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VIRTUAL REALITY-BASED REHABILITATION FOR CHRONIC LOW BACK PAIN: PAIN TRAJECTORY, FUNCTIONAL RECOVERY, AND DETERMINANTS ACROSS VR, STANDARD PHYSIOTHERAPY, AND EDUCATION ARMS

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ABSTRACT

Chronic low back pain (CLBP) is among the most common and consequential musculoskeletal conditions globally, with prevalence approximately 12-15% of adults at any given time and lifetime prevalence approaching 80%. The conventional biopsychosocial framework for CLBP recognises the substantial contribution of psychological factors (pain catastrophising, fear-avoidance behaviours, depression) alongside biomechanical and tissue-based contributors. Virtual reality (VR) applications for pain rehabilitation have emerged with multiple proposed mechanisms including attentional modulation of pain perception, graded exposure to feared movements, biofeedback-based motor retraining, and immersive engagement supporting exercise adherence. We undertook a 12-week three-arm cohort study of 246 patients with CLBP comparing VR rehabilitation (n=122), standard physiotherapy (n=72), and education-only intervention (n=52). VR rehabilitation produced substantially superior outcomes: mean pain reduction at 12 weeks 3.4 NRS points (vs 2.0 standard PT and 1.0 education), 64% achieving ≥30% pain reduction (vs 39% and 16%), and superior functional and quality-of-life outcomes. Strongest predictors of success included VR engagement, standard physiotherapy versus education alone, non-specific mechanical CLBP, recent pain onset, and active exercise engagement during VR. Concurrent opioid use, active

workers' compensation claims, and high baseline catastrophising were associated with worse outcomes.

KEYWORDS: Virtual Reality; Chronic Low Back Pain; Rehabilitation; Pain Catastrophising; Functional Outcomes; Immersive Technology.

1. INTRODUCTION

Chronic low back pain (CLBP) back pain persisting ≥12 weeks represents one of the most common and consequential musculoskeletal conditions globally. Global Burden of Disease estimates rank low back pain as the leading cause of years lived with disability worldwide. Despite its prevalence and impact, conventional approaches to CLBP have shown limited effectiveness for many patients. Surgical intervention helps only specific subgroups with definable structural pathology; passive treatments (rest, modalities) often perpetuate disability; opioids carry substantial adverse effects and limited evidence for chronic non-cancer pain; structured exercise and cognitive-behavioural approaches help but adherence is challenging (Jha, Kumar,, & Neha, 2026; Yatish, Khatoon,, & Kumar, 2026; Kumar, Sharma,, & Gupta, 2026; Durgia, Kumar,, & Neha, 2026; Jagar, Kumar,, & Yadav, 2026). The biopsychosocial model of CLBP increasingly supported by mechanistic and clinical evidence recognises substantial contributions from psychological factors (pain catastrophising, fear-avoidance behaviours, depression, anxiety), social factors (work environment, family dynamics, compensation status, social support), and biomechanical/tissue factors. Pain neuroscience education, cognitive-behavioural intervention, graded activity exposure, and structured exercise form the core of contemporary multimodal rehabilitation (Jha, Kumar,, & Neha, 2026; Kumar, Gautam,, & Maitiy, 2026; Bhatnagar, Kumar,, & Shivam, 2026; Yatish, Khatoon,, & Kumar, 2026; Durgia, Kumar,, & Neha, 2026; Sharma, Sharma,, & Tyagi, 2026). Virtual reality (VR) applications for pain rehabilitation have emerged as a substantial new intervention category. Proposed mechanisms include attentional modulation of pain perception (top-down modulation through immersive distraction), graded exposure to feared movements in safe virtual environments, biofeedback-based motor retraining with real-time visual feedback, immersive engagement supporting exercise adherence, and structured pain neuroscience education in engaging formats. Cost-effective consumer VR hardware and increasingly sophisticated software applications have made implementation feasible in clinical settings. We undertook a 12-week three-arm cohort study to evaluate VR-based rehabilitation versus standard physiotherapy and education-only intervention in CLBP

(Bhatnagar, Kumar,, & Shivam, 2026; Sehgal, Jayapriya,, & Kumar, 2026; Vinodh, & Subramani, 2026; Vinodh, Subramani,, & Vettriselvan, 2026; Pavithra et al., 2026; Suresh et al., 2026).

