Research Article

Neurophysiological Mechanisms, Clinical Effectiveness, and Functional Outcomes of Virtual Reality Based Rehabilitation in Chronic Nonspecific Low Back Pain: A Narrative Review

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Abstract

Background: Chronic nonspecific low back pain (CNSLBP) is a major contributor to musculoskeletal disability, functional limitations, and reduced health-related quality of life. Virtual reality (VR)-based rehabilitation has emerged as an innovative approach integrating therapeutic exercise, sensory feedback, motor learning, and behavioural engagement. However, its comparative effectiveness against conventional physiotherapy remains uncertain.

Objective: To critically examine the neurophysiological mechanisms and clinical effectiveness of VR-based rehabilitation in individuals with CNSLBP, focusing on pain intensity, lumbar range of motion (ROM), functional disability, and health-related quality of life (HRQoL).

Methods: A structured narrative review was conducted using literature retrieved from PubMed, Scopus, Web of Science, PEDro, Cochrane Library, and CINAHL. The search incorporated keywords related to chronic nonspecific low back pain, virtual reality, therapeutic exercise, conventional physiotherapy, and clinical outcomes. Following identification of 770 records, duplicate removal and screening procedures were undertaken. Seventy-five full-text articles were assessed, and 13 studies were included in the final narrative synthesis. Evidence was organised according to intervention characteristics, therapeutic mechanisms, clinical outcomes, and methodological limitations.

Results: The reviewed evidence demonstrated promising improvements in pain intensity and functional disability following VR-based rehabilitation. Li et al. (2024) reported significant immediate improvements in pain intensity (MD = −1.43) and disability (MD = −11.50). Potential therapeutic mechanisms included attentional modulation, sensorimotor integration, graded exposure, and enhanced movement confidence. However, evidence concerning objective lumbar ROM and sustained HRQoL improvements remained limited. Substantial intervention heterogeneity restricted comparisons with conventional supervised exercise therapy.

Conclusion: VR-based rehabilitation represents a promising adjunct to conventional physiotherapy for CNSLBP. Further comparative clinical studies using standardised protocols, objective mobility assessments, and long-term follow-up are warranted to establish its additional clinical effectiveness.

Keywords: Virtual Reality, Low Back Pain, Rehabilitation, Exercise Therapy, Physical Therapy Modalities, Quality of Life, Narrative Review

Introduction:

Low back pain (LBP) is a leading cause of musculoskeletal disability worldwide, contributing substantially to functional limitations, reduced work productivity, and healthcare expenditure. The Global Burden of Disease Study 2021 estimated that approximately 619 million individuals experienced LBP in 2020, with this figure projected to increase considerably by 2050 (GBD 2021 Low Back Pain Collaborators, 2023). Chronic low back pain (CLBP), characterised by persistent or recurrent symptoms lasting longer than three months, represents a particularly complex clinical challenge due to its multidimensional effects on physical functioning, psychological well-being, and health-related quality of life (HRQoL). Contemporary evidence recognises chronic primary LBP as a biopsychosocial condition involving interactions between biological, psychological, and social determinants rather than solely structural or biomechanical abnormalities (World Health Organization [WHO], 2023; Zaina et al., 2023).

Physiotherapy remains central to the evidence-based management of chronic nonspecific LBP, with therapeutic exercise, motor control training, lumbar stabilisation, strengthening, flexibility exercises, and aerobic conditioning forming essential components of rehabilitation. Clinical practice guidelines emphasise individualised exercise prescription, active patient education, and biopsychosocial management to improve pain and functional outcomes (George et al., 2021; WHO, 2023). Nevertheless, treatment effectiveness may be compromised by persistent pain, fear-avoidance behaviour, reduced self-efficacy, and inadequate adherence to prescribed exercise programmes (Vergeld et al., 2021; Verville et al., 2023). These limitations highlight the need

for innovative rehabilitation approaches that enhance patient engagement while preserving established therapeutic exercise principles.

Virtual reality (VR) has emerged as a promising technology for delivering interactive, patient-centred rehabilitation. VR creates computer-generated environments that facilitate interaction through visual, auditory, and sensory feedback. Depending on the degree of immersion, interventions are classified as immersive, typically involving head-mounted displays, or non-immersive, utilising computer screens, motion sensors, and gaming-based platforms. Integration of gamification, real-time feedback, and progressive movement challenges may facilitate repetitive exercise performance, cognitive engagement, and motivation during rehabilitation (Brea-Gómez et al., 2021; Matthie et al., 2022). Consequently, VR offers an opportunity to combine physical exercise with behavioural and sensory stimulation, potentially addressing multiple dimensions of chronic pain.

The therapeutic rationale for VR extends beyond distraction-mediated pain modulation. Immersive sensory stimulation may influence attentional processing and pain perception, while interactive movement tasks facilitate sensorimotor integration through visual feedback. Furthermore, graded exposure to simulated functional activities may reduce movement-related fear and improve confidence in performing previously avoided movements. Integrating pain neuroscience education within VR environments may additionally promote understanding of chronic pain and encourage participation in physical activity (Eccleston et al., 2022; McConnell et al., 2024; Čeko et al., 2024). These complementary mechanisms provide a scientific basis for investigating VR as an adjunct to conventional physiotherapy.

Emerging clinical evidence indicates potential benefits of VR-based interventions for pain reduction and functional improvement in CLBP. Brea-Gómez et al. (2021) reported encouraging findings in their systematic review and meta-analysis. Afzal et al. (2022) investigated VR exercises combined with routine physiotherapy, while Eccleston et al. (2022) explored embodied VR in a randomised controlled pilot trial. Similarly, Garcia et al. (2022) demonstrated the potential of an eight-week home-based behavioural VR programme. Further evidence from Maddox et al. (2023a, 2023b) indicated clinically meaningful improvements in pain intensity and interference following an eight-week home-based intervention, including sustained benefits during extended follow-up. However, behavioural VR programmes incorporating mindfulness, breathing, and pain education should be distinguished from exercise-oriented VR interventions targeting spinal mobility, muscular performance, and functional movement.

Recent evidence syntheses further support the clinical relevance of VR. Li et al. (2024), analysing 20 randomised controlled trials involving 1,059 participants, reported significant immediate improvements in pain intensity (mean difference: −1.43) and Oswestry Disability Index scores (mean difference: −11.50), alongside reductions in pain-related fear. However, substantial heterogeneity and inconsistent maintenance of benefits at follow-up warrant cautious interpretation. Kumar et al. (2024) also reported favourable short-term outcomes, while Lo et al. (2024) identified potential benefits of immersive and non-immersive VR-assisted active training. Collectively, these findings suggest therapeutic promise but highlight variability in intervention characteristics and clinical responses.

