

The Effectiveness of Virtual Reality and Augmented Reality in the Management of Chronic Musculoskeletal Disorders: A Systematic Review

Theodora Plavoukou, Pantelis Staktopoulos, Georgios Papagiannis, Dimitrios Stasinopoulos, Georgios Georgoudis

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Abstract

Background: Chronic musculoskeletal disorders (CMDs), such as osteoarthritis, rheumatoid arthritis, and chronic lower back pain, are leading causes of disability and pose significant health and economic burdens worldwide. Traditional rehabilitation methods, including physical therapy and pharmacological treatments, often face challenges related to patient adherence and long-term effectiveness. Emerging technologies like virtual reality (VR) and augmented reality (AR) have been proposed as innovative rehabilitation tools to enhance patient engagement, reduce pain, and improve mobility.

Objective: This systematic review evaluates the effectiveness of VR and AR in managing CMDs, focusing on their impact on pain relief, functional mobility, psychological well-being, and long-term rehabilitation outcomes.

Methods: A systematic search was conducted in PubMed, PEDro, Cochrane, and Scopus for randomized controlled trials (RCTs) investigating VR or AR interventions in CMD rehabilitation. The inclusion criteria were adult patients with CMDs, VR/AR-based interventions, and validated outcome measures assessing pain, kinesiophobia, disability, balance, or depression. Studies were evaluated for quality using the PEDro scale and the Downs and Black checklist.

Results: From 388 identified studies, 8 RCTs met the inclusion criteria, comprising 621 participants aged 18-75 years. The PEDro scale yielded an average study quality score of 6.75/10, with two studies classified as "excellent" (9/10), four as "good" (6-7/10), and one as "fair" (4/10). VR interventions significantly reduced pain intensity in CMD patients, with studies reporting improvements on the Visual Analog Scale (VAS) and the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC). AR-based rehabilitation demonstrated faster recovery times and enhanced functional mobility in post-surgical patients. Psychological benefits, including reduced anxiety and increased motivation, were also observed, particularly in immersive VR environments. However, methodological heterogeneity across studies limited direct comparisons, and no study directly compared AR and VR effectiveness.

Conclusions: VR and AR offer promising alternatives to conventional rehabilitation for CMDs, demonstrating benefits in pain management, functional recovery, and psychological well-being. However, long-term effectiveness, cost-efficiency, and ethical considerations regarding data privacy remain underexplored. Future research should focus on conducting meta-analyses, long-term follow-ups, cost-effectiveness evaluations, and ethical framework development to facilitate clinical integration. With continued advancements, VR and AR have the potential to revolutionize musculoskeletal rehabilitation by providing personalized, engaging, and scalable treatment options. Clinical Trial: The a priori protocol for the review is published in the International Prospective Register of Systematic Reviews (PROSPERO): CRD42024589007.

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Conclusion: VR and AR offer promising alternatives to conventional rehabilitation for CMDs, demonstrating benefits in pain management, functional recovery, and psychological well-being. However, long-term effectiveness, cost-efficiency, and ethical considerations regarding data privacy remain underexplored. Future research should focus on conducting meta-analyses, long-term follow-ups, cost-effectiveness evaluations, and ethical framework development to facilitate clinical integration. With continued advancements, VR and AR have the potential to revolutionize musculoskeletal rehabilitation by providing personalized, engaging, and scalable treatment options.

Keywords: Virtual Reality, Augmented Reality, Musculoskeletal Disorders, Rehabilitation, Pain Management, Physiotherapy, Digital Health

Introduction

Chronic musculoskeletal disorders (CMDs), such as osteoarthritis, rheumatoid arthritis, chronic lower back pain, fibromyalgia, and neck pain, represent a significant and growing global health concern[1] (Lo HHM et al 2023). In 2017, the global number of prevalent cases of musculoskeletal disorders reached 1.3 billion, leading to 121.3 thousand deaths and 138.7 million disability-adjusted life years (DALYs)[2] (Safiri et al., 2021). These conditions are characterized by persistent pain, stiffness, inflammation, and restricted mobility, typically lasting more than three months. CMDs can severely impair an individual's ability to perform daily tasks, diminishing their quality of life and leading to social and physical limitations, as well as increased psychological stress[3] (Gumaa et al., 2022). Chronic pain in CMDs not only impacts physical health but also activates neural circuits associated with anxiety and depression, compounding psychological distress and hindering effective rehabilitation[4] (Kotelnikova et al., 2020). Since CMDs are a leading cause of disability worldwide,

they impose significant economic burdens due to healthcare costs and lost productivity[5] (Li , 2022). Effective, sustainable management strategies are crucial for improving patient outcomes and minimizing these burdens[6] (Fuchs et al., 2022).

