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Review Article

Effectiveness of Immersive Virtual Reality Simulation Programs Using Head-Mounted Displays in Promoting Physical Activity in Older Adults: A Systematic Review

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virtual reality;
simulation training;
exercise;
frail elderly;
systematic review

Abstract

Background: Given the projected rise in the older population and associated health challenges, there is growing interest in innovative interventions, such as virtual reality, to enhance physical and mental well-being. This systematic review examined the effectiveness of immersive virtual reality simulation programs with head-mounted displays to promote physical activity among older adults.

Methods: Studies were identified by querying PubMed, CINAHL, and Web of Science. A total of 2,365 articles were retrieved, and nine randomized controlled trials published between 2013 and 2023 were included.

Results: The studies indicated significant improvements in physical outcomes such as balance and gait, as well as psychological benefits including reduced anxiety, depression, and stress. Cognitive enhancements and improved quality of life were also noted. Despite concerns about usability and side effects, older adults found the simulation programs engaging and manageable, with minimal adverse effects reported.

Conclusion: This review highlights the promise of virtual reality with head-mounted displays for older adults, emphasizing the need for further research to optimize device design and usability and to explore long-term benefits and broader applicability.

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Introduction

The World Health Organization (WHO) projects that the percentage of the global population aged 60 years and older will almost double, increasing from 12% in 2015 to 22% by 2050 (World Health Organization, 2022). As the elderly population grows worldwide, interest in their health and welfare has intensified. Older adults face increased vulnerability to physical and mental health challenges during the COVID-19 pandemic, with an increased risk of social isolation (Batra, Morgan, & Sharma, 2020; Fanning et al., 2016). Fanning et al. (2016) observed that a rapid decline in physical capabilities can significantly impact older adults' quality of life (QOL), further diminishing their independence. Therefore, enhancing physical activity is essential for improving QOL and independence while lowering the risk of associated chronic diseases (Langhammer, Bergland, & Rydwik, 2018).

In recent years, rapid technological advances have significantly transformed healthcare and rehabilitation systems to enhance the care of older adults. Innovations such as virtual reality (VR), traditionally leveraged in education and entertainment, are increasingly utilized to promote the health of older adults (Calabrò et al., 2017). VR can be a beneficial assistive health technology for older adults, with the potential to assess and increase physical activity and mental conditions and promote overall health in the aging population (Garçon et al., 2016; Tuena et al., 2020). Prior research on using VR to enhance physical activity shows that it can provide experiences that approximate real life without inherent risks (Giakoni-Ramírez, Godoy-Cumillaf, Espoz-Lazo, Duclos-Bastias, & Del Val Martín, 2023). This accessibility enables the general population to participate in the exercise, even those who are hampered by illness (Eisapour, Cao, & Boger, 2020). VR programs can be customized to meet individual exercise needs, preferences, and conditions, offering greater control over intensity and personalized exercise experiences (Mouatt et al., 2020). They have been shown to improve physical and mental health and reduce social isolation, thereby becoming valuable tools in the field of rehabilitation of older adults (Baragash, Aldowah, & Ghazal, 2022).

However, the use of VR devices in older populations raises critical issues regarding usability and adaptability, which could reduce the effectiveness of such innovations. The design of VR devices and interfaces may not fully accommodate the specific ergonomic needs and usability concerns of older users, potentially limiting their accessibility (Lewis & Neider, 2017). Several challenges associated with technology use among older adults have also been reported, including difficulties in navigating interfaces, the potential for cybersickness (Li, Luh, Xu, & An, 2023; Podhorecka, Andrzejczak, Szrajber, Lacko, & Lipiński, 2021), falls or dizziness (Lazar, 2023). These aspects should be considered when implementing VR devices and similar technologies to ensure that they are beneficial tools for the healthcare of older adults.

Many prior studies have attempted to show that VR technologies have the potential to transform care for older adults, which can enhance the physical activity of the aging population. However, successfully integrating these modern technologies into healthcare for older adults involves overcoming drawbacks such as device usability, interface design considerations, and the practical usability of these technologies (Lee, Kim, & Hwang, 2019; Ramalho, Duarte-Mendes, Paulo, Serrano, & Petrica, 2024). Challenges such as the complexity of operating advanced VR with head-mounted displays (HMDs), the necessity for devices tailored to the ergonomic needs of older adults, and variations in capability levels considering specific demographics are critical barriers that must be addressed. Additionally, immersive displays of HMDs can complicate viewing angles and create potential glare, altering visual capabilities. While many studies have explored the use of VR in the health of older adults, the majority have focused on nonimmersive digital game activities and technologies displayed on flat screens such as televisions, computers, or mobile monitors (Bevilacqua et al., 2019; Hao, He, Yu, & Remis, 2023; Salatino et al., 2023). In contrast, we investigated how VR simulation programs using HMDs impact physical activity in older adults and reviewed the reported advantages and disadvantages in the literature.

This systematic review evaluates the research on how VR technologies with HMDs can be used to promote physical activity in older adults. The objective is to ascertain how these innovative technologies are feasible and effective in real-world settings, explicitly focusing on how they can be adapted to improve physical activity (primary outcome) and other related capabilities (secondary outcomes) of older adults.

