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Review Article

Effects of Virtual Reality on Biomechanical Parameters of Gait in Older Adults: A Systematic Review

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KEYWORDS
Biomechanics;
Gait;
Kinematics;
Older adults;
Rehabilitation;
Virtual reality

Abstract *Objectives:* To conduct a systematic review of the literature on the effect of virtual reality (VR) on biomechanical gait parameters (BGPs) in older adults. Specifically, the spatial-temporal parameters of gait, gait velocity, kinematics, and ground reaction forces, and examine how they are affected by VR interventions. To evaluate the effectiveness and validity of VR gait training and subsequently its potential integration into rehabilitation therapies. This review is a valuable contribution to the current literature as it does not limit its focus to a particular disease. By examining a wide range of studies, we sought to provide a comprehensive analysis of the effects of VR on the BGP in older adults. Our findings can inform future research on VR gait training and its potential role in rehabilitation for older adults.
Data Sources: Two authors independently conducted an electronic search from August 18, 2021, to December 17, 2021, using the PubMed, Scopus, and Web of Science databases, including articles published between January 1997 and July 2021.
Study Selection: The search yielded 1226 articles, and after exclusion, 16 articles were included in the analysis.
Data Extraction: The Joanna Briggs Institute appraisal tool for randomized controlled trials and experimental studies, and the Cochrane risk of bias tool, version 2, were used to assess the level of evidence and bias in the studies.

List of abbreviations: BBS, Berg Balance Score; BESTest, Balance Evaluation Systems Test; BGP, biomechanical gait parameters; MeSH, Medical Subject Headings; RCT, randomized controlled trial; TUG, timed Up and Go; VR, virtual reality.
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Data Synthesis: In our synthesis, we included data from 9 studies with a total of 217 subjects. The range of follow-up periods across these studies was 2-10 weeks, and 40% of the studies conducted the study in community-dwelling individuals. Of the randomized controlled trials, 9 had a low-risk level, whereas 1 study had moderate risk. All studies with control groups and low bias levels demonstrated a positive effect of VR intervention on the BGP in older adults.
Conclusions: Consistent evidence suggests that VR intervention has positive effects on gait performance in older adults.

As individuals age, they often develop comorbidities related to the aging process. Among these, gait and balance disorders are particularly prevalent and can lead to a range of negative outcomes. For example, they can increase morbidity rates, raise the risk of falls, result in psychological limitations for older adults who may fear falling, and ultimately, serve as a significant risk factor for institutionalization.[1]

Emerging evidence suggests that exercise, physical therapy, and virtual reality (VR) therapy may be beneficial for some patients with gait and balance disorders. References suggest that combining conventional rehabilitation with new technologies, such as VR—considered one of the top 7 technologies for improving rehabilitation—can improve treatment outcomes.[1] Many researchers and medical professionals have started using it to implement rehabilitation treatments for cognitive or motor systems. This approach provides patients with greater sensory stimulation, an immersive environment, and real-world feedback during motor tasks that reflect motor learning and neuroplasticity.[2]

Additionally, VR is a secure and enjoyable method of rehabilitation that offers therapeutic benefits such as increased motivation and improved concentration to its users.[3] Therefore, the objective of this study was to conduct a systematic literature review on the effect of VR on the gait performance of older adults. Specifically, we aimed to investigate the spatial and temporal parameters of gait, gait velocity, gait kinematics indices, and ground reaction forces, and how they are affected by VR interventions. Although there are similar studies that investigate the effectiveness of exercise, physical therapy, and VR therapy, they primarily focus on neurological pathologies such as Parkinson's disease.[4] Our study aimed to extend this research by exploring these interventions in patients with gait and balance disorders not specifically related to any pathology.

Methods

Protocol and registration

The study protocol was registered in PROSPERO (ID: CRD42021273110) and this systematic review was conducted in accordance with the Preferred Reporting Items for Systematic reviews and Meta-Analyses statement.

Eligibility criteria

The research satisfied the PICOT acronym as follows: Population: older patients (aged ≥60 years) from either the community or hospital setting; Intervention: VR training for gait; Comparison: patients undergoing nonvirtual training, such as physical training; Outcome: improvement of gait performance, and Type of study: randomized controlled trials (RCTs).