Importantly, pain reduction alone does not establish comprehensive functional recovery. Improvements in lumbar range of motion (ROM), trunk performance, functional disability, and HRQoL are equally relevant when evaluating rehabilitation effectiveness. Lumbar ROM contributes to activities involving bending, lifting, and transitional movements, although it should be interpreted alongside functional outcomes. Exercise modality and dosage may influence clinical effectiveness, reinforcing the importance of multidimensional assessment (Liang et al., 2024).

Despite encouraging findings, substantial evidence gaps remain concerning VR technology, immersion levels, exercise dosage, supervision, comparator interventions, and outcome measurement. Existing studies frequently combine behavioural pain-management strategies with movement-based interventions, limiting direct comparisons with conventional supervised exercise. Significant heterogeneity reported by Li et al. (2024) and the feasibility findings of McConnell et al. (2024) further emphasise that technological engagement does not necessarily translate into superior clinical outcomes. Recent evidence also supports continued investigation of VR in chronic nonspecific LBP (García-de-la-Banda-García et al., 2025).

Therefore, the present review aims to critically evaluate VR-based rehabilitation in adults with chronic nonspecific LBP, focusing on its effects on pain intensity, lumbar ROM, functional disability, and HRQoL compared with conventional supervised exercise therapy. It further examines underlying therapeutic mechanisms, methodological limitations, and research priorities to establish the clinical relevance of structured VR-assisted physiotherapy.

Methodology

Study design and methodological approach

The present study adopts a narrative review methodology to critically synthesise the available scientific literature concerning the effectiveness of virtual reality (VR)-based rehabilitation in adults with chronic nonspecific low back pain (CLBP). A narrative review approach was considered appropriate because the existing literature encompasses heterogeneous VR technologies, rehabilitation protocols, therapeutic mechanisms, intervention durations, comparator groups, and clinical outcome measures. Unlike a narrowly focused systematic review, this approach facilitates an integrated interpretation of clinical findings, underlying neurophysiological mechanisms, technological developments, and implications for contemporary physiotherapy practice. The review was structured to provide a comprehensive overview of the available evidence while identifying methodological limitations and priorities for future clinical research. This narrative review was registered in OSF registry with registration number: https://osf.io/m2rqx.

Literature Search Strategy

A comprehensive literature search was undertaken to identify relevant publications addressing VR-based rehabilitation and conventional physiotherapy interventions in individuals with chronic nonspecific LBP. Electronic databases considered for the literature search included PubMed/MEDLINE, Scopus, Web of Science, Cochrane Library, and PEDro. These databases were selected to capture clinical trials, rehabilitation research, systematic reviews, meta-analyses, and relevant interdisciplinary publications concerning digital healthcare and musculoskeletal rehabilitation.

The search strategy incorporated combinations of Medical Subject Headings (MeSH) and free-text keywords. The principal search terms included "chronic low back pain", "chronic nonspecific low back pain", "virtual reality", "immersive virtual reality", "non-immersive virtual reality", "VR-based rehabilitation", "virtual rehabilitation", "therapeutic exercise", "conventional physiotherapy", "lumbar range of motion", "functional disability", "pain intensity", and "health-related quality of life". Boolean operators (AND, OR) were applied to combine search concepts and improve retrieval sensitivity.

The search strategy was designed to identify studies evaluating both the clinical effectiveness and potential therapeutic mechanisms of VR interventions. Additional relevant publications were considered through examination of reference lists of selected systematic reviews, meta-analyses, and clinical investigations.

Study Design

The present study employed a structured narrative review methodology to critically evaluate the available scientific evidence regarding virtual reality (VR)-based rehabilitation in adults with chronic nonspecific low back pain (CLBP). The review was designed to integrate clinical evidence, neurophysiological mechanisms, technological applications, and rehabilitation outcomes associated with VR interventions, with particular emphasis on their comparative effectiveness against conventional supervised physiotherapy. A narrative review approach was considered appropriate because the available literature encompasses diverse VR technologies, intervention protocols, treatment durations, comparator interventions, and outcome assessment methods. These variations limit the direct comparability of findings and necessitate a contextual synthesis rather than statistical pooling of results.

The methodological framework was organised around the principles of transparent literature identification, explicit eligibility criteria, critical evaluation of relevant publications, and thematic evidence synthesis. Particular attention was given to distinguishing exercise-oriented VR interventions from behavioural pain-management programmes, as their therapeutic objectives and proposed mechanisms differ considerably (Eccleston et al., 2022; Maddox et al., 2023a, 2023b). The review also considered the multidimensional nature of CLBP, incorporating biological, psychological, and functional perspectives consistent with contemporary rehabilitation recommendations (WHO, 2023; Zaina et al., 2023).

Literature Search Strategy

A comprehensive literature search was planned across five major electronic databases: PubMed/MEDLINE, Scopus, Web of Science, Cochrane Library, and Physiotherapy Evidence Database (PEDro). These databases were selected to identify relevant clinical trials, observational investigations, systematic reviews, meta-analyses, and rehabilitation-related publications. The search strategy incorporated Medical Subject Headings (MeSH), where available, and relevant free-text keywords to maximise the identification of literature addressing VR-based rehabilitation in CLBP.

The principal search terms included:

- **Population:** Chronic low back pain, chronic nonspecific low back pain, persistent low back pain, and adults with chronic lumbar pain.

- **Intervention:** Virtual reality, immersive virtual reality, non-immersive virtual reality, VR-based rehabilitation, virtual rehabilitation, gaming-based exercise, and interactive exercise.
- **Comparator:** Conventional physiotherapy, supervised therapeutic exercise, lumbar stabilisation, motor control training, and usual care.
- **Outcomes:** Pain intensity, lumbar range of motion (ROM), functional disability, Oswestry Disability Index (ODI), physical performance, pain-related fear, and health-related quality of life (HRQoL).

Eligibility Criteria

Studies were considered relevant when they addressed VR-based rehabilitation in adults diagnosed with chronic nonspecific LBP. Eligibility was determined according to population characteristics, intervention approaches, comparator groups, study designs, and reported clinical outcomes.