Traditional approaches to managing CMDs rely heavily on physical therapy, pharmacological treatments, and lifestyle modifications[3] (Gumaa et al., 2022). While these methods are well-established and can provide relief, they are often met with challenges such as low patient engagement, difficulties in maintaining adherence, and diminishing effectiveness over the long term [6](Fuchs et al., 2022). Many patients struggle to stay motivated through extended rehabilitation programs, particularly in the presence of chronic pain, which can exacerbate psychological distress and complicate the overall management of their condition[5] (Li , 2022). As a result, the demand for more innovative, patient-centered solutions to CMD rehabilitation has increased.

In response to these challenges, technological innovations such as virtual reality (VR) and augmented reality (AR) have emerged as promising alternatives for the rehabilitation of CMDs[7] (Asadzadeh et al 2021). VR creates immersive, computer-generated environments in which patients can engage in interactive exercises[8] (Cao, S. 2016), offering a novel way to distract them from pain while encouraging compliance and active participation in their rehabilitation [3](Gumaa et al., 2022). Studies suggest that VR has the potential to reduce pain, improve mobility, and provide psychological benefits by enhancing patient engagement and reducing anxiety[4] (Kotelnikova et al., 2020). In contrast, AR superimposes digital elements onto the real world, allowing patients to receive real-time feedback on their movements during rehabilitation exercises[9,10] (Da Veiga et al,2022,Toledo-Peral et al 2022). This interactive approach can help patients remain connected to their surroundings while promoting correct movement patterns, making therapy more efficient[5] (Li , 2022).

Evidence supporting the use of VR and AR in managing CMDs is rapidly growing. For example,[6] (Fuchs et al, 2022) demonstrated that VR significantly reduced pain and anxiety in patients undergoing rehabilitation after total knee arthroplasty, although long-term functional outcomes were comparable to traditional physical therapy. Similarly, VR has been shown to enhance patient compliance and improve mobility in individuals with chronic back and neck pain, contributing to psychological well-being in addition to physical recovery[1] (Lo HHM et al., 2023). Additionally, AR-based rehabilitation following knee injuries has been associated with faster recovery times and improved functionality compared to conventional methods[5] (Li , 2022).

Despite the promise these technologies hold, further research is needed to evaluate their long-term effectiveness, cost-efficiency, and the best ways to integrate them into routine clinical practice[9] (Da Veiga et al., 2022). As the accessibility and affordability of VR and AR improve, they have the potential to revolutionize CMD management by offering personalized, engaging, and adaptable rehabilitation experiences[6] (Fuchs et al., 2022).

The present systematic review aims to evaluate the effectiveness of virtual and augmented reality in managing chronic musculoskeletal disorders. Specifically, this review will examine their impact on pain management, mobility, psychological well-being, and long-term functional outcomes. As these technologies continue to develop, understanding their comparative effectiveness and identifying the factors that influence their success in rehabilitation will be crucial for integrating them into standard clinical practice[6,3,5] (Fuchs et al., 2022, Gumaa et al., 2022, Li et al., 2022). Through a comprehensive analysis of the available literature, this review seeks to provide insight into the potential and limitations of VR and AR in the treatment of CMDs, offering a foundation for future clinical applications and research directions.

Methods

Study Protocol and Registration

The study's design is a systematic review based on RCT trials, excluding any previous systematic

reviews and meta-analyses. Our results were based on data from previously published studies. Thus, no ethical approval or patient consent was required. The systematic review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement[11] (Moher D et al, 2009). The a priori protocol for the review is published in the International Prospective Register of Systematic Reviews (PROSPERO): CRD42024589007.

Information Sources

A search for randomized controlled trials (RCTs) was conducted across the databases PubMed, PEDro, Cochrane, and Scopus. A total of 388 studies were identified: 115 articles from PubMed, 10 from PEDro, 48 from Cochrane, and 215 from Scopus. The primary keywords used were: virtual reality, augmented reality, musculoskeletal disorders, physical therapy. Only articles published in English were selected.

Search and Eligibility Criteria

Overall Search Strategy

The search was performed using a combination of the following keywords on May 01, 2024: (musculoskeletal disorders or musculoskeletal pain) AND (virtual reality or augmented reality). The search strategies for each database are presented in the Rayyan® system. In addition, the literature was searched manually from the reference lists of the articles identified from the search of the electronic databases. The inclusion and exclusion criteria of the studies were based on the PICO (Population, Intervention, Comparison, Outcome) method[12,13] (Booth et al,2012, Guyatt et al 2011).