Search strategy

The search was conducted across the PubMed, Scopus, and Web of Science databases, which are available in both English and Spanish. Medical Subject Headings (MeSH) and related keywords were used for the search. In PubMed, the advanced search feature was used by combining MeSH terms from the controlled vocabulary Medical Subject Heading with their synonyms using Boolean operators ("OR" and "AND"): ((((("aged"[MeSH Terms] OR "aging"[MeSH Terms] OR "frail elderly"[MeSH Terms] OR "frail elderly"[MeSH Terms] OR "frail elderly"[MeSH Terms] OR "frail elderly"[MeSH Terms] OR "frail elderly"[MeSH Terms] OR "aging"[MeSH Terms] OR "aged"[MeSH Terms] OR "frail elderly"[MeSH Terms] OR "frail elderly"[MeSH Terms] OR "aged"[MeSH Terms] OR (("geriatric"[All Fields] OR "geriatrics"[MeSH Terms] OR "geriatrics"[All Fields]) AND "patients"[MeSH Terms]) OR (("geriatric"[All Fields] OR "geriatrics"[MeSH Terms] OR "geriatrics"[All Fields]) AND "patients"[MeSH Terms]) OR (("geriatric"[All Fields] OR "geriatrics"[MeSH Terms] OR "geriatrics"[All Fields]) AND "persons"[MeSH Terms]) OR (("senior"[All Fields] OR "seniorities"[All Fields] OR "seniority"[All Fields] OR "seniors"[All Fields]) AND "patients"[MeSH Terms]) OR (("senior"[All Fields] OR "seniorities"[All Fields] OR "seniority"[All Fields] OR "seniors"[All Fields]) AND "persons"[MeSH Terms]) OR (("senior"[All Fields] OR "seniorities"[All Fields] OR "seniority"[All Fields] OR "seniors"[All Fields]) AND "persons"[MeSH Terms]) OR "aged"[MeSH Terms]) AND "gait"[MeSH Terms]) OR "walking"[MeSH Terms] OR "walking"[MeSH Terms] OR "gait analysis"[MeSH Terms] OR "walk test"[MeSH Terms]) AND "virtual reality"[MeSH Terms]) OR "virtual reality exposure therapy"[MeSH Terms]) AND "randomized controlled trial"[Publication Type]. For the Scopus database, keywords were searched within the "Article Title, Abstract and Keywords" filter: TITLE-ABS-KEY ("Virtual reality" OR "virtual reality exposure therapy") AND ("biomechanics" OR kinematics OR electromyography OR kinetics) AND (gait OR walk OR walking OR "gait analysis" OR "walk test") AND ("older adults" OR aged OR "frail elderly" OR aging OR ageing OR elderly OR "geriatric patient" OR "geriatric individuals" OR geriatrics OR senior OR seniorities OR retiree OR "senior citizen" OR "age-old"). Similarly, for the Web of Science database, keywords were searched across all fields:

("Virtual reality" OR "virtual reality exposure therapy") AND ("biomechanics" OR kinematics OR electromyography OR kinetics) AND (gait OR walk OR walking OR "gait analysis" OR "walk test") AND ("older adults" OR aged OR "frail elderly" OR aging OR ageing OR elderly OR "geriatric patient" OR "geriatric individuals" OR geriatrics OR senior OR seniorities OR retiree OR "senior citizen" OR "age-old").

Two of the authors (A.H.A., G.S.Z.) collaborated to determine the search query for each database and agreed on the number of articles to be retrieved (PubMed: 214; Scopus: 981; Web of Science: 31). Afterward, they independently selected the studies. First, they filtered the articles by document type, excluding everything but "journal articles" in each database (such as news articles, conference articles, books, and reviews). Then, they downloaded the comma-separated values document from each database and converted them to Excel[a] format, maintaining the same organizational headings (title, authors, year, source title, volume, issue, page start, page end, link, document type, and source). The 3 documents were then combined into 1, and the article titles were filtered alphabetically to remove duplicates. Moreover, they scrutinized the titles and abstracts of each article and eliminated those that did not meet the inclusion criteria.

Inclusion criteria

The inclusion criteria were as follows: (1) RCTs available in full text (including both open access and subscribed journals); (2) a study population of older adults aged >60 years; (3) articles published between 1997 and July 2021, as the first article describing VR was published in 1997; (4) studies conducted on individuals from the community or those hospitalized; (5) research conducted in low-, middle-, and high-income countries where VR programs are available; (6) older adults aged >60 years capable of performing activities of daily living, with or without background pathology, as developing countries consider individuals aged ≥60 years as older adults. This review does not include updates from articles published after July 2021. Future research may incorporate more recent studies to provide an updated perspective on the topic.

Exclusion criteria

Studies were excluded if they focused exclusively on upper limb assessments unrelated to gait if they involved older adults with visual or hearing impairments, mental or cognitive impairments, life expectancy of <3 months, noncooperation with the study, or failure to meet the inclusion criteria.

Selection of studies

The electronic search was conducted from August 18, 2021, to December 17, 2021. Two of the authors (A.H.A., G.S.Z.) selected the studies independently. The third senior author (R.R.B.) solved disagreements on article inclusion between the 2 authors. Files were imported to Excel, duplicate records were removed, and article selection was carried out by title and abstract. Then, full texts of the selected studies were read. Finally, the inclusion and exclusion criteria were applied to arrive at the final selection.

