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REVIEW

Virtual reality for limb motor function, balance, gait, cognition and daily function of stroke patients: A systematic review and meta-analysis

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Abstract

Aims: To explore the beneficial effects of virtual reality (VR) interventions on upper- and lower-limb motor function, balance, gait, cognition and daily function outcomes in stroke patients.

Design: A systematic review and meta-analysis of randomized controlled trials.

Data Sources: English databases (PubMed, EMBASE, the Cochrane Library, CINAHL, Web of Science, Physiotherapy Evidence Database, ProQuest Dissertations and Theses) and Chinese databases (Chinese BioMedical Literature Service System, WANFANG, CNKI) and the Clinical Trial Registry Platform were systematically searched from inception until December 2019. Additionally, reference lists of the included studies were manually searched.

Review Methods: The methodological quality of studies was scored with the Cochrane 'risk-of-bias tool' and PEDro scale from the Physiotherapy Evidence Database by two independent evaluators.

Results: In total, 87 studies with 3540 participants were included. Stroke patients receiving VR interventions showed significant improvements in Fugl-Meyer assessment of Upper Extremity, Action Research Arm Test, Wolf Motor Function Test, Fugl-Meyer Assessment of Lower Extremity, Functional Ambulation Classification, Berg Balance Scale, Time Up and Go, Velocity, Cadence, Modified Barthel Index and Functional Independence Measure. However, differences between VR intervention and traditional rehabilitation groups were not significant for Box-Block Test, 10 m Walk Test, Auditory Continuous Performance Test, Mini-Mental State Examination and Visual Continuous Performance Test.

Conclusion: This review suggests that VR interventions effectively improve upper- and lower-limb motor function, balance, gait and daily function of stroke patients, but have no benefits on cognition.

Impact: This review identified the positive effects of VR-assisted rehabilitation on upper- and lower-limb motor function, balance, gait and daily function of stroke patients. And, we verified the duration of VR intervention affects some health benefits. The benefit of VR on cognitive function requires further investigation through large-scale multicentre RCTs.

KEYWORDS
balance, cognition, gait, limb motor function, meta-analysis, nursing, stroke, systematic review, virtual reality

1 | INTRODUCTION

Stroke is the most common neurological disease (Park et al., 2019) accounting for nearly a third of deaths worldwide (Wang et al., 2017). Up to 50% of stroke survivors are chronically disabled (Foley et al., 2012), leading to severe effects on daily activities and quality of life of patients. Cognitive and motor impairment and loss of balance and gait are the main factors affecting independent function and activity participation of stroke patients. Due to the complexity of stroke, nurses not only need to meet the role of therapeutic nursing, but also need to work with multidisciplinary teams to promote patients' rehabilitation (Aadal et al., 2013), such as supporting and respecting different rehabilitation needs in their interaction with patients (Kvigne et al., 2005), encourage stroke patients to do rehabilitation exercise, give timely feedback on the progress of rehabilitation, help rehabilitation therapist adjust the rehabilitation plan, and then assist patients to re-enter social life more quickly (Dreyer et al., 2016).

Traditional rehabilitation programs usually face limitations in that training quantity and intensity are less rigorous than guidance (Foley et al., 2012) and enthusiasm for participation is low (Kaur et al., 2012). Virtual reality (VR) is a technology with interactive simulation creating a near-reality environment for users (Rose et al., 2018). VR technology is effectively used not only in diagnosis and teaching but also rehabilitation training (Huang et al., 2018; Ögün et al., 2019), and has been increasingly applied for stroke rehabilitation, intervention activities that need repetition, and specific tasks to improve limb function recovery after stroke (Park et al., 2019). Nurses can use VR equipment to change the clinical environment (Edwards, 2006), create a safer training environment to provide better rehabilitation support and bedside care (Kirkevold, 2010), and enhance the enthusiasm of patients to actively participate in rehabilitation (White et al., 2013). Moreover, VR can provide a richer experience for participants, making the rehabilitation process entertaining and engaging (Laver et al., 2012).

Due to the diversity of VR intervention results, meta-analysis of the evidence is needed to reveal the effects of VR rehabilitation on upper- and lower-limb, balance, gait, cognition and daily function of stroke patients, to explore the effects of different duration of VR intervention on health benefits, and then to provide theoretical basis for follow-up VR rehabilitation.

1.1 | Background

Stroke is the second most common fatal disease in the world (Chen et al., 2018). With the increase of the older population, the incidence of the disease is increasing year by year. Almost 17 million new strokes are reported worldwide each year (Virani et al., 2020). The prevalence rate of stroke in the United States is about 2.5% (Virani et al., 2020). According to stroke screening data, the standardized incidence of the first stroke in Chinese people aged 40–70 increased from 198/100,000 in 2002 to 379/100,000 in 2013, with an average annual growth rate of 8.3% (Institute for Health Metrics & Evaluation, 2017). The recurrence rate one year after the first stroke was as high as 17.1% (Guan et al., 2017). Stroke is caused by poor cerebral blood flow, and there are two main types of stroke: haemorrhagic stroke and ischemic stroke (Jun-Long et al., 2018). Among them, ischemic stroke accounts for 80% of all strokes (Della-Morte et al., 2012).

The prognosis of stroke depends heavily on complications. Patients are often accompanied by complications such as chronic functional impairment and cognitive impairment. The fatality rate at 1 month and 5 years after stroke is about 15% and 50%, respectively (Hankey, 2017; Kernan et al., 2014). Stroke is the leading cause of long-term disability worldwide and dyskinesia is the most common damage after stroke, which exists in 85% of patients with acute stroke (Rathore et al., 2002). It is estimated that 55%–75% of post-stroke patients have functional limitations of the upper- and lower-limbs (Chen et al., 2019). 50%–60% of patients experience varying degrees of motor dysfunction after stroke (Hendricks et al., 2002). Among 2/3 of stroke patients have cognitive decline in different areas, including attention, memory, and executive function (Liu et al., 2017). Due to post-stroke patients have functional and cognitive impairment, functional tasks and daily activities are limited, which may lead to a decline in health-related quality of life (Hankey et al., 2002; Nichols-Larsen et al., 2005).

VR is an interactive computer-generated experience in a simulated environment, which mainly includes auditory and visual feedback (Liu et al., 2019). In recent years, VR technology has been mainly used in clinical rehabilitation (Kannan et al., 2019; Lee, 2019; Oh et al., 2019). VR can provide a more exciting and richer environment than traditional rehabilitation (Mirelman et al., 2013). Therefore, in theory, VR is a potentially beneficial intervention for rehabilitation training in stroke patients. In recent years, accumulating randomized controlled trials (RCTs) have been conducted to compare the effects of VR and traditional rehabilitation intervention programs in stroke patients. Virtual reality technology is reported to be more effective than traditional rehabilitation in improving the upper limb function and hand muscle injury of stroke patients (Choi et al., 2016; Oh et al., 2019). However, according to the reports of Hung et al. (2019) and Kim et al. (2018), both VR and traditional rehabilitation improved upper limb movement function of stroke patients, with no significant differences between the two intervention groups. Another study by Jiang and co-workers showed that VR could improve functional recovery of the upper limb, but had no significant positive effect on functional recovery of wrist and hand or upper limb movement in stroke patients (Jiang, 2017). Conflicting results on lower limb rehabilitation, balance, gait and cognition have been obtained from different studies (Aminov et al., 2018; Bergmann et al., 2018; Liao & Wang, 2014; Zhong et al., 2019). These discrepancies may be attributable to variations in the virtual reality technology and equipment used, the difficulty of VR games used, exercise duration and treatment methods.

Results from RCTs and meta-analyses in the literature are inconsistent. Aminov et al. (2018) reported a positive impact of VR on the upper limb of Fugl–Meyer motor function score (FMA-UE), Functional Independence Measure (FIM), Box-Block Test (BBT) and other parameters in stroke patients. In contrast, the meta-analysis of Zhong et al. (2019) confirmed a positive impact of VR on FMA-UE of stroke hemiplegic patients, but not BBT or FIM. In a systematic review by De Keersmaecker et al. (2019), VR improved the lower extremity balance ability of stroke patients, with significant differences in recorded Time Up and Go test (TUG) scores. In contrast, another systematic review by Perrochon et al. (2019) reported that VR had no major effect on the balance ability of stroke patients. Distinct results on gait and balance function were obtained by the research groups of Wang et al. (2019), Lee et al. (2019) and Casuso-Holgado et al. (2018). These inconsistent findings may be explained by differences in study design, post-stroke time and VR devices. Therefore, the actual benefits of VR as a measure of rehabilitation exercise in stroke patients remain to be established.

