et al., 2020)
40 ≤	5 (36)	(Amjad et al., 2019; Liao et al., 2019; J. S. Park et al., 2020; Tarnanas et al., 2014; Thapa et al., 2020)
Duration		
≤10 h	3 (21)	(Faria et al., 2016; Kim et al., 2011; Optale et al., 2010)
10 < *n* < 20	7 (50)	(Amjad et al., 2019; Maggio et al., 2018; Maier et al., 2020; Monteiro-Junior et al., 2017; Mrakic-Sposta et al., 2018; J. H. Park et al., 2020; J. S. Park et al., 2020)
20≤	4 (29)	(Hughes et al., 2014; Liao et al., 2019; Tarnanas et al., 2014; Thapa et al., 2020)
Age (years old)		
≤70	4 (29)	(Faria et al., 2016; Kim et al., 2011; Maggio et al., 2018; Maier et al., 2020)
70 < *n* < 80	7 (50)	(Hughes et al., 2014; Liao et al., 2019; Mrakic-Sposta et al., 2018; J. H. Park et al., 2020; J. S. Park et al., 2020; Tarnanas et al., 2014; Thapa et al., 2020)
80≤	2 (14)	(Monteiro-Junior et al., 2017; Optale et al., 2010)
Not reported	1 (7)	(Amjad et al., 2019)
Immersive level		
Full-immersive	4 (29)	(Liao et al., 2019; Optale et al., 2010; J. H. Park et al., 2020; Thapa et al., 2020)
Semi-immersive	7 (50)	(Amjad et al., 2019; Hughes et al., 2014; Kim et al., 2011; Maggio et al., 2018; Monteiro-Junior et al., 2017; Mrakic-Sposta et al., 2018; Tarnanas et al., 2014)
Non-immersive	3 (21)	(Faria et al., 2016; Maier et al., 2020; J. S. Park et al., 2020)
Content of VR training		
VR-based physical and cognitive training	3 (21)	(Amjad et al., 2019; Liao et al., 2019; J. S. Park et al., 2020)
VR-based cognitive training	11 (79)	(Faria et al., 2016; Hughes et al., 2014; Kim et al., 2011; Maggio et al., 2018; Maier et al., 2020; Monteiro-Junior et al., 2017; Mrakic-Sposta et al., 2018; Optale et al., 2010; J. H. Park et al., 2020; Tarnanas et al., 2014; Thapa et al., 2020)

Note: Percentages may not sum to 100, due to the effects of rounding.

Effect of VR on EF

Global EF

Three studies (Maggio et al., 2018; Maier et al., 2020; Mrakic-Sposta et al., 2018) assessed the global EF using the FAB scale. Only one study using semi-immersive VR reported a statistically significant improvement ($P < 0.01$) compared to its control group (Maggio et al., 2018). However, the effect size could not be determined because of insufficient data.

Working memory (WM)

WM was measured by the DST-B scale in five studies. A meta-analysis was conducted on four studies (Kim et al., 2011; J. H. Park et al., 2020; J. S. Park et al., 2020; Tarnanas et al., 2014), while one study (Monteiro-Junior et al., 2017) was excluded as it lacked post-training data. From the forest plot, it can be seen there was no overall statistically significant difference on WM (MD = 0.20, 95% CI [-0.10, 0.50], $P = 0.20$, Figure 2) between the intervention and control groups.

Inhibition control

Three studies (Liao et al., 2019; J. H. Park et al., 2020; Tarnanas et al., 2014) have assessed the inhibition control using the Stroop Color and Word Test (SCWT), but the results did not reveal a significant difference between the intervention and control groups in those studies.

Cognitive flexibility

The use of a Trail Making Test-B (TMT-B) to assess cognitive flexibility was reported in seven of the studies (Amjad et al., 2019; Faria et al., 2016; Liao et al., 2019; Maier et al., 2020; J. S. Park et al., 2020; Tarnanas et al., 2014; Thapa et al., 2020), involving a total of 235 participants. Two studies (Faria et al., 2016; Maier et al., 2020) were excluded from the meta-analysis because of missing data and poor data. Finally, five studies were included in the meta-analysis. A significant positive difference can be observed between the intervention and control groups (MD = −42.48, 95% CI [-84.03, −0.92], $P = 0.05$, $I^2 = 99\%$, Figure 3).