Methods

Search Strategy

This study was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines provided by the PRISMA group (Moher, Liberati, Tetzlaff, & Altman, 2009). Three databases were searched: PubMed, Cumulative Index to Nursing and Allied Health Literature (CINAHL), and Web of Science. A list of the retrieved documents was compiled, and duplicates were removed. The bibliographic management software EndNote X9 was used to uniformly manage the bibliographic information of all documents. The search terms were based on the research population (P) of "older adults," the intervention (I) of "immersive virtual reality" and "head-mounted display," the comparison (C)

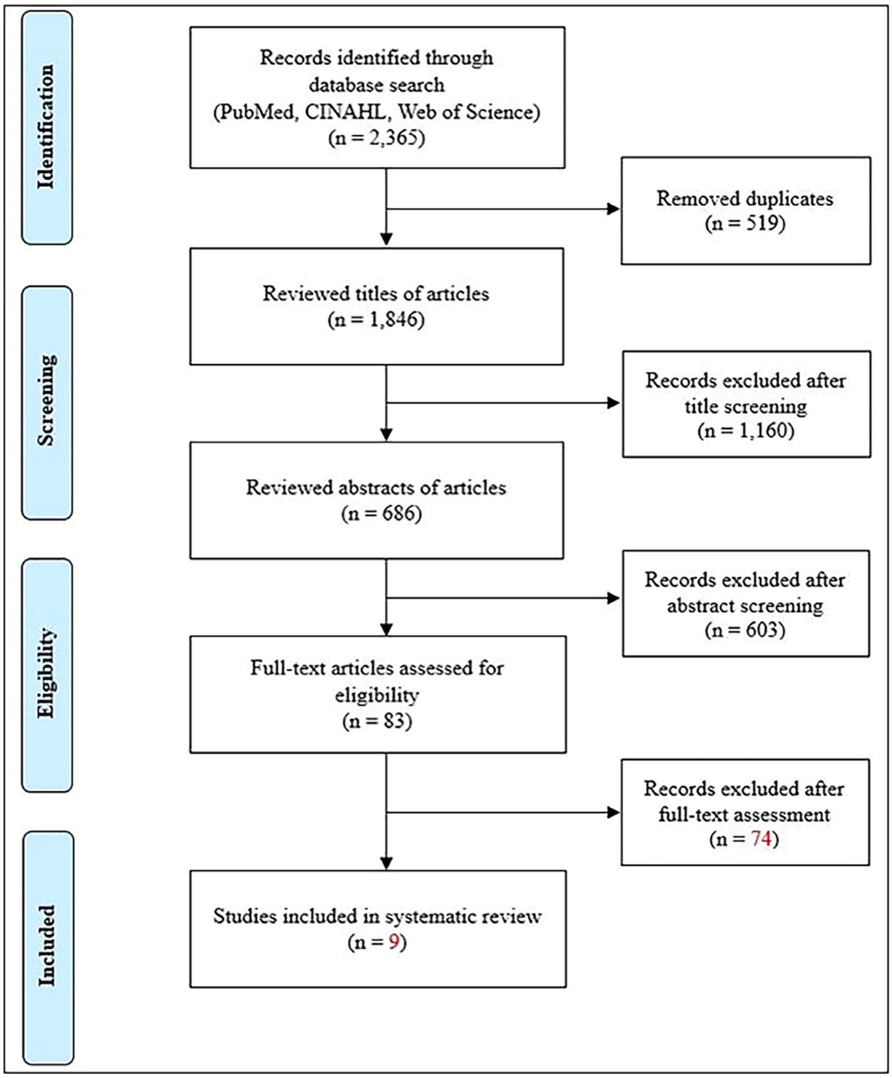

Figure 1 PRISMA flowchart of the identification and selection of studies (Source: Page et al., 2021).

of "traditional exercise programs" or "nonimmersive digital games," and the outcome variable (O) of "physical activity," including various synonyms to compose the search terms. The selection criteria for the review included: (1) studies involving older people without severe disease; (2) VR simulation program studies using HMDs; (3) randomized controlled trials (RCTs); and (4) studies published in English.

The PRISMA flowchart was utilized to detail the step-by-step process of literature selection based on the study aim and selection criteria (Figure 1). A total of 2,365 articles were retrieved from PubMed, CINAHL, and Web of Science. After initially removing 519 duplicate articles, 1,846 articles were reviewed by title. Subsequently, 686 articles were further reviewed by abstract, and 603 articles that did not meet the inclusion criteria were removed. A full-text review was conducted on 83 articles, and 74 articles that were inappropriate were excluded, resulting in a final selection of nine articles. Two researchers independently evaluated the literature search and selection and compared the results. Any discrepancies were resolved through re-evaluation of the original articles and discussion.

Risk of Bias Assessment

The risk of bias in the studies was assessed using the Cochrane Risk of Bias (RoB) 2.0 (Sterne et al., 2019). The Cochrane RoB 2.0 consists of bias arising from (1) the randomization process, (2) deviations from the intended interventions, (3) missing outcome data, (4) measurement of the outcome, and (5) selection of the reported result. Two researchers independently conducted quality appraisals using this tool, and any disagreements were resolved through joint review and discussion. The assessment results were categorized into three levels according to the content of