Extraction of data

The data were exported to an Excel spreadsheet, using data extraction forms created by the authors for this review. The following data were extracted from each selected article: author(s) and year of publication, study design, sample size, mean age, VR interventions, tests performed, biomechanical gait parameters (BGPs) evaluated, and main outcomes. Only tests that assessed gait and lower limb measurements were considered. The main BPGs assessed were balance (static, dynamic), strength, gait stability (kinematics, angular kinematics), walking parameters (balance, speed, performance), temporal gait parameters (velocity, stride time, step time, cadence), spatial gait parameters (step length, stride length, single limb support), fall efficiency, functional status, sway length and speed, endurance, flexibility, agility, and motor coordination.

Risk of bias in individual studies

The Joanna Briggs Institute appraisal tool for RCTs and experimental studies[b] was used to assess the evidence level of the studies. The Cochrane risk of bias tool, version 2,[c] for RCTs was used to assess bias. Any disagreements were resolved by consensus or by the involvement of a third author.

Summary of measures and analysis of results

Gait parameters were compared between the VR group and control group through tests that evaluate gait and balance performance (timed Up and Go [TUG] test, BBS, 6-meter Walk Test).

Results

Selection of studies

An electronic search was conducted from August 18, 2021, to December 17, 2021, which retrieved a total of 1226 articles: 214 from PubMed, 981 from Scopus, and 31 from Web of Science. Of the retrieved articles, 1170 were removed as duplicates, and 314 were excluded because they were systematic reviews, letters, or books. There were 856 articles screened based on the study's criteria, and 783 were excluded because they did not address the central issue of the study (607), did not align with the targeted population (69), targeted cognitive, visual, or hearing impairments (24), were protocols, literature reviews, or case studies (21), or were not full texts (5). The remaining 73 studies were assessed for eligibility, and 57 studies were excluded as they focused exclusively on upper limb assessments unrelated to gait. These studies primarily addressed rehabilitation with exoskeletons or bedside therapy and did not examine gait parameters. Ultimately, 16 studies were included (figure 1).

