

A – Research concept and design
 B – Collection and/or assembly of data
 C – Data analysis and interpretation
 D – Writing the article
 E – Critical revision of the article
 F – Final approval of article

Received: 2024-03-02

Accepted: 2024-09-17

Published: 2024-09-23

The effect of virtual reality applications on treatment outcomes in lower extremity rehabilitation: a systematic review

Hande Tunc*^{1,A-F} , Mehtap Kilicoz Bakar^{1,2,A-F} , Selim Ozden^{1,A-D,F} ,
 Gokce Leblebici^{3,D-F} , Devrim Tarakci^{1,A,D-F} 

¹ Department of Physical Therapy and Rehabilitation, Graduate School of Health Sciences, Istanbul Medipol University, Turkey

² Department of Physical Therapy and Rehabilitation, Faculty of Health Sciences, Istanbul Aydın University, Turkey

³ Department of Physical Therapy and Rehabilitation, Faculty of Health Sciences, Istanbul Medeniyet University, Turkey

*Corresponding author: Hande Tunc, Department of Physical Therapy and Rehabilitation, Graduate School of Health Sciences, Istanbul Medipol University, Turkey; email: hande.tunc1@std.medipol.edu.tr

Abstract:

A noticeable trend in rehabilitation is the growing use of virtual rehabilitation (VR) in musculoskeletal-related areas. Yet, despite growing interest, the levels of evidence available are insufficient to warrant its clinical use in orthopedic rehabilitation. This study intends to explore the impact of these applications in the context of orthopedic treatment. The research covers the period from 2010 to 2023, utilizing databases such as PubMed, Web of Science, PEDro, and Cochrane. The study design adheres to the PRISMA protocol, and the quality and risk of bias were assessed by the Revised Cochrane Risk-of-bias Tool for Randomized Trials and PEDro scale from the Physiotherapy Evidence Database. This study encompasses 12 studies, with the selected articles categorized based on balance, muscle strength, and pain. All of the selected studies achieved high methodological quality on the PEDro scale. The findings indicate that both VR-based exercise therapy and conventional therapy show promising results in determined outcomes, but VR applications typically yielded superior or comparable results to conventional treatments for balance and muscle strength. Also, VR applications were found to have roughly equivalent effects on pain as conventional treatments. The use of VR applications might be seen as an alternative to conventional approaches, depending on the primary objectives of the treatment and the specific needs and expectations of the patient.

Keywords: balance, muscle strength, pain, rehabilitation

Introduction

Medical fields are currently subject to rapid advancements in new technology, which have been responsible for enhancing diagnosis and treatment processes [1]. One such technology is virtual reality (VR), whose increasingly popularity has proven to offer several benefits, particularly in the field of rehabilitation [2]. VR systems are computer

interfaces that provide a virtual environment through software and hardware integration. These systems engage individuals in real-time through various stimuli such as visual, auditory, or haptic feedback [3]. They create a sense of reality by enabling movements within a 3D environment and by providing multisensory feedback that stimulates brain areas related to motor movements and perception, intensifying bioelectric signals; this



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stimulation promotes brain reorganization, neuroplasticity, and motor learning [4,5].

Orthopedic rehabilitation is crucial for function restoration, with treatment success largely relying on the right mix of therapies and regulated progress [6]. VR systems have been adopted in neurological and pediatric rehabilitation, and their applications are also expanding in areas such as cardiopulmonary and orthopedic rehabilitation, and Psychiatry. A noticeable trend in relevant literature reviews is the growing use of VR in musculoskeletal-related areas. A review of randomized and non-randomized studies examining VR technologies and orthopedic patients also emphasized that VR systems are effective for remote rehabilitation, but the protocols and technologies used in the included studies differed [2]. It was also noted that clinicians need more guidance on the scope of VR systems and the approach to choosing appropriate protocols for their needs [7]. Yet, despite growing interest, the available studies and levels of evidence are insufficient to warrant its clinical use in orthopedic rehabilitation [2,7,8]. The vast coverage of the field, the diverse treatment approaches, and inconsistencies in research methodology, make it challenging to arrive at a consensus on practices.

Orthopedic rehabilitation through VR bears distinct advantages over traditional methods, including improved accessibility, ease of use, increased patient participation, and better compliance due to its gamified, home-based approach. This technique also remedies common issues such as consistency in interventions, treatment adherence, and remote progress tracking. Patient compliance is particularly crucial post-orthopedic surgery, as studies have linked non-compliance with rehabilitation protocols to increased pain, stiffness, and weakness [9]. VR-based rehabilitation has the potential to eliminate many of these barriers. Numerous research studies across various domains have shown that VR-based exercises can positively impact muscle strength, especially balance [10-13]. Feng et al. [10] report that balance and gait improved when VR was applied to individuals with Parkinson's disease, and Zahedian-Nasab et al. [11] and Sadeghi et al. [12] that it improved fall risk and balance in elderly individuals; these findings are also supported by those of Cho et al. [13] concerning children with Cerebral Palsy. These findings hint at the potential of VR-based rehabilitation as a solid alternative to conventional methods.