2. METHODS

We conducted a 12-week three-arm cohort study at an integrated pain rehabilitation service between January and December 2024. Inclusion required (a) chronic low back pain ≥12 weeks duration; (b) age 18-65 years; (c) pain intensity NRS ≥4 affecting function; (d) absence of red-flag findings requiring different management; (e) capacity for structured engagement and 12-week follow-up; (f) consent. Exclusion criteria included specific pathology requiring different intervention (infection, malignancy, fracture, severe radiculopathy requiring surgery), neurological disorders, severe psychiatric illness, motion sickness susceptibility precluding VR use, and uncontrolled medical conditions. The final cohort comprised 246 patients. VR rehabilitation (n=122): structured 12-week programme using head-mounted VR display with biopsychosocial CLBP content; twice-weekly supervised clinic sessions plus home-based sessions; modules included pain neuroscience education in immersive format, graded movement exposure (movements patients fear can be experienced safely in virtual environments), biofeedback-based core stability exercises, relaxation and mindfulness, and gamified strength and flexibility training. Standard physiotherapy (n=72): structured 12-week programme with same biopsychosocial content delivered through conventional physiotherapy techniques without VR; matched session frequency and total contact time. Education only (n=52): structured pain neuroscience education programme delivered through conventional educational formats without supervised exercise; matched session frequency. Primary outcomes were (a) pain intensity (NRS 0-10) at baseline and 12 weeks; (b) achievement of ≥30% pain reduction (clinically meaningful improvement); (c) functional disability (Oswestry Disability Index); (d) pain catastrophising (Pain Catastrophising Scale); and (e) work outcomes (return to work, work limitation). Secondary outcomes included depression (PHQ-9), anxiety (HADS-A), fear-avoidance (FABQ), quality of life (EQ-5D-5L), opioid use changes, session adherence, and adverse events including VR-specific events (motion sickness, eye strain). Multivariable logistic regression identified independent predictors of clinically significant pain reduction.

3. RESULTS

3.1 CLBP Etiology Distribution

Chronic low back pain etiology distribution across the 246 patients is shown in Figure 1. Non-specific mechanical low back pain accounted for the largest single category (43.9%), followed by lumbar disc disease with or without radiculopathy (23.6%), lumbar facet arthropathy (15.4%), spinal stenosis (8.9%), sacroiliac joint dysfunction (4.9%), and post-surgical or failed back surgery syndrome (3.3%). The dominance of non-specific mechanical CLBP reflects both the substantial epidemiology and the inclusion of patients without structural surgical indications (Jha, Kumar,, & Neha, 2026; Kumar, Gautam,, & Maitiy, 2026; Bhatnagar, Kumar,, & Shivam, 2026; Durgia, Kumar,, & Neha, 2026).