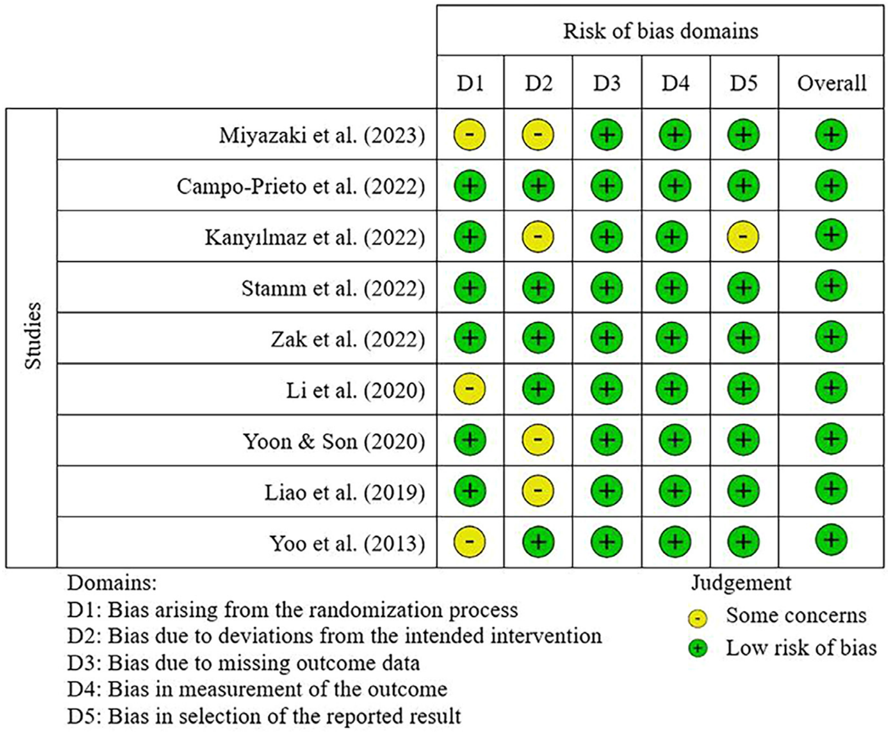

Figure 2 Risk of bias in included studies.

the literature: *low risk of bias, some concerns, and high risk of bias*.

Three studies were allocated to *some concerns* as bias arose from the randomization process (Li et al., 2020; Miyazaki et al., 2023; Yoo, Chung, & Lee, 2013). The remainder reported proper randomization, showing a *low risk of bias*. Four studies were found to show *some concerns* as bias due to deviations from intended interventions (Kanyılmaz et al., 2022; Liao, Chen, Lin, Chen, & Hsu, 2019; Miyazaki et al., 2023; Yoon & Son, 2020). Attrition in the statistical analysis was not accounted for. One study was judged as having *some concerns* due to selection of the reported result (Kanyılmaz et al., 2022). Furthermore, bias due to missing outcome data and bias in outcome measurements was well managed in all studies, resulting in a *low risk of bias* (Figure 2).

Results

General Characteristics and Research Methodology of the Included Studies

Nine RCTs were included in the systematic review. The general characteristics of the included studies are summarized in Table 1. The earliest study included in this review was published in 2013, and most of the studies were published after 2020 (n = 7). However, no studies have used a theoretical framework.

Table 1 – General Characteristics of the Included Studies.

Variable	Category	n
Publication Year	≤2019	2
	≥2020	7
Type of Study	Randomized control group	9
Use of Theoretical Framework	No	9
Mean Age of Participants	70-74 years	5
	75-79 years	2
	≥80 years	2
Gender	Both men and women	7
	Only women	2
Sample Size	<30	6
	30-59	2
	≥60	1
Setting	Gym	1
	Home	1
	Hospital	1
	Nursing home	1
	Not mentioned	5

The mean age of the participants was reported as 70-74 years in five studies, 75-79 years in two studies, and ≥80 years in two studies. Seven studies included both men and women, and two studies included only women. Most studies had a sample size of <30 (n = 6).

The research methodologies used in the included studies are presented in Table 2. Half of the studies conducted the intervention for 31-45 minutes per session (n = 5). The

Table 2 – Intervention and Measurements of the Included Studies.

Variable	Category	N
Intervention Time (Per Session)	<30 minutes	2
	31-45 minutes	5
	46-60 minutes	2
Intervention Frequency (Per Week)	2	1
	3	6
	5	2
Intervention Period	2 weeks	1
	3 weeks	2
	4 weeks	3
	10 weeks	1
	12 weeks	2
Follow-Up Frequency	1	7
	2	2
Follow-Up Period*	Immediately after intervention	9
	Post 4 weeks of intervention	1
	Post 24 weeks of intervention	1
Dependent Variables*		
Physical Aspects (Primary Outcomes)	Balance	6
	Gait	5
	Fall efficacy	2
	Range of motion	1
	Hand grip	1
	Knee function	1
	Back pain	1
Secondary Outcomes	Psychological aspects	
	Depression	2
	Affect	2
	Anxiety	1
	Cognitive aspects	
	Memory	2
	Attention	2
	Visuospatial ability	1
	Executive function	1
	Naming	1
	Quality of life	2
	VR and HMD usability	
	Experience of need satisfaction and system usability	3
	Side effect by using HMD	1

Note. HMD = head-mounted display; VR = virtual reality.
* Duplicated.

interventions were provided in three sessions per week in six studies and five sessions per week in two studies. The intervention period was four weeks in three studies, three weeks in two studies, and twelve weeks in two studies.

