J. Phys. Ther. Sci. 36: 457–470, 2024

The Journal of Physical Therapy Science

Review Article

Effects of virtual reality on the balance performance of older adults: a systematic review and meta-analysis

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Abstract. [Purpose] Virtual reality has been increasingly used to improve the balance performance of older adults; however, the effect remains inconclusive. This study aimed to examine the effects of virtual reality on the balance performance of older adults through a systematic review and meta-analysis. [Methods] The PubMed, MEDLINE, CINAHL, Cochrane Library, and PEDro electronic databases were searched. Only randomized clinical trials published in English from January 1st, 1980, to September 30, 2022, were included and reviewed. Outcome measures included the Berg Balance Scale, Timed Up and Go Test and Activity-specific Balance Confidence scale. [Results] The results showed that virtual reality training for older adults led to significant improvements in Berg Balance Scale scores and Timed Up and Go Test times compared with non-virtual reality training. However, such an outcome was not observed with regard to the Activity-specific Balance Confidence scale. [Conclusion] Virtual reality training is effective in improving both static and dynamic balance among older adults. However, its effect on their self-confidence regarding balance is not significant.
Key words: Balance performance, Virtual reality, Older adults

(This article was submitted Mar. 5, 2024, and was accepted May 4, 2024)

INTRODUCTION

Falls are a common cause of injury and hospitalization among older adults. Approximately 28–35% of people over the age of 65 experience a fall each year. As the population ages, more people will be at risk of falls[1)]. Falls are caused by various factors that are broadly categorized as either internal (personal) or external (environmental) factors[2, 3)]. For people over the age of 65 years, the risk of falls is largely affected by declines in muscle mass, muscle strength, and balance[4)].

Balance control refers to one’s ability to maintain the body’s center of mass within the base of support[5, 6)]. The ability to maintain balance is a very complex process that involves multiple systems and requires rapid and precise changes to prevent falls[7)]. The maintenance of good balance requires robust integration of and coordination among the sensory, central nervous, and neuromuscular systems of the body[8)]. Thus, abnormal or inadequate sensory input due to aging of the sensory system

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may also make older adults more prone to falling[9]. Moreover, poor stereo acuity in older adults is a common contributing factor with respect to hip fractures caused by falls[10]. Therefore, to prevent falls among elderly individuals, it is necessary to improve their proprioceptive functions and restore their balance performance [11, 12]. Regular balance training for people over 60 years should improve basic elements of balance performance.

Although balance exercises are often recommended for older adults, all such exercises may not be suitable for every aged person. The conventional balance training methods include the following: asking older adults to stand on one foot with their eyes closed, to walk on a balance beam and to train in different directions on a balance board[13]. However, the main limitations of such training are as follows: lack of environmental and visual stimulation, repetitive training with the same movements, lack of motivation, and the challenge of finding an appropriate dose such that the patient does not lose interest[14–16]. Thus, determining how to make balance training more effective and interesting is an important issue related to the prevention of falls among elderly individuals.

Virtual reality is a computer generated three-dimensional virtual world which provides users with an analog experience of a virtual environment and the objects in it as they do in the real world. In VR balance exercises, participants visually move to different targets and bodies in the game pro version when performing tasks and somatosensory, and vestibular systems in improve balance and fear of falling in older women with a history of falls[17, 18] Further, VR can offer repetitive interactive games and activities. It makes balance training interesting. However, the number of repetitions and the exercise duration which make balance training effective are not yet understood. The research question for this meta-analysis was to explore balance-related exercises in older adults and to compare VR and non-VR. There are a variety of methods for detecting balance, fall prevention and self-balance confidence, such as the Berg Balance Scale (BBS), the Timed Up and Go test (TUG) and the Activity-specific Balance Confidence (ABC) scale. The ABC scale is often used as an indicator of fear of falls. Studies have shown that fear of falls may limit individual' physical activity and then tends to decreasing balance control. Very few studies mentioned the effect of VR on the self-confidence regarding balance (ABC scale). Therefore, we included ABS as an outcome measure in the study. Some studies have stated that balance training programs should include 3–6 weeks of VR intervention to be considered effective[15, 19, 20]. One study indicated that there was no statistically significant difference between training on the Nintendo WiiTM (Nintendo, Kyoto, Japan) and traditional physical therapy in improving balance among older adults over 65 years of age[21]. Therefore, further research is needed to determine the optimal duration and most effective VR balance training programs for older adults.

The purpose of this study was to systematically review studies on VR balance trainings given to elderly individuals, focusing on the duration of intervention, the design of the training content, the target outcomes, and the efficacy of the outcome measurement tool. This study also aims to understand the influence of VR training on confidence in balance or falls prevention. Thus, a meta-analysis was conducted to answer the following questions: (1) Does VR intervention improve balance performance among elderly individuals? (2) Does VR intervention improve older adults' self-confidence in their ability to control their balance? (3) What is the "minimum duration/dose" of VR training that can be considered effective for older adults' balance performance?

The answers to the above research questions could provide clinicians with a robust template regarding the use of VR in future intervention programs concerning older adults' balance performance.

PARTICIPANTS AND METHODS

This review was registered on the PROSPERO site (Registration number: CRD42021257390). The study was conducted in accordance with the methodological recommendations proposed by the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA 2020) set[22].

Eligibility criteria were formulated based on the PICOS framework[23]. Eligibility criteria were based on the PICOS framework[23].

(1) Participants: Participants were >60 years of age. (2) Intervention: We included studies that used VR training (e.g., computer games) to assess the effects of VR on balance performance among elderly individuals.