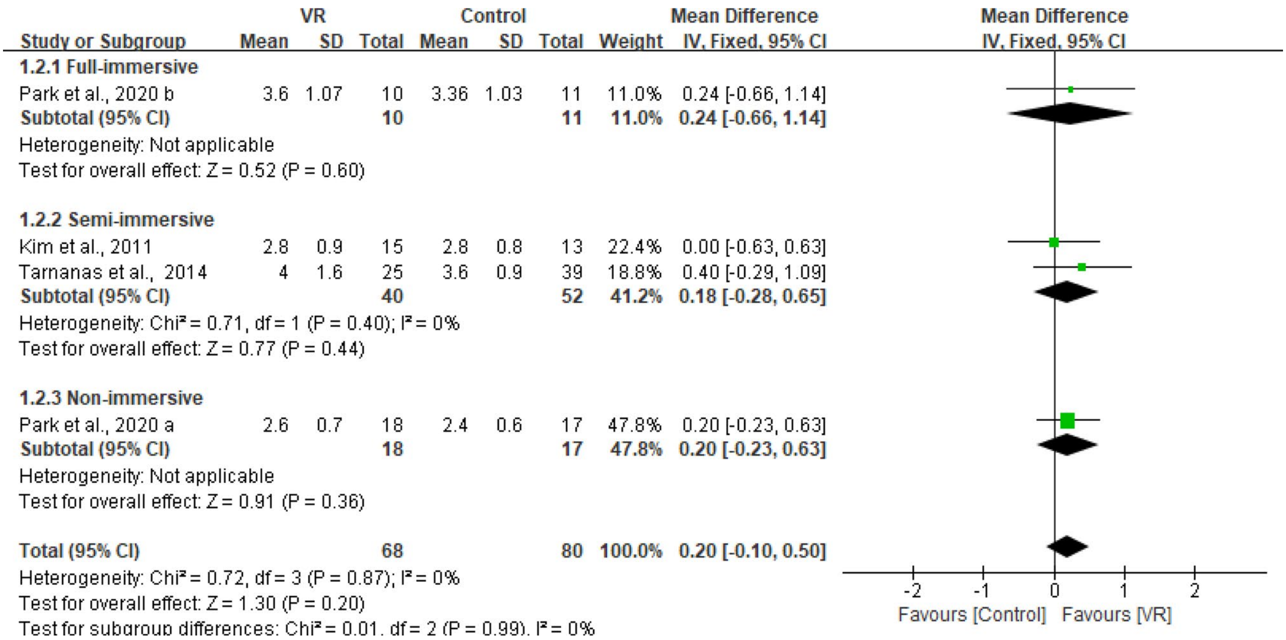

Figure 2. The effect of virtual reality on working memory.