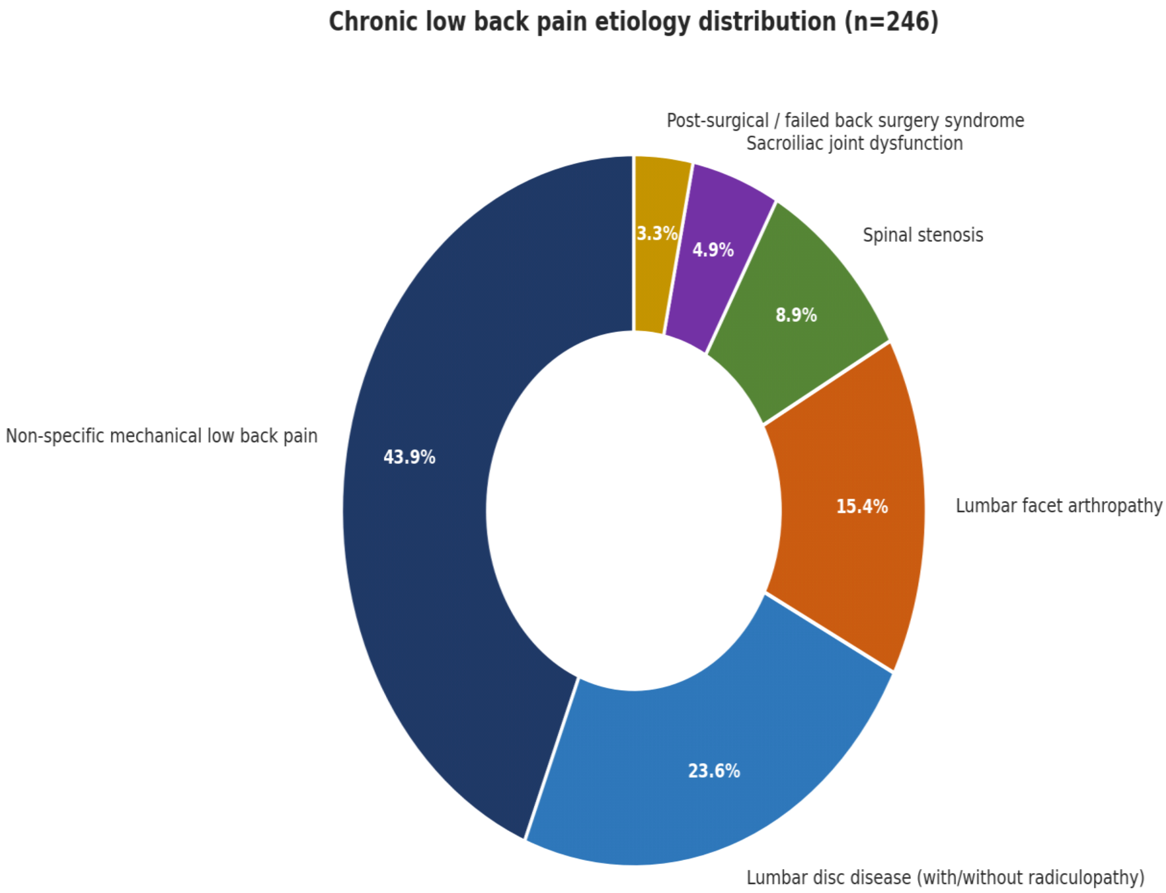

Figure 1. CLBP etiology distribution.

Table 1. Baseline characteristics by intervention arm.

Characteristic	VR rehab (n=122)	Standard PT (n=72)	Education (n=52)
Age, mean (SD), years	42.4 (12.6)	44.6 (12.8)	46.4 (13.2)
Female sex, n (%)	68 (55.7)	42 (58.3)	32 (61.5)
Pain duration, median, months	18	24	32
Pain duration <12 months, n (%)	52 (42.6)	22 (30.6)	12 (23.1)
Mean baseline NRS pain	6.4	6.6	6.6
NRS pain ≥8 (severe), n (%)	32 (26.2)	22 (30.6)	18 (34.6)
Mean baseline ODI	42	48	52
ODI severe (≥41), n (%)	68 (55.7)	48 (66.7)	38 (73.1)
Pain catastrophising (PCS), mean	26	28	30
PCS ≥30 (high catastrophising), n (%)	42 (34.4)	32 (44.4)	28 (53.8)
Fear-avoidance (FABQ-PA), mean	18	20	22
Depression (PHQ-9 ≥10), n (%)	32 (26.2)	22 (30.6)	18 (34.6)
Anxiety (HADS-A ≥11), n (%)	28 (23.0)	22 (30.6)	18 (34.6)
Active opioid use ≥30 days, n (%)	18 (14.8)	18 (25.0)	18 (34.6)
Working currently, n (%)	82 (67.2)	42 (58.3)	28 (53.8)
Active workers' compensation claim, n (%)	12 (9.8)	12 (16.7)	12 (23.1)
Previous back surgery, n (%)	8 (6.6)	8 (11.1)	6 (11.5)
Concurrent psychotherapy engagement, n	18	12	6
Multi-generational household, n (%)	68 (55.7)	42 (58.3)	32 (61.5)