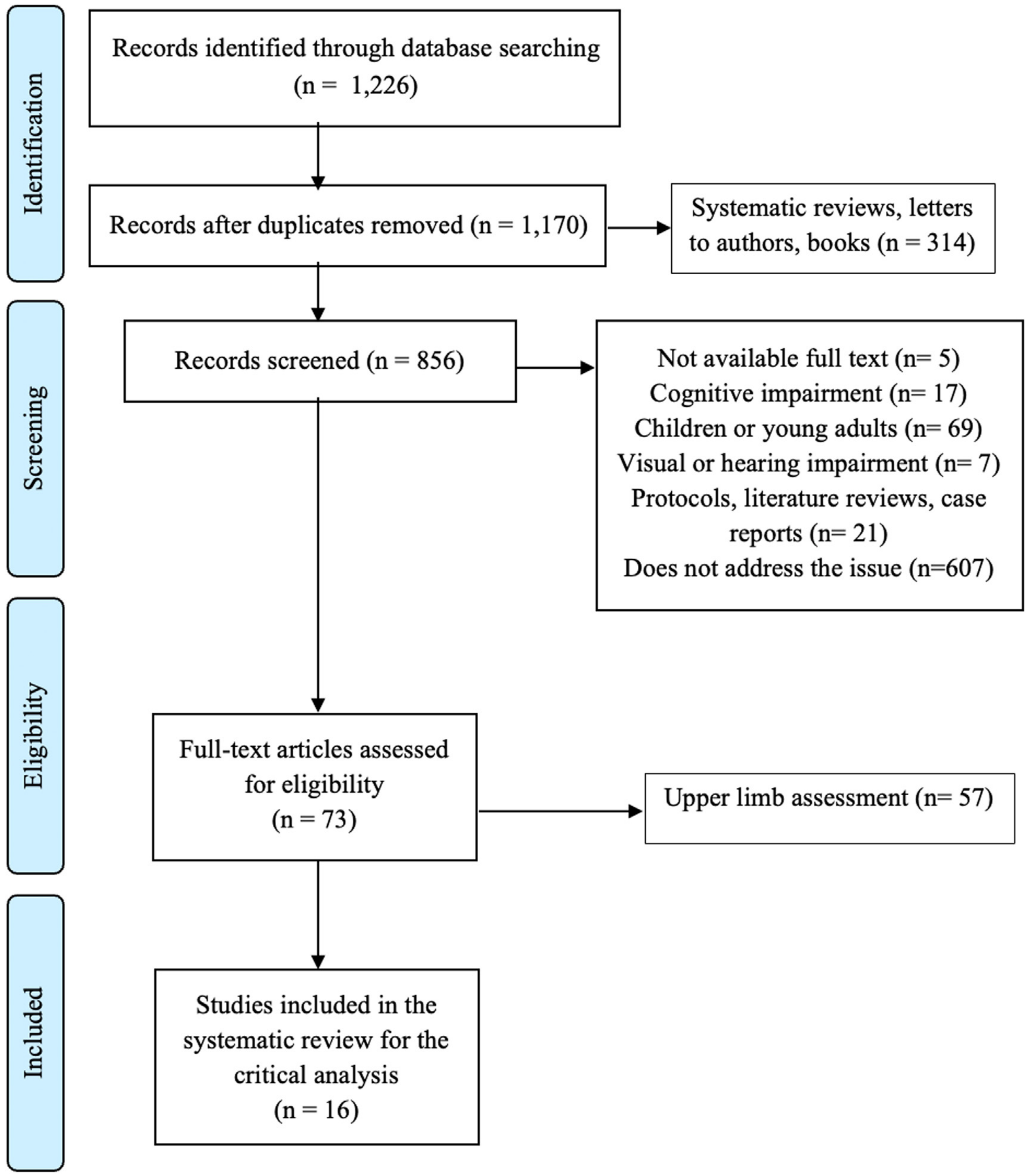

Fig 1 Flow diagram of study selection.

Characteristics of the studies

The included studies were published between 1997 and July 2021, and 10 were RCTs,[5-14] whereas 6 were experimental trials with pretest and posttest designs.[15-20] Table 1 outlines the articles included in this critical analysis and their essential aspects. Among the included studies, 11 integrated VR interventions only,[1,2,5-9,12,15,17-21] whereas 5 combined VR with traditional interventions.[10,11,13,14,16] Most of the studies used sample sizes of 14-143 participants, and the average/mean age of the participants was 71.4 years. Two studies used a sample size consisting only of male participants,[8,11] whereas the rest included men and women.

Risk of bias and analysis of results

The evidence level of the 16 included studies was evaluated using the Joanna Briggs Institute appraisal tool for RCTs and experimental studies. This tool consists of 8-13 questions with “yes,” “no,” “unclear,” and “not applicable” answer options. The authors assessed the risk of bias based on the percentage of “yes” answers provided in the 13 questions for RCTs and 9 questions for quasi-experimental studies. The risk of bias threshold was established as high-risk (0-49%), moderate (50%-69%), and low (≥70). Fourteen studies were deemed to have a low risk of bias, and 2 were determined to have a moderate risk of bias (Tables 2 and 3). Among the 6 experimental studies, 5 had low-risk levels (Table 2). Of the

Table 1 Summary of data extraction.

Authors and Year of Publication	Study Design	VR Sample Size	VR Mean Age	Control Sample Size	Control Mean Age	VR Type	Tests	BGPs	BGP In VR Experimental Group (EG) Vs Control Group (CG)	Main Outcome (Effectiveness of VR Interventions)
Anson et al,[5] (2018)	RCT	20	75.7	20	75.8	Trunk motion virtual feedback treadmill walking	BESTest, mini-BESTest (mBEST), BBS, TUG, ABC scale, 6MWT	Statics and dynamic balance, biomechanical limitations, stability limits, postural responses, gait stability, sensory orientation	EG > CG EG: ↑ BEST and mini-BEST tests EG=CG in BBS, TUG, ABC scale, 6MWT	Older adults ***improved*** their dynamic balance after training using trunk motion virtual feedback treadmill walking.
Cho & lee,[20] (2013)	RCT	7	64.6	7	65.1	VR walking training with an electrical walkway system	BBS, TUG	Walking balance, temporal gait parameters (velocity and cadence), and spatial gait parameters (step length, stride length, and single limb support)	EG > CG EG: ↑ BBS, ↓ TUG, ↑ velocity, ↑ cadence	This study demonstrated the ***positive effects*** of the VR training program on gait performance.
Fishbein et al,[6] (2019)	RCT	11	66	11	64.4	VR dual-task walking	10MWT, TUG, ABC scale, and BBS	Walking speed, step length, walking performance	EG > CG EG: ↑ BBS, ↓ 10MWT, ↑ ABC scale EG=CG in TUG	This study demonstrates the potential of VR-based dual-task walking intervention to ***improve*** walking and balance in people after stroke.

(*continued*)

Table 1 (*Continued*)