In addition, the effects of different duration of VR intervention on the functional recovery of patients are still unclear. According to the study of Han et al. (2017), when the duration of aerobic exercise is 8–12 weeks, it can better improve the cardiopulmonary fitness of patients. When the exercise time lasts for more than 4 weeks, it can be of the greatest benefit to the improvement of cognitive function, balance ability and endurance of stroke patients (Han et al., 2017). The same conclusion was reached in the study of Kim et al. (2019). However, Laver et al. (2017) found that there was no significant difference in the recovery of upper limb function in stroke patients with different treatment duration.

Therefore, this systematic review and meta-analysis was performed by comprehensive searching of English and Chinese electronic databases (from inception until 31 December 2019), strictly including RCT studies and assessing 16 outcome measures, to further evaluate the effectiveness of VR on upper- and lower-limb motor, balance, gait and cognition and explore the effects of different duration of VR intervention on functional recovery of stroke patients.

2 | METHODS

2.1 | Aims

The aim of this systematic review and meta-analysis was to evaluate the effects of VR on limb motor function, balance, gait, cognition and daily function of stroke patients, and to identify whether the duration of VR intervention affects health benefits.

2.2 | Design

This systematic review was registered at the website of International Prospective Register of Systematic Reviews and conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA).

2.3 | Search methods

English and Chinese electronic databases were comprehensively searched from inception until 31 December 2019, including PubMed, EMBASE, the Cochrane Library, Physiotherapy Evidence Database (via the PEDro website), CINAHL, ProQuest, Web of Science, ProQuest Dissertations and Theses, Chinese BioMedical Literature Service System, WANFANG, CNKI, and Clinical Trial Register Platform. The search terms used were 'stroke', 'cerebrovascular disorders', 'virtual reality', 'user-computer interface' and their synonyms or translation in Chinese. The reference lists of included studies were additionally reviewed.

Studies were included with the following criteria: (1) population: stroke patients over 18 years of age, (2) design: RCT, (3) intervention: VR rehabilitation therapy, and (4) control: conventional rehabilitation or placebo therapy.

Studies were excluded based on the following criteria: (1) full text was unavailable, (2) incomplete information (unable to get the required data), (3) protocol, (4) duplicate records, (5) studies written in languages other than English or Chinese.

2.4 | Outcome measures

Sixteen outcomes were examined: (1) recovery of limb movement and function using Upper Extremity Fugl-Meyer assessment (FMA-UE), Action Research Arm Test (ARAT), Wolf Motor Function Test (WMFT), Box-Block Test (BBT), Lower Extremity Fugl-Meyer Assessment (FMA-LE), and Functional Ambulation Classification (FAC), (2) balance and gait using Berg Balance Scale (BBS), 10 m Walk Test (10MWT), Time Up and Go (TUG), and Velocity and Cadence scores, (3) cognition using Mini-Mental State Examination (MMSE), Auditory Continuous Performance Test (ACPT), Visual Continuous Performance Test (VCPT), (4) daily function using Functional Independence Measure (FIM) and Modified Barthel Index (MBI).

2.5 | Search outcome

Initially, a total of 9948 related studies were identified. Among these, 6499 duplicate records were removed, 3313 studies were excluded following screening of the title and abstract, 25 did not meet the inclusion criteria, and 24 were protocols or contained incomplete information. Finally, 87 RCTs (53 in English and 34 in Chinese) were included for meta-analysis. A flow diagram of the literature screening process is illustrated in Figure 1.

2.6 | Quality appraisal

The risk of bias of the included studies was assessed with the Cochrane 'risk-of-bias tool' (Jonathan, 2011) by the two researchers. The criteria included: (1) allocation concealment, (2) random sequence generation, (3) blinding of outcome assessment, (4) blinding of participants and personnel, (5) incomplete outcome data, (6) selective reporting, and (7) any other bias. Each study was classified as having 'low', 'high' or 'unclear' risk of bias.

The quality of the included studies was also evaluated using the Physiotherapy Evidence Database (PEDro) Scale (Maher et al., 2003). The PEDro scale included 11 items, and its score depended on whether such items are met by the included studies. Each satisfied item (except the first one) contributes 1 point to the total score, which ranged from 0 to 10 points. The total score was divided into three level: (1) high quality (score 6–10), (2) fair quality (score 4–5) and (3) poor quality (score ≤ 3).

2.7 | Study selection and data extraction

Two researchers independently selected studies using the specified inclusion and exclusion criteria. After screening the title and abstract, the full texts of the potentially eligible studies were further evaluated. We extracted the following data: title, published year, published journal, first author, sample size, research design, baseline characteristics of participants, intervention measures and outcomes. The third reviewer was involved in resolving the discrepancies between the two researchers.

2.8 | Data synthesis and analysis

Review Manager Software Revman (version 5.3) was applied for data processing and analysis. The I^2 test was used to analyse heterogeneity. At $p > .1$ and $I^2 < 50\%$, the included studies were considered homogeneous and the fixed-effects model was used to analyse the pooled results. At $I^2 > 50\%$, the source of heterogeneity was assessed, focusing on the data extraction method, clinical intervention measures, research design, sensitivity, and other factors. The random-effects model was applied for further analysis. Subgroup analysis was conducted to explore the effects of different VR intervention duration (≤4 weeks or ≥5 weeks) on health benefits. All outcomes were reported as mean difference (MD) and 95% confidence interval (CI). p values <.05 were statistically significant.

3 | RESULTS

3.1 | Study characteristics

In total, 87 studies including 3540 participants were reviewed (shown in Table 1). Among these studies, the average age of participants ranged from 46.3 to 72.8 years in the VR group and 47.5 to 76.4 years in the control group. The VR group contained 1029 males and 662 females, while the control group included 971 males and 687 females. Three studies had no information on gender. Overall, 852 and 812 cerebral infarction and 431 and 435 cerebral haemorrhage cases were identified in the VR and control groups, respectively. The mean time of onset to stroke ranged from 12.7 days to