(3) Controls: Control interventions, including the effects of non-VR training on balance in older adults.

(4) Outcome: The primary outcome of this study was the use of the BBS, TUG, and ABC scale. This systematic review included randomized controlled trials that assessed the effects of VR on balance in older adults.

Balance ability comprises dynamic balance and static balance. Static balance is our ability to hold our body in a specific position and posture, while dynamic balance is our ability to maintain balance while moving our body and walking. Balance ability can be detected in various ways. The outcome measures related to balance included scores on the BBS, TUG, and ABC scale. The BBS evaluates aspects of both static balance and dynamic balance, such as stepping tasks and functional reach tasks; it is an efficient evaluation tool that has demonstrated good reliability and validity[20, 24–27]. Scores on the BBS range from 0 to 56, with a higher score indicating a better ability to maintain balance and a score less than 45 indicating a greater risk of falls[28]. In addition, the TUG is designed to evaluate the risk of falling and to measure the progress of balance performance (while sitting, standing, and walking). If a community-dwelling older adult takes 14 seconds or longer to complete this test, her or his risk of falling is considered high[29]. Shorter times indicate better performance. Finally, the ABC scale has been shown to exhibit retest reliability, high internal consistency, and effectiveness; it can also assess the level of confidence in maintaining balance and stability to perform activities of daily living. Specifically, the questionnaire contains 16 items related to basic daily tasks (e.g., walking around the house or walking up and down the stairs) and outdoor/community tasks (e.g., walking in a crowded shopping mall or using escalators to move). These items are rated on a scale with a range of 0 to 100. A score of zero represents no confidence, while a score of 100 represents complete confidence; a score lower than 50 indicates a low level of physical functioning characteristic of home care clients, whereas a score higher than 80 indicates high levels of confidence and physical function[30)].

To compare the literature on VR training for older adults, relevant papers were identified by searching databases from the 1980s to September 30, 2022. The methods employed for the data search included computerized database collection and a manual search of reference materials for related literature. The databases searched in this study included PubMed (January 1966), MEDLINE, CINAHL (January 1982), the Cochrane Library, and the Physiotherapy Evidence Database (PEDro). The keywords and Medical Subjects Headings (MeSH) terms were "virtual reality", "older adults", "The Berg Balance Scale (BBS)", "The Timed Up and Go (TUG) test " and "Activities-specific Balance Confidence scale (ABC)" and "balance". We used the population, intervention, comparison, outcomes, and study (PICOS) principle proposed by the Cochrane Collaboration: intervention (VR), comparison (conventional therapy (CT) or non-VR training intervention), outcomes (BBS, TUG, and ABC scale)) and study design (randomized controlled trial (RCT)). Additionally, the Boolean operators "AND"/"OR" were used.

The inclusion criteria for this systematic review were as follows: 1) written in English; 2) participants were healthy adults aged 60 years or older; 3) randomized controlled trial; 4) compared VR with balance exercises and non-VR with balance exercises; and 5) examined immersive VR, semi-immersive VR, or nonimmersive VR. The exclusion criteria were as follows: participants with a specific neurologic disorder and patients with an orthopedic disorder.

Duplicate publications and non-English publications were excluded. Full-text open-access articles were selected for the review. Thereafter, the two authors independently re-evaluated the eligibility of the remaining citations by examining the titles, abstracts, and texts of the articles. Any disagreements between the authors (Wan-Yun Huang and Rong-Ju Cherng) were resolved by discussion.

The quality of the selected relevant studies was assessed using PEDro scores. The PEDro scale consists of 11 items. The first item relates to external validity, and it is not included in the score. The remaining 10 items are summed, with a maximum score of 10. A score of 8 points or higher indicates a high-quality article, and a score of 5 or less points indicate a low-quality article[31)].

Moreover, the quality of the literature was evaluated by the two authors. Any disagreements were resolved by discussion or by consulting a person with relevant domain expertise.

The literature search revealed that each assessment tool was reported by a different number of studies, as shown in Fig. 1. Review Manager software version 5.3 (Nordic Cochrane Centre, the Cochrane Collaboration, Copenhagen, Denmark) was used for data analysis and the risk of bias assessment. The effects were estimated using the Der Simonian and Laird random effects methods, and they were expressed as mean differences (MDs) with a 95% confidence interval (95% CI) in accordance with the guidelines established by Cooper et al. The effect sizes were calculated for the BBS, TUG, and ABC scale outcomes as part of the summary statistics. The effect sizes of the interventions were defined as small (MD <10% of the scale), moderate (MD=10% to 20% of the scale) or large (MD >20% of the scale).

To reduce the impact of heterogeneity on statistical analysis, a heterogeneity test was also performed prior to this study's meta-analysis. In cases of high heterogeneity (I^2>50%), the random effects model was used to pool the study results for the outcomes. When heterogeneity was not found to be significant (I^2<50%), the fixed effects model was applied[32–34)].

RESULTS

A total of 697 potentially eligible articles were identified, of which 671 were excluded (Fig. 1). These articles were excluded for the following reasons: irrelevant titles; abstracts in proceedings; review articles; or nonoriginal articles. The full texts of the 26 remaining articles were screened, a process that was considered a qualitative synthesis of the literature on VR and balance performance among elderly individuals.

All the data and results are presented in Table 1[35–51)]. This table also includes a description of each study, including the author's name(s), years of publication, sample sizes, sex, age, content of intervention, intervention dosage, and main findings in terms of the measures of balance ability. Some studies that used VR interventions employed Wii Fit balance training, visual feedback balance interventions, VR training with three-dimensional (3D) video games and Microsoft Xbox 360, and dynamic balance exercises coupled with computer games.