Interventions

The interventions in the studies included in this systematic review involves the use of virtual reality (VR) and augmented reality (AR) technologies for the rehabilitation of patients with chronic musculoskeletal disorders. The VR and AR interventions consisted of rehabilitation programs that included interactive exercises such as balance training, mobility exercises and therapy through virtual simulations. In most cases, patients in the intervention groups received support through these technologies, often combined with conventional rehabilitation treatments like physiotherapist-guided programs or home-based exercise routines. In the control groups, patients underwent more traditional treatment methods, such as conventional physiotherapy in a clinic or conservative care without the use of VR/AR technologies.

Outcome

Measures

The primary outcome measures assessed in the included studies were pain recordings, kinesiophobia, disability, balance and depression levels. These outcomes were evaluated using various validated assessment tools and aimed at determining the effectiveness of VR and AR rehabilitation in improving these key functional parameters in individuals with chronic musculoskeletal disorders.

Inclusion Criteria

For this systematic review, only randomized controlled trials (RCTs) were selected, with no restrictions on the publication year. Participant Characteristics: Adult patients with chronic musculoskeletal disorders. Types of Interventions: The articles had to assess the effect of virtual reality or augmented reality either as a standalone therapy or in comparison with another intervention. Outcome Measures: The factors evaluated were, Pain AND/OR Kinesiophobia AND/OR Disability AND/OR Balance AND/OR Depression .

Exclusion Criteria

The exclusion criteria included: patients under 18 years old, studies without described protocols, incomplete articles, systematic reviews or meta-analyses, case studies, and articles written in languages other than English.

Data Extraction and Management

The "RAYYAN" platform was used to include all articles and to eliminate any duplicate entries. In the first stage, two independent reviewers blindly screened the titles and abstracts of the articles and

removed those deemed unsuitable. In the subsequent stage, the two reviewers examined the full texts of the articles based on the predefined inclusion and exclusion criteria. After identifying the appropriate RCTs, data extraction was performed.

Risk of Bias

In this systematic review, the PEDro scale and the Modified Downs and Black checklist were used to assess the risk of bias. Two independent reviewers TP, PS applied these tools and rated the randomized controlled trials (RCTs). Any disagreements between the two reviewers were resolved through discussion or with the help of a third evaluator GG