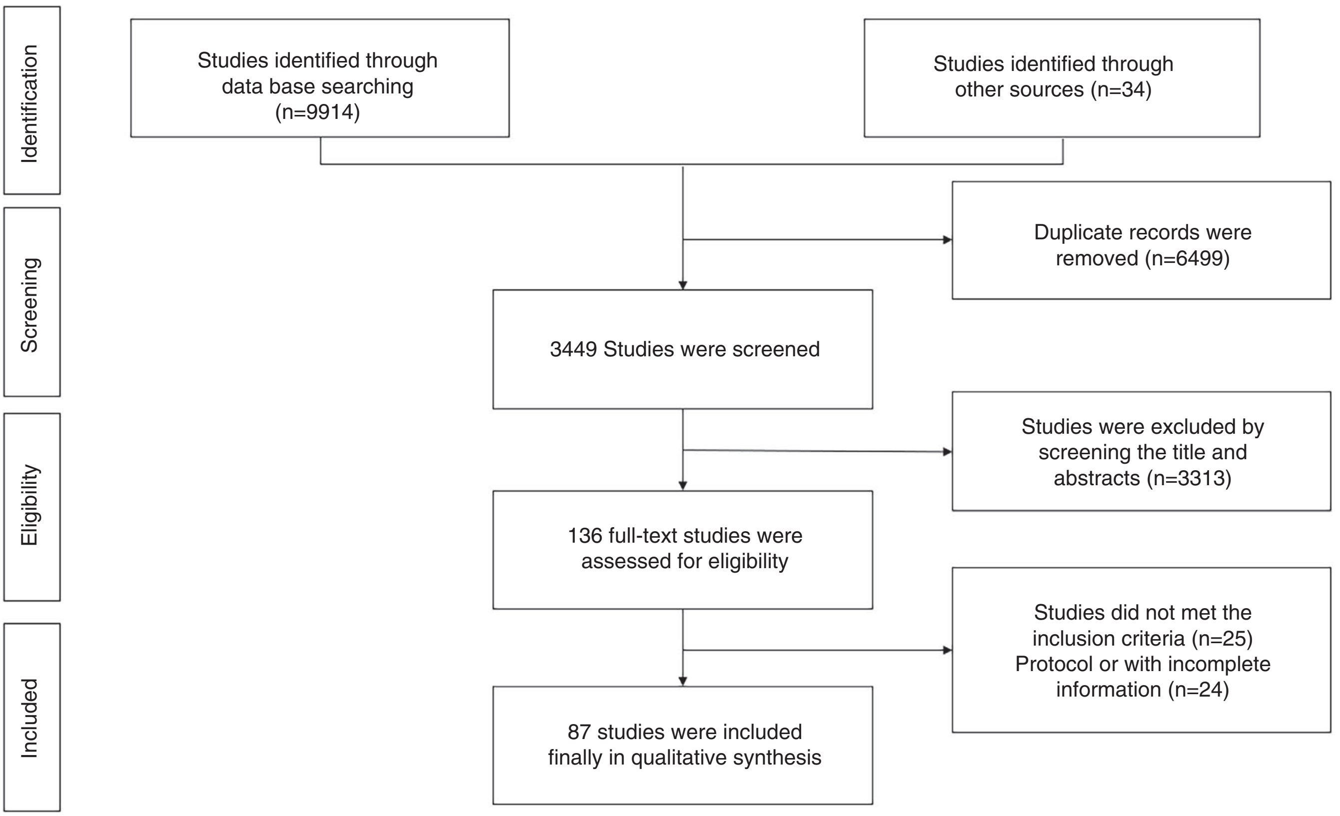

FIGURE 1 Flow diagram of the literature screening process

18.4 years in the VR group and 13.2 days to 19.2 years in the control group.

3.2 | Risk of bias and quality

The risk of bias was presented in Figure S1. Overall, 32 studies did not report details of the random assignment method, while 24 studies used the allocation concealment process. Due to the limitations of experimental conditions, only three studies implemented blinding of participants. And blind method was implemented to outcome assessment in 33 studies. Furthermore, the risk of selective reporting and other bias was low.

The mean PEDro score assessing the methodological quality was 5.6 (*SD* 1.2), which ranged from 3 to 9 (Table 1). Among 87 studies, 32 studies (36.8%) were highlighted with high quality, and only one study was of low quality.

3.3 | Effectiveness of VR interventions

3.3.1 | Outcomes of upper limb movement and function

Thirty-eight studies (1773 participants) reported FMA-UE as an outcome. Moderate heterogeneity ($p < .001$, $I^2 = 67\%$) was observed among these studies. Results of meta-analysis using the random-effects model showed that the VR group had better FMA-UE scores than the control group (MD = 6.75, 95% CI = 5.58–7.93, $p < .001$; Figure 2a). Subgroup analyses disclosed significant differences in FMA-UE between the two groups regardless of whether the duration of the intervention period was ≤4 weeks or ≥5 weeks (Table 2).

Overall, 12 studies (541 participants) used BBT as an outcome measure. There was moderate heterogeneity among studies ($p < .001$, $I^2 = 70\%$) and the random-effects model was used for meta-analysis. No significant differences in BBT were observed between VR and control groups (MD = 1.73, 95% CI = −2.18–5.64, $p = .13$; Figure 2b). Subgroup analyses were further conducted to determine the effects of the duration of intervention on BBT. The two groups showed no significant differences in BBT irrespective of the length of the intervention period (≤4 or ≥5 weeks; Table 2).

Four studies (213 participants) focused on ARAT as an outcome. Meta-analysis with the fixed-effects model showed a greater improvement in ARAT in the VR intervention relative to the control group (MD = 7.18, 95% CI = 4.27–10.08, $p < .001$; Figure 2c). No significant homogeneity was observed among these studies ($p = .18$, $I^2 = 38\%$).

Six studies (317 participants) reported WMFT as an outcome. Pooled results obtained with the fixed-effects model showed that VR intervention exerted a greater effect on WMFT than traditional rehabilitation (MD = 4.43, 95% CI = 2.46–6.40, $p < .001$; Figure 2d). The included studies showed no heterogeneity ($p = .13$, $I^2 = 41\%$).

3.3.2 | Outcomes of lower limb movement and function

In total, 16 studies including 732 participants assessed FMA-LE. Significant heterogeneity among the studies was observed ($p < .001$, $I^2 = 77\%$) and the random-effects model used for analysis. The results showed a greater beneficial effect of VR rehabilitation on FMA-LE compared with traditional intervention (MD = 3.01, 95% CI = 1.91–4.11, $p < .001$; Figure 2e). Subgroup analyses further revealed that VR intervention over both ≤4 and ≥5 week periods had a significant positive effect on FMA-LE (Table 2).

Five studies (260 participants) reported FAC. High heterogeneity was observed across the remaining studies ($p = .003$, $I^2 = 75\%$). The random-effects model used for meta-analysis disclosed better FAC scores in the VR than control group (MD = 0.47, 95% CI = 0.14–0.79, $p = .005$; Figure 2f).

3.3.3 | Outcomes of balance and gait

In total, 21 studies (633 participants) evaluated BBS as an outcome measure. High heterogeneity was observed among the studies ($p < .001$, $I^2 = 80\%$). The pooled results obtained with the random-effects model revealed that VR influenced BBS to a greater extent than control intervention (MD = 3.51, 95% CI = 2.10–4.92, $p < .001$; Figure 3a). Subgroup analyses showed that VR intervention delivered over both ≤4 and ≥5 weeks had significant positive effects on BBS (Table 2).

Seventeen studies (457 participants) used TUG as an outcome. VR had a greater effect in improving TUG (MD = −2.10, 95% CI = −3.52 to −0.73, $p = .003$; Figure 3b). We observed moderate heterogeneity among these studies ($p < .001$, $I^2 = 64\%$) and the random-effects model was used for meta-analysis. Interestingly, subgroup analyses showed a significant difference in TUG between the VR and control groups when the duration of intervention was ≤4 weeks, but no significant differences over ≥5week periods (Table 2).

Four studies (138 participants) reported 10MWT. No significant differences between the VR and control groups were evident (MD = −1.45, 95% CI = −6.89–3.98, $p = .60$; Figure 3c) with the fixed-effects model. Heterogeneity was low ($p = .29$, $I^2 = 20\%$) among these studies.

Nine studies (310 participants) provided data on gait velocity. We observed no heterogeneity in these studies ($p = .85$, $I^2 = 0\%$) and the fixed-effects model was used for meta-analysis. The VR group was more improved than the control intervention group in terms of velocity (MD = 11.79, 95% CI = 8.48–15.11, $p < .001$; Figure 3d). Subgroup analyses further showed that VR interventions (both ≤4 weeks and ≥5 weeks) exerted significant positive effects on gait velocity.

In total, nine studies (262 participants) evaluated gait cadence. Due to the low heterogeneity of the included studies ($p = .12$, $I^2 = 37\%$), pooled results were obtained with the fixed-effect model, which revealed that the VR group improved cadence to a better extent than the control group (MD = 8.35, 95% CI = 4.54–12.16,