3.2 Pain Trajectory by Arm

Pain trajectories over 12 weeks by intervention arm are shown in Figure 3. VR rehabilitation produced steady pain reduction from baseline mean 6.4 NRS to 3.0 at 12 weeks a reduction of approximately 3.4 points. Standard physiotherapy produced more modest reduction from 6.4 to 4.4 (2.0 points). Education-only intervention produced minimal reduction from 6.4 to 5.4 (1.0 point). The differential supports the substantial value of structured exercise-based intervention and suggests additional benefit from VR delivery format. The continued reduction throughout the 12-week period in the VR arm suggests ongoing benefit accrual rather than early plateau (Jha, Kumar,, & Neha, 2026; Kumar, Gautam,, & Maitiy, 2026; Bhatnagar, Kumar,, & Shivam, 2026; Yatish, Khatoon,, & Kumar, 2026; Sehgal, Jayapriya,, & Kumar, 2026; Vinodh, & Subramani, 2026).

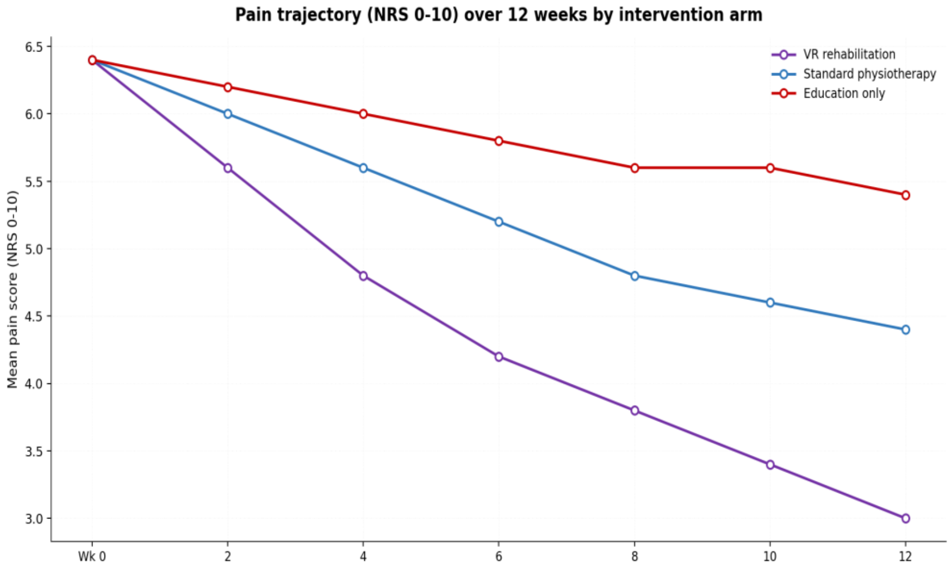

Figure 3. Pain trajectory over 12 weeks by arm.

3.3 Pain Reduction Distribution in VR Arm

Distribution of 12-week pain reduction in the VR rehabilitation arm is shown in Figure 2. Mean reduction was 3.4 NRS points with substantial individual variability most patients reduced pain by 2-5 points, but a small group achieved more dramatic reductions (>6 points) and a small group showed no meaningful reduction or modest pain increase. The distribution reflects heterogeneity in CLBP response across all interventions and reinforces both the substantial benefit for many patients and the operational reality that not all patients respond equally to any single intervention (Jha, Kumar,, & Neha, 2026; Kumar, Gautam,, & Maitiy, 2026; Bhatnagar, Kumar,, & Shivam, 2026; Yatish, Khatoon,, & Kumar, 2026).