Authors and Year of Publication	Study Design	VR Sample Size	VR Mean Age	Control Sample Size	Control Mean Age	VR Type	Tests	BGPs	BGP In VR Experimental Group (EG) Vs Control Group (CG)	Main Outcome (Effectiveness of VR Interventions)
Lee,[7] (2020)	RCT	28	81	28	79.4	Gait training using VR	BBS and TUG	Postural balance, gait stability, spatiotemporal gait parameters (velocity, cadence, stride time, step, time), spatial gait parameter (stride length, step length and width)	EG > CG EG: ↓TUG, ↓ step width, ↑ velocity, ↑ stride, and ↑ step length EG=CG in BBS	VR gait training with nonmotorized treadmill has been shown to ***improve*** balance and gait ability in the elderly.
Lee & shin,[19] (2013)	Experimental Design	27	73.8	28	74.3	VR exercise program	BBS, TUG, Modified Falls Efficacy Scale	Balance, velocity, cadence, falls efficacy	EG>CG EG: ↑ BBS, ↓ TUG, ↑ gait speed and cadence, ↑ falls efficacy	The VR program ***improved*** the participants' BGP parameters, making it effective to reduce fall risks among older adults with diabetes.
Lin et al,[8] (2020)	RCT	38	64.5	107	66.9	VR training	Manual muscle testing scale, postural assessment for stroke, Barthel scale	Muscle strength, functional status	EG > CG EG: ↑ muscle strength, = functional status	VR training combined with early rehabilitation among older adults with acute stroke ***increases*** their muscle strength and maintains functional status.

(*continued*)

Table 1 (*Continued*)

Authors and Year of Publication	Study Design	VR Sample Size	VR Mean Age	Control Sample Size	Control Mean Age	VR Type	Tests	BGPs	BGP In VR Experimental Group (EG) Vs Control Group (CG)	Main Outcome (Effectiveness of VR Interventions)
Mirelman et al,[9] (2010)	RCT	9	62	9	62	Feedback robot interfaced with a VR simulation training		Self-selected walking speed, gait kinetics: onset of push-off, gait kinematics: Range of Motion (ROM)	EG > CG EG: ↑ ankle power at push-off, ↑ ROM, ↑ velocity	VR-based training interventions ***improve*** the recovery of force and power among elderly adults with hemiparesis, improving their motor control at the ankles.
Parijat et al,[17] (2015)	Experimental Design	12	70.5	12	74.2	Simulated slips using a VR perturbation training		Stride length, duration, velocity, and width	EG > CG EG: ↓ stride length, ↑ step width and ↑ stride velocity EG = CG in stride duration	The results indicated a ***beneficial effect*** of the VR training in reducing slip severity and recovery kinematics in healthy older adults.
Parijat et al,[18] (2015)	Experimental Design	12	70.5	12	74.2	Simulated slips using a VR perturbation training		Muscle activation, angular kinematics, frequency of falling	EG>CG EG: ↑ trunk flexion, ↓ knee flexors activation time, ↓ knee co-activation, ↓ trunk flexion time, ↑ muscle activation, ↓ frequency of falling	VR training generates perturbation among healthy older adults ***creating better*** motor skill recovery reactions

(*continued*)

Table 1 (*Continued*)

Authors and Year of Publication	Study Design	VR Sample Size	VR Mean Age	Control Sample Size	Control Mean Age	VR Type	Tests	BGPs	BGP In VR Experimental Group (EG) Vs Control Group (CG)	Main Outcome (Effectiveness of VR Interventions)
Park et al,[16] (2015)	Experimental Design	15	66.5	15	65.2	VR game exercise and ball exercise	TUG	Dynamic balance	EG > CG EG: ↓ TUG	This study indicated that the VR game exercise may ***improve*** balance and gait of elderly individuals in communities.
Rutkowski et al,[10] (2020)	RCT	38	60.4	34	62.1	Traditional pulmonary rehabilitation and VR training	Fullerton test (TUG, 6MWT)	Dynamic balance	EG > CG EG: ↓TUG and ↓6MWT	A pulmonary rehabilitation program strengthened by using VR was ***beneficial*** to improve the physical health and fitness of patients with chronic obstructive pulmonary disease.

6MWT, 6-Meter Walk Test; 10MWT, 10-Meter Walk Test; ABC, Activities-specific Balance Confidence; CG, control group; EG, experimental group; mBEST, Mini Balance Evaluation Systems Test.

Table 2 Experimental studies (n = 6) evaluated with the Joanna Briggs Institute tool.

Author & Year	Cause and Effect	Similar Comparison	Similar Treatment	Control Group	Baseline Follow-Up Measures	Follow-up	Same Measures	Reliable Measures	Appropriate Statistical Analysis	Bias risk Yes (100%)
Cho & Lee,[20] (2013)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Low 100%
Lee & Shin,[19] (2013)	Yes	Not sure	No	Yes	Yes	Yes	Yes	Yes	Yes	Low 77.8%
Parijat et al,[17] (2015)	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Low 77.8%
Parijat et al,[18] (2015)	Yes	Not sure	Yes	Yes	No	No	Not sure	Yes	Yes	Moderate 55.6%
Park et al,[16] (2015)	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Low 77.8%
Yom et al,[15] 2015	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Low 88.9%

RCT studies, 9 had low-risk levels, whereas one had a moderate risk (Table 3).