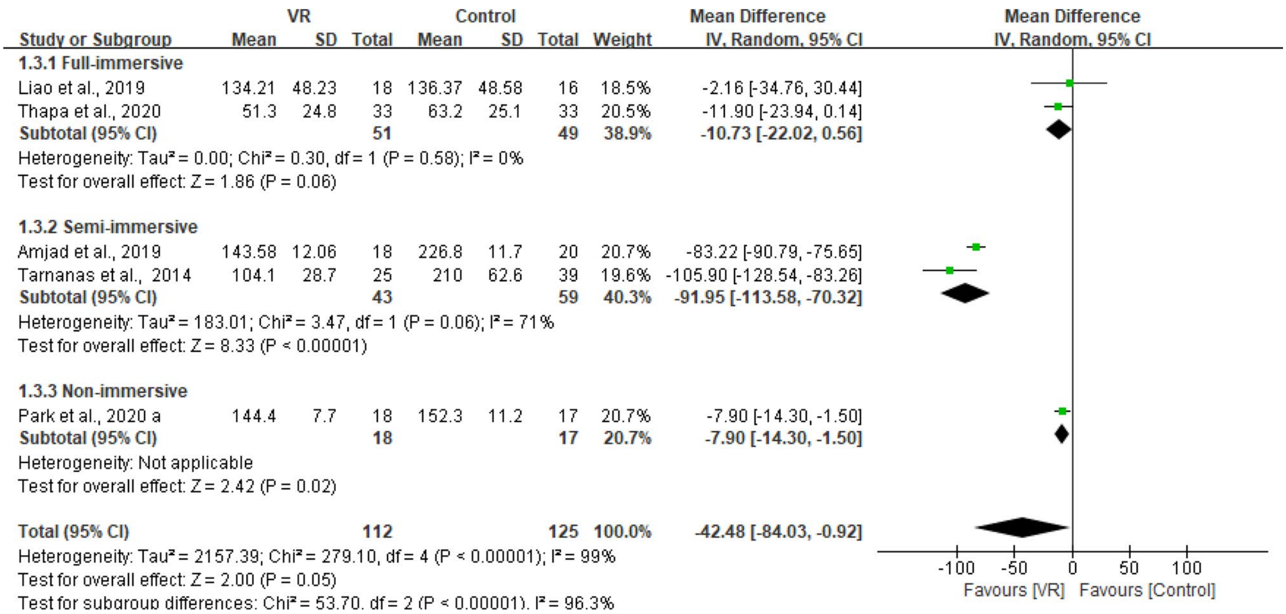

Figure 3. The effect of virtual reality on cognitive flexibility.

Global cognitive function

All 14 studies except one (Liao et al., 2019) tested the effect of VR-based training on global cognitive function in individuals with MCI. However, we extracted data from only 10 of the studies with a total of 320 participants due to the lack of well-presented data for the mean and SD for the remaining three studies (Maier et al., 2020; Monteiro-Junior et al., 2017; Optale et al., 2010). According to the meta-analysis, VR training resulted in an overall significant improvement on global cognitive function compared with the control group (SMD = 0.63, 95% CI [0.06, 1.20], $P = 0.03$, $I^2 = 81\%$; Figure 4).

Attention

Seven of the studies with a total of 229 participants (Amjad et al., 2019; Faria et al., 2016; Kim et al., 2011; Liao et al., 2019; Mrakic-Sposta et al., 2018; J. S. Park et al., 2020; Thapa et al., 2020) were included in the meta-analysis which assessed attention using the TMT-A scale. However, one study (Mrakic-Sposta et al., 2018) was excluded from the meta-analysis due to the lack of post-training data. From the forest plot, it could be seen that there was an overall significant positive difference between the experimental and control groups (MD = −12.31, 95% CI [-24.59, −0.04], $P = 0.05$, $I^2 = 94\%$, Figure 5).

Short-term memory

Short-term memory was evaluated by the DST-F scale in five of the studies. However, a meta-analysis was conducted with four out of the five studies (Kim et al., 2011; J. H. Park et al., 2020; J. S. Park et al., 2020; Tarnanas et al., 2014), while one study (Monteiro-Junior et al., 2017) was excluded as it lacked post-training data. The forest plot showed there was an overall significant positive difference in short-term memory (MD =