Given the range of research and subjects studied to date, no existing study has examined the influence of lower extremity VR applications on balance, muscle strength, and pain in orthopedic rehabilitation. Therefore, this study intends to explore the impact of these applications on balance, muscle strength, and pain in the context of orthopedic treatment.

Materials and methods

Study Design

The study design adheres to the guidelines set forth by the 'Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA)' method. Additionally, the reviewed studies were subjected to risk analyses using the Revised Cochrane Risk-of-Bias Tool for Randomized Trials (RoB 2): Short Version. The study was prospectively registered with the record number CRD42023424372 in the PROSPERO system.

Eligibility Criteria

The selection of studies for the review was based on the specific inclusion and exclusion criteria detailed below.

Inclusion Criteria: This review involves male and female individuals diagnosed with an orthopedic disease and participating in either non-invasive or surgical treatment programs. Studies are being conducted to determine if VR training should be included as a component of the rehabilitation plan to treat these conditions. The present review only included studies that report on balance, pain, and lower extremity muscle strength, and were conducted as randomized controlled clinical trials, with a minimum PEDro score of 7. In addition, all included studies had to provide pre- and post-treatment comparisons and be published in English.

Exclusion Criteria: The following publications were excluded: non-randomized or partially randomized studies, retrospective studies, case reports, letters to editors, conference papers, book chapters, and protocol studies. It also will not consider studies without the specified research outcome measures.

Search Strategy and Selection Process

Three independent researchers (H*, M*, S*) conducted a thorough search of relevant studies across multiple databases, including PubMed, Web of Science, Cochrane, and PEDro. This review focused on keywords such as 'foot', 'ankle', 'knee', 'hip', 'lower extremity', 'lower limb', 'rehabilitation', 'physiotherapy', 'orthopedic rehabilitation', 'VR', 'virtual rehabilitation', 'exergame', 'augmented reality', and 'gamification', connected using 'AND'. The researchers only included randomized controlled trials published between 2010 and 2023 relevant to the field. A fourth researcher (D*) held the final say in any disagreements.

Methodological Quality and Risk-of-Bias of the Studies

The methodological quality of all studies included in the review was evaluated by three independent researchers using the Physiotherapy Evidence Database (PEDro) scoring system. This system evaluates studies based on 11 criteria, with potential scores ranging

up to 10 points. A score of six or above on this scale indicates a high-quality study, while a score of 5 or below reflects low quality. This evaluation method is not only validated by previous studies [14] but is also widely utilized in the clinical research rating of systematic reviews.

The risk of bias in the randomized controlled trials was evaluated using the Cochrane risk analysis tool, RoB 2: Short Version. This tool focuses on various research aspects to gather bias risk information. Each domain's bias risk score is then computed for an aggregate score, which is subsequently categorized as low, medium, or high risk. The evaluation was completed by three independent researchers.

Primary Outcomes

The review primarily focused on the outcomes of balance, muscle strength, and pain.

Results

Study Characteristics

The review incorporated 12 studies with a total of 1009 participants of both sexes (603 female and 406 male) (Figure 1). Only one study comprised solely male subjects. Participant ages varied from 21.1 to 72.2 years, and their educational backgrounds ranged from elementary school to university. Varied contexts were employed for the VR interventions, including postoperative total knee replacement, knee and hip arthroplasty, post-ankle instability, knee osteoarthritis, and geriatric rehabilitation, with most focusing on balance and mobility programs. While the vast majority of studies employed intervention and control group comparisons, Sadeghi et al. [13], compared the effectiveness of VR therapy across four groups (balance training, VR, mixed, and control group), while Koo et al. [15], used VR therapy on both groups, differing only in duration (full or half term). Table 1 provides detailed information on the participants, the methods applied, and the results of the individual studies.