Follow-up measurements were taken after the intervention (only once) in seven studies and twice (post-intervention 1 and 2) in two studies. Physical activity (primary outcome), including measures such as balance and gait, was assessed alongside various secondary outcomes, including psychological factors (i.e., depression and affect), cognitive functions (i.e., memory and attention), overall QOL, and HMD usability.

Effects of VR Simulation Programs Using HMDs in Older Adults

Table 2 and Table 3 show detailed measurements, tools, and main results related to the effects of the VR simulation programs on physical aspects-the primary outcome variables of interest in this systematic review- and the secondary outcomes of psychological and cognitive aspects, QOL, and HMD usability in older adults.

The frequent measures for the physical aspects (primary outcome variables) were balance, gait, and fall efficacy, reported in six, five, and two studies, respectively. Range

Table 3 – Detailed Data Extraction of Each Study.

Author (Year)	Study aim	Country	Population	Sample Size (EG/CG)	Drop Out (EG/CG)	Gender (M:F) (%)	Mean Age	Intervention	Measurements (Tools)	Follow-Up	Main Results
Miyazaki et al. (2023)	To examine the effects of visuospatial ability and cervical spine ROM among older adult residents	Japan	Institutionalized older adults	24 (14/10)	4 (2/2)	(37.5: 62.5)	88.2	VR traveling program - 3 times/week - 30 minutes/session - for 4 weeks	1. Physical Assessment -Cervical Spine ROM - The motor function of the neck : flexion, extension, right and left rotation, right and left lateral flexion 2. Cognitive Assessment-Visuospatial ability 1) Montreal Cognitive Assessment (MoCA) (Ziad et al., 2005) 2) The Money Road Map Test (MRMT) (Money et al., 1965) 3. Psychological Assessment -Mood state 1) Center for Epidemiologic Studies Depression (CES-D) (Radloff, 1977) 2) Positive And Negative Affect Schedule (PANAS) (Watson, 1988)	2 times • Pre • Post (4 weeks)	• EG showed significant improvements in visuospatial/executive (p = .0141), naming (p = .0017), language (p = .0377), abstraction (p = .0001) in MoCA sub-scores, visuospatial ability independent of memory capacity (MRMT) (p = .0084) and mood state (PANAS) (p = .0435). Active Flexion (p = .0198), Passive Flexion (p = .0169), Passive Right Rotation (p = .0124). • No statistical significance was found in the attention, delayed recall, orientation (MoCA), depression (CES-D), Active/Passive Extension, Active Right Rotation, Active /Passive Left Rotation, Active/Passive Right/left Lateral Flexion (Cervical Spine ROM).

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Table 3 (continued)

Author (Year)	Study aim	Country	Population	Sample Size (EG/CG)	Drop Out (EG/CG)	Gender (M:F) (%)	Mean Age	Intervention	Measurements (Tools)	Follow-Up	Main Results
Campo-Prieto et al. (2022)	To examine the effects of an IVR exergame program on physical function, QOL, & player experience (cybersickness, usability, & postgaming experience)	Spain	Institutionalized older adults	24 (13/11)	None	(16.67:83.33)	84.95	IVR exergame program - 3 times/week - 18 minutes/session - for 10 weeks	1. Physical Assessment 1) Balance and Gait: Tinetti test (Tinetti et al., 1986) 2) Functional mobility, lower limb function (1) Timed Up & Go test (TUG) (Podsiadlo & Richardson, 1991) (2) Five Times Sit-To-Stand test (FTSTS) (Guralnik et al., 1994) 3) Hand Grip Strength (HGS) 2. QOL : 12-item Short Form Survey (SF-12) (Ware et al., 1996) 3. Usability 1) Cybersickness: Simulator Sickness Questionnaire (SSQ) (Campo-Prieto et al., 2021) 2) Usability: System Usability Scale (SUS) (Brooke, 1995) 3) Player experience: Game Experience Questionnaire (GEQ postgame module) (Ijsselsteijn et al., 2013)	3 times • Pre • Post 1 (10 weeks) • Post 2 (14 weeks)	• EG showed significant improvements in balance ($p < .001$), gait ($p < .001$), total score (Tinetti) ($p < .001$), handgrip (HGS) ($p < .001$) of the physical function, & the physical component of QOL score ($-0.29 \pm 6.26 \rightarrow 2.34 \pm 13.09$). • It showed low negative experience on the game experience and good postgaming usability. There were no cybersickness symptoms.

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Table 3 (continued)