TABLE 1 Characteristics of the included studies

	Author, Year	Country	Participants Intervention/ Control (*n*/*n*)	Intervention	Control	Dosage	Outcomes included in this review	PEDro
1	Fei Huang (2019)	China	30/30	BioMaster VR interactive training	Conventional OT training	70–100min/d 5d/w,8w	FMA-UE	5
2	Kuijie Fu (2019)	China	18/18	STB–110 VR training	Routine cognitive rehabilitation	30min/d 6d/w,4w	MMSE	5
3	Kyeongjin Lee, (2019)	Korea	21/21	Speed-interactive pedaling training with stationary bike by MOTOmed viva	Conventional therapy	40min/d 5d/w,6w	FMA-LE, Gait (Cadence)	6
4	Lakshmi Kannan (2019)	USA	13/12	Cognitive-motor exergame training by Wii Fit	Conventional balance training	6w, 20sessions	BBS, TUG	4
5	Lei Xu (2019)	China	30/30	VR-assisted training using GaitWatch	Regular rehabilitation training	20min/d 6d/w,6w	FMA-LE, FAC, Gait (Velocity, Cadence)	5
6	Lu Fang (2019)	China	30/30	VR training using Xbox360	Conventional occupational therapy	15min/d 5–6d/w,12w	BBS	5
7	Mina Park (2019)	Korea	12/13	VR-based rehabilitation with Smart Board	Conventional rehabilitation	60min/d 5d/w,4w	MBI	7
8	Muhammed Nur ÖGÜN (2019)	Turkey	33/32	Upper extremity immersive VR rehabilitation program with Leap Motion	Conventional therapy	60min/d 3d/w,6w	FMA-UE, ARAT, FIM	9
9	Shuang Chen (2019)	China	20/20	VR rehabilitation therapy by Motekforce link	Traditional physical rehabilitation therapy	40min/d 5d/w,12w	FMA-LE, BBS Gait (Velocity, Cadence)	7
10	Xiang Xiao (2019)	China	16/19	VR training by Kinect somatosensory interaction	Conventional OT training	40min/d 5d/w,4w	FMA-UE, MBI	6
11	Yijin Zhao (2019)	China	35/35	VR training by BioMaster and Flextable	Conventional Occupational therapy training	50min、d 5d/w,4w	FMA-UE, MBI	6
12	Young-Bin Oh (2019)	Korea	17/14	Joystim for the VR combined with real instrument training	Standardized treatment program	30min/d 3d/w,6w	FMA-UE, BBT, MMSE	7
13	Zhibin Li (2019)	China	25/25	Upper limb intelligent feedback training system	Conventional OT training	45min/d 6d/w,4w	FMA-UE, WMFT, MBI	5
14	Ayça UTKAN KARASU (2018)	Turkey	12/11	Balance exercise with Wii Fit and Wii Balance Board	Conventional balance rehabilitation exercise	20min/d 5d/w,4w	BBS, TUG	7
15	Chunxia He (2018)	China	20/20	Upper limb intelligent feedback training system	Scapula motion control training	20 ~ 60min/d 5d/w	FMA-UE	5
16	Fang Lu (2018)	China	20/20	Lokomat training robot with VR	Conventional rehabilitation therapy	60min/d 5d/w,4w	FMA-LE, FAC	5
17	Huanxia Zhou (2018)	China	30/30	BioMaster virtual reality interactive training	Routine rehabilitation	30min/time 2time/d,6w	FMA-UE, MBI	5
18	Jaeho Park (2018)	Korea	12/16	Virtual reality robot-assisted gait training by Lokomat	Gait training using a treadmill	45min/d 3d/w,6w	FMA-LE, TUG, BBS, MBI	5

(Continues)

TABLE 1 (Continued)

	Author, Year	Country	Participants Intervention/Control (n/n)	Intervention	Control	Dosage	Outcomes included in this review	PEDro
19	John Cannell (2018)	Australia	35/38	iMCR intervention individualized prescription of the repetitive exercises	Physical therapy	60min/d 8–40sessions	BBT	8
20	Ju-Hong Kim (2018)	Korea	12/12	VR training using virtual reality games by Wii	Traditional rehabilitation therapy	40min/d 5d/w,12w	FMA-UE	4
21	Junzhi Zhu (2018)	China	21/22	Kinect gaming and OT training	OT training	60min/d 6d/w,2w	FMA-UE, WMFT	5
22	Pawel Kiper (2018)	Italy	68/68	VR rehabilitation with a 3-dimensional motion tracking system	Conventional rehabilitation	2h/d 5d/w,4w	FMA-UE, FIM	8
23	Sevgi Ikbali Afsar (2018)	Turkey	19/16	Xbox Kinect game system	Conventional therapy for upper extremity	60min/d 5d/w,12w	FMA-UE, BBT	6
24	Wenfeng Li (2018)	China	20/20	Kinect-based VR rehabilitation training	Routine rehabilitation training	30–40min/d 7d/w,4w	FMA-LE, BBS, 10MWT, Gait (Velocity, Cadence)	6
25	Won-Seok Kim (2018)	Korea	11/8	Kinect-based VR for upper limb recovery	Conventional OT for upper limb recovery	30min/d 5d/w,2w	FMA-UE, BBT, MBI	8
26	Xiaoxiao Han (2018)	China	18/18	VR Wii game training	Conventional PT	30min/d 5d/w,2w	FMA-UE	5
27	Yana Li (2018)	China	15/15	Four limbs combined with VR by Motek Medical	Routine rehabilitation training	20min/d 5d/w,4w	FMA-LE	4
28	Yanqun Hu (2018)	China	33/33	VR rehabilitation and cognitive intervention by Wii	Conventional intervention	50min/d 4–6d/w,4w	FMA-UE and FMA-LE, MMSE	5
29	Dae-Sung Park (2017)	Korea	10/10	Kinect-based VR training	Conventional PT	30min/d 7d/w,6w	FMA-LE, BBS, 10MWT	6
30	Iris Brunner (2017)	Norway	57/55	VR training with the YouGrabber system	Conventional training	60min/d 4 ~ 5d/w,4w	ARAT, BBT, FIM	6
31	Kyeong Woo Lee (2017)	Korea	25/25	VR game training with Neuro-X	conventional rehabilitation training	60min/d 5d/w,2w	MBI	5
32	Liang Li (2017)	China	48/48	Virtual somatosensory exercise training by Wii	Routine rehabilitation therapy	30min/d 3d/w,12w	FMA-UE and FMA-LE, BBS, MBI	5
33	Martina Maier (2017)	Spain	6/5	Cognitive training scenarios using Rehabilitation Gaming System set-up	Routine cognitive tasks	30min/d 5d/w,6w	FMA-UE, MMSE, MBI	5
34	Qian Zhu (2017)	China	67/67	Virtual kitchen rehabilitation training	Conventional therapy	60min/d 5d/w,8w	FMA-UE, MBI	5
35	Qing Liu (2017)	China	20/20	BioMaster VR interactive training	Routine rehabilitation training	45min/d 5d/w,10w	FMA-UE, MBI	5
36	Ana Lúcia Faria (2016)	Portugal	9/9	Virtual simulation of a city-Reh@City	Conventional rehabilitation	20min/d 2–3d/w,12w	MMSE	5

(Continues)

TABLE 1 (Continued)

	Author, Year	Country	Participants Intervention/ Control (n/n)	Intervention	Control	Dosage	Outcomes included in this review	PEDro
37	Gustavo Saposnik (2016)	Canada	71/70	VR using the Nintendo Wii gaming system	Recreational activity	60min/d 5d/w,2w	WMFT, BBT, FIM, MBI	7
38	Joon-Ho Shin (2016)	Korea	24/22	VR training by RAPAEL Smart Glove	Occupational therapy training	60min/d 7d/w,4w	FMA-UE	7
39	Keng-He Kong (2016)	Singapore	33/35	Virtual game training by Wii Sports	PT and OT	60min/d 4d/w,3w	FMA-UE, FIM	5
40	Lili Miao (2016)	China	30/30	VR training using the sling device	Routine rehabilitation therapy	80min/d 6d/w,4w	FMA-UE, MBI	5
41	Myung-Mo Lee (2016)	Korea	5/5	Canoe game-based virtual reality training program by Wii Sports Resort	Conventional rehabilitation program	30min/d 3d/w,4w	FMA-LE, BBS, TUG, FMA	5
42	Taesung In (2016)	Korea	13/12	Virtual reality reflection therapy	Conventional rehabilitation program	30min/d 5d/w,4w	BBS, TUG	5
43	Wangxiang Mai (2016)	China	20/20	Virtual game training by Xbox Kinect	Routine rehabilitation therapy	40min/d 5d/w,4w	FMA-UE, WMFT	5
44	Yanwei Liu (2016)	China	40/40	Virtual reality training by BioMaster	Routine rehabilitation training	45min/d 5d/w,4w	FMA-LE, Gait (Velocity)	5
45	Changho Yom (2015)	Korea	10/10	Virtual environment system ankle exercise by X-note	Conventional PT	30min/d 5d/w,6w	TUG, Gait (Velocity, Cadence)	6
46	Gozde Iyigun Yatar (2015)	Cyprus	15/15	Wii Fit balance training	Conventional exercise training	60min/d 3d/w,4w	BBS, TUG	4
47	Gui Bin SonG (2015)	Korea	20/20	Performed training using the Xbox Kinect	Training using an ergometer bicycle	30min/d 5d/w,8w	TUG	3
48	In-Wook Lee (2015)	Korea	10/10	VR exercise by BioRescue	Proprioceptive neuromuscular facilitation	45min/d 3d/w,6w	BBS, TUG	4
49	Jin Seok Huh (2015)	Korea	23/17	VR training with BalPro	Conventional PT	30min/d 5d/w,2w	BBS, FAC, TUG, MBI	5
50	Llorens Rodríguez (2015)	Spain	10/10	VR-based training	Conventional therapy	60min/d 5d/w,4w	BBS	8
51	Peishun Chen (2015)	China	40/40	Virtual reality training by BioMaster	Routine rehabilitation training	30min/d 7d/w,4w	FMA-LE, FAC, MBI	5
52	Tülay Tarsuslu Simsek (2015)	Turkey	20/22	Virtual games training by Wii sports and Wii Fit packages	Routine therapy program	44–60min/d 3d/w,10w	FIM	7
53	Wenjun Pang (2015)	China	17/17	Virtual reality training by Bometric Ltd	Routine therapy	45min/d 5d/w,6w	FMA-UE, MBI	5
54	Xiaochuan Rong (2015)	China	28/28	BioMaster virtual reality interactive training	Routine therapy	20 ~ 30min/d 6d/w,4w	FMA-UE	5