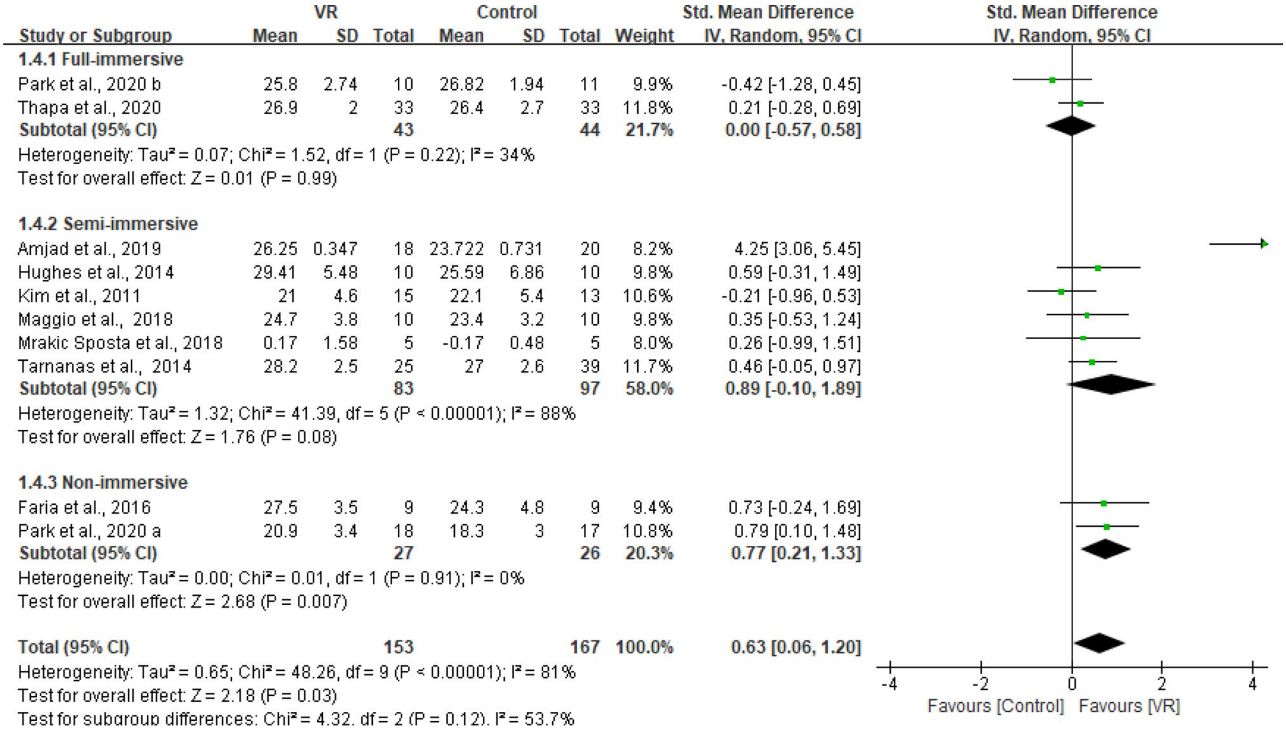

Figure 4. The effect of virtual reality on global cognitive function.