The durations of the VR therapy sessions ranged from 30 to 60 minutes, as shown in Table 1. Regarding the frequencies of the programs, 13 studies applied 3 VR training sessions per week, 8 studies applied 2 sessions per week. Regarding the duration of the intervention, 16 studies applied VR training for 3–6 weeks, and the other studies conducted this training for 8–13 weeks.

The PEDro scores of the included studies ranged from 3 to 8, with an average score of 5.96 (Table 2). Ultimately, 3 studies were considered to be high-quality (PEDro ≥8).

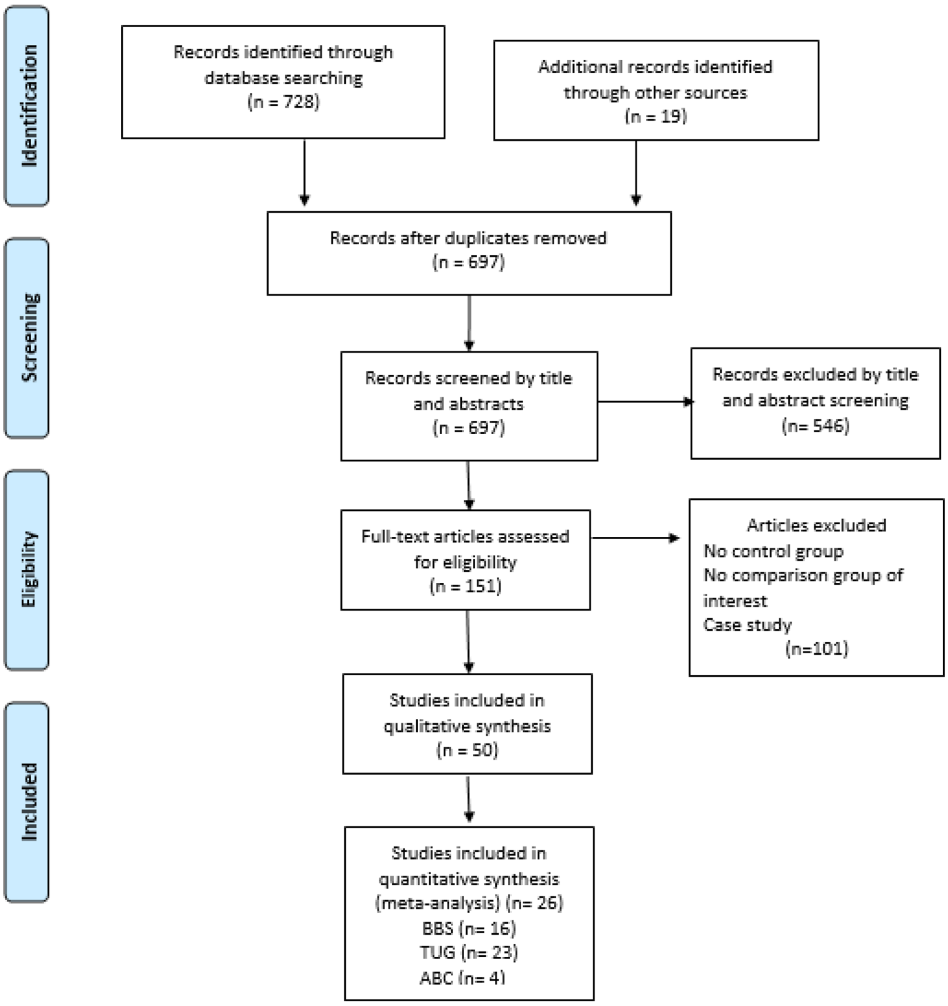

Fig. 1. Flowchart of the selection of included studies.
BBS: Berg Balance Scale; TUG: the Timed Up and Go test; ABC: the Activity-specific Balance Confidence scale.

The risk of bias analysis for the included studies is summarized in Fig. 2. This figure shows that 80% of the studies demonstrated selection bias regarding random sequence generation, and 52% of them failed to conceal allocation. In fact, most of the studies showed performance bias because the participants and personnel were not blinded. Only approximately 32% of the studies adopted blind assessors. Furthermore, 36% of the included studies had a low risk of attrition bias (incomplete outcome data).

In total, 16 studies that included 525 participants assessed static balance performance using the BBS. As the I^2 value of 78% indicated high heterogeneity, the random effects model was applied in this analysis. The results showed that participants receiving VR intervention (n=263) significantly increased their scores on the BBS compared with participants in the control group (n=262). The pooled MD showed that VR training improved balance ability significantly more than non-VR training (MD=3.41; 95% CI=2.33, 4.48; p<0.00001; Fig. 3).

Approximately 23 studies comprising 823 participants assessed dynamic balance performance using the TUG. Since the I^2 value of 66% indicated high heterogeneity, the random effects model was used for pooled analysis. The results showed that participants receiving VR intervention (n=422) took significantly less time to complete the TUG than those in the control group (n=413). The pooled outcomes were as follows: MD=−0.87; 95% CI=−1.38, −0.36 (p=0.0008; Fig. 4).

Only four studies examined the participants' self-confidence regarding their balance control with the ABC scale. The pooled analysis did not show a significant difference between the VR and control groups (MD=7.98; 95% CI=−7.26, 23.23; p=0.30; Fig. 5). In addition, the level of heterogeneity was found to be high (I^2 of 80%).