(Continues)

TABLE 1 (Continued)

Author, Year		Country	Participants Intervention/ Control (*n*/*n*)	Intervention	Control	Dosage	Outcomes included in this review	PEDro
55	Yezhu Yang (2015)	China	30/30	Virtual reality training by Wii	Routine therapy	45min/time 2times/d 5d/w,8w	FMA-UE	5
56	Anke I. R. Kottink (2014)	Netherlands	8/10	Rehabilitation game by FurballHunt	Conventional reach exercises	30min/d 3d/w,4w	FMA-UE, ARAT	6
57	Cuihua Liu (2014)	China	30/28	VR training with BIOMaster	Routine treatment	20–30min/d 6d/w,4w	FMA-LE, 10MWT	5
58	Dong Jin Lee (2014)	Korea	12/12	VR reflection equipment	Conventional PT	55min/d 5d/w,4w	BBT	5
59	Hua Wu (2014)	China	20/19	Virtual reality training by BioMaster	Motor imagery therapy	30min/d 6d/w,8w	FMA-UE, MBI	5
60	Jen-Wen Hung (2014)	China	13/15	Wii Fit VR training	Routine rehabilitation training	30mind 2d/w,12w	TUG	7
61	Joon-Ho Shin (2014)	Korea	7/9	VR by RehabMaster	Occupational therapy	30min/d 5d/w,2w	FMA-UE, MBI	5
62	Jun Hwan Choi (2014)	Korea	10/10	Commercial gaming-based VR therapy using Wii	Conventional occupational therapy	30min/d 5d/w,4w	FMA-UE, BBT, MMSE, ACPT, VCPT, MBI	8
63	Ki Hun Cho (2014)	Korea	15/15	Treadmill walking training by JT–400 based real-world video recording	Standard rehabilitation	30min/d 3d/w,6w	BBS, TUG, Gait (Velocity, Cadence)	7
64	Linrong Liao (2014)	China	21/21	Virtual reality robot training system	Conventional robot training	30min/d 5d/w,8w	FMA-LE, TUG	4
65	Ming Liang (2014)	China	30/30	Virtual kitchen training	Conventional occupational therapy	40min/d 5d/w,3w	FMA-UE, MBI	5
66	Pawel Kiper (2014)	Italy	23/21	VR Rehabilitation System by 3D motion-tracking system	Traditional stroke rehabilitation	60min/d 5d/w,4w	FMA-UE, FIM	5
67	Qian Yu (2014)	China	17/17	Virtual reality technology training	Routine rehabilitation	60min/d 5d/w,4w	FMA-UE, MBI	5
68	Roberto Lloréns (2014)	Spain	15/15	VR training by Kinect	Conventional physical therapy	45min/d 3d/w,8w	BBS	8
69	Suhyun Lee (2014)	Korea	10/8	Bilateral upper extremity VR training	bilateral upper extremity training	30min/d, 5d/w,6w	BBT	6
70	Xiang Xiao (2014)	China	10/10	VR-enhanced body weight-supported training by Vicon Nexus	Conventional physiotherapy	20–40min/d 5d/w,3w	FMA-LE, Gait (Cadence), 10MWT	5
71	Yijin Zhao (2014)	China	15/15	VR training	Conventional physiotherapy	30min/d 6d/w,2w	Gait (Velocity)	5

(Continues)

TABLE 1 (Continued)

	Author, Year	Country	Participants Intervention/ Control (*n*/*n*)	Intervention	Control	Dosage	Outcomes included in this review	PEDro
72	Yoon Bum Song (2014)	Korea	10/10	VR treatment by IREX	Conventional balance training	25min/d 3d/w,3w	BBS	4
73	GyuChanG Lee (2013)	Korea	7/7	Training using video games played on the Xbox Kinect	Conventional OT	60min/d 3d/w,6w	FIM	4
74	HyeonHui Sin (2013)	Korea	18/17	Virtual reality training using Xbox-Kinect	Conventional occupational therapy	30min/d 1d/w,6w	FMA-UE, BBT	6
75	Ki Hun Cho (2013)	Korea	7/7	Virtual walking training program with real-world video recording (VRRW)	PT and OT	90min/d 5d/w,6w	BBS, TUG, Gait (Velocity, Cadence)	7
76	Luciana Barcala (2013)	Brazil	10/10	Balance training with visual biofeedback using Wii Fit	Conventional PT	60min/d 2d/w,5w	BBS, TUG	7
77	Ming Liang (2013)	China	16/17	Virtual kitchen upper extremities training	Traditional occupational therapy	40min/d 5d/w,3w	FMA-UE, MBI	5
78	Yu-Hyung Park (2013)	Korea	8/8	Virtual Reality-based postural control program	Conventional PT	60min/d 5d/w,4w	Gait (Velocity, Cadence)	5
79	Jae-Sung Kwon (2012)	Korea	13/13	Virtual reality training by IREX VR system on upper extremity function	Conventional occupational therapy	30min/d 5d/w,4w	FMA-UE	5
80	JH Crosbie (2012)	UK	9/9	VR training	Conventional arm therapy	30 ~ 45min/d 3d/w,3w	ARAT	8
81	Kihoon Jo (2012)	Koera	15/14	VR-based training by IREX	Traditional therapy	60min/d 5d/w,4w	WMFT	5
82	Ki Hun Cho (2012)	Korea	11/11	VR balance training by Wii	Conventional PT and OT	90min/d 5d/w,6w	BBS, TUG	5
83	Mindy F. Levin (2012)	Canada	8/6	Goal-directed tasks via virtual games and virtual supermarket	Conventional therapy	45min/d 3d/w,3w	FMA-UE, BBT, WMFT	6
84	So Hyun Lee (2012)	Korea	20/20	VR training by Balance Control Trainer	Conventional PT	20min/d 5d/w,4w	FAC, TUG, BBS, MBI	8
85	Tae Sung In (2012)	Korea	11/8	Virtual Reality Reflection Therapy program	Conventional therapy	30min/d 5d/w,4w	FMA-UE, BBT	4
86	Bo Ryun Kim (2011)	Korea	15/13	VR- and computer-based cognitive rehabilitation with IREX system	Computer-based cognitive rehabilitation	30min/d 2d/w,4w	MMSE, MBI, ACPT, VCPT	5
87	Mónica da Silva Cameirao (2011)	Spain	8/8	Rehabilitation Gaming system by Wii	Occupational therapy	20min/d 3d/w,12w	MBI	5

Note: 10MWT, 10m Walk Test; ACPT, Auditory continuous performance test; ARAT, Action Research Arm Test; BBS, Berg Balance Scale; BBT, Box-Block Test; FAC, Functional Ambulation Classification; FIM, Functional Independence Measure; FMA, Fugl-Meyer assessment; FMA-LE, lower-extremity Fugl-Meyer Assessment; FMA-UE, upper extremity Fugl-Meyer assessment; MBI, Modified Barthel Index; MMSE, Mini-Mental State Examination; OT, occupational therapy; PT, physical therapy; TUG, Time UP and Go; VCPT, Visual continuous performance test; VR, virtual reality; WMFT, Wolf motor function test.