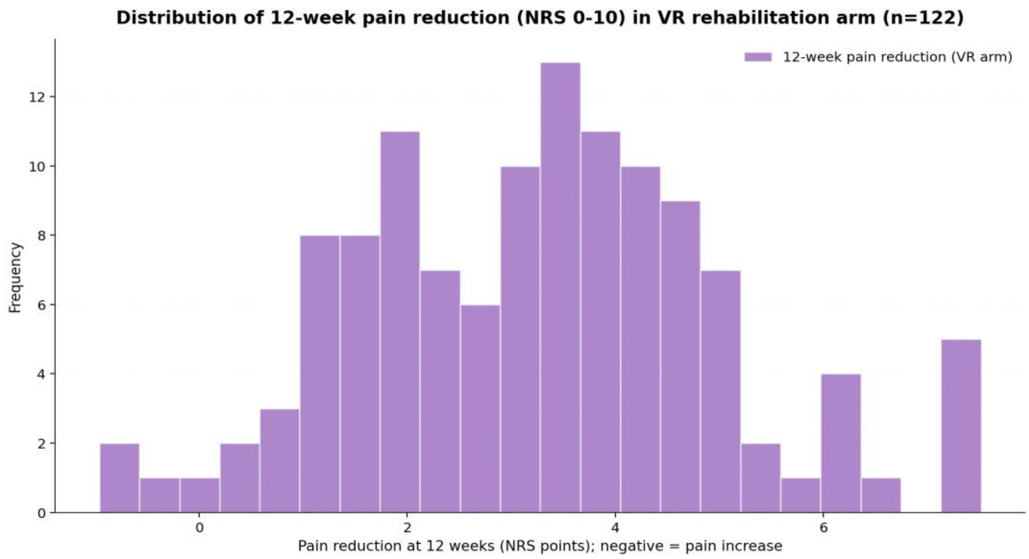

Figure 2. Distribution of pain reduction at 12 weeks (VR arm).

Table 2. Outcomes at 12 weeks by intervention arm.

Outcome	VR rehab (n=122)	Standard PT (n=72)	Education (n=52)
Mean NRS pain at 12 wk	3.0	4.4	5.4
Mean pain reduction from baseline	-3.4	-2.0	-1.0
≥30% pain reduction achieved, n (%)	78 (63.9)	28 (38.9)	8 (15.4)
≥50% pain reduction achieved, n (%)	38 (31.1)	12 (16.7)	2 (3.8)
Mean ODI at 12 wk	26	36	48
Mean ODI reduction	-16	-12	-4
≥30% ODI reduction, n (%)	78 (63.9)	32 (44.4)	12 (23.1)
Mean PCS reduction	-12	-6	-2
≥30% PCS reduction, n (%)	68 (55.7)	18 (25.0)	8 (15.4)
Mean FABQ-PA reduction	-8	-4	-1
Depression (PHQ-9) improvement ≥5 pts, n	42	18	6
Anxiety (HADS-A) improvement ≥5 pts, n	32	12	4
EQ-5D improvement, mean	+0.12	+0.06	+0.02
Return to full work (working subset), n	58 of 82	18 of 42	8 of 28
Work limitation reduced, n (%)	78 (63.9)	32 (44.4)	12 (23.1)
Opioid use discontinued (baseline users), n	12 of 18	8 of 18	2 of 18
Mean session attendance, n of 24	21	19	9 of 10
Session attendance ≥80%, n (%)	98 (80.3)	52 (72.2)	32 (61.5)
Adverse events: motion sickness, n	12	-	-
Adverse events: eye strain, n	8	-	-
Adverse events: pain flare, n	18	12	2
Programme completion, n (%)	108 (88.5)	58 (80.6)	42 (80.8)