Table 1. Description of the studies included in the systematic review

Author(s) (data)	N (F/M)	Mean Age (SD) (years)	VR intervention	Control intervention	Intervention protocol	Outcome
Campo-Prieto et al.[35]	12 (? /?)	IVR: 91.67 ± 1.63	Immersive virtual reality	Group sessions	6 min+45 min	Tinetti Test
(2022)	IVR:6	Control: 90.83 ± 2.64	Training	(General mobility)	group sessions	Timed Up and Go Test (TUG)
Lee[27]	Control:6	VRGT: 81 ± 6.89	Virtual Reality Gait Training	Standard treadmill training	5 days/week	Simulator Sickness Questionnaire (SSQ)
(2021)	56 (31/25)	Control: 79 ± 6.15	with Non-Motorized	without virtual reality	10 weeks	System Usability Scale (SUS)
Hwang et al.[36]	VRGT: 28	Experimental:	Treadmill	Tabletop activity-based	50 min/day	Berg Balance Scale (BBS)
(2021)	Control: 28	70.1 ± 3.9	Reality-based cognitive training	cognitive training	5 days/week	One-Leg-Standing (OLS) test
Zahedian-Nasab et al.[16]	18 (9/9)	Control: 69.2 ± 4.1	(VRCT)	Routine programs	4 weeks	Timed Up and Go Test (TUG)
(2021)	Experimental: 9	Intervention:	Dove Console	(Jogging, table tennis, and	30 min/day	Functional Reach test (FRT)
Phu et al.[37]	Control:12	69 ± 7.72	Balance exercise	some artistic activities)	3 days/week	Gait parameter
(2019)	60 (16/44)	Control: 72 ± 7.80	(Xbox Kinect)	Control group	6 weeks	The Korean Mini-Mental State Examination (K-MMSE)
	Intervention: 30	BRU: 79 ± 5	Wii Fit, Balance Rehabilitation	education regarding their	30–60 min/day	Trail Making Test (TMT)
	Control: 30	Exercise: 76 ± 5.5	Unit (BRU)	falls risk	2 days/week	Digit Span Test (DST)
	195 (130/65)	Control: 79 ± 5			6 weeks	The 10-m Walking Test (10MWT)
	BRU: 63				30 min/day	Timed Up and Go Test (TUG)
	Exercise: 82				2 days/week	Berg Balance Scale (BBS)
	Control: 50				6 weeks	Timed Up and Go Test (TUG)
						The Falling Efficacy Scale (FES)
						The Falls Efficacy Scale-International (FES-I)
						Tanita Digital Scale
						Body Mass Index (BMI)
						5 Times Sit to Stand (5STS)
						Timed Up and Go Test (TUG)
						4 Square Step Tests (FSST)
						Gait speed
						Handgrip strength
Anson et al.[15]	40 (29/11)	ER: 75.7 ± 5.3	Visual feedback (VFB) balance	Control group	30 min	BESTest and mBEST scores
(2018)	VFB: 20	CG:75.8 ± 6.5	training during treadmill walking	Treadmill walking	3 days/week	Berg Balance Scale (BBS)
	Non-VFB: 20				4 weeks	Timed Up and Go Test (TUG)
						Activities-specific Balance Confidence Scale (ABC)
						6 min walk test (6MWT)
						Self-reported fall history in the previous 12 months

SD: standard deviation; VR: virtual reality; F: female; M: male; EG: experimental group; CG: control group.

Table 1. Continued

Author(s) (data)	N (F/M)	Mean Age (SD) (years)	VR intervention	Control intervention	Intervention protocol	Outcome
Haeger et al.[38] (2018)	37 (20/17) intervention group:16 control group: 21	Intervention group: 70.25 (± 3.77) control group: 72.38 (± 4.17)	A commercially available driving simulator (Carnetsoft BV, Groningen, NL) intervention group	Control group	50–60 min 3 days/week 4 weeks	The Precue task The D2-Attention task The Attention Window task The Grid Span task The Switching tasks The PAQ-50+ Timed Up and Go test (TUG) The Mini-Mental State Examination (MMSE)
Htut et al.[20] (2018)	84 (37/47) PE: 21 VRE: 21 BE: 21 CG: 21	Mean age: 75.8 ± 5.19 PE: 75.9 ± 5.65 VRE: 75.8 ± 4.89 BE: 75.6 ± 5.33 CG: 76.0 ± 5.22	Virtual reality-based exercise (VRE)	Control group Physical exercise (PE)	30 min/day 3 days/week 8 weeks	Berg Balance Scale (BBS) Timed Up and Go test (TUG) Muscle strength by 5 Times Sit to Stand (5TSTS) Hand grip strength (HGS) of the left and right hands Cognition by Myanmar-translated Montreal Cognitive Assessment (MoCA) Timed Up and Go Test cognition (TUG-cog) Falls Efficacy Scale International (FES-I) Borg Category Ratio Scale (Borg CR-10)
Lee et al.[39] (2017)	40 (23/17) VR group: 21 CG group: 19	EG:76.15 ± 4.55 CG:75.71 ± 4.91	Wii Fit gaming VR training with 3D Video games	Control group fall prevention education	60 min, 2 days/week 6 weeks	Static balance: good balance system and one leg stance test Dynamic balance: Berg Balance Scale (BBS) Functional reach test Timed Up and Go Test (TUG) Sit to stand test
Padala et al.[40] (2017)	30 (4/26) VR group: 15 CG group: 15	EG: 67.5 ± 8.1 CG: 69.0 ± 3.8	EG Wii-Fit program	Control group Brain-Fitness program	45 min, 3 days/week 8 weeks	Berg Balance Scale (BBS) Mini Mental State Exam (MMSE)
Queiroz et al.[41] (2017)	27 (16/11) EG: 13 CG: 14	EG: 60 ± 4.1 CG: 60.7 ± 3.6	EG the Microsoft Xbox 360 Kinect™ console	Control group The aerobic exercise training program	60 min 3 days/week 12 weeks	30-s chair stand test “Arm curl” test Timed Up and Go Test (TUG) 2-minutes step” test (2MST)
Ingenito et al.[42] (2016)	14 (8/6) EG: CG:	EG: 85.6 ± 8.8 CG: 74.4 ± 12.1	EG the Nintendo Wii bowling game	Control group their usual routine	30 min 2 days/week 8 weeks	Berg Balance Test (BBS) Timed Up and Go Test (TUG)

SD: standard deviation; VR: virtual reality; F: female; M: male; EG: experimental group; CG: control group.