Results

/Findings

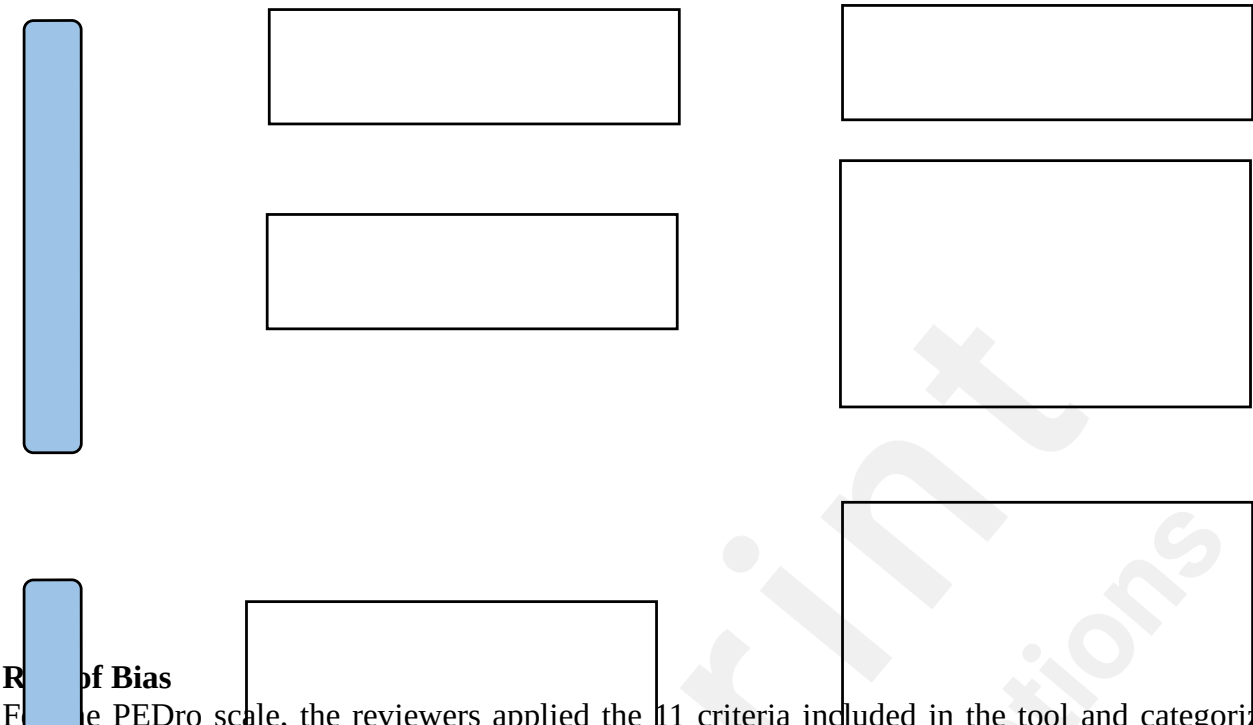
Search and Selection

The total number of studies identified from the database search using the keywords was 388. Specifically, 115 articles were found in PubMed, 10 in PEDro, 48 in Cochrane, and 215 in Scopus. After removing duplicate articles, 312 remained, and following the review of titles and abstracts, 8 studies were selected. Finally, after thoroughly reviewing the full texts, all 8 studies met the criteria for inclusion in this systematic review. In total, the 8 studies included provided a combined 621 participants number of patients with chronic musculoskeletal disorders.

Flow chart

Identification

Records identified through
database searching
(n= 388)



Results of Bias

For the PEDro scale, the reviewers applied the 11 criteria included in the tool and categorized the studies based on their total scores: 0-3 were considered "POOR," 4-5 "FAIR," 6-8 "GOOD," and 9-10 "EXCELLENT." Any disagreements between the two reviewers were resolved through discussion or with the help of a third evaluator.

Article	1	2	3	4	5	6	7	8	9	10	11	Score
Bettger et al 2020[19]	+	+	-	+	-	-	-	+	+	+	+	6/10
Fuchs et al 2022[6]	+	+	-	+	-	-	-	-	-	+	+	4/10
Pekyavas et al 2017[16]	+	+	+	+	-	-	-	+	-	+	+	7/10
Ebrahimi et al 2021[17]	+	+	+	+	-	-	+	+	+	+	-	7/10
Thomas et al 2016[18]	-	+	+	+	-	-	-	+	-	+	+	6/10
Nambi et al 2020[14]	+	+	+	+	+	-	+	+	+	+	+	9/10
Li et al 2022[5]	+	+	-	+	-	-	-	+	+	+	+	6/10
Riaz et al 2024[15]	+	+	+	+	+	-	+	+	+	+	+	9/10
Average												6,75/10

Table 1. PEDro Scale Criteria

The above randomized controlled trials evaluated with the PEDro scale, gave an average score of 6,75/10, indicating good quality. More specifically, two studies scored 9/10 excellent [14,15](Nambi et al 2020, Riaz et al 2024), two studies scored 7/10 [16,5](Pekyavas et al 2017, Ebrahimi et al 2021), three studies scored 6/10 (Thomas et al., 2016, Bettger et al., 2020, Li, 2022), all of which are considered good quality according to the scale. However, one study scored 4/10[6] (Fuchs et al,

2022) which classifies it as a fair-quality study .

Based on the Downs and Black checklist, two studies were classified as fair[16,5] (Pekyavas et al., 2017, Li, 2022), five studies were classified as good [19,5,6,18,14](Bettger et al., 2020, Riaz et al., 2024, Fuchs et al., 2022, Thomas et al., 2016, Nambi et al., 2020) and one study classified as excellent[17] (Ebrahimi et al., 2021).

RCT	Down's and Black Score	Quality of study
Pekyavas et al 2017[16]	17/28	FAIR
Bettger et al 2020[19]	25/28	GOOD
Nambi et al 2020[14]	24/28	GOOD
Li et al 2022[5]	16/28	FAIR
Riaz et al 2024[15]	23/28	GOOD
Fuchs et al 2022[6]	22/28	GOOD
Ebrahimi et al 2021[17]	27/28	EXCELLENT
Thomas et al 2018[18]	22/28	GOOD

POOR (≤ 14) = RED

FAIR (15-19)= YELLOW

GOOD (20-25) = BLUE

EXCELLENT (26-28)= GREEN

Study Characteristics

From the **388 initially identified studies**, only **8 randomized controlled trials (RCTs)** met the inclusion criteria, comprising a total of **621 participants**. The age range of participants varied from **18 to 75 years**, covering both **young adults and older individuals** undergoing rehabilitation programs utilizing VR/AR technologies.