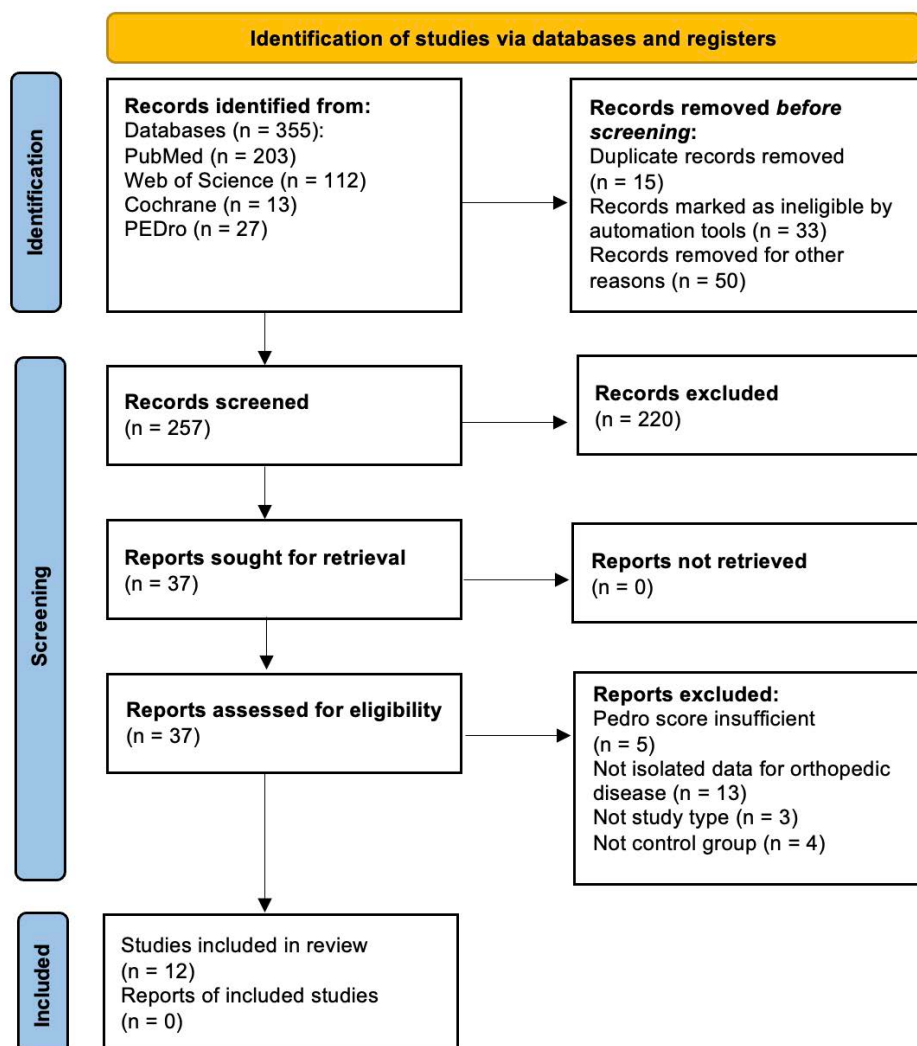


Fig. 1. Flow chart

Tab. 1. The characteristics of the included studies

Study	Device	Participants	Outcome Measures	Intervention	Frequency and session	Results
Fung et al. (2012) [25]	Nintendo Wii Fit™	50 individuals who have undergone TKA	Length of outpatient rehabilitation, 2-minute walk test, knee ROM, timed standing, ABC Scale, Lower Extremity Functional Scale and NPRS (every 2 weeks until discharge)	TG: physiotherapy session followed by 15 minutes of Wii Fit gaming activities. The games encouraged lateral and multidirectional weight shifting, and provided visual feedback regarding postural balance. CG: physiotherapy session followed by 15 minutes of lower extremity strengthening and balance training exercises. Both control and study interventions were provided in addition to and following each regularly scheduled 60-minute physiotherapy session	Every 2 weeks until discharge each group: 75 min	There were no significant differences between groups. Wii Fit is potentially acceptable as an adjunct to physiotherapy intervention for patients following total knee replacement.
Piqueras et al. (2013) [19]	Custom image processing program	133 individuals who have undergone TKA	muscle strength, ROM, WOMAC, TUG, VAS	TG: 1-h interactive virtual telerehabilitation for 10 days CG: standard clinical protocol of TKA rehabilitation consisting of 1-h sessions for 10 days	10 days/ 60 min	Patients in the interactive virtual telerehabilitation group achieved improvements in the functional variables similar to those achieved in the conventional therapy group. A 2-week interactive virtual telerehabilitation programme is at least as effective as conventional therapy.
Koo et al. (2018) [15]	Augmented reality integrates VR and analog MT via a real-time image processing technique	22 individuals who have undergone TKA	Short Form Geriatric Depression Scale, VAS, WOMAC, 6 minute walking test	Groups are received analgesia and enhanced reality therapy. Evaluation was performed 5, 12, 33 days after the initiation of enhanced reality.	Full term intervention group: 5 weekdays over 2 weeks) half term intervention group: (HFI: intervention was provided for 1 week).	Analgesia in the 2-week therapy group was effective until the third evaluation, whereas in the other group, it was effective only until the second evaluation. Improvement in ROM in the 2-week group was also maintained until the third evaluation.