Author (Year)	Study aim	Country	Population	Sample Size (EG/CG)	Drop Out (EG/CG)	Gender (M:F) (%)	Mean Age	Intervention	Measurements (Tools)	Follow-Up	Main Results
Kanyılmaz et al. (2022)	To examine the effects of VR vestibular rehabilitation exercises with real-world environments on the physical function (static and dynamic balance, & functional mobility dizziness) & psychological aspect (fear of falling, anxiety, & depression)	Turkey	Older adults who present to an ear, nose, & throat complaining of dizziness	32 (16/16)	6 (3/3)	(38.46:61.54)	70.0	VR vestibular rehabilitation exercises - 5 times/week - 30 minutes/session - for 3 weeks	1. Physical Assessment 1) Balance ability (1) Dynamic balance: Berg Balance Test (BBT) (Berg et al., 1992), (translated into Turkish by Sahin et al., 2008) (2) Postural stability tests: Dynamic Posturography Biodex Balance System (Parraca et al.,2011) (3) Functional mobility: Timed Up & Go test (TUG) (Jones et al., 1999) (4) Falls Efficacy Scale-International (FES-I) (Yarley et al., 2005), (translated into Turkish by Ulus et al., 2012) 2) Vestibular Questionnaire Data (1) Dizziness symptoms scale: Vertigo Symptom Scale (VSS) (Yardley et al., 1992), (translated into Turkish by Yanik et al., 2008) (2) Dizziness Disability Scale: Dizziness Handicap Inventory (DHI) (Jacobson & Newman, 1990), (translated into Turkish by Canbal et al., 2016) 2. Psychological Assessment (of dizziness) 1) Geriatric Depression Scale (GDS) (Yesavage et al., 1983), (translated into Turkish Ertan et al., 1997) 2) Hamilton Anxiety Scale (HAS) (Hamilton, 1959), (translated into Turkish by Yazıcı et al., 1998)	3 times • Pre • Post 1 (3 weeks) • Post 2 (24 weeks)	• EG showed statistically significant improvements in dizziness symptoms (VSS), dizziness disability (DHI), and total scores, balance (BBT) of the physical assessment, & anxiety (HAS) of the psychological assessment at the 6-months after the treatment (all ps <.05). • There was no statistical significance in functional mobility (TUG), fall efficacy (FES-I), & depression (GDS).

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Table 3 (continued)

Author (Year)	Study aim	Country	Population	Sample Size (EG/CG)	Drop Out (EG/CG)	Gender (M:F) (%)	Mean Age	Intervention	Measurements (Tools)	Follow-Up	Main Results
Stamm et al. (2022)	To examine the effects of a VR multimodal therapy in elderly patients with chronic low back pain on the physical function (changes in pain intensity & functional ability) & psychological aspect (fear- avoidance beliefs)	Germany	Older adults with chronic back pain	22 (11/11)	None	(36.36:63.64)	75.25	VR multimodal therapy - 3 times/week - 30 minutes/session - for 4 weeks	1. Physical Assessment (Pain-related Assessment) 1) Self-reported current pain intensity: Numeric Rating Scale (NRS) 2) Severity of chronic pain : Chronic Pain Grade Questionnaire (CPGQ) (Von Korff et al., 1992) 3) Back pain-related disability : Hannover Functional Ability Questionnaire (Ffb-H-R) (Kohlmann & Raspe, 1996) 2. Psychological Assessment - Fear-avoidance beliefs : Tampa Scale of Kinesiophobia (TSK-11) (Woby et al., 2005) 3. Usability (Player Experience) 1) Degree of immersion : Technology Usage Inventory (TUI); Technology-specific and psychological factors that contribute to the actual use of a technology) 2) Experience with interactive products : User Experience Questionnaire (UEQ) 4. QOL : 12-Item Short Form Survey (SF-12) (Ware et al., 1996)	2 times • Pre • Post (4 weeks)	• EG showed statistically significant improvements in the functional capacity (Ffb-H-R) (p = .026) of the physical assessment. • There was no statistical significance in pain intensity (NRS), severity of chronic pain (CPGQ), fear-avoidance beliefs (TSK-11), & QOL. • It showed a higher degree of immersion after using VR, and the participants rated VR as above average regarding user experience (UEQ).

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Table 3 (continued)

Author (Year)	Study aim	Country	Population	Sample Size (EG/CG)	Drop Out (EG/CG)	Gender (M:F) (%)	Mean Age	Intervention	Measurements (Tools)	Follow-Up	Main Results
Zak et al. (2022)	To examine the effects of a VR OCULUS-based rehabilitation program on physical function (balance, gait, & aerobic ability) & dual-task performance	Australia	Older adults	60 (45/15)	None	(40:60)	77.6	Physiotherapy programs with VR solutions Exp. Group • E1: VR Group • E2: Dual-task + VR Group • E3: OCULUS Group - 3 times/week - 30 minutes/session - for 3 weeks	1. Physical Assessment 1) Balance ability (1) Berg Balance Scale (BBS) (Berg, 1992) Part one, (2) 10-M Walk test (10 MW) (Wolf et al., 1999) (3) Part one (POMA B) (Abrams et al., 1999) (4) Single-Leg Stance test (SLS) (Jacobs et al., 2006) 2) Gait (1) Timed Up & Go test (TUG) (Podsiadlo & Richardson, 1991) (2) Part two (POMA G) (Abrams et al., 1999) 3) Aerobic endurance : 2 Minutes Step test (2MS) (Rikli & Jones, 1999) 2. Dual-task Assessment - Trail-Making Test (TMT) (Corrigan, 1987)	2 times • Pre • Post (3 weeks)	• E3 (OCULUS) showed significantly higher scores in gait (TUG), and static balance (SLS) with closed eyes ($p < .001$) of the physical assessment. • E2 (Dual-task + VR) showed significantly higher scores in static balance (SLS) with open eyes ($p < .001$) of the physical assessment. • There was no statistical significance in balance (BBS, POMA total, 10MW), aerobic endurance (2MS), & dual-task ability (TMT).
Li et al. (2020)	To examine the effects of VR multitasking motion video games on the physical function, cognitive function, & player experience	Japan	Older adults	20 (10/10)	Not mentioned	(35:65)	73.1	VR motion video game - 3 times/week - 45 minutes/session - for 4 weeks	1. Physical Assessment 1) Balance ability : One-Leg Sanding Balance Test (OLSBT) (Vellas et al., 1997) 2. Cognitive Assessment 1) Working memory : Adaptive n-Back Test (Susanne et al., 2010) 2) Reasoning : Raven's Standard Progressive Matrices (SPM) (Burke, 1972) 3) Attention : Attention Network Task (ANT) 3. Usability (Player Experience) 1) Positive Affect Negative Affect Schedule (PANAS) (Watson & Clark, 1994) 2) Intrinsic Motivation Inventory (IMI) (Ryan, 1982) 3) Player Experience of Needs Satisfaction (PENS) (Deci & Ryan, 2000)	2 times • Pre • Post (4 weeks)	• EG showed statistically significant improvements in working memory (n-Back) ($p < .001$), reasoning (SPM) ($p < .05$), attention (ANT) ($p < .001$) in terms of cognitive assessment, also in balance (OLSBT) (time: $p < 0.05$) in terms of physical assessment. • There was a negative correlation ($p < .05$) between the average IMI and improvement in response time for ANT and a positive correlation ($p < .05$) between the average IMI and improvement in accuracy for SPM. • They presented a good game experience during the intervention (PENS).

