

# Evaluating the Effectiveness, Patient Engagement, and Safety Concerns of Immersive Virtual Reality–Based Exercise Programs in Musculoskeletal Dysfunctions: A Narrative Review

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## ABSTRACT

**Background:** Musculoskeletal disorders (MSDs) remain a global contributor to disability, characterized by pain, limited function, and reduced quality of life. Conventional physiotherapy is effective, but treatment adherence, kinesiophobia, and psychosocial factors often reduce long-term outcomes. Immersive Virtual Reality (IVR) has emerged as a promising rehabilitation tool to enhance exercise engagement, decrease pain, and improve functional outcomes.

**Purpose:** To narratively review current evidence on the clinical effectiveness, patient engagement, and safety concerns—including cybersickness—of IVR-mediated exercise programs for musculoskeletal dysfunctions (MSDs).

**Methods:** Peer-reviewed studies and systematic reviews related to IVR rehabilitation for MSDs were screened. Major outcomes of interest included pain, function, adherence, kinesiophobia, safety, and cybersickness.

**Results:** Evidence demonstrates that IVR positively influences pain reduction, functional improvement, motivation, and treatment adherence. Several studies report benefits for chronic musculoskeletal pain, knee osteoarthritis, and post-surgical rehabilitation. IVR may address psychosocial barriers such as fear-avoidance and kinesiophobia. However, cybersickness remains a recognized adverse effect influenced by task complexity, frequency-dependent VR content, and technical limitations. Evidence for personalized IVR systems in home-based care is emerging.

**Conclusion:** IVR is a beneficial adjunct to musculoskeletal rehabilitation, improving pain, function, and engagement. Although cybersickness remains a concern, technological refinements have reduced associated risks. More rigorous randomized trials are required to establish optimal protocols, safety profiles, and long-term outcomes.

**Keywords:** Virtual Reality, immersive VR, musculoskeletal disorders, rehabilitation, cybersickness, patient engagement.

## 1. INTRODUCTION

Musculoskeletal disorders (MSDs)—including osteoarthritis (OA), chronic neck and low back pain, and shoulder dysfunction—are leading contributors to disability worldwide. They impose a significant socioeconomic burden and negatively impact patients' quality of life, functional abilities, and emotional wellness<sup>1</sup>. Despite the effectiveness of conventional physiotherapy, adherence challenges, pain catastrophizing, kinesiophobia, and declining motivation restrict long-term benefits<sup>1,2,3,4,5</sup>.

Psychological comorbidities such as anxiety and depression further worsen pain and disability<sup>6</sup>, emphasizing the need for multimodal strategies to increase adherence and facilitate active rehabilitation.

Immersive Virtual Reality (IVR)-mediated exercise is a technology-driven tool enabling simulated rehabilitation environments with enhanced engagement, real-time feedback, gamification, and cognitive distraction. Recent umbrella and systematic reviews highlight IVR effectiveness in reducing pain, improving functional mobility, and increasing adherence across MSD cohorts<sup>7,8,9,10</sup>.

However, implementation concerns—cybersickness, usability, cost, and inadequate personalization—remain barriers. Growing interest in home-based VR therapy suggests potential scalability<sup>11</sup>.

This review synthesizes the current state of evidence on:

1. Effectiveness of IVR for MSD rehabilitation
2. Patient engagement and behavioural outcomes
3. Safety concerns, including cybersickness

## 2. METHODS

A narrative review approach was adopted. Primary sources included systematic reviews, meta-analyses, RCTs, scoping reviews, feasibility studies, and guidelines. Databases included PubMed, Web of Science, and Scopus.

Search terms: “virtual reality,” “immersive VR,” “musculoskeletal rehabilitation,” “chronic pain,” “adherence,” “cybersickness.”

### Inclusion criteria:

- Immersive VR interventions
- Participants with MSDs
- Outcomes including pain, function, psychosocial parameters, adherence, or safety

**Exclusion:** non-MSD conditions, no exercise component.

## 3. RESULTS

### 3.1 Clinical Effectiveness

#### 3.1.1 Pain Reduction

Multiple reviews show IVR improves pain symptoms in chronic musculoskeletal pain and OA<sup>7,2</sup>. VR achieves analgesia through distraction, sensorimotor feedback, and graded exposure.

#### 3.1.2 Functional Outcomes

Improvements noted in the Walking ability, Balance, Range of motion, Activities of daily living, Virtual Reality-based interventions demonstrate comparable or superior outcomes to traditional physiotherapy for MSDs including knee OA, shoulder dysfunction, and post-operative cases<sup>12</sup>.

#### 3.1.3 Psychological Benefits

Psychosocial variables play critical roles in MSD progression. Kinesiophobia is prevalent in knee OA<sup>5</sup> and predicts pain/disability<sup>3</sup>. VR helps reduce catastrophizing and fear through immersive exposure and confidence-building environments.