Table 1. Continued

Author(s) (data)	N (F/M)	Mean Age (SD) (years)	VR intervention	Control intervention	Intervention protocol	Outcome
Kwok et al.[43] (2016)	80 (68/12) Gym: 40 Wii: 40	Gym: 69.8 ± 7.5 Wii: 70.5 ± 6.7	Nintendo Wii Active gaming exercises	Gym intervention (including 20 minutes of home exercises)	1-hour 1 day/week 12 weeks.	MFES Knee extensor strength (KES) Timed-Up-and-Go Test (TUG) Gait speed 6-minute walk test
Tsang et al.[26] (2016)	79 (48/31) Wii Fit balance training: 39 conventional balance training: 40	Wii Fit balance training: 82.3 ± 3.8 conventional balance training: 82.0 ± 4.3	Wii Fit balance training	Conventional balance Training	1-hour 3 days/week 6 weeks.	Berg Balance Scale (BBS) Timed Up and Go Test (TUG) Limits of stability Test test
Yeşilyaprak et al.[13] (2016)	18 (12/6) VR group: 7 conventional exercise group: 11	VR group: 70.1 ± 4.0 conventional exercise group: 73.1 ± 4.5	Virtual reality-based balance exercises	Conventional exercise group	55 min, 3 days/week 6 weeks	Berg Balance Scale (BBS) Timed Up and Go test (TUG) Standing balance tests Falls Efficacy Scale International (FES-I)
Park et al.[25] (2015)	24 (5/19) VR: 12 BE: 12	VR: 66.5 ± 8.1 BE: 65.2 ± 7.9	VR group Wii Fit balance exercise	Ball exercise	30 min 3 days/week 8 weeks	30 sec sway length Average sway speed with the open eyes Timed Up and Go Test (TUG)
Hsieh et al.[44] (2014)	8 (4/4) EG: 4 CG: 4	EG: 60.25 ± 5.5 CG: 67.25 ± 8.1	Virtual reality balance training	Control group	30 min 5 days/week 6 weeks	Timed-Up-and-Go Test (TUG) Berg Balance Scale (BBS)
Schwenk et al.[24] (2014)	32 (21/11) Intervention: 17 Control: 16	Intervention: 84.3 ± 7.3 Control: 84.9 ± 6.6	Interactive balance training program	Control group	45 min 2 days/week 4 weeks	30-second standing The CoM sways The Alternate-Step-Test (AST) Timed-up-and-go (TUG) Gait assessment
Bieryla et al.[45] (2013)	12 (10/2) EG:6 CG:6	EG: 82.5 ± 1.6 CG: 80.5 ± 7.8	Wii Fit training	Control group their normal daily activities	30 min, 3 days/week 4 weeks	Berg Balance Scale (BBS) Fullerton Advanced Balance Scale (FAB) Functional Reach (FR) Timed Up & Go Test (TUG)
Lai et al.[46] (2013)	30 (17/13) Group A: 15 Group B: 15	Group A: 70.6 ± 3.5 Group B: 74.8 ± 4.7	Group A: interactive video-game based (IVGB) training	Group B Control group No exercise	30 min 3 days/week 6 weeks	Berg Balance Scale (BBS) Timed Up and Go (TUG) Test Modified Falls Efficacy Scale (MFES) Unipedal Stance Test (UST) The XMSS stepping test

SD: standard deviation; VR: virtual reality; F: female; M: male; EG: experimental group; CG: control group.