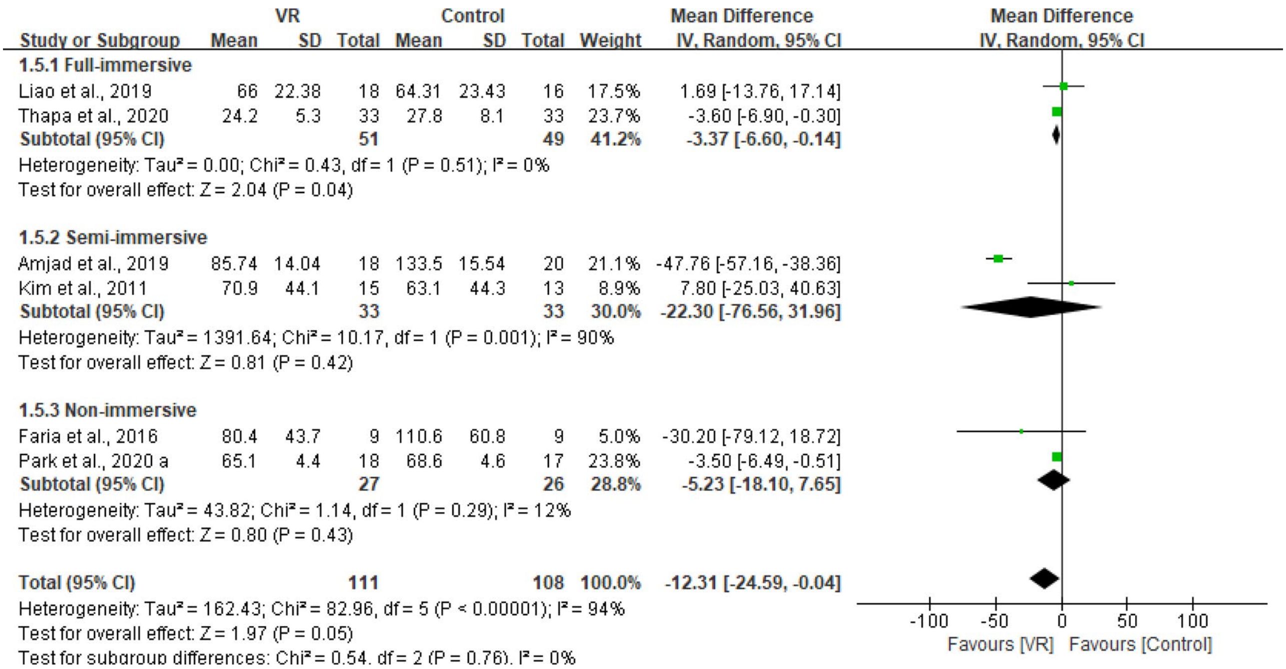

Figure 5. The effect of virtual reality on attention.

0.64, 95% CI [0.25, 1.03], $P = 0.001$, Figure 6) between the intervention and control groups.

Effect of the type of VR

Subgroup analysis based on the level of immersive VR were performed on cognitive flexibility, WM, global cognitive function, attention, and short-term memory. No significant differences among the subgroups were found for most of these outcomes, except for cognitive flexibility ($P < 0.01$). However, a greater number of significant positive results for cognitive flexibility, global cognitive function, and short-term memory were achieved in the subgroup using non-immersive VR compared to the subgroups using the other two types of VR.

Compliance and attrition factors

Dropouts were reported in eight studies (Amjad et al., 2019; Hughes et al., 2014; Liao et al., 2019; Maier et al., 2020; Mrakic-Sposta et al., 2018; Optale et al., 2010; J. S. Park et al., 2020; Tarnanas et al., 2014; Thapa et al., 2020), and all participants completed all the assessments and interventions in the remaining six studies. The dropout rate ranged from 3% to 20% in the eight studies; in three (Liao et al., 2019; Maier et al., 2020; Mrakic-Sposta et al., 2018) of them, the dropout rate was over