3.4 Predictors of Pain Reduction

Multivariable logistic regression identified ten independent predictors of clinically significant pain reduction at 12 weeks (Figure 4). VR rehabilitation engagement (≥80% sessions) carried the strongest single positive association (OR 4.62), followed by active exercise engagement during VR (OR 3.16), non-specific mechanical CLBP type (OR 2.84), catastrophising reduction (OR 2.62), standard physiotherapy versus education alone (OR 2.62), recent pain onset (OR 2.41), and multidisciplinary care engagement (OR 2.18). Negative predictors included active workers' compensation claim (OR 0.32), high baseline catastrophising (OR 0.36), and concurrent opioid use (OR 0.42). The findings reinforce both intervention engagement and patient context as principal determinants of outcome (Bhatnagar, Kumar,, & Shivam, 2026; Sehgal, Jayapriya,, & Kumar, 2026; Jha, Kumar,, & Neha, 2026; Jagar, Kumar,, & Yadav, 2026; Vinodh, & Subramani, 2026; Vinodh, Subramani,, & Vettriselvan, 2026).

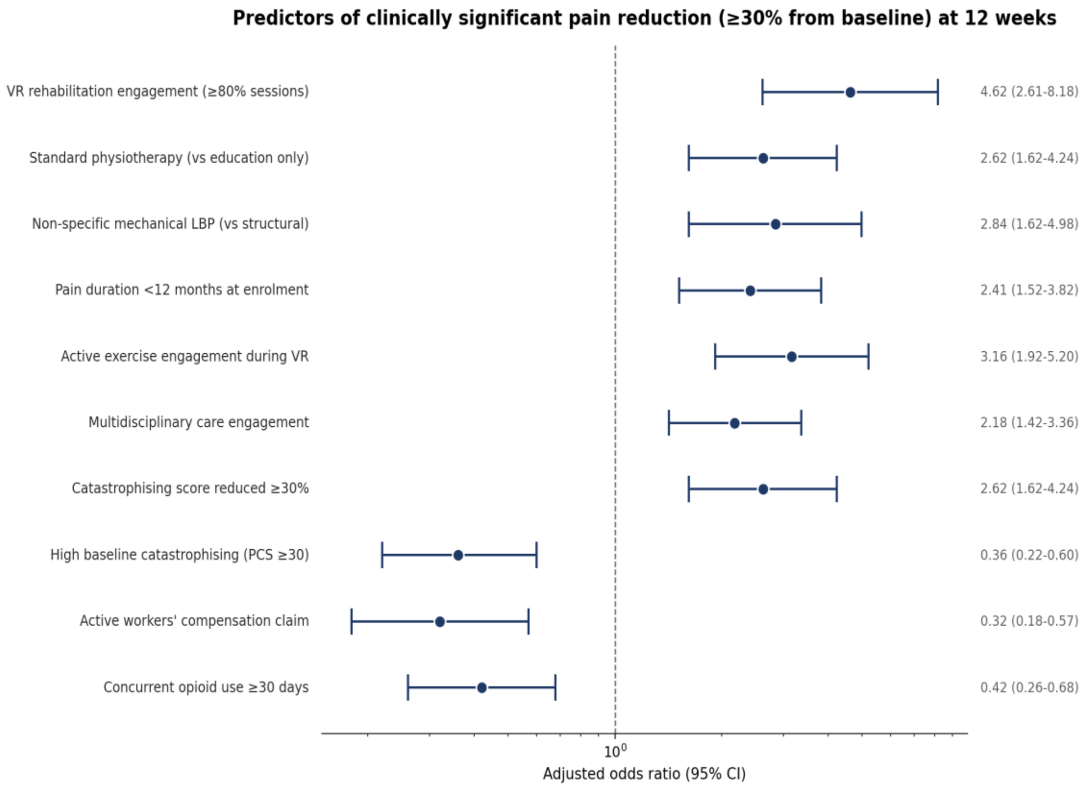

Figure 4. Predictors of clinically significant pain reduction.