Ku et al.(2018) [18]	3D-ARS	44 elderly individuals	FAC, MBI, BBS, TUG, FMA, Tetrax posturography	TG: 3D-ARS training CG: conventional physical fitness program such as lower-extremity strengthening and balance training	30 minutes, 3 times per week, for 4 weeks	There is improvement in both groups, but parameters such as balance, weight distribution and fall risk are better in TG.
Kim et al. (2019) [24]	Nintendo Wii	21 individuals with Functional Ankle Instability	static and dynamic balance (Biodex Balance System)	TG: strength and balance exercises were done for 10 minutes each using a program included in the Nintendo Wii Fit Plus. CG: four ankle strength exercises using the TheraBand and the balance exercises were performed for 10 minutes each.	30 minutes, 3 times per week, for 4 weeks	VR exercise is more effective in the overall direction (static) and medial-lateral direction (dynamic) of balance than conventional method.
Bettger et al. (2020) [22]	Virtual Exercise Rehabilitation Assistant (VERA)	247 individuals who have undergone TKA	hospitality cost, KOOS, pain, falls, knee flexion and extension ROM, 10-m gait speed	TG: virtual PT program (involving an avatar coach and telerehabilitation with remote clinician oversight by a physical therapist) CG: followed their care team's recommendations for all preoperative and postoperative medical and rehabilitative care	6 weeks	Receive virtual PT with VERA had significantly lower 3-month health-care costs relative to usual care. Virtual PT was as effective and safe as traditional PT (except in terms of the rate of falls).
Gionala et al. (2020) [23]	Virtual Reality Rehabilitation System	85 individuals with total knee arthroplasty	intensity of pain, knee injury, health-related quality of life, overall perceived effect, functional independent measurement, medication assumption, isometric strength of quadriceps and hamstrings, flexion range of motion, proprioception	CG: traditional rehabilitation EG: VR rehabilitation Both groups performed passive knee movement and functional exercises (stair climbing and flat walking) on the Kinetec continuous passive knee motion system	60 minutes/day sessions until discharge (around 10 days after surgery)	VR-based rehabilitation is not superior to traditional rehabilitation in terms of pain relief, medication use, and other functional outcomes, but it does appear to improve overall proprioception.

Sadeghi et al. (2021) [13]	Sport Xbox Kinect	64 elderly individuals	Isokinetic quadriceps and hamstring strength in dominant and non-dominant legs, single-legged stance on hard and foam surfaces, tandem stance, timed up-and-go and walking speed	CG: waiting list BT: Traditional balance training VR: virtual reality balance training MIX: BT + VR	40 minutes, 3 times per week, for 8 weeks	MIX provided greater improvements in strength, balance, and functional mobility than BT, VR, and CG; VR demonstrated better balance and functional mobility than CT and CG; and CT showed better balance and functional mobility than CG.
Fuchs et al. (2022) [21]	Samsung Gear VR	55 elderly individuals	State-Trait Anxiety Inventory Visual analog scale Western Ontario and McMaster Universities Arthritis Index	CG: conventional physiotherapy and CPM device (Continuous passive motion device) were applied. EG: Exercise Group: conventional physiotherapy and CPM device (Continuous passive motion device) were applied, additional VR method was applied.	2 days, each session 15 minutes	After the intervention, pain and anxiety decreased in both groups, but there was no difference between the groups. There was no difference in WOMAC scores between groups at the six-month postoperative examination.
Pournajaf et al. (2022) [20]	Virtual Reality Rehabilitation System	56 individuals with unilateral total knee replacement between the ages of 45 and 80	Timed Up and Go (functional mobility) walking speed, pain intensity, lower extremity muscle strength, independence in daily living activities, gait and postural parameters	CG : conventional therapy EG: VR based balance training	15 session, 5 times/week, each session 45 minutes	VR-based balance training may improve gait and postural outcomes for individuals with total knee replacement. VR-based balance training, although not superior to the Control group findings, can be considered as an alternative to the traditional approach. and can be added regularly to the rehabilitation program for individuals with total knee prosthesis.
Mete et al. (2022) [16]	MarVAJED® (Marmara Visual Auditory Joint Education Device)	60 patients with knee osteoarthritis between the ages of 40-65	Pain intensity range of motion functional status kinesiophobia proprioceptive acuity, muscle strength	CG: traditional physiotherapy EG: traditional physiotherapy + exercise	5 days a week for 6 weeks Exergame: 20 min	Exercise combined with traditional physiotherapy programs in patients with knee OA provided more positive improvements in pain, freedom of movement, postural stability, kinesiophobia, proprioceptive acuity and functional status compared to the traditional physiotherapy program alone.