FIGURE 2 Forest plot showing limb movement and function

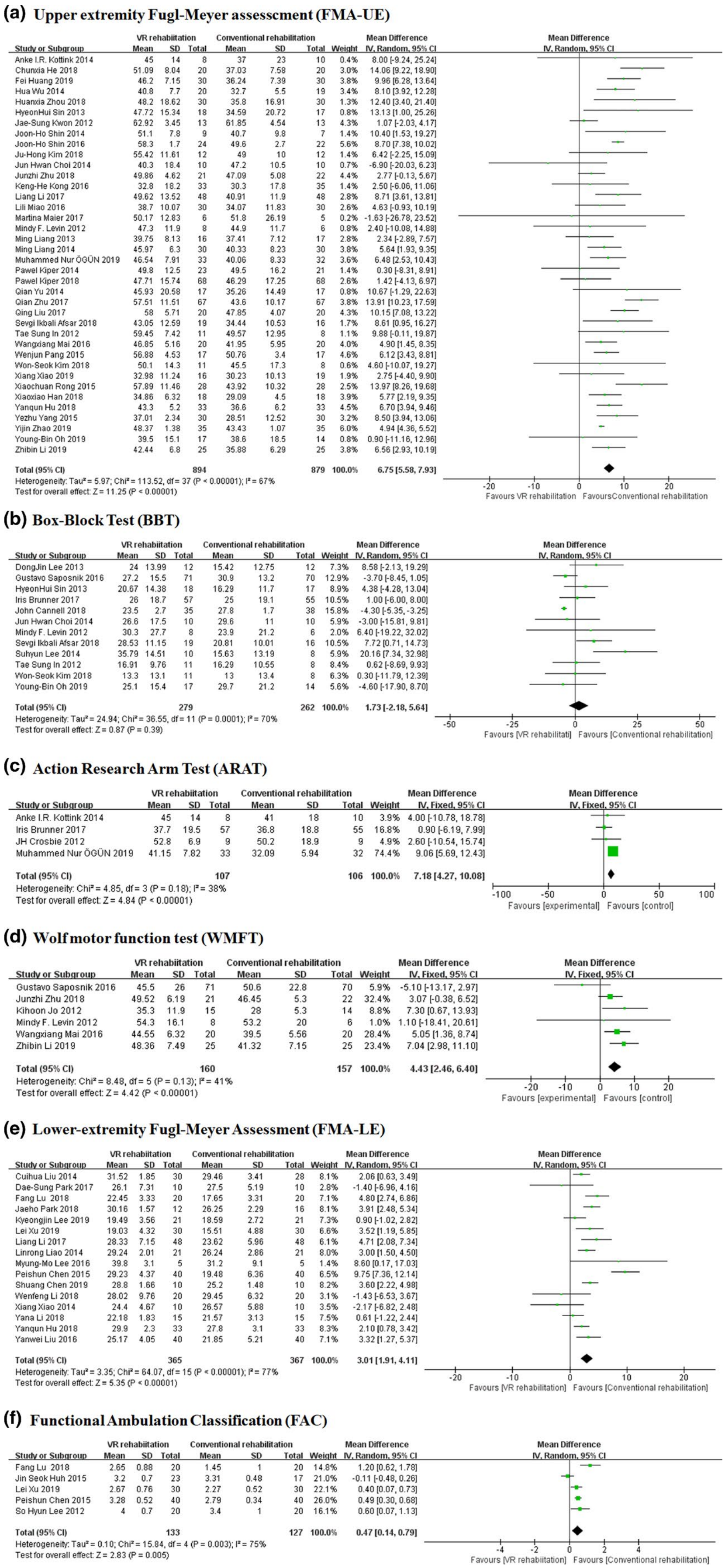

TABLE 2 Meta-Analysis of the effects of virtual reality on stroke patients

Outcomes	Number of studies	Number of participants	Heterogeneity	MD	95%CI	*p*	Subgroup analysis: Intervention duration	MD (95%CI)	*p*
FMA-UE	38	1773	I^2 = 67%, *p* < .001	6.75	5.58 to 7.93	<.001	≤4 weeks	5.30 (4.01 to 6.59)	<.001
							≥5 weeks	9.12 (7.48 to 10.75)	<.001
BBT	12	541	I^2 = 70%, *p* < .001	1.73	−2.18 to 5.64	.13	≤4 weeks	−0.69 (−3.86 to 2.49)	.67
							≥ 5 weeks	6.83 (−0.88 to 14.54)	.08
ARAT	4	213	I^2 = 38%, *p* = .18	7.18	4.27 to 10.08	<.001	≤4 weeks	1.69 (−4.06 to 7.45)	.56
							≥5 weeks	—	—
WMFT	6	317	I^2 = 41%, *p* = .13	4.43	2.46 to 6.40	<.001	—	—	—
FMA-LE	16	732	I^2 = 77%, *p* < .001	3.01	1.91 to 4.11	<.001	≤4 weeks	2.72 (0.52 to 4.93)	.02
							≥ 5 weeks	3.30 (2.35 to 4.25)	<.001
FAC	5	260	I^2 = 75%, *p* = .003	0.47	0.14 to 0.79	.005	≤4 weeks	0.50 (0.06 to 0.94)	.03
							≥5 weeks	—	—
BBS	21	633	I^2 = 80%, *p* < .001	3.51	2.10 to 4.92	<.001	≤4 weeks	4.40 (1.58 to 7.22)	.002
							≥5 weeks	2.81 (1.23 to 4.40)	<.001
TUG	17	457	I^2 = 64%, *p* < .001	−2.10	−3.52 to −0.73	.003	≤4 weeks	−2.48 (−4.03 to −0.92)	.002
							≥ 5 weeks	−1.81 (−3.78 to 0.17)	.07
10MWT	4	138	I^2 = 20%, *p* = .29	−1.45	−6.89 to 3.98	.60	≤4 weeks	−1.32 (−6.98 to 4.35)	.65
							≥5 weeks	—	—
Gait velocity	9	310	I^2 = 0%, *p* = .85	11.79	8.48 to 15.11	<.001	≤4 weeks	10.16(6.40 to 13.92)	<.001
							≥ 5 weeks	17.48(10.45 to 24.51)	<.001
Gait cadence	9	262	I^2 = 37%, *p* = .12	8.35	4.54 to 12.16	<.001	≤4 weeks	2.46 (−3.41 to 8.33)	.41
							≥ 5 weeks	12.64 (7.63 to 17.64)	<.001
MMSE	7	210	I^2 = 66%, *p* = .007	0.81	−0.41 to 2.03	.19	≤4 weeks	1.02 (0.21 to 1.83)	.01
							≥ 5 weeks	0.52 (−2.40 to 3.44)	.73
ACPT	2	48	I^2 = 87%, *p* = .006	0.03	−0.12 to 0.17	.74	—	—	—
VCPT	2	48	I^2 = 40%, *p* = .20	−0.03	−0.09 to 0.02	.20	—	—	—
MBI	27	1315	I^2 = 72%, *p* < .001	7.02	4.96 to 9.08	<.001	≤4 weeks	6.71 (4.16 to 9.25)	<.001
							≥5 weeks	8.03 (3.77 to 12.29)	<.001
FIM	8	622	I^2 = 18%, *p* = .29	2.52	0.32 to 4.72	.02	≤4 weeks	0.62 (−2.35 to 3.58)	.68
							≥5 weeks	4.93 (1.65 to 8.22)	.003

p <.001; Figure 3e). Subgroup analyses showed no marked differences in cadence between the two groups for intervention periods ≤4 weeks, while differences were significant at ≥5 weeks (Table 2).

3.3.4 | Outcomes of cognition

Seven studies (210 participants) evaluated MMSE as an outcome and showed no significant differences between VR and control groups (MD = 0.81, 95% CI = −0.41–2.03, *p* = .19; Figure 4a). Heterogeneity was moderate (*p* = .007, I^2 = 66%) and the random-effects model used for meta-analysis. Subgroup analyses showed significant differences in MMSE scores between the two groups for intervention periods ≤4 weeks but not ≥5 weeks (Table 2).

ACPT was reported in two studies (48 participants). No significant differences were observed between VR and control groups (MD = 0.03, 95% CI = −0.12–0.17, *p* = .74; Figure 4b) with the random-effects model. Heterogeneity was high (*p* = .006, I^2 = 87%).

VCPT was evaluated in two studies (48 participants) with low heterogeneity (*p* = .20, I^2 = 40%). No significant differences in were observed between VR and control groups (MD = −0.03, 95% CI = −0.09–0.02, *p* = .20; Figure 4c) with the fixed-effects model.