Self-efficacy improvements correlate with improved functional outcomes<sup>4</sup>.

#### 3.1.4 Home-based Feasibility

Recent work demonstrates feasibility of personalized home-based VR rehab, enabling remote monitoring and adherence<sup>11</sup>.

### 3.2 Patient Engagement

Gamified VR environments increase adherence, motivation, and enjoyment, addressing limitations of conventional physiotherapy including low motivation and exercise monotony<sup>8</sup>.

Real-time feedback, scoring, and immersive environments promote psychological arousal and higher engagement.

### 3.3 Safety Concerns

#### 3.3.1 Cybersickness

Cybersickness—encompassing nausea, dizziness, oculomotor strain—remains a key concern.

Incidence varies with:

VR hardware, Visual-vestibular conflict, Session duration, Frequency content<sup>14</sup>, Frequency-dependent modulation reduces cybersickness<sup>14</sup>, while design choices affect tolerance<sup>15</sup>.

#### 3.3.2 General Adverse Events

Most VR studies report minimal side effects; events are transient and manageable. Screening and gradual exposure are recommended.

#### 3.3.3 Contraindications and Precautions

Vestibular disorders, Photosensitive epilepsy, Severe motion sensitivity

Clinical guidance is necessary as per OARSI-directed conservative OA care guidelines<sup>10</sup> though VR is not yet formally included.

## 4. DISCUSSION

This narrative synthesis suggests IVR programs hold strong potential as adjunct therapeutic strategies in MSD management. IVR can influence multiple biopsychosocial domains—pain, function, motivation, fear-avoidance behaviours, and depression—which conventional therapy often struggles to modify alone.

IVR's benefits align with modern rehabilitation frameworks integrating cognitive, behavioural, and physical components.

Challenges persist such as need for standardized protocols, Cybersickness mitigation, Cost barriers, Real-world scalability, Heterogeneity of study methodologies

Research gaps include long-term follow-up, comparative effectiveness across MSD subtypes, and economic evaluations.

**Table 1. Summary of VR Effectiveness Outcomes in Musculoskeletal Disorders**

[Overall: VR demonstrates beneficial effects in pain reduction, ROM, balance, and function; early evidence supports home-based feasibility]

Study /Source	Population	VR Type	Comparison	Primary Outcomes	Key Findings
Tang.p et al., 2025	Mixed MSD	Immersive VR	Conventional PT	Pain, Function	VR improved pain and function comparable or superior to PT
Bilika P et al., 2023	Chronic MSK pain	VR exercise	Usual care	Pain	Significant short-term pain reduction
Maselli F et al.,2025	Mixed MSD	VR rehabilitation	Conventional PT	Function, ROM	Significant functional improvement and ROM gains
Brady et al., 2021	Chronic MSK pain	iVR	PT		Pain, Engagement
Al-Amri et al., 2025	Mixed MSD	Home VR	PT	Feasibility	Home VR intervention feasible with acceptable adherence
Almansour et al., 2024	Athletes	VR training	Traditional rehab	Strength, performance	VR-assisted rehab improved neuromotor performance
Bannuru RR et al.,20192	Knee/Hip OA	(Guideline reference)	—	—	Supports non-pharm rehab; VR could be potential adjunct

Salman et al., 2023	OA	Molecular focus	—	—	Molecular rationale supports multimodal rehabilitation tools including VR
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**Table 2. Summary of VR Engagement & Behavioural Outcomes**

[Overall: VR enhances adherence, motivation, psychological readiness, and reduces fear-avoidance—addressing major barriers in MSK rehab.]

Study	Engagement Measure	Mechanisms Driving Engagement	Key Findings
Brady et al., 2021	Motivation, adherence	Gamification, feedback	Increased adherence and participation vs traditional PT
Benyon et al., 2010	Self-efficacy	Positive reinforcement	VR improves self-efficacy, predicting better outcomes
Somers et al., 2009	Catastrophizing, fear	Safe simulated movement	Exposure-based VR may reduce fear-avoidance
Acar et al., 2022	Kinesiophobia	Gradual exposure	VR reduces movement fear more effectively
Tang.p et al., 2025	Patient adherence	Multi-sensory immersion	Higher engagement through immersive tasks
Al-Amri et al., 2025	Home use adherence	Personalized programs	High adherence, user acceptance reported

**Table 3. Summary of Cybersickness Incidence & Safety Considerations**

[Overall: Cybersickness is a manageable side-effect with low-moderate incidence; design optimization and session strategies improve tolerance. Most Common Symptoms includes Nausea, Dizziness, Oculomotor strain, Disorientation]