Gonzalez et al. (2022) [17]	Wii Fit plus™	73 patients over 50 years of age	WOMAC Berg Balance Scale, distance covered by the six-minute walk test, and weight load on the lower extremities	CG: traditional physiotherapy EG: traditional physiotherapy + virtual reality with Nintendo Wii console	12 sessions, 2 times per week, for 6 weeks traditional physiotherapy: 10 min virtual reality: 10 min	In the short term, the addition of virtual reality via the Nintendo Wii and the Wii Balance Board platform showed statistically significant differences in the function of patients undergoing total hip replacement surgery, but these differences were of minimal clinical significance
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ABC- Activity-specific Balance Confidence Scale, BBS- Berg Balance Scale, CG- Control Group, FAC- Functional Ambulation Category, FMA- Fugl Meyer Assessment, KOOS- Knee injury and Osteoarthritis Outcome Score, MBI- Modified Barthel Index, NPRS- Numeric Pain Rating Scale, OA- Osteoarthritis, ROM- Range of Motion, SF-36- Short Form-36, TG- Treatment Group, TKA- Total Knee Arthroplasty, STAI- State-Trait Anxiety Inventory, TUG- Timed “Up & Go” test, VAS- Visual Analog Scale, WOMAC- Western Ontario and McMaster Universities Osteoarthritis Index

Risk-of-Bias Analysis and Quality of Studies

The 12 studies' risk-of-bias, assessed using the Cochrane risk analysis tool, is detailed in Table 2. Six studies presented some concerns [13,16-20] while five showed a high risk-of-bias [15,21-24], and only one reflected a low

risk-of-bias [25]. The most significant methodological limitation was the inability to blind patients and physiotherapists due to the nature of the treatment's. Additionally, outcome measurement bias and selective reporting were key areas contributing to the overall risk of bias.

Tab. 2. Risk of bias analysis of studies

	Risk of bias arising from the randomization process	Risk of bias due to deviations from the intended interventions (effect of assignment to intervention)	Risk of bias due to deviations from the intended interventions (effect of adhering to intervention)	Risk of bias due to missing outcome data	Risk of bias in outcome measurement	Risk of bias in selection of the reported result	Overall
Fung et al. (2012) [25]							
Piqueras et al. (2013) [19]							
Koo et al. (2018) [15]							
Kim et al., 2019 [24]							
Ku et al. (2019) [18]							
Bettger et al. (2020) [22]							
Gianola et al., 2020 [23]							
Sadeghi et al. (2021) [13]							
Fuchs et al. (2022) [21]							
Zavala-Gonzalez et al. (2022) [17]							
Mete et al. (2022) [16]							
Pournajaf et al. (2022) [20]							

High Risk of Bias Low Risk of Bias Unclear Risk

Despite these concerns, all the studies were of high quality according to PEDro score analysis (Table 3). However, as with bias, all but two studies identified that both therapists and patients were aware of the treatment [13,19].

VR Systems

In the included studies, VR application was applied specific to rehabilitation-specific technologies (serious

games, VR consoles, VR head-mounted system, specially developed augmented reality systems etc.) , but some studies used commercially-produced technologies as a treatment tool.

Studies Using Rehabilitation-Specific VR System

In a study by Pournajaf et al. [20] the Virtual Reality Rehabilitation System (VRRS; Khymeia Group, Italy)

Tab. 3. PEDro quality assessment scale

Study	Eligibility Criteria were Specified	Rando mization	Allocation was Concealed	Groups Similarity at Baseline	Subject Blinding	Therapist Blinding	Assessor Blinding	Participation of Individuals	Intention to Treat	Differences Between Groups	Reporting Treatment Effect and Variability	Total
Fung et al. (2012) [25]	Y	Y	Y	Y	N	N	Y	Y	Y	N	Y	8
Piqueras et al. (2013) [19]	Y	Y	Y	Y	Y	N	N	Y	Y	N	Y	8
Koo et al. (2018) [15]	Y	Y	Y	Y	N	N	Y	Y	Y	Y	Y	9
Kim et al., 2019 [24]	Y	Y	Y	Y	N	N	N	Y	Y	Y	Y	8
Ku et al. (2019) [18]	Y	Y	Y	Y	N	N	N	Y	Y	Y	Y	8
Bettger et al. (2020) [22]	Y	Y	Y	Y	N	N	N	Y	Y	N	Y	7
Gianola et al., 2020 [23]	Y	Y	Y	Y	N	N	Y	Y	Y	N	Y	8
Sadeghi et al. (2021) [13]	Y	Y	Y	Y	Y	N	N	Y	Y	Y	Y	9
Fuchs et al. (2022) [21]	Y	Y	Y	Y	N	N	N	Y	Y	N	Y	7
Zavala- Gonzalez et al. (2022) [17]	Y	Y	Y	Y	N	N	Y	Y	Y	Y	Y	8
Mete et al. (2022) [16]	Y	Y	Y	Y	N	N	Y	Y	Y	Y	Y	9
Fung et al. (2012) [25]	Y	Y	Y	Y	N	N	Y	Y	Y	N	Y	8

was used to enhance balance. The VRRS system transfers weight onto a balance board, allowing users to move on-screen visuals like balls within a certain visual field. The effectiveness of VR-based rehabilitation, compared to traditional methods, was assessed using the stabilometric platform of the VRRS. A similar approach was taken by Gianola et al. [23].