A **notable gender imbalance** was observed across the studies. Specifically, **one study included only male participants** (Nambi et al., 2020), **two studies exclusively included female participants** (Riaz et al., 2024; Ebrahimi et al., 2021), while the remaining six studies involved **mixed-gender populations**. Overall, **women represented approximately 60% of the total sample**, which could influence the generalizability of the findings.

Most studies focused on **knee-related conditions (37.5%)**, such as **total knee arthroplasty (TKA) and post-traumatic osteoarthritis**[19,14,5] (Bettger et al., 2020; Nambi et al., 2020; Li, 2022). Additionally, **25% of studies investigated chronic lower back pain and joint-related pain**[18,17] (Thomas et al., 2016; Ebrahimi et al., 2021), while **two studies (25%) examined shoulder dysfunctions**, specifically **subacromial impingement syndrome and scapular dyskinesis** [16] (Pekyavas et al., 2017; Pekyavas & Ergun, 2020). One study (12.5%) explored the use of VR for **osteoporosis and bone mineral density improvements**[15] (Riaz et al., 2024).

All VR/AR interventions were **integrated into structured rehabilitation programs**, with intervention durations ranging from **3 days to 24 weeks**. **Seventy-five percent (75%) of the studies involved supervised sessions (either in-person or remote through tele-rehabilitation)**, while **25% combined at-home rehabilitation programs**. The VR/AR technologies utilized varied, including **virtual training simulations, exergaming, motion-tracking therapy, and augmented reality-guided exercises**. Control groups across studies primarily engaged in **traditional rehabilitation methods**, such as **therapist-guided physiotherapy or conservative treatment without technological assistance**.

The **heterogeneity of the included studies**, particularly regarding **participant distribution, rehabilitation techniques, and intervention duration**, highlights the necessity for further exploration of **personalized VR/AR programs tailored to specific conditions and patient demographics**. The diversity in **methodologies and sample populations** also underscores the importance of future **meta-analyses** to comprehensively assess the overall effectiveness of these technologies in musculoskeletal rehabilitation.

Study (Country)	Sample, Age, Pathology	Experimental Group	Control Group	Outcome Measures	Main Results	Duration	Supervision	Adverse Events
Abdullah et al. (2020, Saudi Arabia)[14]	60 participants, 18-25 years, Post-traumatic OA after ACL injury	VR Training with Pro-Kin System (progressive knee-strengthening tasks, e.g., ball shooting).	Supervised conventional exercise programs	VAS, WOMAC, BMP, Inflammatory biomarkers	Significant improvement in pain, disability, and inflammatory markers ($p<0.001$). No difference in BMP measures.	4 weeks	Supervised	3 total group reasons
Yavas et al. (2017, Turkey)[16]	30 participants, ~40.6 years, SAIS and Scapular Dyskinesis	Wii-Based Exergaming (e.g., boxing, tennis, with Theraband resistance).	Home exercise program	VAS, Neer, Hawkins, SRT, SAT, LSST, SPADI	Better functional outcomes (Neer, SRT, SAT) in VR group ($p<0.05$). Both groups improved pain intensity ($p<0.05$).	6 weeks	Supervised (VR), Home	None
Alotaibi et al. (2022, Saudi Arabia)[5]	40 participants, ~33 years, Post-op rehab for knee injuries	AR-based rehab (Virtual knee joint simulation, progressive movement tasks, and roaming scene games).	Conservative therapy	HSS, VAS	Higher HSS scores and faster recovery in AR group ($p<0.05$).	6 weeks	Not specified	None
Alizadeh et al. (2024, Iran)	52 participants, 48-70 years, Osteopenia	Kinect-Based VRT (Full-body motion)	Regular active lifestyle	FRAX, BMD, HFP, HPMO	Improved BMD and reduced fracture risk	24 weeks	Supervised (VR)	9 total (transpostion), control

		tracking with Kinect for progressive exercises).			in VRT group ($p<0.001$). Limited changes in control group.			
ger et al. (20, USA)	306 participants, ~65 years, TKA	Virtual PT (telehealth-guided, adaptive home-based therapy).	Traditional PT	KOOS, PROMIS	Virtual PT was noninferior for knee function. Fewer hospital readmissions in virtual PT group ($p=0.007$).	12 weeks	Remote supervision	5 Virtual Traditional (person-up).
mas et (2016, A)[18]	52 participants, 18-50 years, Chronic Low Back Pain (CLBP)	VR Dodgeball (15-minute sessions, sagittal plane target-reaching game).	No intervention	TSK, CES-D, RMDQ, MPQ	Significant reduction in expected pain ($p=0.001$), but no differences between groups.	3 days	Supervised	1 disqualification (unrelated medical)
himi et (2021,) [17]	26 females, ~30 years, Patellofemoral Pain (PFP)	VRT (Xbox Kinect: 24 sessions of adaptive movement-based games).	Lifestyle education	mSEBT, VAS, Kujala Questionnaire, SF-36	Significant improvement in balance, pain, function, and QoL in VRT group ($p<0.001$).	8 weeks	Supervised	2 to COVID (control personal (interv)
hs et al. (22, el)[6]	55 participants, ~70 years, TKA	VR alongside physiotherapy (VR headset during CPM therapy sessions).	Conventional physiotherapy	STAI, VAS, WOMAC	Reduced pain and anxiety in both groups. No significant WOMAC score differences at 6-month follow-up ($p>0.05$).	2 days	Supervised	12 discharges per group