Table 1. Continued

Author(s) (data)	N (F/M)	Mean Age (SD) (years)	VR intervention	Control intervention	Intervention protocol	Outcome
Schoene et al.[47] (2013)	32 EG: 15 CG: 17	EG: 77.5 ± 4.5 CG: 78.4 ± 4.5	DDR games (Dance Revolution)	Control group usual activities	15–20 min 2–3 days/week 8 weeks	Choice Stepping Reaction Time (CSRT) Physiological Profile Assessment (PPA) Timed Up & Go Test (TUG) Sit to Stand 5 times (5STS) Alternate Step Test (AST) Trail Making Test (TMT)
Singh et al.[48] (2013)	36 (36/0) Experimental group: 18 Control group: 18	Experimental group: 61.12 ± 3.72 Control group: 64.00 ± 5.88	Interactive virtual-reality games (The Wii Fit)	Therapeutic balance exercise group	30 min 2 days/week 6-weeks	Ten Step Test (TST) Postural sway (overall performance index, OPI) Timed Up and Go test (TUG)
Bateni[49] (2012)	12 (7/5) PT: 4 EG: 5	PT:72 ± 12 EG: 79 ± 13	EG (Wii Fit balance training)	Control group (Physical therapy balance training)	3 days/week 4 weeks	Berg Balance Scale Bubble Test
Franco et al.[50] (2012)	32 (25/7) Wii Fit: 11 Matter of balance: 11 Control: 10	Wii Fit: 79.8 ± 4.7 Matter of balance: 77.9 ± 6.9 Control: 76.9 ± 6.3	Wii Fit Matter of Balance	Control No intervention	10–15 min 2 days/week 3 weeks	The Berg Balance Scale The Tinetti Gait and Balance Assessment The SF-36
Laver et al.[21] (2012)	44 (35/9) Wii Fit group: 22 Conventional therapy: 22	Wii Fit group: 85.2 ± 4.7 Conventional therapy: 84.6 ± 4.4	Wii Fit Group interactive gaming program	Conventional physiotherapy	25 min 5 days/week 1 week	Timed Up and Go test Short Physical Performance Battery (SPPB) The Modified Berg Balance Scale (MBBS) The Timed Instrumental Activities of Daily Living (TIADL) test The Functional Independence Measure (FIM) The Activity-specific Balance Confidence Scale (ABC) The EQ5D
Szturm et al.[51] (2011)	27 (19/8) EG (14) CG (13)	EG: 80.5 (6) CG:81 (7)	Dynamic balance exercise coupled with computer games.	Typical rehabilitation program	45 min 2 days/week 8 weeks	Berg Balance Scale (BBS) Timed Up and Go Test (TUG) Spatial-temporal gait parameters Activities-specific Balance Confidence Scale (ABC) Clinical Test of Sensory Interaction and Balance (CTSIB)

SD: standard deviation; VR: virtual reality; F: female; M: male; EG: experimental group; CG: control group.

Table 2. PEDro Scores of the included studies

Study	Eligibility criteria	Random allocation	Concealed allocation	Baseline comparability	Participant blinded	Clinician blinded	Assessor blinded	Data for at least 1 outcome from >85% of Participants	No missing Data or if Missing intention-to-Treat Analysis	Between-groups analysis	Point estimates and variability	Total score (/10)
Campo-Prieto[35] (2022)	yes	1	0	1	0	0	0	1	1	1	1	6
Lee[27] (2021)	yes	1	0	1	0	1	1	1	1	1	1	8
Hwang et al.[36] (2021)	yes	0	0	1	0	0	0	1	1	1	1	5
Zahedian-Nasab et al.[16] (2021)	yes	1	1	1	0	0	0	1	1	1	1	7
Phu et al.[37] (2019)	yes	0	0	1	0	0	0	1	1	1	1	5
Anson et al.[15] (2018)	yes	1	1	1	0	0	1	1	0	1	1	7
Haeger et al.[38] (2018)	yes	0	0	1	0	0	0	0	0	1	1	3
Htut et al.[20] (2018)	yes	1	1	1	0	0	1	1	1	1	1	8
Lee et al.[39] (2017)	yes	1	1	1	0	0	1	1	0	1	1	7
Padala et al.[40] (2017)	yes	1	1	1	0	0	0	1	1	1	1	7
Queiroz et al.[41] (2017)	yes	1	0	1	0	0	1	0	0	1	1	5
Ingenito et al.[42] (2016)	yes	0	0	1	0	0	0	1	1	1	1	5
Kwok et al.[43] (2016)	yes	1	1	1	0	0	1	0	0	1	1	6
Tsang et al.[26] (2016)	yes	1	1	1	0	0	0	1	1	1	1	7
Yeşilyaprak et al.[17] (2016)	yes	1	1	1	0	0	0	1	0	1	1	6
Park et al.[25] (2015)	yes	1	0	1	0	0	0	0	0	1	1	4
Hsieh et al.[44] (2014)	no	0	0	1	0	0	0	1	1	1	1	5
Schwenk et al.[24] (2014)	yes	1	1	1	0	0	1	1	0	1	1	7
Bieryla et al.[45] (2013)	yes	1	0	1	0	0	0	0	0	1	1	4
Lai et al.[46] (2013)	yes	1	0	1	0	0	1	1	1	1	1	7
Schoene et al.[47] (2013)	yes	1	1	1	0	0	0	1	0	1	1	6
Singh et al.[48] (2013)	yes	1	0	1	0	0	0	1	0	1	1	5
Bateni[49] (2012)	yes	1	1	1	0	0	0	1	0	1	1	6
Franco et al.[50] (2012)	yes	1	0	1	0	0	0	1	0	1	1	5
Laver et al.[21] (2012)	yes	1	1	1	0	0	1	1	1	1	1	8
Szturm et al.[51] (2011)	yes	1	1	1	0	0	0	1	0	1	1	6

1= yes, 0=n. PEDro: physiotherapy evidence database.

DISCUSSION

The aim of the study was to examine the effect of VR intervention on balance performance among older adults through a systematic review and a meta-analysis of previous research. The results indicated that VR training was effective in improving static and dynamic balance among older adults, as evaluated by the BBS. VR training was also noted to be effective in improving functional mobility and reducing the risk of falls, as evaluated by the TUG. However, there was no significant effect of VR training on the ABC scale.

Our meta-analysis demonstrates that VR groups using a somatosensory game intervention demonstrated significant improvements with respect to the BBS[20, 21, 24, 25, 45, 44, 46]. The smallest minimum detectable change in scores on the BBS among elderly people was 3.3[52]. Moreover, in a VR intervention with a duration of 3–6 weeks, the concomitant MD value was found to be 3.14 (1.86 to 4.41; $p<0.00001$). When the VR intervention lasted for 8–12 weeks, the MD was found to be 4.84 (3.41 to 6.26; $p<0.000001$). The results of our study showed that virtual reality training improved participants' mean balance scores as a result of BBS enhancement. Therefore, these results implied that the intervention might have a sufficient duration and intensity for the argument that VR intervention would facilitate clinically detectable balance improvement in older adults.