Mete et al. [16] examined the MarVAJED® (Marmara Audio-Visual Joint Training Device), an exergaming program with a joint training device. The system assesses joint range of motion (ROM) and provides auditory and visual biofeedback support to enhance joint control while facilitating exercise control.

Bettger et al. [22] utilized the Virtual Exercise Rehabilitation Assistant (VERA; Reflexion Health) system. VERA is a 3D tracking technology that measures pose and movement. It features an avatar, essentially a digital simulation of a coach, that demonstrates and guides the participant's activity. This avatar provides visual and auditory instructions as well as immediate feedback on the quality of the exercise.

Studies Using Commercial VR Systems

In study by Lee Fuchs et al. [21], the study group (VR group) used a Samsung Gear VR head-mounted display, which projected three-dimensional images.

Other researchers explored various gaming platforms. For instance, Gonzalez et al. [17], used the Nintendo Wii, Kim et al. [24], employed the Nintendo Wii Fit Plus, and Fung et al. [25] utilized the Nintendo Wii Fit™. The Wii Fit™ is applauded for its accessibility and affordability. It includes a balance board akin to a power plate, which gauges player weight distribution. The analysis is then conducted by the integrated software, offering feedback on performed exercises or games. The system encourages users to meet their fitness goals through an interactive video game environment.

Sadeghi et al. [13] employed three different minigames during the VR sessions: The Light Race (Stomp It) from 'Your Shape' fitness package and 'Target Kick' and 'Goal-keeper' from the 'Sport Xbox Kinect' game package. Ku et al. [18] implemented an interactive three-dimensional augmented reality system (3D-ARS). This system facilitated participant training through a realistic 3D interactive balance exercise. With the integration of a kinetic sensor system, it also assessed movement parameters and joint angles.

A study by Koo et al. [15] employed augmented reality. Augmented reality integrates VR and analog MT via a real-time image processing technique. The system is comprised of five separate units: a patient positioning tool, a scanning tool, an image acquisition unit, an image processing unit, and an image display unit. This two-part system offers a real-time visual representation of the pa-

tient's limb, obtained via a webcam positioned beneath the table. This allows the patient to perform both unrestricted and limited movements during the application process.

A study by Piqueras et al. [19] used a conventional webcam, a standard computer, and a custom image processing program, together with a regular monitor. The cutting-edge virtual telerehabilitation system used an all-in-one computer (ASUS EeeTop 1602), which featured a desktop screen displaying the TKA application, operating on a licensed version of Windows XP Home (Microsoft, USA). The system incorporated a wireless setup for recording patient movements, including two sensors and a low-bandwidth mobile internet device. Exercise equipment included sensor-attaching straps (one placed on the top of the knee, the other on the foot's bone), weights, and a stretch band.

VR Interventions and balance

The review consisted of 12 clinical studies, seven of which explored the impact of VR interventions on balance. Both static and dynamic balance were assessed through various tests. Three studies utilized the Time Up and Go test domain [18-20] whereas the Berg Balance Test [17,18], Posturography [18,19] and the Biodex Balance System [23] were applied in two, two, and one study, respectively. In addition, the Activity Specific Balance Confidence Scale, Single Leg Stance Test, Tandem Stance Test, and Fugl-Meyer Motor Assessment Balance section tests were employed to assess static and dynamic balance.

Of the seven studies assessing balance [13,16-20,23], three found VR applications to be superior to traditional methods. Three other studies found both methods to be equally effective, while only one study concluded that traditional approaches were more effective than VR treatments in enhancing balance.

Zavala-Gonzalez et al. [17], found significant improvements in both groups following treatment interventions, with larger improvements in the VR treatment group. This observed benefit from VR treatment was supported by Ku et al. [13], and Sadeghi et al. [18], who also reported significantly more favorable results in VR therapy compared with conventional treatment, specifically in balance parameters.

In contrast, Fung et al. [25] and Piqueras et al. [19] reported no significant difference between VR and conventional treatment groups at the end of treatment, while Pournajaf et al. [20], stated both groups improved equally. Furthermore, Kim et al. [24], reported conventional exercise therapy outperformed VR therapy.

VR Interventions and muscle strength

Five of the 12 clinical studies scrutinized the effect of VR interventions on muscle strength. Each study assessed the strength of the quadriceps and hamstring muscles, and one added an evaluation of tibialis anterior muscle

strength. The methodologies for muscle strength assessment varied between studies, including the use of an isokinetic dynamometer (two studies [13,16,] an isometric dynamometer (two studies [19,23] and the Medical Research Council (MRC) scale (one study) [20].