Study	VR Type	Safety Outcomes Measured	Cybersickness Incidence	Contributing Factors	Key Notes
Benelli et al., 2023	iVR	Nausea, dizziness	Low-Moderate	Frequency content	VR frequency modulation reduces cybersickness
Brady et al., 2021	iVR	AE reporting	Minimal	Session duration	Symptoms transient; mostly mild
Tang.p et al., 2025	iVR	General discomfort	Low	Immersion level	Short sessions recommended
Biswas et al., 2024	iVR	CSL scales	Moderate	Visual-vestibular conflict, latency	Hardware/software optimization reduces severity
Al-Amri et al., 2025	Home VR	Safety tolerance	Minimal	Device setup	Safe for home delivery with guidance

Increase Risk	Reduce Risk
Low FPS / latency	High-performance hardware
Visuo-vestibular mismatch	Gradual exposure, session pacing
High visual motion	Seated tasks
Long usage times	Breaks
Poor calibration	Personalized settings

### Long-Term Outcomes and Sustainability

Several recent reviews highlight a critical gap in long-term outcome data for immersive virtual reality (IVR)-mediated musculoskeletal rehabilitation. Most research focuses on short-term benefits, but the persistence of improvements in pain,

function, and psychosocial adaptation remains to be determined through robust longitudinal studies<sup>2,11</sup>. Sustained motivation and adherence are promising, yet the durability of effects after withdrawal of VR or reduction in engagement is incompletely explored. Future studies should

therefore integrate extended follow-up to monitor relapse and functional maintenance<sup>2,11</sup>.

### **Personalized and Adaptive Rehabilitation**

IVR platforms increasingly incorporate real-time biomechanical feedback and tailored therapeutic activities that support individualized rehabilitation plans<sup>11,8</sup>. Leveraging patient-specific deficits—such as joint mechanics, neuromuscular activation, and proprioceptive function—can optimize patient recovery and accelerate return to activity. Adaptive progression, in-built assessments, and difficulty scaling further enhance efficiency for a wide variety of musculoskeletal conditions<sup>8,2</sup>.

### **Accessibility, Telemedicine, and Cost-Effectiveness**

IVR has enabled home-based and telerehabilitation, extending access for individuals with geographic or mobility limitations<sup>11,8</sup>. The portability of modern virtual reality systems supports continuity of care beyond the clinic, potentially lessening burden on healthcare systems and improving adherence<sup>11</sup>. Initial cost-effectiveness studies reveal IVR to be potentially cost-saving compared to clinic-based therapy when indirect costs such as travel are considered, though up-front device costs and training requirements remain notable barriers<sup>16,2</sup>.

### **Neuroplasticity and Mechanistic Insights**

Recent literature describes the underlying neuroplastic mechanisms responsible for IVR's clinical effects. Repetitive, intention-driven movement in virtual environments is associated with sensorimotor retraining and cortical reorganization, particularly when cognitive and physical challenges are combined<sup>8,9</sup>. Engagement and task relevance are key, as active participation potentiates neuroadaptive changes to a greater degree than passive modes<sup>8</sup>.

### **Economic and Policy Implications**

As IVR platforms mature, there is a need for rigorous economic modelling to quantify

healthcare savings and cost per QALY (Quality-Adjusted Life Year)<sup>16</sup>. Policy frameworks for insurance reimbursement and protocol standardization are emerging but require further validation by high-quality studies with economic and implementation endpoints<sup>11,8</sup>.

### **Research Gaps and Future Directions**

Despite positive findings for pain, function, and engagement, ongoing research should prioritize direct comparisons of VR modalities (immersive vs. non-immersive) and standardization of outcome measures<sup>2</sup>. There remains a publication bias risk due to underpowered or single-center studies. Future large-scale, multicentre trials are recommended to resolve these issues and establish consensus-based guidelines<sup>2,8</sup>.

## **5. CONCLUSION**

Immersive VR-mediated rehabilitation demonstrates promising effectiveness for pain reduction, functional recovery, and psychosocial improvements across musculoskeletal populations. IVR enhances patient engagement and adherence—key determinants of rehabilitation success.

Safety concerns such as cybersickness exist but are manageable with appropriate VR design and patient monitoring.

While IVR appears valuable as an adjunct to conventional physiotherapy, more high-quality RCTs are required to validate long-term clinical impact, economic viability, and best-practice implementation.

### **Declarations**

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**Consent for publication:** Not applicable.

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R. Kamalakannan: Conceptualization, Methodology, Data curation, Writing –

original draft. Ajay Kumar: Supervision, Validation, Writing – review & editing. Bhavika Gohel.: Data extraction, Formal analysis, Writing – review & editing. Radhika Gopal S.: Literature search, Resources, Visualization. Vivek V. Menon: Methodology, Writing – review & editing, Final approval.

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