Table 3 Summary of Studies

Discussion

This systematic review explored the effectiveness of virtual reality (VR) and augmented reality (AR) technologies in managing chronic musculoskeletal disorders (CMDs). The primary outcomes of interest included **pain, balance, and functional disability**, which are crucial in rehabilitation for individuals with CMDs. These outcomes were consistently measured using validated assessment tools, ensuring **objective and comparable data across studies**. However, the studies included in this review exhibited **considerable methodological variability**, particularly in **sample characteristics, intervention duration, and outcome measurement**, limiting the ability to draw robust conclusions.

Pain was one of the most frequently measured outcomes. Pain intensity was primarily assessed using the **Visual Analog Scale (VAS)** and the **Western Ontario and McMaster Universities Arthritis Index (WOMAC)**, which are widely used in musculoskeletal research. Studies such as **Nambi et al. (2020)[14]** and **Fuchs et al. (2022)[6]** found that **VR interventions led to significant pain reduction compared to traditional rehabilitation approaches**. Similarly, **Li et al. (2022)[5]** and **Ebrahimi et al. (2021)[17]** reported that **both AR and VR therapies resulted in lower post-rehabilitation pain scores**, supporting their role as effective pain management strategies. The immersive nature of VR, which **engages patients in interactive exercises and distracts from pain perception**, is a key mechanism underlying these improvements. However, **the absence of a structured heterogeneity assessment across studies weakens the ability to generalize these findings**, as factors such as **gender distribution, pathology type, and intervention duration** varied considerably between studies. Future studies should incorporate **formal heterogeneity analyses**, such as **I² statistics or subgroup analyses**, to determine whether certain patient populations benefit more from VR-based pain interventions.

In addition to pain management, **balance and functional disability** were also key outcomes. Balance was frequently assessed using the **Modified Star Excursion Balance Test**, while functional disability was evaluated using the **Kujala score** and other validated scales. **Ebrahimi et al. (2021)[17]** demonstrated that **VR training significantly improved both balance and functional mobility in patients with patellofemoral pain syndrome**. Similarly, **Pekyavas et al. (2017)[16]** and **Riaz et al. (2024)[15]** reported **notable improvements in mobility and functionality following VR interventions**, further supporting the role of VR in neuromuscular re-education. However, **the lack of meta-analysis in this review prevents a quantitative synthesis of these effects**, making it difficult to assess the **overall impact of VR/AR on balance and mobility across different rehabilitation contexts**. Conducting a meta-analysis in future reviews would allow for a **more robust comparison of VR/AR effectiveness relative to conventional rehabilitation**.

AR-based interventions have also shown **promising results**, particularly in **post-surgical rehabilitation**. **Li et al. (2022)[5]** found that **AR-based rehabilitation programs not only improved pain scores but also significantly reduced recovery time** for patients following knee surgery. The ability of AR to **overlay real-time digital guidance onto rehabilitation exercises** provides **instant feedback**, improving **movement accuracy and adherence to therapy**. This is particularly beneficial in **home-based rehabilitation settings**, where **patient engagement and compliance often decline**. However, **none of the included studies directly compared AR to VR interventions**, leaving **uncertainty regarding their relative effectiveness**. Future research should focus on **direct comparative trials between VR and AR interventions** to determine **which technology is more effective for specific patient populations**.

Furthermore, the psychological benefits of VR and AR interventions were highlighted in several studies. Chronic musculoskeletal pain is frequently accompanied by **psychological comorbidities such as anxiety and depression**, which can negatively impact rehabilitation outcomes. **Fuchs et al.**

(2022)[6] reported that **VR interventions significantly reduced anxiety levels in patients undergoing rehabilitation after total knee arthroplasty**. The **immersive and engaging nature of VR may help mitigate psychological distress by shifting focus away from pain and towards interactive, goal-oriented activities**. However, **few studies formally assessed mental health outcomes using validated anxiety and depression scales**, highlighting a need for **future research to systematically evaluate the psychological effects of VR and AR interventions**.