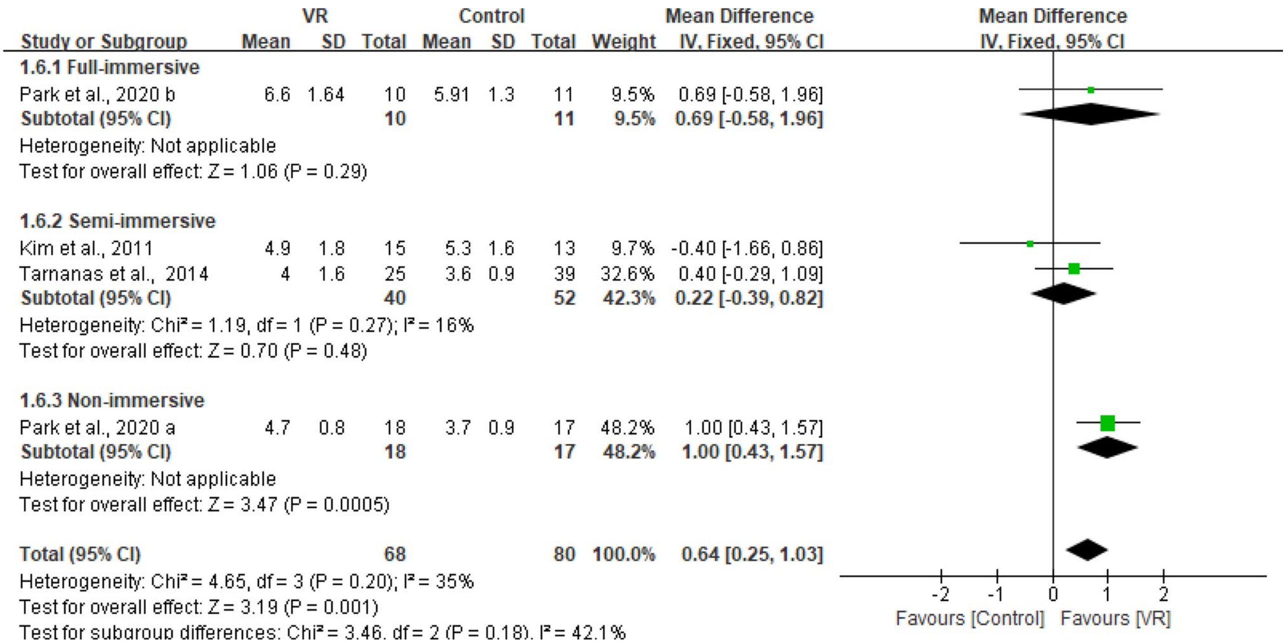

Figure 6. The effect of virtual reality on short-term memory.

15%, mainly because of loss contact, hospitalization, dissatisfaction with the VR training or technical problems.

Discussion

This review aimed to determine the effect of VR on EF in older adults with MCI. According to the results, VR had a significant positive overall effect on cognitive flexibility, global cognitive function, attention, and short-term memory, compared to the control groups, offering a general conclusion that VR training may have a positive effect on EF in older adults with MCI.

Current work indicates that VR has a significant positive effect on cognitive flexibility, but no significant effect on WM and inhibition control. After looking at an analysis of the insignificant results, it seems that the heterogeneity between the EF outcome measurements and the training content of the VR program may have led to the negative results. For example, the content of the VR in five of the studies (Kim et al., 2011; Monteiro-Junior et al., 2017; J. H. Park et al., 2020; J. S. Park et al., 2020; Tarnanas et al., 2014) that reported the outcome measures of WM, such as driving (J. S. Park et al., 2020), making fruit cocktails (J. H. Park et al., 2020), and playing soccer (Kim et al., 2011), tended to focus on more on short-term memory and attention than on WM, the ability to store and process information (Baddeley, 1992). A similar mismatch between test and training content occurred regarding inhibition control. Therefore, an optimized strategy would be to orient training programs toward training goals. The following two reasons may explain the significant effect of VR on cognitive flexibility. Firstly, cognitive flexibility refers to the ability to switch flexibly between different tasks. Accordingly, a VR program will commonly contain two or more tasks specifically requiring cognitive flexibility. In addition, cognitive flexibility is a high-level cognitive control that involves basic cognitive skills, thus the improvement in attention and global cognitive function may be what is promoting the improvement in cognitive flexibility.

A significant improvement over control groups was reported in the global cognitive function and attention in VR groups. Regarding the result for attention, explanations for this phenomenon can be elaborated as follows: firstly, all of the included studies emphasized that VR can motivate and fully engage the participants by creating an artificial interactive environment; secondly, attention was the target training domain in the eight studies (Faria et al., 2016; Maggio et al., 2018; Maier et al., 2020; Mrakic-Sposta et al., 2018; J. H. Park et al., 2020; J. S. Park et al., 2020; Tarnanas et al., 2014). As for the result of global cognitive function, given that various kinds of VR were provided, including juice making (Thapa et al., 2020), shopping (J. S. Park et al., 2020), playing games (Maier et al., 2020), and practicing Tai Chi (Liao et al., 2019), the participants were exposed to a rich virtual environment involving various cognitive abilities, which may have led to the enhancement of their global cognitive function.

According to the subgroup analysis of the different outcomes, there is weak evidence to suggest which level of immersive VR was the most beneficial. However, a subgroup difference ($P < 0.01$) was achieved for cognitive flexibility. It can be seen from the forest plot that a significant positive difference was achieved in the subgroup using semi-immersive VR, and there was no overlap of the 95% CI in comparison with the other two subgroups. Thus, indirect evidence supports the hypothesis that semi-immersive VR was better than full-immersive VR and non-immersive VR for promoting cognitive flexibility. Except for that, according to the meta-analysis positive significant differences can be found mostly when using non-immersive VR. However, a definitive conclusion that non-immersive VR is the most effective in clinical practice cannot be made due to the lack of experimental studies directly comparing the effect of non-immersive VR with the other two types of VR.