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Table 3 (continued)

Author (Year)	Study aim	Country	Population	Sample Size (EG/CG)	Drop Out (EG/CG)	Gender (M:F) (%)	Mean Age	Intervention	Measurements (Tools)	Follow-Up	Main Results
Yoon and Son (2020)	To examine the effects of VR FIVR exercise program on the physical function (balance & knee function)	South Korea	Elderly women who total knee replacement patients	36 (18/18)	6 (3/3)	(0:100) All women	72.06	VR FIVR exercise program - 5 times/week - 20 minutes/session - for 2 weeks	1. Physical Assessment 1) Balance ability : Using Biorescue device (static balance, dynamic balance, sitting, standing, anterior, posterior, left, right, movements, CoM; The Motion of Body Center of Mass During Walking) 2) Gait ability : Timed Up & Go test (TUG) (Podsiadlo, 2006) 3) Knee function : Western Ontario and McMaster Universities (WOMAC) (Bellamy, 1989)	2 times • Pre • Post (2 weeks)	• EG showed statistically significant improvements in surface area of ellipse (SAE) ($p = .003$), length ($p = .001$) of the static balance ability, & in all variables dynamic balance ability ($p < .001$) in terms of the physical assessment. • There was no statistical significance in gait ability (TUG) and knee function.
Liao et al. (2019)	To examine the effects of VR physical and cognitive training programs on physical function & dual-task gait performance	Taiwan	Older adults with cognitive impairment	42 (21/21)	8 (3/5)	(32.35:67.65)	74.3	VR physical and cognitive training program - 3 times/week - 60 minutes/session - for 12 weeks	1. Dual-task Assessment (physical & cognitive assessment) 1) Single task: walking at their preferred walking speed 2) Cognitive dual task: walking while executing a serial subtraction by three tasks, starting from a randomized 3-digit number 3) Motor dual task: walking while carrying a tray with glasses of water 2. Cognitive Assessment 1) Trail Making Test (TMT) (translated into Chinese by Wang et al., 2018) 2) Stroop Color and Word Test (SCWT) (modified by Wang et al., 2018)	2 times • Pre • Post (12 weeks)	• EG showed significant improvements in gait speed ($p = .002$), stride length ($p = .003$) of the motor dual-task gait, and gait speed ($p = .003$), stride length ($p = .001$), dual-task costs of cadence ($p = .024$) in the dual-task assessment.

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Table 3 (continued)

Author (Year)	Study aim	Country	Population	Sample Size (EG/CG)	Drop Out (EG/CG)	Gender (M:F) (%)	Mean Age	Intervention	Measurements (Tools)	Follow-Up	Main Results
Yoo et al. (2013)	To examine the effects of VR Otago exercises on the physical function (balance & gait) & psychological aspect (fall efficacy)	South Korea	Elderly women	21 (10/11)	Not mentioned	(0:100) All women	74.27	VR Otago exercise - 3 times/week - 60 minutes/session - for 12 weeks	1. Physical Assessment 1) Balance ability : Berg Balance Scale (BBS) (Berg et al., 1995) 2) Gait ability (velocity, cadence, step length, stride length) : GAITRite system (McDonough et al., 2001) 3) Fall efficacy : Falls Efficacy Scale-International (FES-I) (modified by Kempen et al., 2008)	2 times • Pre • Post (12 weeks)	• EG showed statistically significant improvements in balance (BBS) ($p < .001$), gait velocity ($p = .001$), gait cadence ($p < .001$), left side stride length ($p = .041$), right side step length ($p = .011$), right side stride length ($p = .019$) of the physical assessment. • EG showed statistically significant improvements in the fall efficacy (FES-I) (p=.019).