The authors used Cochrane's risk of bias tool, version 2, to assess the risk of bias levels in RCT studies. The results showed that 7 of the 10 studies had a low risk of bias, 2 had some concern, and 1 had a high risk. All studies had low risks in the randomization process, intended interventions, and outcome measurement. However, one study indicated missing outcome data,[7] and two studies showed selection biases.[10,14]

Two authors (A.H.A. and G.S.Z.) independently scored the Joanna Briggs Institute appraisals, and the level of agreement was determined using Cohen's kappa coefficient (κ) in SPSS version 25.[d] Table 4 summarizes the results, showing a significant κ value of 1 ($P<.001$), indicating excellent agreement between the 2 authors.

The heterogeneity of the studies prevented a quantitative and statistical analysis of the results through meta-analysis. This was primarily due to the lack of a standardized scientific method, including measurement parameters, types of tests, and VR equipment used across the studies.

Results of the studies

This systematic review included 9 studies with a low risk of bias, focusing on the relation between VR and BPGs in older adults. Various assessments such as BESTest, mini-BESTest, Berg Balance Score (BBS), TUG, Activities-specific Balance Confidence scale, Modified Falls Efficacy Scale, and others were used to evaluate gait performance.

The studies used diverse VR interventions, including trunk motion virtual feedback treadmill walking,[5] virtual walking training with real-world video tracks,[20] VR dual-task walking,[6] and gait training with video game consoles and motion tracking cameras.[9,17] The Xbox Kinect Sensor System (Microsoft Corporation, Redmond, WA, USA) was used by 5 studies (31.25%).[8,10,11,13,14] The Glasstron Head Mounted Display (Sony) by 2 studies (12.5%),[17,18] the Wii system (Nintendo Co, Ltd) by 1 study (6.25%),[16] and the PlayStation console (Sony Interactive Entertainment Inc) by 1 study (6.25%).[19] The remaining studies used various other VR equipment.[5-7,9,12,15,20]

Significant improvements in gait and balance were observed. One study reported a 30.6% improvement in One-Leg Stand and a 10% reduction in TUG scores, confirming VR gait training's effectiveness in enhancing postural balance.[7] Another study found significant improvements in One-Leg Stand, BBS, Functional Reach Test, and TUG scores (all $P=.001$), with increased velocity, cadence, and Modified Falls Efficacy Scale scores.[19] A third study showed significant differences in stride length, stride duration, and step width between treadmill walking with and without VR, with stride length initially decreasing by up to 11.9% and then increasing by 2.0% after adaptation ($F[6, 76]=16.56$; $p=.001$).[17]

Three studies consistently showed positive results for BBS and TUG tests. One study reported significant improvement in walking balance, gait parameters, velocity, and cadence based on BBS and TUG scores.[20] Another study found improvements in BBS, Functional Reach Test, and Lateral Reach Test tests post-VR intervention, whereas one study found no significant difference in TUG test results.[6] Another

Table 3 RCT studies (n = 10) evaluated with the Joanna Briggs Institute tool.

Author & Year	Randomization	Concealed Group Allocation	Treatment Groups Similar At Baseline	Blind to Treatment	Blind Researchers	Blind Outcome Assessors	Same Measures	Completed Follow-Up	Participants Were Analyzed in Randomized Groups Allocated	Same Outcome Measures For Treatment Groups	Reliable Outcome Measure	Appropriate Statistical Analysis	Appropriate Design	Bias Risk (Yes %)
Anson et al,[5] (2018)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Low 100%
Fishbein et al,[6] (2019)	Yes	Not sure	Yes	Yes	Yes	Yes	Yes	Yes	Not sure	Yes	Yes	Yes	Yes	Low 84.6%
Lee,[7] (2020)	Yes	Yes	Not sure	Yes	No	Not sure	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Low 76.9%
Lin et al,[8] (2020)	Yes	Not sure	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Low 84.6%
Mirelman et al,[9] (2010)	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Not sure	Yes	Yes	Yes	Yes	Low 84.6%
Rutkowski et al,[10] (2020)	Yes	No	Yes	No	Yes	Not sure	Yes	No	Yes	Yes	Yes	Yes	Yes	Low 69.2%
Schwenk et al,[12] (2016)	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Not sure	Yes	Yes	Yes	Yes	Low 84.6%
Sadeghi et al,[11] (2021)	Yes	Not sure	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Low 92.3%
Segura et al,[14] (2019)	Yes	No	Yes	No	Yes	Yes	Yes	Yes	Not sure	Yes	Yes	Yes	Yes	Low 84.6%
Yousefi & daneshmandi,[13] (2021)	Yes	Not sure	Not sure	No	No	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Moderate 53.8%

Table 4 Agreement on risk biases-kappa results.