Of the 12 studies reviewed, five examined the impact of VR applications on muscle strength. Two of these found that while the effectiveness was limited, VR applications did prove to be better than traditional methods [13,19]. In contrast, the other three studies found no difference in effectiveness between the two methods [16,20,23].

Gianola et al. [23] report significant improvements in both the conventional exercise and VR groups following treatment; however, no superior enhancement was noted in the VR group. Similarly, neither Pournajaf et al. [20], nor Mete et al. [16], found VR treatment to surpass conventional treatment regarding muscle strength. In a comparison of conventional exercise and interactive virtual telerehabilitation (IVT) exercises, Piqueras et al. [19], reported the IVT group to achieve superior quadriceps muscle strength, but not hamstring muscle strength. Sadeghi et al. [13], noted superior quadriceps muscle strength in the VR group when comparing balance exercises to VR exercises; however, they failed to identify any superiority for combined exercises (balance exercises + VR exercises).

VR Interventions and pain

Of the 12 clinical studies reviewed, eight investigated the impact of VR on pain. Most of these studies utilized the visual analog scale (VAS) to assess pain levels [15-17,20-23,25]. Just one study confirmed that VR applications were superior to conventional methods in relieving pain [17]. Another study proposed that blending VR applications with traditional methods effectively managed pain [16]. The remainder found VR applications and conventional methods to have comparable effectiveness in pain management.

Fuchs et al. observed no difference in pain assessments between traditional physiotherapy and VR therapy [21]. Similar results were reported by Pournajaf et al. [20], Gianola et al. [23], and Koo et al. [15], who all concluded that there was no significant difference between these two treatment approaches. However, Jonathan Zavala-Gonzalez et al. [17], found VR exercises to offer better results in reducing pain than traditional therapy, as revealed by VAS, but this variation did not translate to any clinical difference. Conversely, Mete et al. [19], reported that combining exergaming with traditional physiotherapy proved significantly more effective at alleviating pain than standalone traditional physiotherapy. Pain score assessments using the Knee Injury and Osteoarthritis Outcome Score (KOOS) and the Numerical Pain Rating Scale showed no significant differences in pain between

groups receiving VR interventions and traditional treatments [22,25].

Discussion

The aim of this systematic review is to investigate the effect of VR applications on balance, muscle strength and pain in the context of orthopedic treatment. It included data from 12 studies encompassing 1009 patients. VR applications are typically seen as superior or as effective as conventional methods for improving muscle strength and balance. However, their efficacy for pain management is generally similar to traditional techniques. Hence, when selecting a VR application, it is important to consider the desired treatment parameters and the main objectives of treatment. Even though the results indicate a positive influence on balance muscle strength and pain, some variability is seen in the research outcomes, which may be due to differences in study design. Notably, the bias analysis reveals a high risk-of-bias, mainly associated with the research methodology: a factor that could significantly impact the effectiveness of VR-related treatments.

Effects of VR on balance

The review confirms that VR positively impacts balance parameters, which aligns with previous research findings [26,30]. One review examining VR use in lower body rehabilitation for various orthopedic conditions found VR outcomes comparable to conventional exercises, suggesting that VR can be as effective as traditional methods [37,38]. Recent studies by Baltacı et al. [27] and Yıldırım Şahan et al. [28] found no significant difference in balance parameters post-VR treatment for anterior cruciate ligament injuries or pes planus compared to those undertaking conventional exercises. These studies both reported similar outcomes with VR, despite varying clinical settings and patient demographics.

The key benefits of VR include increased patient enjoyment, enhanced exercise adherence through immersive applications, adjustable difficulty levels, and a sense of accomplishment from performing challenging tasks virtually [29,39]. This sense of achievement can boost patient confidence in their treatment. It is generally accepted that these positive emotional responses, combined with the treatment, act as a 'regulating' factor, leading to internal system reorganization and resulting in outcomes comparable to traditional exercises [26,40].

Conversely, a systematic review by Li et al. [30] found VR to be superior to traditional treatments for improving balance in stroke patients. They suggest that the engaging nature of VR and its ability to break monotony promote better patient participation, and that this may explain the differing results. However, stroke patients typically

demonstrated lower balance scores before intervention, which might overemphasize the statistically significant post-treatment improvements noted within the group [41].

Meanwhile, Mete et al. [16] found that the group receiving both conventional treatments and VR exhibited significant improvements in various parameters compared to the group receiving only conventional exercises. This supports the widely-accepted view that VR works best as an adjunct to conventional treatments [26,42].

Effects of VR on lower extremity muscle strength

Our findings indicate that VR exercises positively influence muscle strength [13,19,20]. However, the VR exercises did not demonstrate any consistent superiority over traditional physiotherapy. Notably, only two studies indicated VR to be significant advantage in strengthening the quadriceps muscle [16,17]. This suggests that while VR can be beneficial, its effectiveness might be contingent upon specific variables such as the type of exercise employed, the target muscle groups, and the overall rehabilitation goals.