From the results of the included studies, it can be seen that the effect of VR on EF may be associated with the content of the training protocol. Three studies (Amjad et al., 2019; Liao et al., 2019; J. S. Park et al., 2020) using VR-based physical and cognitive training together reported a larger number of positive effects on EF compared to the reports of other studies using VR-based cognitive training alone, which may indicate that physical training can also help improve EF. This finding is consistent with the previous review (Hötting & Röder, 2013), showing that physical training helps improve cognitive function, suggesting that combining the two types of training may be more effective for people with cognitive impairment. Furthermore, studies using magnetic resonance imaging (MRI) have shown that a human's gray matter in the frontal brain regions (Colcombe et al., 2006) and the hippocampus (Erickson et al., 2011) increased after physical exercise interventions. Physical exercise prepares the brain to respond to cognitive training, which will then trigger changes in neurons in specific networks associated with training skills. Therefore, VR-based physical and cognitive training together may be better than just VR-based cognitive training alone.

The overall attrition rate in the 14 studies seems good (less than 15%), except for three studies (Liao et al., 2019; Maier et al., 2020; Mrakic-Sposta et al., 2018) in which it was from 16% to 20%. The main reasons for the high attrition rate in these three studies included dissatisfaction with randomization, hospitalization, and low motivation. Although a number of studies have shown that VR training can improve the participants' motivation, which is the main reason for the high compliance rate, we still need to optimize the program to get more subjects to participate and persist in training so as to achieve the best state. Strategies for improving the adherence rate in older people with MCI may include the following aspects: provide more support and feedback during the training period; choose a suitable training format for the participants, such as endurance/resistance training, which can significantly affect the adherence rate (Di Lorito et al., 2020); choose shorter (in weeks) or less frequent (in weekly sessions) interventions as that may make it easier for people to adhere to the training (Xu et al., 2020).

Conclusion

In conclusion, VR is a promising technology that can be used to enhance EF. More accurately, VR has a positive effect on cognitive flexibility, but a non-significant effect on WM and inhibition control. Additionally, it was shown to have a positive significant effect on global cognitive function, attention, and short-term memory in older adults with MCI. Semi-immersive VR was found to be more effective in improving cognitive flexibility compared with the other two types of VR. In addition, VR-based physical and cognitive training together may help improve EF more than VR-based cognitive training can by itself, but further studies with direct comparisons between these two training protocols are needed to verify this conclusion. Last but not least, reducing the attrition rate can increase the reliability of a study. Thus, it is necessary to optimize the training program to guarantee that more participants will engage in and complete the whole process so as to achieve the optimum training results.

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Appendix 1: Searching strategies

PubMed

1. ('Virtual Reality'[Mesh]) OR virtual reality 12799
2. 'Cognitive Dysfunction'[Mesh] OR mild cognitive impairment 151014
3. ('Executive Function'[Mesh]) OR executive function 43445

1AND 2 AND 3 84

Embase

1. 'virtual reality'/exp OR 'virtual reality' 24166
2. 'mild cognitive impairment'/exp OR 'mild cognitive impairment' 34739
3. 'executive function'/exp OR 'executive function' 50765

1 AND 2 AND 3 39

Cochrane library

1. virtual reality OR VR 5552
2. mild cognitive impairment OR MCI 5174
3. executive function 5632

1 AND 2 AND 3 25

Cinahl

1. virtual reality OR VR 8654
2. mild cognitive impairment OR MCI 8719
3. executive function 10131

1 AND 2 AND 3 5

PsycINFO

1. virtual reality OR VR 14486
2. mild cognitive impairment OR MCI 16615
3. executive function 33775

1 AND 2 AND 3 18