Regarding the improvement of balance ability induced by VR interventions compared to other treatments, this study obtained the following results: individuals using VR intervention achieved better balance performance than those using

Fig. 2. Risk of bias assessment of the included studies.

conventional balance training. The former group yielded a significantly higher BBS score over three weeks[26]. Traditional balance exercise training will also improve the balance ability of older adults at 8 weeks[20, 51]. The VR intervention improved the balance ability of older adults more effectively than the non-VR intervention. A VR intervention lasting eight weeks can produce clinically detectable improvements in both static and dynamic balance performances among older adults.

The most likely reason behind this finding is that VR training provides cueing stimuli to improve balance ability in a motor-controlled, safe, and engaging environment, in addition to offering real-time performance feedback. The VR device used for training has four strain gauge load sensors that track body movements and provide visual feedback on such movements through a motion-detection system in a VR environment (with a 3D display)[42]. If the external environment changes, this shift is reflected by voluntary changes in trunk motion and internal sensory feedback, which leads to increased awareness of body movements during walking and improves static and dynamic balance performance[17].

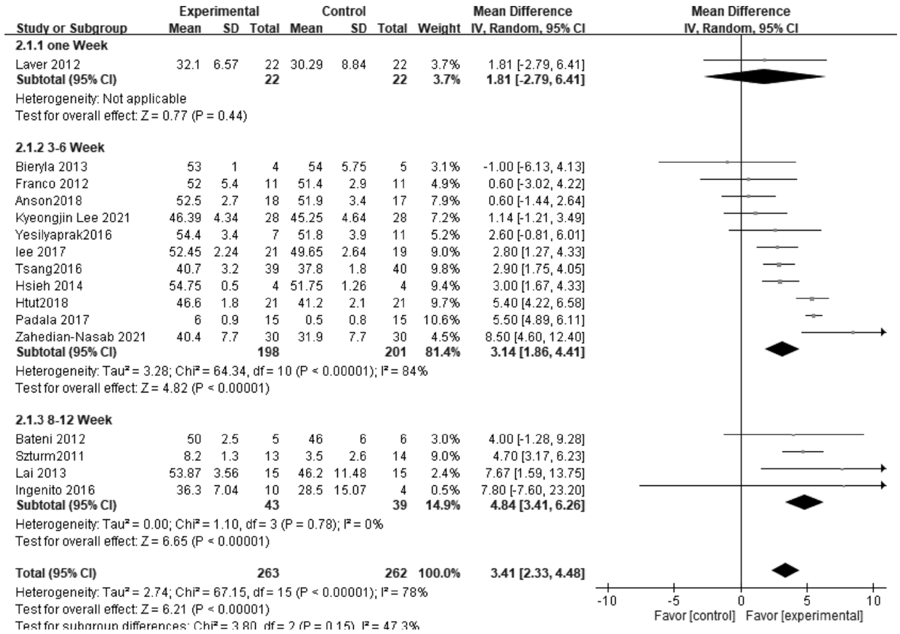

Fig. 3. Forest graph of the sensitivity analysis on the BBS between VR vs. non-VR. BBS: Berg Balance Scale; VR: virtual reality.

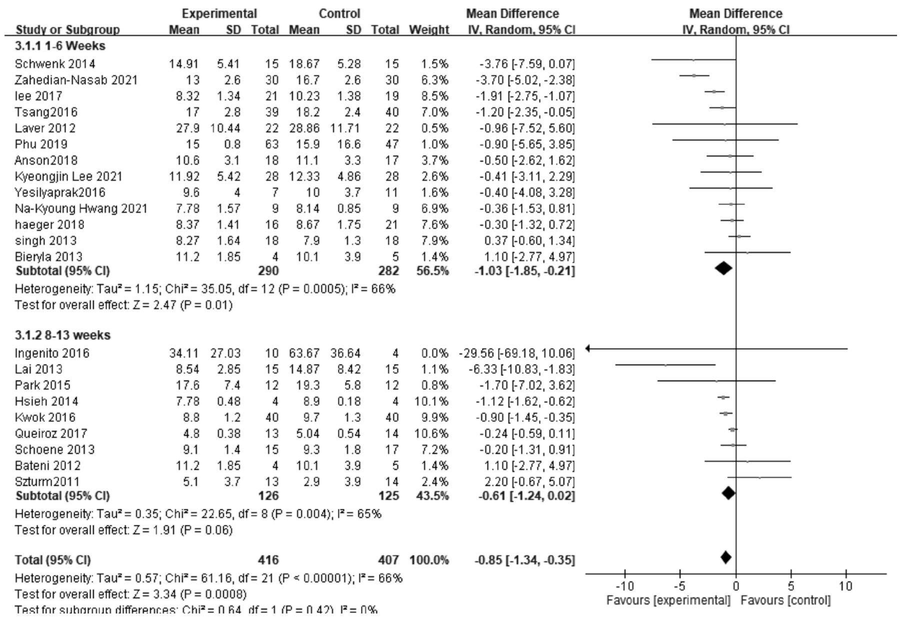

Fig. 4. Forest graph of the sensitivity analysis of the TUG between VR vs. non-VR. TUG: the Timed Up and Go test; VR: virtual reality.