Inclusion criteria

The review considered the following categories of publications:

1. Studies involving adults aged 18 years or older with chronic nonspecific LBP persisting or recurring for more than three months.
2. Clinical investigations evaluating immersive or non-immersive VR-based rehabilitation.
3. Studies incorporating VR-assisted therapeutic exercise, interactive movement training, motor control activities, functional rehabilitation, or behavioural pain-management interventions.
4. Comparative studies evaluating VR interventions against conventional physiotherapy, supervised therapeutic exercise, usual care, or other appropriate control interventions.
5. Randomised controlled trials, quasi-experimental studies, controlled clinical trials, observational studies, systematic reviews, and meta-analyses.
6. Publications reporting at least one relevant outcome, including pain intensity, lumbar ROM, functional disability, physical performance, pain-related fear, or HRQoL.
7. Peer-reviewed publications available in English.

Exclusion criteria

Studies were excluded when they involved acute or subacute LBP without separately identifiable chronic populations, specific spinal pathologies such as vertebral fractures, malignancy, spinal infection, or inflammatory spinal disorders, or postoperative populations without a separately reported nonspecific LBP subgroup. Studies involving exclusively paediatric populations, animal experiments, surgical interventions, and pharmacological management without a relevant VR rehabilitation component were also excluded. Conference abstracts without sufficient methodological information, editorials, opinion articles, and publications lacking accessible outcome information were not considered for the primary clinical evidence synthesis.

Study Selection Process

A structured literature search was conducted to identify relevant studies investigating the effectiveness of virtual reality (VR)-based rehabilitation in individuals with chronic nonspecific low back pain (CNSLBP). Six electronic databases, including PubMed, Scopus, Web of Science, PEDro, Cochrane Library, and CINAHL, were searched to identify relevant scientific publications. The search was supplemented by manual screening of reference lists of potentially relevant articles to identify additional eligible studies. A total of 725 records were retrieved from the electronic databases, comprising PubMed (n = 185), Scopus (n = 210), Web of Science (n = 145), PEDro (n = 65), Cochrane Library (n = 48), and CINAHL (n = 72). An additional 45 records were identified through reference-list searching, resulting in 770 records.

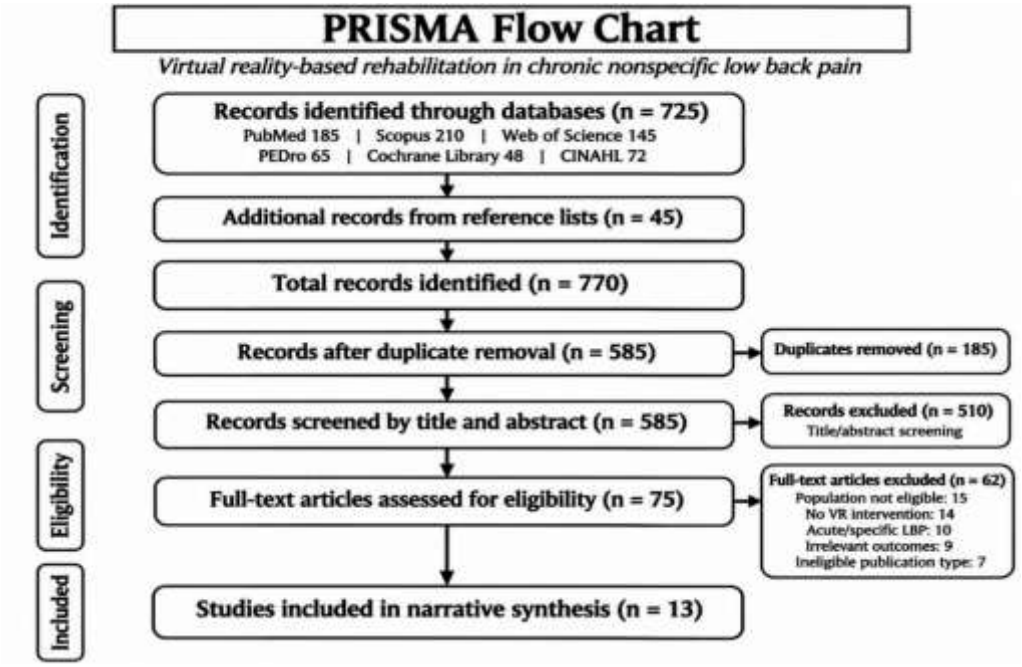
Following duplicate removal, 585 unique records remained for title and abstract screening. Of these, 510 records were excluded because they did not satisfy the relevance criteria. Subsequently, 75 full-text articles were assessed for eligibility. Sixty-two articles were excluded for the following reasons: inappropriate population (n = 15), absence of VR intervention (n = 14), acute or specific low back pain (n = 10), irrelevant outcome measures (n = 9), and ineligible publication type (n = 7). Finally, 13 studies were included in the narrative synthesis. The study identification and selection process is presented in the PRISMA flow diagram.

The identification and selection of relevant literature were organised into sequential stages. Initially, records retrieved from the selected electronic databases were examined for relevance to the review objectives. Duplicate publications identified across databases were intended to be removed before screening. Titles and abstracts were then assessed to determine their potential eligibility according to the predefined inclusion and exclusion criteria.

Subsequently, potentially relevant full-text articles were examined to establish their suitability for inclusion in the narrative synthesis. Particular attention was given to the diagnosis and duration of LBP, characteristics of VR interventions, comparator treatment, methodological design, and availability of relevant clinical outcomes. Publications were classified according to their primary contribution to the review, including neurophysiological mechanisms, exercise-based VR rehabilitation, behavioural VR interventions, comparative clinical effectiveness, and evidence synthesis.

The selection process was designed to maintain transparency and minimise inappropriate inclusion of studies addressing unrelated musculoskeletal conditions. A PRISMA-inspired flow diagram may be used to illustrate the number of records identified, duplicates removed, publications screened, full texts assessed, and studies considered in the final synthesis. However, because this is a narrative review, PRISMA reporting should not be interpreted as establishing that the review was conducted as a systematic review. (see Figure 1)

Figure 1: PRISMA Flow Chart



DATA EXTRACTION AND EVIDENCE CLASSIFICATION

Relevant information from the selected publications was organised using a structured data extraction framework. The extracted variables included:

- Author(s) and year of publication.
- Country and clinical setting.
- Study design and sample characteristics.
- Duration and chronicity of low back pain.
- VR technology and immersion classification.
- Intervention frequency, duration, and exercise characteristics, where reported.
- Comparator intervention and treatment supervision.
- Outcome assessment instruments.
- Principal findings and clinical implications.
- Methodological limitations and reported adverse events.