3.3.5 | Outcomes of daily function

Twenty-seven studies (1315 participants) described the effects of VR relative to control interventions on MBI. Differences in

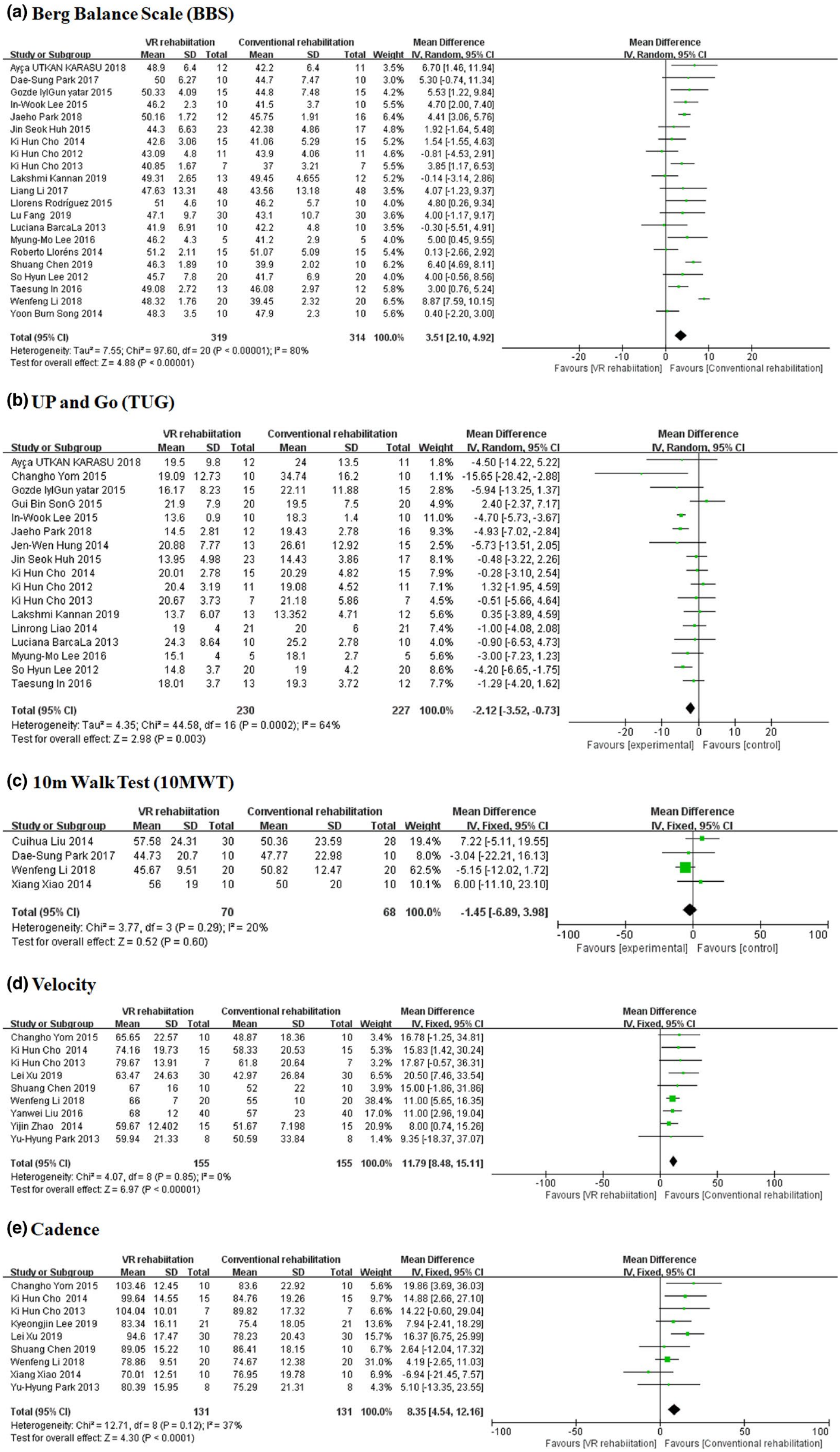

FIGURE 3 Forest plot showing balance and gait

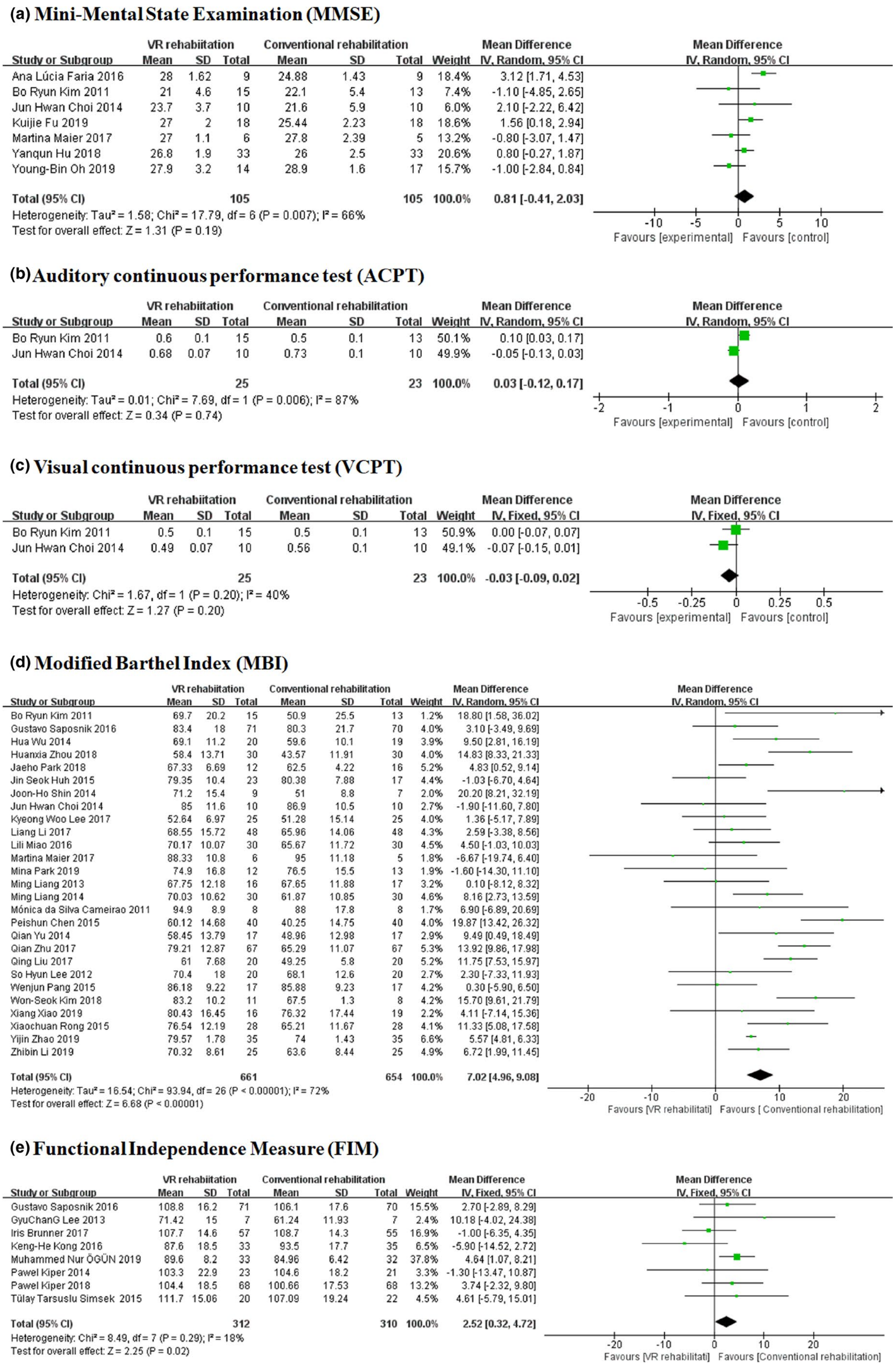

FIGURE 4 Forest plot showing cognition and daily function

MBI scores were significant between the groups (MD = 7.02, 95% CI = 4.96–9.08, p <.001; Figure 4d). Due to the moderate heterogeneity among studies (p <.001, I^2 = 72%), the random-effects model was used. Subgroup analyses showed that VR intervention periods of both ≤4 and ≥5 weeks had significant positive effects on MBI.

FIM was reported in eight studies (622 participants) with low heterogeneity (p = .29, I^2 = 18%). We observed significant differences in FIM between the VR and control groups (MD = 2.52, 95% CI = 0.32–4.72, p = .002; Figure 4e) with the fixed-effects model. Differences in FIM between the two subgroups were not significant for intervention periods ≤4 weeks but significant for interventions ≥5 weeks (Table 2).

3.4 | Sensitivity analysis

Sensitivity analysis was conducted by omitting each study in turn and recalculating the pooled relative risks. No single study significantly influenced the overall results of FMA-UE, WMFT, BBT, FMA-LE, FAC, BBS, TUG, 10MWT, gait velocity and cadence, MMSE and MBI. However, the pooled data on ARAT and FIM were influenced by the study of Ögün et al. (2019), which showed that no significant differences in these outcome measures were evident between VR and control groups after removal of this study from the meta-analysis.