The variety of VR exercises used across studies, including weight-bearing, motion range, and balance, highlights the flexibility of VR as a tool. However, the lack of emphasis on resistance-based exercises may partly explain why more pronounced differences in muscle strength between VR and traditional therapy groups were not consistently observed [32]. Resistance training is a well-established method for increasing muscle strength, particularly in older populations. As indicated by a meta-analysis, incorporating resistance exercises into VR programs could enhance their efficacy, especially for middle-aged and elderly individuals [33,34]. This aligns with other research suggesting that VR exercises, when tailored for strength, can yield comparable or even superior outcomes to traditional methods [35].

In contrast to the limited use of resistance-focused exercises, the overall positive outcomes from VR interventions suggest that VR has intrinsic benefits beyond just strength training. The immersive nature of VR allows for real-time interactions and the simulation of real-world tasks that might be difficult or unsafe to perform in traditional settings [18,36]. This makes VR an appealing and innovative option for orthopedic rehabilitation. Furthermore, the enjoyment participants derive from virtual exercises, as reported in various studies, adds an additional layer of motivation, transforming therapy into a more engaging and enjoyable experience compared to conventional methods [13,19,20].

Given these findings, future research should explore the integration of resistance exercises within VR programs to fully harness their potential for enhancing muscle strength [32]. Additionally, studies should continue to compare the effectiveness of VR and traditional thera-

pies across different patient populations and conditions to establish clearer guidelines for clinical practice [34].

Effects of VR on lower extremity pain

The reviewed studies indicate that VR exercises had positive effects on pain management; however, the content of these VR exercises varies widely. The research predominantly used the Visual Analog Scale (VAS) and the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) for pain assessment. They found no considerable difference in pain levels between conventional treatment and VR exercises. An exception was a study by Zavala-Gonzalez et al. [17], which found VR exercises to be significantly more effective in relieving pain than traditional physical therapy. Mete et al. [16] also propose that combining traditional physiotherapy with exergaming was more effective than traditional physiotherapy alone. Therefore, it appears that VR exercises have a comparable impact on pain parameters to conventional exercises. Furthermore, integrating VR exercises with conventional methods seems to yield substantial improvements in pain management during orthopedic rehabilitation. This supports the notion that VR exercises could serve as a preferred, safe strategy for managing pain in orthopedic rehabilitation [43,44].

In addition to its benefits on muscle strength and pain, VR-based therapy offers the convenience of at-home treatment, eliminating the need to visit a therapy center. This offers substantial time and cost savings, particularly for orthopedic patients who may struggle with attending appointments in person. Such a feature is invaluable during instances when patients are unable to physically attend their appointments [45,46].

This compilation includes many studies that encounter a major limitation of VR: the inability to blind patients and practitioners. This poses particular significance while assessing post-treatment results as it can potentially introduce bias; as such, careful consideration is required during evaluation [47]. Notably, unlike other research, the studies included in the present review did not indicate any adverse events. Nonetheless, it is crucial to recognize that one study reported fear and refusal to use to the application among the VR group, and another noted discomfort with the device [21,23]; both studies dealt with geriatric patient populations. The limitations linked to VR might be attributed to *inter alia* the higher vestibular sensitivity and reduced adaptability often observed within this demographic [45,48].

Limitations and Suggestions for Further Future Research

The quality of the studies included in this review was determined using the internationally-validated PEDro scoring system and all included studies were RCTs.

Also, the included studies were of generally high quality, and included a number of recent studies that provide an overview of current approaches.

However, the study has some limitations which should be considered when interpreting the results. Firstly, the virtual reality interventions used in the studies demonstrated considerable heterogeneity: no specific conditions were studied, and the applications were performed with different devices and different procedures. Also, only English-language articles were included.

Conclusion

This systematic review evaluates the impact of virtual reality (VR) applications on balance, lower extremity muscle strength, and pain. The analysis of the gathered studies indicated that VR applications typically yielded results that were either superior to or comparable with conventional treatments for balance and muscle strength. However, considering that most studies examined VR in conjunction with standard physiotherapy, it is crucial to determine whether VR is more effective as a standalone treatment or as an adjunct therapy.

VR applications were found to have roughly equivalent effects on pain to conventional treatments. These findings suggest that VR can serve as a valuable adjunct to conventional treatments, offering significant benefits depending on the primary treatment goals and the specific needs and expectations of the patient.

In conclusion, while VR applications may achieve comparable results to conventional treatments for balance and muscle strength, their effects on pain are roughly similar to those of conventional therapies.

Funding

This research received no external funding.

Conflicts of interest

The authors declare no conflict of interest.

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