Studies were additionally categorised according to intervention characteristics. Exercise-oriented VR interventions were distinguished from behavioural VR programmes incorporating mindfulness, breathing exercises, biofeedback, and pain neuroscience education. This classification was considered important because these approaches may influence pain and disability through different therapeutic pathways (Eccleston et al., 2022; Garcia et al., 2022; Maddox et al., 2023a, 2023b). (see Table 1) (see Figure 2,3)

Table 1. Characteristics of studies investigating VR-based rehabilitation in chronic low back pain

Author and year	Study design	Population	Sample size	VR intervention	Comparator	Duration	Main outcomes
Brea-Gómez et al. (2021)	Systematic review and meta-analysis	Adults with CLBP	Extract from included trials	Different VR interventions	Conventional care/control	Variable	Pain, disability

Eccleston et al. (2022)	Pilot RCT	Adults with low back pain	Verify full text	Embodied VR intervention	Control intervention	Trial-specific	Pain-related outcomes
Garcia et al. (2022)	Randomised controlled trial	Adults with chronic LBP	Verify full text	Home-based behavioural VR	Sham VR	8 weeks	Pain, pain interference
Maddox et al. (2023)	Randomised controlled trial	Adults with chronic LBP	Verify full text	Home-based behavioural VR	Sham intervention	8 weeks	Pain intensity, pain interference
Li et al. (2024)	Systematic review and meta-analysis	Adults with chronic LBP	1,059 participants across 20 RCTs	VR-based training	Various controls	Variable	Pain, disability, fear
McConnell et al. (2024)	Multicentre feasibility RCT	Adults with chronic LBP	Verify full text	VR pain neuroscience education	Control/usual care	Trial-specific	Feasibility, pain outcomes
García-de-la-Banda-García et al. (2025)	Systematic review	Adults with chronic nonspecific LBP	Extract from review	VR-based rehabilitation	Various controls	Variable	Clinical effectiveness
Author and year	Study design	Population	Sample size	VR intervention	Comparator	Duration	Main outcomes
Brea-Gómez et al. (2021)	Systematic review and meta-analysis	Adults with CLBP	Extract from included trials	Different VR interventions	Conventional care/control	Variable	Pain, disability
Eccleston et al. (2022)	Pilot RCT	Adults with low back pain	Verify full text	Embodied VR intervention	Control intervention	Trial-specific	Pain-related outcomes
Garcia et al. (2022)	Randomised controlled trial	Adults with chronic LBP	Verify full text	Home-based behavioural VR	Sham VR	8 weeks	Pain, pain interference

Figure 2. Proposed neurophysiological mechanisms of VR-based rehabilitation in chronic low back pain

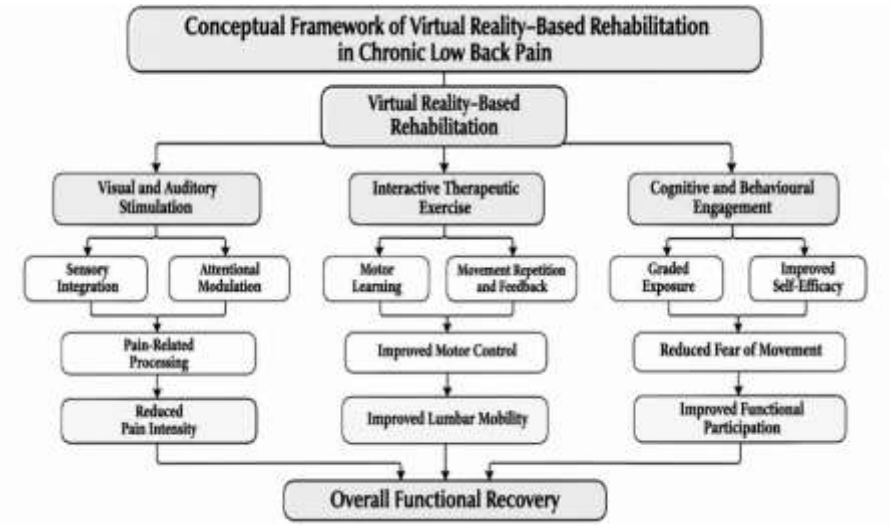
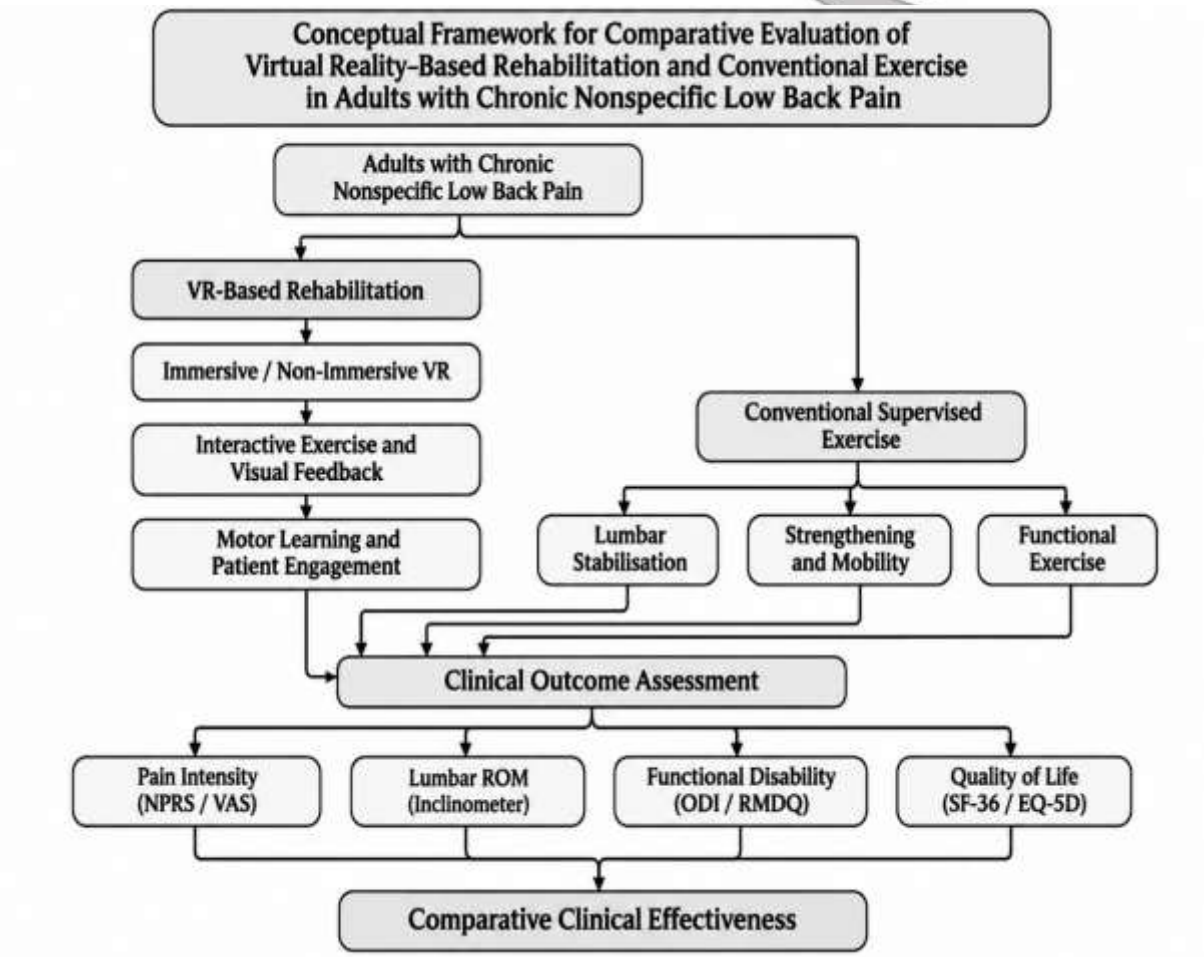