Identified Gaps and Future Directions

Despite the **positive findings**, this review identified **significant gaps in the literature** that require further exploration. A **major limitation** is the **lack of long-term follow-up data**. While most studies demonstrate **short-term improvements in pain, mobility, and functionality**, it remains **unclear whether these benefits persist beyond six months or one year**. Future research should prioritize **longitudinal studies** to determine the **long-term sustainability of VR/AR rehabilitation effects** and whether **these technologies outperform traditional rehabilitation over time**.

Another **critical consideration** is the **economic feasibility** of VR and AR implementation in routine clinical practice. Although **Li et al. (2022)[5]** suggested **potential cost-saving benefits** such as **shorter recovery times and fewer repeat visits**, **no study included a comprehensive cost-benefit analysis**. VR and AR interventions require **specialized equipment, software, and therapist training**, which can **increase initial healthcare costs**. For VR/AR to become **viable rehabilitation tools**, future research should examine **cost-effectiveness across different healthcare systems**, considering **accessibility, scalability, and financial sustainability**.

Moreover, **ethical and regulatory challenges** surrounding VR/AR use in rehabilitation remain largely unaddressed. The **collection of biometric data, motion tracking, and patient interaction within virtual environments** raises concerns regarding **data privacy and security**. **No study in this review explicitly discussed patient consent, data protection measures, or ethical frameworks for VR/AR rehabilitation**. The absence of standardized **ethical and regulatory guidelines** poses a significant barrier to widespread clinical adoption. Future research should work towards **establishing ethical best practices and policy recommendations** to ensure **patient safety and data confidentiality** in VR/AR applications.

Conclusion

This systematic review presents **VR and AR as promising tools** for enhancing **pain management, balance, and functional recovery in CMD patients**, offering a **potentially effective alternative to conventional rehabilitation**. However, several critical concerns **must be addressed** before these technologies can be fully integrated into **clinical practice**. Future research should focus on:

1. **Conducting meta-analyses** to synthesize findings across studies and assess overall effectiveness.
2. **Implementing long-term follow-up studies** to determine the **sustainability of VR/AR rehabilitation benefits**.
3. **Evaluating cost-effectiveness** to assess **economic feasibility and healthcare system scalability**.
4. **Addressing ethical concerns** by developing **standardized regulatory frameworks for data security and patient safety**.

By addressing these gaps, VR and AR technologies have the potential to revolutionize **rehabilitation practices**, making **personalized, engaging, and interactive rehabilitation** more **accessible and effective** for individuals with **chronic musculoskeletal disorders**.

Implications for Physiotherapy Practice

Integrating **VR and AR into physiotherapy** has the potential to **significantly enhance rehabilitation outcomes** by providing **immersive, interactive, and patient-centered therapy options**. These technologies **improve patient adherence** by making rehabilitation exercises

engaging and gamified, which is particularly important for **long-term compliance** in CMD management. As VR and AR **become more affordable and accessible**, they could play a **key role in both clinical and home-based rehabilitation**, bridging the gap between **clinical supervision and independent recovery programs**.

However, **physiotherapists must be adequately trained** to incorporate **VR/AR technologies into standard rehabilitation protocols**, and **healthcare policies must support reimbursement models** for digital rehabilitation solutions. Future advancements in **tele-rehabilitation and AI-driven VR therapy** could further **enhance patient outcomes**, making **VR and AR integral components of modern physiotherapy**.

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PRISMA 2020 Checklist for the Systematic Review: "The Effectiveness of Virtual Reality and Augmented Reality in the Management of Chronic Musculoskeletal Disorders"

Section 1: Title

1. Title: *Identifies the report as a systematic review.* (Found in the Title section)

Section

2:

Abstract

2. Structured summary: *Provides background, objectives, methods, results, and conclusions.* (Found in the Abstract section)

Section

3:

Introduction

3. Rationale: *Describes the rationale for the review in the context of existing knowledge.* (Found in the Introduction section)
4. Objectives: *Provides an explicit statement of the objective(s) or question(s) the review addresses.* (Found in the Objective section)

Section

4:

Methods

5. Eligibility criteria: *Specifies the inclusion/exclusion criteria using PICO.* (Found in the Methods section under "Search and Eligibility Criteria")
6. Information sources: *Specifies all databases and sources searched, including last search date.* (Found in the Methods section under "Information Sources")
7. Search strategy: *Presents the full search strategies for all databases, registers, and websites.* (Found in the Methods section under "Overall Search Strategy")
8. Selection process: *Specifies how studies were screened and selected.* (Found in the Methods section under "Data Extraction and Management")
9. Data collection process: *Explains how data was extracted from included studies.* (Found in the Methods section under "Data Extraction and Management")
10. Data items: *Lists key variables for extraction (e.g., outcomes, interventions, funding sources).* (Found in the Methods section under "Outcome Measures")
11. Study risk of bias assessment: *Specifies methods used to assess risk of bias.* (Found in the "Risk of Bias" section)
12. Effect measures: *Specifies summary measures (e.g., risk ratios, mean differences).* (Found in the Methods section)
- 13.