Symmetric Measures					
		Value	Asymptotic standard error	Approximate T	Approximate significance
Measure of Agreement	Kappa (κ)	1.000	.000	4.000	.000
No. of valid cases		16			

No., number

reported decreased step width and increased stride and step length after VR intervention.[7]

Overall, VR interventions improved physical performance tests, including BEST and mini-BEST tests, walking balance, gait parameters, velocity, and cadence.[5,20] Another study found improvements in arm curl, chair stand, back scratch, chair sit and reach, TUG, and 6-minute walking tests after VR interventions.[10] All studies with control groups and low risk of bias indicated positive effects of VR on the BPGs in older adults.

Discussion

This study assessed the effects of VR on BPGs in older adults using the PICO strategy, the Preferred Reporting Items for Systematic Reviews and Meta-Analyses protocol, and the PROSPERO registration. In total, 3 electronic databases were searched, from which 16 articles were selected according to the inclusion and exclusion criteria. To date, there have been no published systematic reviews, and only 3 ongoing reviews registered in PROSPERO, that evaluate the effects of VR on the gait of older adults. Our review is a valuable contribution to the current literature because we do not restrict our focus to a particular disease, as seen in one of the articles on Parkinson's disease[4] or chronic obstructive pulmonary disease.[10]

The review included RCTs. Outcomes were uniform about the positive effect of VR on gait in the elderly. All the articles suggested that VR training resulted in improvement in walking performance, although they arrived at this conclusion based on different tests that assessed gait performance and different BPGs. Comparisons across studies were hard to perform owing to the difference in methods and the VR equipment used. Two articles used the same VR equipment, but with different measurements to assess gait performance for each.

Various mechanisms appear to be associated with the enhancement of gait after VR interventions. Some studies evaluated slip recovery after induced falls,[17,18] whereas others have examined dual tasking with distractions[6] or exercise gaming in motivating and competitive environments.[20] However, the common thread among all these studies is that, compared to the control group, the experimental group that received VR interventions demonstrated an improvement in gait.

Care providers can use VR programs to assist older individuals with gait after illnesses or accidents, either through video-recorded or simulated programs that can be implemented independently or combined with conventional forms of rehabilitation. According to Tieri et al[1] (2018), VR programs help achieve the primary goal of rehabilitation, which is to improve the quality of independent living and the efficient performance of daily activities. Although standard rehabilitation programs have been shown to improve gait, this review found evidence that older adults with gait impairment demonstrated greater improvements after VR interventions than control groups that received passive interventions, such as educational programs, or only exercise interventions with treadmill walking, and ball exercises, among others.[5-9,16-18,20] Therefore, this study supports the idea that the combination of traditional and VR interventions results in more positive effects than independent implementation, and VR interventions provide more favorable outcomes than conventional interventions,[1] which is consistent with the findings of Feng et al.[2]

This study found clear evidence that VR can have a positive effect on the BPGs. The test that most studies had in common was the TUG test, with 5 studies demonstrating a decrease in time, indicating improved TUG test results.[7,10,16,19-20] Other test results that showed improvement after the intervention include the results of BEST and mini-BEST tests, the Activities-specific Balance Confidence scale, and the 6- and 10-Meters Walk Test.[5,6,10] Some articles measured and provided evidence of improved results in gait performance with only BPGs, as seen in Table 1. However, there was wide individual variation in step width, stride, and length after VR. Three studies found that VR training improved fall risk,[17-19] providing supporting evidence that VR training not only enhances gait performance but also reduces fall risk and improves fall efficacy.

Some studies had limitations in their methods, including heterogeneity in the damaged brain area, which could have affected the level of performance after the intervention, particularly in the case of stroke patients. Another limitation was the lack of long-term follow-up evaluation, which limited the ability to assess the durability of the intervention's effects.

Study limitations

This review has its limitations, including data variation related to different equipment and programs used in interventions, as well as the use of different tests to measure BPGs. Sample size power calculation and error tests were also rarely performed. However, this review exhibits some clear strengths. Positive effects after VR were found on the psychological and cognitive performance of older adults in one of the studies, including improved mood states.[8] Additionally, the review found that VR was highly accepted by the older adult community, contrary to the expectations of some of the authors. Patients were motivated to attend their rehabilitation programs and enjoyed the training.[6,8,10,16,19-20] This knowledge could be used to increase rates of adherence at rehabilitation hospitals, thus contributing to improved functional outcomes. Future studies should further investigate not only motivational factors, psychological and cognitive performance, but also factors that could hinder training in more detail.

This study suggests that combining traditional and VR interventions has a more positive effect than implementing them independently. However, subsequent studies are needed to ensure homogeneity at baseline for chronically ill patients and to evaluate the long-term sustainability of the improvement seen during the interventions. Additionally, future studies should consider the influence of participants' physical activity levels on the study results. Nevertheless, based on the findings of this study, it is recommended to include VR in traditional rehabilitation when possible, especially when the only rehabilitation includes a passive intervention. This recommendation has important implications for real-world applications.