Figure 3. Conceptual framework for comparing VR-based rehabilitation and conventional supervised exercise therapy



Thematic Synthesis of Evidence

A descriptive and thematic synthesis approach was adopted to integrate findings across the included literature. Evidence was organised into five principal domains.

Theme 1: Neurophysiological and behavioural mechanisms. This domain examined the potential contribution of sensory stimulation, attentional modulation, sensorimotor integration, graded exposure, and pain neuroscience education to pain management and movement confidence (Brea-Gómez et al., 2021; Matthie et al., 2022; McConnell et al., 2024; Čeko et al., 2024).

Theme 2: Effects on pain intensity. Findings concerning changes in pain severity were examined using reported outcome measures and comparative treatment effects. The pooled findings reported by Li et al. (2024), including the immediate post-intervention mean difference of −1.43, were considered in relation to intervention characteristics and study heterogeneity.

Theme 3: Lumbar mobility and physical functioning. Evidence concerning lumbar ROM, movement performance, and exercise-related functional improvements was examined, with consideration of exercise modality and dosage (Liang et al., 2024).

Theme 4: Functional disability and HRQoL. Findings involving the ODI, pain interference, functional participation, and quality of life were synthesised to distinguish symptom improvement from broader functional recovery.

Theme 5: Comparative effectiveness and clinical applicability. VR-assisted rehabilitation was evaluated in relation to conventional supervised physiotherapy, considering intervention delivery, patient engagement, adherence, supervision, and sustainability of clinical benefits (Afzal et al., 2022; Kumar et al., 2024; Lo et al., 2024).

Critical Appraisal of Available Evidence

A critical appraisal of the methodological quality and interpretability of the selected publications was incorporated into the narrative synthesis. Randomised controlled trials were examined with reference to participant allocation, randomisation procedures, blinding where applicable, intervention fidelity, completeness of follow-up, outcome measurement, and reporting of between-group differences. Systematic reviews and meta-analyses were evaluated in relation to their search strategies, study selection procedures, methodological assessment, heterogeneity, and consistency of reported findings. (see Table 2, 3,4)

Table 2. Classification of virtual reality technologies and their applications in low back pain rehabilitation

VR classification	Technology	Rehabilitation application	Proposed therapeutic mechanism	Clinical relevance
Immersive VR	Head-mounted display	Simulated movement activities	Sensory immersion and attentional modulation	Pain management and movement confidence
Non-immersive VR	Computer screen or television	Interactive therapeutic exercise	Visual feedback and motor learning	Trunk mobility and exercise participation
Motion-tracking VR	Sensors and cameras	Real-time trunk movement tracking	Movement feedback and coordination	Lumbar movement control
Gaming-based VR	Interactive gaming systems	Goal-oriented physical activities	Motivation and repetitive practice	Exercise adherence
Embodied VR	Virtual representation of the patient's body	Body perception and movement tasks	Body representation and sensory integration	Pain-related movement behaviours
Behavioural VR	Guided virtual therapeutic environment	Relaxation, breathing, mindfulness and pain education	Cognitive and attentional modulation	Pain interference and self-management

Table 3. VR-based rehabilitation intervention parameters and exercise prescription

Intervention component	Parameters to extract	Proposed clinical application
Warm-up	5–10 minutes, where reported	Gentle trunk and lower-limb mobility
Lumbar mobility training	Flexion, extension, lateral flexion and rotation	Improve spinal movement
Core stabilisation	Progressive trunk activation and stabilisation tasks	Improve trunk motor control
Functional movement training	Squatting, reaching, bending and lifting simulations	Improve activity-related movement
Balance and coordination	Weight shifting and controlled postural tasks	Improve sensorimotor control
Aerobic exercise	Walking or simulated locomotor activities	Improve general physical conditioning
Cool-down	Relaxation and breathing exercises	Promote recovery
Feedback	Visual, auditory and performance-based feedback	Improve movement awareness
Progression	Task complexity, movement range and exercise difficulty	Support graded rehabilitation

Table 4. Comparative clinical outcomes of VR-based rehabilitation versus conventional supervised exercise

Outcome domain	Assessment tool	Expected direction of improvement	Evidence to compare	Clinical interpretation
Pain intensity	NPRS/VAS	Reduction	Within-group and between-group changes	Symptom improvement
Lumbar flexion	Inclinometer	Increased ROM where restricted	Pre- and post-intervention measurements	Spinal mobility
Lumbar extension	Inclinometer	Increased ROM where restricted	Pre- and post-intervention measurements	Functional spinal movement
Functional disability	ODI	Reduction in disability score	Between-group difference	Improvement in daily activities
Functional disability	RMDQ	Reduction in disability score	Between-group difference	Functional independence
Quality of life	SF-36	Improvement in relevant domains	Physical and mental component scores	Overall health status
Kinesiophobia	Tampa Scale	Reduction	Pre- and post-intervention scores	Movement confidence
Exercise adherence	Attendance and adherence records	Increased adherence	Completion rates	Treatment engagement

Particular consideration was given to the clinical and statistical heterogeneity reported in previous evidence syntheses. Li et al. (2024) identified substantial variation across VR-based interventions, while McConnell et al. (2024) highlighted the feasibility and acceptability of integrating VR-delivered pain neuroscience education into outpatient physiotherapy without establishing clear superiority in patient-reported outcomes. Similarly, findings from Maddox et al. (2023a, 2023b) were interpreted in the context of behavioural pain-management interventions rather than automatically generalised to exercise-based VR rehabilitation.