Note. CG = control group; EG = experimental group; F = female; FIVR = full immersion virtual reality; IVR = immersive virtual reality; M = male; QOL = quality of life; ROM = range of motion; VR = virtual reality.

of motion, hand grip, knee function, and back pain were measured in each of the one study. VR simulation programs have shown significant improvements in balance and gait, as measured using the Tinetti test (Campo-Prieto, Cancela-Carral, & Rodríguez-Fuentes, 2022). They also showed significant improvements in balance ability as measured using the Berg Balance Test (BBT) (Kanyılmaz et al., 2022; Yoo et al., 2013), the Biorescue device (Yoon & Son, 2020), and the One-Leg Standing Balance Test (OLSBT) (Li et al., 2020). Static balance measured using the Single-Leg Stance test (SLS) showed significant improvements in a study by Zak et al. (2022). Significant improvements were observed in gait speed, cadence, and stride length (Li et al., 2020; Yoo et al., 2013). However, one study reported no significant improvement in gait ability (Yoon & Son, 2020). Fall efficacy was measured using the Fall Efficacy Scale-International (FES-I) in two studies. One study showed a significant improvement (Yoo et al., 2013), however, another did not show statistical significance in fall efficacy (Kanyılmaz et al., 2022).

Psychological measures (secondary outcomes) of participants, such as depression, affect, and anxiety, were measured in three studies. VR simulation programs have demonstrated statistically significant improvements in affect using the Positive and Negative Affect Schedule (PANAS) (Miyazaki et al., 2023) and anxiety and depression using the Hospitalized Anxiety and Depression Scale (HADS) (Kanyılmaz et al., 2022).

Cognitive aspects (secondary outcomes) of participants, such as memory and attention, were measured in each of the two studies, and visuospatial ability, executive function, and naming were measured in each of one study. VR simulation programs have shown statistically significant improvements in memory capacity measured using the Money Road Map Test (MRMT) (Miyazaki et al., 2023). Additionally, improvements in working memory were measured using the adaptive n-Back Test (Li et al., 2020), and attention was measured using the Attention Network Task (ANT) (Li et al., 2020). However, there was no statistically significant improvement in attention and naming measured by using the Montreal Cognitive Assessment (MoCA) (Miyazaki et al., 2023).

QOL (secondary outcome) was measured using the 12-item Short Form Survey (SF-12) in two studies of VR simulation programs. One study presented a statistically significant improvement (Campo-Prieto et al., 2022), while another reported no significant improvement in QOL (Stamm, Dahms, Reithinger, Ruß, & Müller-Werdan, 2022).

HMD usability outcomes (secondary outcomes) of participants, such as need satisfaction and system usability, were measured in three studies, and the side effects of using HMD were measured in one study. The experience of need satisfaction of VR with HMD usability was measured using the Game Experience Questionnaire (GEQ) and System Usability Scale (SUS), which showed low negative experiences with the game experience and good postgaming usability (Campo-Prieto et al., 2022). Additionally, measurements using the Experience of Needs Satisfaction (PENS) revealed a positive game experience during the intervention (Li et al., 2020). Player experiences of immersion and interaction were measured using the Technology Usage Inventory (TUI) and User Experience Questionnaire (UEQ), which showed a higher degree of immersion after the use of VR, and participants rated VR as having above-average scores for user experiences (Stamm et al., 2022). Campo-Prieto et al. (2022) used the Simulator Sickness Questionnaire (SSQ) to measure side effects of using HMDs and found no significant symptoms of cybersickness. This indicates that the technology is feasible.

Discussion

This systematic review examined existing RCTs that explore the use of VR simulations with HMDs to enhance physical activity among older adults. The findings suggest that VR simulation programs using HMDs significantly improved older adults' physical activity (primary outcome). Additionally, it was found that, alongside physical activity, these programs had a significant positive impact on psychological and cognitive dimensions and overall QOL (secondary outcomes), while the use of HMDs did not lead to notable negative issues, such as cybersickness.

Most of the studies examined in our review demonstrated significant improvements in older adults' physical activity such as balance and gait. These technologies simulate real-life controlled environments, helping older adults enhance their physical capabilities in realistic settings (Šlosar et al., 2022). Improvements in balance and gait can directly reduce the risk of falls and enhance independent living capabilities and overall QOL in older adults (Dunsky, 2019). Moreover, VR with HMDs offers engaging and motivating exercise experiences and encourages long-term participation among older adults (Karamians, Proffitt, Kline, & Gauthier, 2020). Future research should focus on how these technologies can be more effectively tailored to the needs of older users, thereby improving their ease of use and accessibility. Such studies will clarify how VR with HMDs can enhance older adults' physical health and pave the way for broader adoption of these technologies. In addition, VR technologies can provide real-time feedback on exercise performance (Geisen & Klatt, 2022). This enables older participants to interact directly with healthcare providers or program managers to refine their movements, thus maintaining interest in and encouraging sustained physical activity.

The included studies of Campo-Prieto et al. (2022) and Stamm et al. (2022) demonstrate the user-friendliness and high immersion levels of VR systems, highlighting their strong usability and minimal negative experiences for older adults. These results indicate that the VR technology can meet the complex needs of older adults. However, it is important to recognize that some studies advocate one-on-one assistance during VR sessions to ensure safety (Miyazaki et al., 2023), including presession safety training by physicians and the use of support equipment to prevent unexpected falls (Campo-Prieto et al., 2022). Other research advocates that exercise be supervised by healthcare providers (Stamm et al., 2022; Zak et al., 2022). Nevertheless, the future goal of VR technologies should be to develop tools that older adults can use independently (Hamad & Jia, 2022). For example, a previous study showed that the use of a virtual coach allowed seniors to exercise safely and independently at home (Beristain Iraola et al., 2021). This virtual coach was designed to be perceived as a socially integrated entity within the physical environment, thereby enhancing users' engagement and adherence to exercise routines (Beristain Iraola et al., 2021). Further research is required to fully realize the potential of VR with HMDs to improve the lives of older adults. Designs and contents should be customized for older adults, assessing their acceptance of VR and HMD technologies, and evaluating their engagement and sustainability. Additionally, strategies to bridge the age-related digital divide are critical to lower barriers to these technologies and improve accessibility for older adults (Seifert & Schlomann, 2021). With these improvements, VR with HMDs can help older individuals remain independent and integrate these technologies into their daily physical activity routines, ultimately improving their QOL.