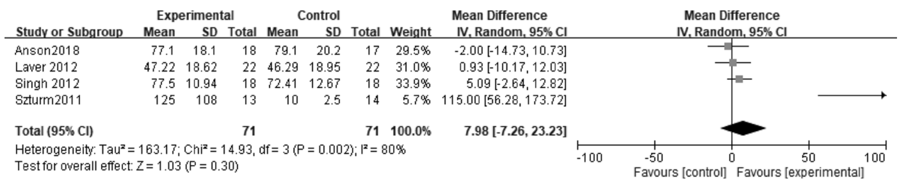

Fig. 5. Forest graph of the sensitivity analysis on the ABC scale between VR vs. non-VR. ABC: the Activity-specific Balance Confidence scale; VR: virtual reality.

Furthermore, VR-based training yielded significantly and slightly better results on the TUG over eight weeks[43]. VR with balance exercise training is physically and mentally challenging for older adults. During VR with balance exercise training, the direction, rate and speed of movement will constantly change and require rapid balance control of the body[48]. VR improved TUG scores over conventional balance training. Indeed, VR intervention requires older people to respond to visual and somatosensory input while performing various tasks in technologically simulated scenarios. Three types of VR are available: (1) immersive VR, where participants wear a VR head-mounted display or data gloves, controllers, and other sensing devices in the virtual space[53] (e.g., head-mounted display, World of WarCraft, Birdly, Nefertari); (2) semi-immersive VR, where participants use a computer screen or cast a screen and use multidimensional perceptual interaction systems that stimulate visual, auditory, tactile, and other perceptual needs[54] (e.g., flight simulator); and (3) nonimmersive VR, where the given scenario involves almost no VR technology but rather comprises a high-resolution display in a computer screen or a display projected onto a screen[13]. Notably, nonimmersive VR demonstrates the few side effects[55, 56]. A video game is a great example of a nonimmersive VR experience.

For older adults, self-confidence regarding activity-specific balance performance is important for activities of living. A lack of confidence in balance may lead to inactive lifestyles, which pose a disadvantage for elderly individuals. VR can simultaneously challenge proprioception, vision, vestibular sense and other sensory systems that affect balance control. This research analysis combines virtual reality (VR) with balance exercises to improve self-confidence. Four studies have measured balance self-confidence in older adults following VR interventions using the ABC scale and showed no statistically significant differences between the VR group and non-VR group[17, 21, 51, 57]. The ABC scale is a self-administered questionnaire designed to assess fear of falls[58]. and has a strong correlation (r=0.34–0.73) with common fall assessment tests[59]. However, the average ABC-6 scores recorded by the two groups in the study showed improvements of approximately 8% and 14%, respectively[57]. Therefore, it can be inferred that increasing balance confidence through participation in a VR intervention with balance training may reduce the risk of falls. The study performed by Singh noted that the duration of intervention had a significant effect on ABC scale scores in both the experimental and control groups[48]. Therefore, this study deduced that participation in VR interventions increases balance confidence and reduces the risk of falls among older adults. Although no statistical significance was found for the ABC scale (p=0.30), in the collected studies, increases in participants' scores on the ABC scale represented improvements in balance confidence after pretest and posttest ABC scale scores. It also implied that VR intervention improves self-confidence regarding balance control in older adults. Future studies are needed to confirm that VR interventions can improve self-confidence in balance control.

Aging of the body affects the interplay of somatosensory and visual systems during balance control[60]. The study showed that at least three weeks of VR training is necessary for the intervention to be effective in improving balance performance among elderly individuals. Additionally, to be effective in reducing the risk of falls, more than eight weeks of VR training is necessary. Generally, combined with VR games through Kinect, it can be said that these activities have different motor abilities, such as weight transfer, multidirectional displacement, high repetitions, auditory and visual feedback, decision-making and attention, thereby generating motivation to perform the task, and the individual will be able to achieve skill transfer to daily life and reduce the risk of falls[61]. With the advancement of technology, virtual reality has more commercialized applications and can be used by older people independently at home[40]. In this meta-analysis, the subjects were reportedly able to safely use immersive Wii Fit, and no adverse events were reported. Moreover, some studies designing VR-based balance exercises using video games at home have also been perceived positively by therapists[13, 44, 62].

Older people usually need more time to respond to balance control training. Likewise, VR intervention requires long-term training to effectively reduce the risk of falls. Therefore, combined VR training in virtual and physical environments can provide older adults with the opportunity to interact and receive intuitive feedback on their movement. The feedback from VR intervention also has the physiological reserve capacity to meet the related challenges in various situations and increase older people's self-confidence in their balance ability[63].

There were certain limitations in the present study. First, non-English manuscripts were excluded from this review. Second, the studies included in this meta-analysis had a high level of heterogeneity due to different types of non-VR and VR treatment. Whether VR can be used as an alternative to traditional exercise therapy remains unclear; more samples are needed to obtain higher-quality scientific evidence.

This systemic review and meta-analysis concluded that VR-based balance exercises training will also improve the balance ability of older adults. VR intervention improves the balance ability of older adults more than non-VR intervention. VR intervention over eight weeks can produce clinically detectable improvements in both static and dynamic balance performances among older adults. However, there was no significant effect with respect to the activity-specific balance confidence (ABC) scale. The results of a study showed that the value of the ABC scale of the VR group increased from 76.9 to 77.1, which may make it more difficult to identify measurable change in balance confidence[17].

Conference presentation

Wan-Yun Huang, Rong-Ju Cherng, (2019, Nov). A meta-analysis of the effect of virtual reality in improving balance performance in older adults. 2019, AHLA, Ho Chi Minh City, Vietnam.

Funding

Funding was provided by Kaohsiung Veterans General Hospital (Project VGHKS109-131).

Conflict of interest

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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