The evidence was therefore interpreted according to the methodological characteristics, clinical relevance, and applicability of individual studies rather than solely on the statistical significance of reported outcomes. (see Table 5,6,7) (see Figure 4)

Table 5. Methodological quality and limitations of included studies

Author/year	Study design	Randomisation	Allocation concealment	Blinding	Sample size adequacy	Follow-up	Overall limitations
Eccleston et al. (2022)	Pilot RCT	Assess	Assess	Assess	Assess	Assess	Pilot study limitations
Garcia et al. (2022)	RCT	Assess	Assess	Assess	Assess	Assess	Behavioural VR intervention
Maddox et al. (2023)	RCT	Assess	Assess	Assess	Assess	Assess	Generalisability and intervention specificity
McConnell et al. (2024)	Feasibility RCT	Assess	Assess	Assess	Assess	Assess	Feasibility rather than definitive efficacy
Other eligible RCTs	RCT	Assess	Assess	Assess	Assess	Assess	Complete after extraction

Author/year	Study design	Randomisation	Allocation concealment	Blinding	Sample size adequacy	Follow-up	Overall limitations

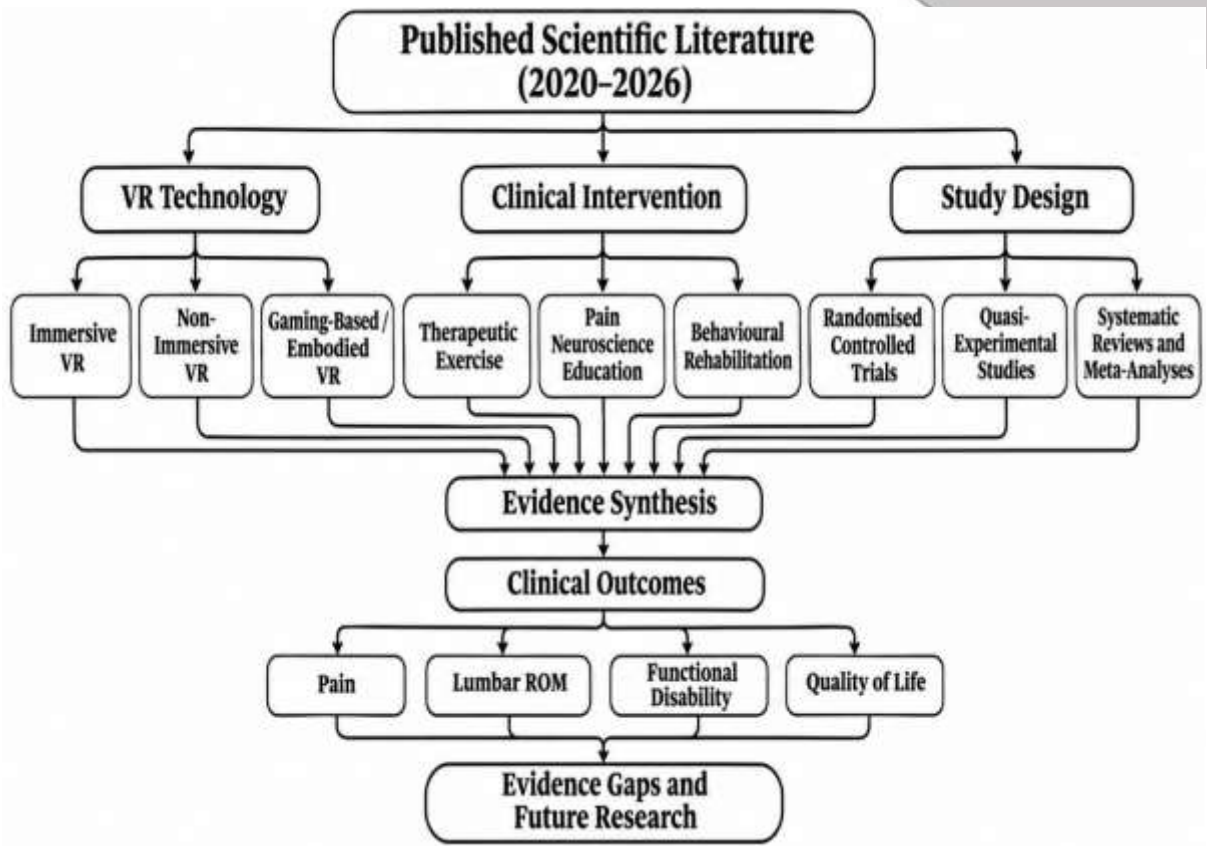
Table 6. Evidence gaps and future research recommendations

Identified evidence gap	Scientific implication	Future research recommendation	Identified evidence gap
Limited direct comparison with supervised exercise	Comparative effectiveness remains uncertain	Conduct controlled comparative studies	Limited direct comparison with supervised exercise
Heterogeneity in VR technology	Difficult to identify optimal VR modality	Standardise VR intervention classification	Heterogeneity in VR technology
Inconsistent intervention dosage	Limited reproducibility	Establish intervention reporting standards	Inconsistent intervention dosage
Limited objective lumbar ROM data	Mobility benefits remain unclear	Include inclinometer-based measurements	Limited objective lumbar ROM data
Short follow-up periods	Long-term effectiveness uncertain	Include 3–6-month follow-up	Short follow-up periods
Limited assessment of adherence	Engagement mechanisms poorly understood	Record attendance and home exercise completion	Limited assessment of adherence
Limited cost-effectiveness evidence	Clinical implementation uncertain	Include healthcare utilisation and cost analysis	Limited cost-effectiveness evidence
Limited integration of biopsychosocial outcomes	Mechanisms of improvement remain unclear	Assess kinesiophobia, self-efficacy and pain interference	Limited integration of biopsychosocial outcomes