4 | DISCUSSION

To our knowledge, the current meta-analysis is the most comprehensive investigation examining the efficacy of VR in stroke rehabilitation to date, including 87 RCTs (3540 participants) with the assessment of 16 outcome indicators and subgroup analyses based on the duration of intervention. Our findings indicate that VR improves limb function, walking ability, balance, gait velocity, cadence, and daily life activities to a greater extent than conventional rehabilitation. However, VR had a similar effect on improvement of cognition as conventional rehabilitation therapy.

Virtual reality technology has '3I' characteristics, specifically, immersion, interactivity and imagination (Subramanian & Prasanna, 2018). VR games have distinct clinical advantages compared with traditional therapies as they offer a challenging and interesting environment. The VR devices used in this study included Wii, BioMaster, Xbox Kinect, and Rapael Smart Board™. Our results suggest that VR intervention in a game form has beneficial effects on recovery of limb movement and function, consistent with the findings of Lee and Chun (2014) and Gibbons et al. (2016) In subgroup analysis of the effects of VR on limb function, FMA-UE and FMA-LE scores were improved regardless of the intervention duration. Moreover, longer periods of VR delivery were associated with greater improvement. VR is reported to improve fine motor activities and sensory feedback (Kim et al., 2018) but the finger function is not suitable for short-term rehabilitation and the shortest intervention duration that can exert therapeutic effects remains to be established.

The positive results of VR training in this study are consistent with data from previous meta-analyses on the effect of VR on the balance of stroke patients (Aminov et al., 2018). However, opposite findings were obtained in a systematic review by Casuso-Holgado et al. (2018), which only included 11 studies. BBS was the most frequent outcome evaluating the static and dynamic balance, which covered the key point of balance more fully than TUG. Some reviews have reported the positive findings in favour of VR as rehabilitation therapy (Mohammadi et al., 2019; Lee et al., 2019. Miyamoto and co-workers showed a strong correlation between BBS and TUG (Miyamoto et al., 2009). We additionally obtained compelling evidence on the effectiveness of VR in improving gait velocity and cadence in post-stroke patients. The gait characteristics of most stroke patients include shortening of the single leg support phase, hyperextension of the knee joint in the support phase, reduction of hip joint flexion in the affected side, foot drooping, and slowing down of gait speed (Zhao et al., 2014). Therefore, the main goals of gait training for stroke patients are to improve walking speed and posture. During gait training, the effectiveness of VR in improving gait function may be affected by the degree of immersion (i.e. non-, semi- or fully immersive). Recent studies have shown that more immersive VR systems are more beneficial for training, compared with less immersive systems (Menin et al., 2018; Tieri et al., 2018). However, the issue of whether the level of immersion is correlated with improvement in gait function remains to be established. In addition, our collective data suggest that a VR intervention period of least five weeks is required to obtain improve gait cadence to a greater extent than traditional rehabilitation.

The MBI and FIM were found to be better in VR group than that in the conventional rehabilitation group. This result suggested that VR induces a marked improvement in daily life function and self-care of patients, which may be attributed to the improvement of muscle strength through VR training (Lee, 2013). With the improvement of daily function, stroke patients' subjective well-being would also be gradually improved (Allen et al., 2002). From a long-term point of view, the improvement of daily function could not only reduce the rate of rehospitalization, but also an important predictor of hospital stays and mortality (Nunes & Queirós, 2017). Our results differ from those reported by Subramanian and Prasanna (2018) which only included two studies published in 2014 (Lee & Chun, 2014) and 2015(Zheng et al., 2015). In this article, research intervention design involved not only VR intervention alone but also VR in combination with non-invasive brain stimulation (Subramanian & Prasanna, 2018). Furthermore, compared with traditional rehabilitation, the advantages of VR on FIM were not evident until a period of >5 weeks. FIM is an 18-item measurement tool exploring physical, psychological and social functions that reflects the daily function of patients.

Cognitive impairment in stroke patients is common. However, the overall effects of VR on MMSE, ACPT and VCPT were not encouraging. The limited number of studies included for analysis may affect data on the advantages of VR rehabilitation. Our results showed no significant benefits of VR rehabilitation on cognition, compared with conventional rehabilitation therapy, consistent with the findings of Aminov et al. (2018). These findings may be attributed to the fact that cognitive function training is not the main purpose of current VR interventions. The lack of VR programs tailored for cognitive function training is the main reason for insufficient evidence to date. In addition, the result that VR had no significant effect on cognition may be have something to do with the assessment tools. Mini-Mental State Examination (MMSE), Auditory Continuous Performance Test (ACPT) and Visual Continuous Performance Test (VCPT) were used to evaluate the cognitive function of stroke patients. Although the American Academy of Neurology recommended MMSE as an important tool for detecting early cognitive impairment in its guidance (Petersen et al., 2001), many researchers doubt the accuracy of this scale (Ciesielska et al., 2016; Espino et al., 2001; Mitchell, 2009; Van et al., 2017). ACPT and VCPT were originally designed to detect persistent attention deficit in patients, they usually were used to assess patients' alertness and cognitive performance (Arble et al., 2014). Therefore, these two tools were more widely used in the assessment of attention deficit hyperactivity disorder in children, but rarely in the cognitive assessment of stroke patients. So, better assessment tools are needed to study the effect of VR on cognitive function in stroke patients in the future. Furthermore, impairment of cognitive function among stroke patients can lead to anxiety, fidgeting behaviours, and impairment of social functioning (Kim et al., 2019). Using different VR systems, patients can be trained in a comfortable, safe, and immersive environment, which may benefit cognitive ability (Sánchez et al., 2013). Further studies are required to ascertain the potential benefits of VR on cognition in stroke patients.

4.1 | Study strengths and limitations

The main strength of this systematic review is that we analysed the effects of VR on upper- and lower-limb motor function, balance, gait, cognition and daily function of stroke patients, including 87 randomized controlled trials from 15 countries and regions, which was the most comprehensive systematic review to date. Second, we conducted a more rigorous quality assessment of included studies, using Cochrane 'risk-of-bias tool' and PEDro scale, respectively, both of which have their own focus and advantages. Third, we further identified whether the duration of VR intervention affects health benefits. Additionally, this systematic review was conducted in strict accordance with the guideline of PRISMA.

Our study has several limitations that may affect the interpretation of the results. First, the type of VR program used may influence rehabilitation progress. Subgroup analysis was difficult in this review due to the range of VR programs used in different studies. Further studies are needed to compare the effects of different VR intervention types. Second, differences in baseline characteristics, form, dosage, and frequency of VR interventions resulted in increased heterogeneity among the included studies. According to the results of sensitivity analyses, no single study significantly influenced the overall results of most outcomes in this review. However, pooled data on ARAT and FIM were influenced by one study and the effects of VR on these parameters should be further examined via large-scale RCTs. In addition, this review failed to demonstrate the superiority of VR intervention over traditional training in terms of improvement in cognition, which may be attributed to the limited reports available that have focused on cognition as an outcome. Most VR projects to date have been focused on the rehabilitation of physical function, and effects on cognition thus require further evaluation.

5 | CONCLUSIONS

Data from this review indicate that VR is more effective in improving limb function, walking ability, balance, gait velocity, cadence and daily function than conventional rehabilitation. The issue of whether VR has advantages over traditional interventions in terms of improving cognitive function requires further investigation through large-scale multicentre RCTs.

AUTHOR CONTRIBUTIONS

Made substantial contributions to conception and design, or acquisition of data, or analysis and interpretation of data (BHZ, DL, YL, JNW, QX); Involved in drafting the manuscript or revising it critically for important intellectual content (BHZ, DL, YL, JNW, QX); Given final approval of the version to be published. Each author should have participated sufficiently in the work to take public responsibility for appropriate portions of the content (BHZ, DL, YL, JNW, QX); Agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved (BHZ, DL, YL, JNW, QX).

CONFLICT OF INTEREST

No conflict of interest has been declared by the authors.

OPEN RESEARCH BADGES

This article has earned a Preregistered Research Designs badge for having a preregistered research design, available at https://www.crd.york.ac.uk/PROSPERO/#myprospero.

PEER REVIEW

The peer review history for this article is available at https://publons.com/publon/10.1111/jan.14800.

DATA AVAILABILITY STATEMENT

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

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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