Several studies found that VR simulation programs significantly improved older adults' psychological aspects, such as mood (Miyazaki et al., 2023), anxiety (Kanyılmaz et al., 2022), and depression (Kanyılmaz et al., 2022). These insights are important, given the high rates of depression and social isolation among older adults. VR can improve psychological well-being by facilitating virtual emotional engagement and social interaction. For example, a study by Schutte and Stilinović demonstrated that VR could evoke social emotions, such as gratitude, and connect individuals to the wider virtual world, even those in isolated settings like homes or care facilities (Schutte & Stilinović, 2017). This sense of connection can alleviate loneliness and increase psychological resilience. VR simulations should be customized to consider psychological factors, physical functioning, diet, and health status (Grønning et al., 2018). Pardini et al. also confirm that customized VR environments and experiences can address issues such as anxiety in older adults (Pardini et al., 2023). Future VR simulation programs for the care of older adults should be personalized to meet each user's situation and preferences. This approach can maximize the therapeutic potential of VR to enhance physical and psychological well-being and improve the QOL of older adults.

Older adults often experience a decline in sensory functions, such as vision and hearing. However, the literature indicates that older participants are receptive to VR with HMDs (Campo-Prieto et al., 2022; Li et al., 2020; Stamm et al., 2022), which challenges the preconceived notion that older adults may have difficulty using these advanced technologies because of sensory decline or ergonomic issues (Nicosia et al., 2022). VR devices should be customized for the sensory abilities of older adults. Such customized VR simulation programs will become even more essential, especially for older adults with certain medical conditions, enabling wider adoption of VR technology in senior healthcare.

However, it is important to note that not all studies showed improved outcomes. While many studies reported significant benefits in physical activity, psychological well-being, and cognitive function, some studies did not observe statistically significant improvements. These inconsistencies highlight the need for further research to better understand the factors that influence the effectiveness of VR with HMD interventions in older adults.

Based on the findings of this systematic review, several specific improvements can be suggested for VR technology with HMDs to better cater to older adults. First, ergonomic design is crucial. HMDs should be lightweight and feature adjustable devices to ensure comfort during use. Simplifying the user interface with voice-activated commands and larger text can enhance usability for those with visual impairments. Additionally, customizable settings for motion sensitivity and visual contrast can help reduce issues like cybersickness (Lewis & Neider, 2017). Safety features such as virtual boundaries and alerts for prolonged use are essential to prevent accidents like falls. Developing VR content tailored to older adults, such as virtual tours and cognitive exercises, can make the experience more engaging and relevant (Lee et al., 2019). Lastly, comprehensive training and technical support, including instructional videos and workshops, can significantly improve older adults' proficiency with VR technology (Tuena et al., 2020). By implementing these improvements, VR technology with HMDs can become more accessible, comfortable, and effective tools for promoting physical activity and overall well-being in older adults.

Limitations

Although this systematic review presented mostly positive results, there are some important limitations. First, the participants in the included studies were relatively healthy older adults, which may not represent the broader older adult population, especially those with severe diseases or physical disabilities. This limits the generalizability of the findings. Future research should target a more diverse range of older adults, including those with various health conditions, to provide more comprehensive recommendations on how VR with HMD technologies can help older adults perform their daily activities and rehabilitate individuals with chronic conditions. Second, the duration of the interventions and follow-up periods in the included studies was relatively short. The long-term effects of VR interventions in older adults remain unclear. Future studies should include longer follow-up periods to assess the sustainability of the benefits observed. Third, there is a lack of standardized protocols and outcome measures across the included studies, making it difficult to compare results directly and complicating the ability to conduct a meta-analysis. The development and adoption of standardized VR intervention protocols and outcome measures are necessary to enhance the comparability and reproducibility of future research findings. Finally, while the review found minimal adverse effects such as cybersickness, it is essential to conduct further research to investigate potential negative effects and ensure the safety and comfort of older adults using VR technologies.

Conclusion

This systematic review of RCTs demonstrates that VR simulation programs using HMDs significantly enhance physical activity and overall well-being in older adults. The reviewed studies showed notable improvements in balance, gait, and psychological aspects, contributing to reduced fall risk and greater independence and QOL in older adults. While VR programs have been well received by older adults-with positive usability and minimal negative effects- future research should address usability challenges and customize VR experiences to meet the specific needs of older users. More studies are needed to assess the long-term benefits of VR interventions and their applicability to older adults with varying health conditions. By tailoring VR technologies to the ergonomic and sensory needs of older adults, these innovations can become an integral part of healthcare and rehabilitation, promoting sustained physical activity and further enhancing the QOL of older adults.

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Declaration of competing interest

The authors declare that there are no competing interests.

CRediT authorship contribution statement

Kyoung-A Kim: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Validation, Writing – original draft. **Jeong-Ah Ahn:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Supervision, Validation, Visualization, Writing – review & editing.

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