Table 7. Summary of outcome domains, mechanisms and clinical implications

Clinical outcome	Potential VR mechanism	Clinical implication
Pain reduction	Attentional modulation and pain-related cognitive processing	Improved symptom management
Lumbar ROM	Visual feedback and repetitive movement practice	Improved spinal mobility
Trunk motor control	Sensorimotor feedback and motor learning	Improved movement coordination
Functional disability	Task-oriented simulated activities	Improved daily functional performance
Quality of life	Engagement and self-management	Improved participation
Kinesiophobia	Graded exposure and movement confidence	Reduced fear of movement
Adherence	Gamification and interactive feedback	Improved rehabilitation participation

Figure 4. Evidence mapping framework for VR-based rehabilitation in chronic low back pain



Methodological Considerations and Limitations

The narrative review methodology provides an opportunity to integrate heterogeneous evidence and explore clinical implications that may not be adequately represented through quantitative comparisons alone. Nevertheless, certain methodological limitations must be acknowledged. Differences in VR equipment, immersion levels, intervention protocols, exercise intensity, treatment duration, and outcome assessment may introduce substantial variability into the interpretation of findings. Furthermore, restricting the literature to English-language publications may result in language-related selection bias.

Another important consideration is the limited availability of direct comparative evidence evaluating structured VR-assisted therapeutic exercise against conventional supervised physiotherapy using standardised outcome measures. Consequently, findings from behavioural VR interventions, home-based programmes, and exercise-oriented rehabilitation should be interpreted separately. The review does not aim to establish pooled treatment effects or causal superiority but rather to provide a critical understanding of the available evidence and identify priorities for future comparative clinical investigations.

Ethical Considerations

As the present investigation is based exclusively on previously published scientific literature, it does not involve direct recruitment of human participants, collection of identifiable patient information, or experimental interventions. Therefore, institutional ethical approval and informed consent are not applicable. The review methodology emphasises accurate representation of published findings, appropriate attribution of original research, and transparent interpretation of the available scientific evidence.

Discussion

The present narrative review critically examines the potential effectiveness of virtual reality (VR)-based rehabilitation in individuals with chronic nonspecific low back pain (CNSLBP), with particular emphasis on pain intensity, lumbar range of motion (ROM), functional disability, and health-related quality of life (HRQoL). The emerging evidence indicates that VR represents a promising technology-assisted rehabilitation approach that integrates therapeutic exercise, interactive visual feedback, sensory stimulation, cognitive engagement, and behavioural modification. Nevertheless, its clinical effectiveness must be interpreted in relation to variations in technological modalities, intervention protocols, treatment intensity, and outcome assessment. Although

available studies demonstrate favourable effects on selected clinical outcomes, the comparative superiority of VR over conventional supervised exercise therapy remains insufficiently established.

Effectiveness of VR-based rehabilitation on pain intensity

Pain reduction represents one of the most frequently investigated outcomes of VR-based interventions in chronic low back pain. The proposed therapeutic effects may be associated with attentional modulation, multisensory integration, distraction, and modification of pain-related cognitive and behavioural responses. Li et al. (2024), in a systematic review and meta-analysis involving 20 randomised controlled trials and 1,059 participants, reported a significant immediate reduction in pain intensity (MD = −1.43; 95% CI: −1.86 to −1.00). However, the substantial statistical heterogeneity (I^2 = 95%) and absence of statistically significant benefits at short-term follow-up indicate considerable variability in treatment responses and uncertainty regarding the sustainability of these effects.

Consistent findings were reported by Huang and Chen (2025), whose meta-analysis of 15 randomised controlled trials involving 711 participants demonstrated a significant reduction in pain intensity measured using the Visual Analogue Scale (MD = −1.69; 95% CI: −2.47 to −0.88). Their subgroup analysis suggested potentially greater improvements with immersive VR and higher-frequency interventions. Nevertheless, the presence of substantial heterogeneity and possible publication bias warrants cautious interpretation. Collectively, these findings support the potential role of VR as an adjunct to established physiotherapy interventions rather than demonstrating its definitive superiority over conventional rehabilitation.

An important consideration is the distinction between behavioural VR interventions and exercise-oriented VR rehabilitation. Behavioural programmes frequently incorporate mindfulness, relaxation, breathing exercises, and pain education, whereas exercise-based interventions emphasise movement repetition, trunk control, and functional activities. Maddox et al. (2023) demonstrated clinically meaningful improvements following an eight-week home-based behavioural VR intervention compared with sham VR. However, these findings should be interpreted within the context of behavioural pain management and should not be directly extrapolated to the effectiveness of VR-based therapeutic exercise.

Lumbar mobility, functional disability, and quality of life

Lumbar ROM represents an important physical outcome because movement restrictions may compromise bending, lifting, reaching, and other activities of daily living. VR-based therapeutic exercise may facilitate movement exploration through interactive feedback, progressive task challenges, and repetitive functional practice. These characteristics may encourage patients to participate in movements that they previously avoided because of pain-related apprehension.

Despite this potential, evidence concerning objectively measured lumbar mobility remains comparatively limited. Most available investigations have prioritised pain intensity, disability, and kinesiophobia, with relatively fewer studies examining lumbar flexion, extension, and rotation using standardised measurement procedures. Consequently, improvements in perceived pain cannot automatically be interpreted as evidence of improved spinal mobility. Future investigations should incorporate digital inclinometers and validated lumbar mobility assessment procedures to establish the extent to which VR produces measurable biomechanical improvements.

Functional disability is another clinically important outcome because CNSLBP can adversely affect occupational performance, household activities, social participation, and independence. Li et al. (2024) reported an immediate post-intervention improvement in Oswestry Disability Index (ODI) scores (MD = −11.50; 95% CI: −20.00 to −3.01). However, the absence of significant differences at short-term follow-up raises questions regarding the long-term maintenance of these improvements. Similarly, Huang and Chen (2025) reported favourable effects on disability, with a pooled ODI mean difference of −5.92 (95% CI: −7.97 to −3.86). Differences between these estimates may reflect variations in participant characteristics, intervention protocols, comparator treatments, and included studies. Therefore, the magnitude of pooled improvements should be interpreted cautiously rather than regarded as definitive evidence of clinical superiority.