Conclusions

This systematic review consistently found positive effects of VR on gait performance among older adults. VR exercise programs improved various BPGs, including balance, muscle strength, gait stability, walking speed, and fall risk. Care providers used a range of VR programs to enhance gait performance in older adults, especially those with injuries or illnesses. Further research is needed to fully establish the effectiveness of VR on gait parameters in older adults and to expand our understanding of this promising intervention.

Supplier

a. Microsoft Excel Spreadsheet.
b. Joanna Briggs Institute appraisal tool for randomized controlled trials and experimental studies
c. Cochrane risk of bias tool, version 2.
d. SPSS version 25.

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References

1. Tieri G, Morone G, Paolucci S, Iosa M. Virtual reality in cognitive and motor rehabilitation: facts, fiction and fallacies. Expert Rev Med Devices 2018;15:107–17.
2. Feng H, Li C, Liu J, et al. Virtual reality rehabilitation versus conventional physical therapy for improving balance and gait in Parkinson's disease patients: a randomized controlled trial. Med Sci Monit 2019;25:4186–92.
3. Cho C, Hwang W, Hwang S, Chung Y. Treadmill training with virtual reality improves gait, balance, and muscle strength in children with cerebral palsy. Tohoku J Exp Med 2016;238:213–8.
4. Nehrujee A, Vasanthan L, Lepcha A, Balasubramanian S. A Smartphone-based gaming system for vestibular rehabilitation: a usability study. J Vestib Res 2019;29:147–60.
5. Anson E, Ma L, Meetam T, et al. Trunk motion visual feedback during walking improves dynamic balance in older adults: assessor blinded randomized controlled trial. Gait Posture 2018;62:342–8.
6. Fishbein P, Hutzler Y, Ratmansky M, Treger I, Dunsky A. A preliminary study of dual-task training using virtual reality: influence on walking and balance in chronic poststroke survivors. J Stroke Cerebrovasc Dis 2019;28:104343.
7. Lee K. Virtual reality gait training to promote balance and gait among older people: a randomized clinical trial. Geriatrics (Basel) 2020;6:1.
8. Lin R-C, Chiang S-L, Heitkemper MM, et al. Effectiveness of early rehabilitation combined with virtual reality training on muscle strength, mood state, and functional status in patients with acute stroke: a randomized controlled trial. Worldviews Evid Based Nurs 2020;17:158–67.
9. Mirelman A, Patritti BL, Bonato P, Deutsch JE. Effects of virtual reality training on gait biomechanics of individuals post-stroke. Gait Posture 2010;31:433–7.
10. Rutkowski S, Rutkowska A, Kiper P, et al. Virtual Reality Rehabilitation in Patients with Chronic Obstructive Pulmonary Disease: a Randomized Controlled Trial. Int J Chron Obstruct Pulmon Dis 2020;15:117–24.
11. Sadeghi H, Jehu DA, Daneshjoo A, et al. Effects of 8 weeks of balance training, virtual reality training, and combined exercise on lower limb muscle strength, balance, and functional mobility among older men: a randomized controlled trial. Sports Health 2021;13:606–12.
12. Schwenk M, Grewal GS, Holloway D, Muchna A, Garland L, Najafi B. Interactive sensor-based balance training in older cancer

patients with chemotherapy-induced peripheral neuropathy: a randomized controlled trial. Gerontology 2016;62:553–63.
13. Yousefi Babadi S, Daneshmandi H. Effects of virtual reality versus conventional balance training on balance of the elderly. Exp Gerontol 2021;153:111498.
14. Segura-Ortí E, Pérez-Domínguez B, Ortega-Pérez de Villar L, et al. Virtual reality exercise intradialysis to improve physical function: a feasibility randomized trial. Scand J Med Sci Sports 2019;29:89-94.
15. Yom C, Cho H-Y, Lee B. Effects of virtual reality-based ankle exercise on the dynamic balance, muscle tone, and gait of stroke patients. J Phys Ther Sci 2015;27:845–9.
16. Park E-C, Kim S-G, Lee C-W. The effects of virtual reality game exercise on balance and gait of the elderly. J Phys Ther Sci 2015;27:1157–9.
17. Parijat P, Lockhart TE, Liu J. Effects of perturbation-based slip training using a virtual reality environment on slip-induced falls. Ann Biomed Eng 2015;43:958–67.
18. Parijat P, Lockhart TE, Liu J. EMG and kinematic responses to unexpected slips after slip training in virtual reality. IEEE Trans Biomed Eng 2015;62:593–9.
19. Lee S, Shin S. Effectiveness of virtual reality using video gaming technology in elderly adults with diabetes mellitus. Diabetes Technol Ther 2013;15:489–96.
20. Cho KH, Lee WH. Virtual walking training program using a real-world video recording for patients with chronic stroke: a pilot study. Am J Phys Med Rehabil 2013;92:371–84.
21. Salzman B. Gait and balance disorders in older adults. Am Fam Physician 2010;82:61–8.