Synthesis methods: *Explains data synthesis approach, including how missing data were handled.* (Found in the Results section under "Results/Findings") 14. Reporting bias assessment: *Describes methods to assess risk of bias due to missing results.* (Found in the "Risk of Bias" section) 15. Certainty assessment: *Describes methods used to assess certainty in evidence.* (Found in the "Risk of Bias" section)

Section**5:****Results**

16. Study selection: *Describes the search and selection process, ideally using a flow diagram.* (Found in the Results section under "Search and Selection", including PRISMA flow diagram) 17. Study characteristics: *Cites each included study and presents its characteristics.* (Found in the Results section under "Study Characteristics") 18. Risk of bias in studies: *Presents assessments of risk of bias for each included study.* (Found in the "Risk of Bias" section) 19. Results of individual studies: *Presents summary statistics for each outcome.* (Found in the Results section under "Findings") 20. Results of syntheses: *Summarizes characteristics and risk of bias among contributing studies.* (Found in the Results section under "Findings") 21. Reporting biases: *Presents assessments of risk of bias due to missing results.* (Found in the "Risk of Bias" section) 22. Certainty of evidence: *Presents assessments of certainty in evidence for each outcome.* (Found in the "Risk of Bias" section)

Section**6:****Discussion**

23. Discussion: a. *Provides a general interpretation of the results in the context of other evidence.* (Found in the "Discussion" section) b. *Discusses limitations of the evidence included in the review.* (Found in the "Discussion" section) c. *Discusses limitations of the review processes used.* (Found in the "Discussion" section) d. *Discusses implications for practice, policy, and future research.* (Found in the "Discussion" and "Implications for Physiotherapy Practice" sections)

Section**7:****Other****Information**

24. Registration & Protocol: a. *Provides registration information, including register name and registration number.* (Found in the Methods section under "Study Protocol and Registration") b. *Indicates where the review protocol can be accessed or states if it was not prepared.* (Found in the Methods section) c. *Describes and explains any protocol amendments.* (Not applicable in this review) 25. Support: *Describes sources of financial or non-financial support for the review.* ✕ (No funding details found in the document) 26. Competing interests: *Declares any competing interests of review authors.* (Found in the "Funding & Conflicts of Interest" section, if applicable) 27. Availability of data, code, and other materials: *Reports availability of collected data and analysis code.* (Found in the "Data Availability" section, if applicable)

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March 13, 2025**To:**

Editor-in-Chief

Journal of Medical Internet Research (JMIR)
<https://www.jmir.org>

Subject: Manuscript Submission – “The Effectiveness of Virtual Reality and Augmented Reality in the Management of Chronic Musculoskeletal Disorders: A Systematic Review”

Dear Editor,

I am pleased to submit our manuscript entitled **“The Effectiveness of Virtual Reality and Augmented Reality in the Management of Chronic Musculoskeletal Disorders: A Systematic Review”** for consideration for publication in the *Journal of Medical Internet Research (JMIR)*.

This work forms part of my PhD research at the **University of West Attica** and presents a comprehensive systematic review of the existing literature on the use of **Virtual Reality (VR)** and

Augmented Reality (AR) in the rehabilitation of individuals with **chronic musculoskeletal disorders**. Our findings demonstrate that immersive technologies such as VR and AR can significantly reduce pain, enhance functional mobility, and improve psychological well-being. These technologies show strong potential as evidence-based digital tools in modern physiotherapy and rehabilitation practice.

We believe that *JMIR*, with its established reputation in digital health innovation and medical internet research, is the ideal platform for disseminating our findings. The scope of the journal aligns closely with our study's emphasis on integrating advanced technologies into healthcare and rehabilitation.

This manuscript is original, has not been published, and is not currently under review by any other journal. All authors have approved the final version and agree with its submission to *JMIR*.

We appreciate your time and consideration, and we look forward to the opportunity to contribute to the journal. Please do not hesitate to contact us if additional information is required.

Sincerely,

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