HRQoL requires greater consideration in future VR rehabilitation research. Persistent pain may influence sleep, psychological well-being, social participation, and physical independence. Behavioural VR programmes may address some of these dimensions through relaxation and cognitive strategies, whereas exercise-oriented VR may primarily improve physical activity and functional performance. Incorporating validated measures such as the SF-36 and EQ-5D would facilitate a more comprehensive evaluation of whether improvements in pain and disability translate into meaningful changes in overall health status.

Neurophysiological and behavioural mechanisms

The therapeutic rationale for VR extends beyond conventional exercise delivery. Immersive and interactive environments provide visual, auditory, and movement-related feedback that may facilitate sensorimotor integration, motor learning, and movement confidence. Repetitive task-oriented practice combined with immediate feedback may improve movement awareness and encourage progressive participation in functional

activities. Additionally, graded exposure to simulated movements may help address fear-avoidance behaviours and negative expectations associated with spinal movement.

Kinesiophobia is particularly relevant in CNSLBP because fear of movement can contribute to activity restriction, reduced physical conditioning, and persistent disability. Li et al. (2024) reported immediate improvements in Tampa Scale for Kinesiophobia scores, although these benefits were not consistently maintained during follow-up. Huang and Chen (2025) similarly identified favourable effects on movement-related fear. These observations suggest that VR may provide a supportive environment for graded movement exposure and behavioural engagement. However, the precise neurophysiological mechanisms underlying these improvements remain insufficiently established.

Importantly, pain reduction may occur independently of measurable improvements in lumbar mobility. This distinction suggests that changes in pain perception, movement-related confidence, and behavioural responses may contribute to functional recovery without corresponding structural or biomechanical changes. Accordingly, combining psychological assessments with objective physical outcome measurements is essential for understanding the multidimensional effects of VR rehabilitation.

Comparison with conventional physiotherapy and clinical implications

Conventional supervised exercise therapy remains an essential component of evidence-based management for chronic low back pain. Trunk strengthening, motor control exercises, lumbar stabilisation, flexibility training, and functional conditioning are commonly incorporated into individualised rehabilitation programmes. The World Health Organization (2023) recommends structured exercise interventions as part of the non-surgical management of chronic primary low back pain.

The potential advantage of VR lies in its ability to enhance exercise participation through gamification, interactive tasks, and immediate performance feedback. However, technological innovation should not be equated with therapeutic superiority. VR is more appropriately considered an alternative method of delivering and augmenting rehabilitation exercises rather than an established replacement for conventional physiotherapy. Its effectiveness may depend on exercise prescription, progression, treatment exposure, therapist supervision, and individual patient characteristics.

From a clinical perspective, VR may be particularly useful as an adjunctive approach for improving patient engagement, facilitating repetitive movement practice, and supporting home-based rehabilitation. Nevertheless, implementation should consider equipment accessibility, digital literacy, cybersickness, patient tolerance, financial implications, and the availability of appropriate clinical supervision. Integrating VR with patient education, individualised therapeutic exercise, functional training, and behavioural strategies may provide a more comprehensive rehabilitation approach.

Research gaps and future directions

Several methodological limitations currently restrict the interpretation of VR-based rehabilitation outcomes. Substantial heterogeneity exists in equipment, immersion levels, intervention duration, exercise intensity, treatment frequency, and comparator interventions. Furthermore, relatively few studies have directly compared structured VR-based therapeutic exercise with equivalent conventional supervised exercise protocols. Objective lumbar ROM, trunk muscle performance, functional capacity, and HRQoL also remain comparatively under-investigated.

Future research should prioritise adequately powered comparative clinical trials incorporating standardised intervention protocols, validated outcome measures, and extended follow-up assessments. Direct comparisons between immersive VR, non-immersive VR, and conventional exercise therapy are necessary to establish the additional therapeutic contribution of virtual environments. Evaluating pain intensity, lumbar ROM, functional disability, HRQoL, kinesiophobia, and exercise adherence would provide a more comprehensive understanding of treatment effectiveness.

Furthermore, implementation studies should investigate feasibility, cost-effectiveness, acceptability, and technological accessibility across different healthcare settings, particularly in resource-variable environments.

Clinical significance and overall interpretation

The available evidence supports investigating VR as an adjunct to conventional physiotherapy rather than assuming that it should replace established exercise-based rehabilitation. A two-group comparative quasi-experimental study evaluating VR-based rehabilitation against conventional supervised exercise therapy would address an important clinical evidence gap. Assessment of pain intensity, lumbar ROM, functional disability, and HRQoL, supplemented by kinesiophobia and exercise adherence, would provide clinically meaningful evidence regarding comparative treatment responses.

Overall, contemporary evidence demonstrates promising short-term improvements in pain intensity and functional disability following VR-based rehabilitation in individuals with chronic low back pain. However, its comparative superiority over conventional supervised exercise therapy, particularly concerning objective lumbar mobility and sustained improvements in quality of life, remains insufficiently established. Integrating VR

with individualised, evidence-based physiotherapy therefore represents a potentially valuable direction for future musculoskeletal rehabilitation research.

Conclusion

Virtual reality (VR)-based rehabilitation represents a promising technology-assisted approach for managing chronic nonspecific low back pain by integrating therapeutic exercise, sensory feedback, motor learning, and behavioural engagement. Contemporary evidence indicates potential improvements in pain intensity, functional disability, and movement-related fear, suggesting that VR may offer additional opportunities to enhance patient participation and rehabilitation experiences. However, its effectiveness in improving objective lumbar range of motion, functional performance, and health-related quality of life remains insufficiently established.

Furthermore, considerable heterogeneity in VR technologies, intervention protocols, treatment intensity, and outcome measurements limits the generalisability of existing findings. Importantly, the superiority of VR-based rehabilitation over conventional supervised exercise therapy has not been conclusively demonstrated. Future research should prioritise adequately designed comparative clinical investigations incorporating standardised intervention protocols, objective lumbar mobility assessments, validated functional outcome measures, and longer follow-up periods. Integrating VR with evidence-based physiotherapy principles may provide a more comprehensive and patient-centred rehabilitation approach. Further quasi-experimental and randomised controlled studies are warranted to establish its additional clinical value, feasibility, cost-effectiveness, and applicability across diverse healthcare settings. Such evidence will contribute to developing scientifically validated VR-assisted rehabilitation protocols and advancing digital innovation in contemporary musculoskeletal physiotherapy practice.

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