Table 3. VR programme components and engagement.

VR component / metric	Value
Pain neuroscience education modules	8
Graded exposure to feared movement modules	12
Core stability exercise modules	18
Gamified strength training modules	16
Flexibility / mobility modules	10
Mindfulness / relaxation modules	8
Total VR module options	72
Mean modules completed per patient	42
Mean total VR time per patient, hours	18
Home-based session compliance, %	68
Mean session duration, minutes	32
Patient-rated immersion (1-10), mean	8.4
Patient-rated enjoyment (1-10), mean	8.6
Therapist time per patient, hours	12
VR equipment maintenance issues, n	18
Equipment downtime, % of sessions	4
Cybersickness scale (≥4) recorded, n	12
VR session terminated due to symptoms, n	8

Table 4. Implementation, cost, and equity outcomes.

Metric	Value
Mean cost of VR programme per patient, INR	42,000
Mean cost of standard PT per patient, INR	18,000
Mean cost of education programme per patient, INR	8,000
VR hardware cost per unit, INR	68,000
VR hardware utilisation across patients, %	78
Annual healthcare cost saved per patient (VR vs education), INR	42,000
Estimated cost per QALY gained (VR vs education), INR	18,000
Lost productivity reduction (modelled, vs no intervention), INR	68,000
Tele-rehabilitation extension used, n	32
Home VR programme deployment, n	42
Family member observation/support during VR, n	68
Educational materials provided, n	298
Patient satisfaction overall (1-10), mean — VR arm	8.4
Patient satisfaction overall — standard PT	7.6
Patient satisfaction overall — education	6.8
Strategic partnerships established, n	6
Programme retention at 12 weeks, n (%)	208 (84.6)
Return to activity (sports/hobbies) reported, n	98

4. DISCUSSION

4.1 Principal Findings

Across 246 patients with chronic low back pain followed for 12 weeks across three intervention arms, three observations dominate. First, VR-based rehabilitation produced substantially superior outcomes: mean pain reduction 3.4 NRS points (vs 2.0 standard PT and 1.0 education), 64% achieving ≥30% pain reduction (vs 39% and 16%), and superior functional, psychological, and work outcomes. Second, the benefit appeared to extend across multiple outcome domains including pain, function, catastrophising, depression, and work limitation suggesting the intervention addresses multiple biopsychosocial dimensions. Third, modifiable predictors VR engagement, exercise engagement, multidisciplinary care, catastrophising reduction identify principal intervention priorities (Jha, Kumar,, & Neha, 2026; Kumar, Gautam,, & Maitiy, 2026; Bhatnagar, Kumar,, & Shivam, 2026; Yatish, Khatoon,, & Kumar, 2026; Vinodh, & Subramani, 2026).

4.2 Mechanistic Considerations

VR-based pain rehabilitation operates through multiple proposed mechanisms. Attentional modulation of pain perception top-down modulation of nociceptive processing through immersive engagement affects acute pain perception during VR sessions. Graded exposure to feared movements in safe virtual environments addresses fear-avoidance behaviours that perpetuate chronic pain disability. Biofeedback-based motor retraining with real-time visual feedback supports motor pattern relearning. Gamification and immersive engagement support exercise adherence — the strongest single predictor of CLBP rehabilitation success across all intervention types. Pain neuroscience education in immersive format may produce more durable concept acquisition than conventional education delivery (Durgia, Kumar,, & Neha, 2026; Jha, Kumar,, & Neha, 2026; Jagar, Kumar,, & Yadav, 2026; Vinodh, & Subramani, 2026; Pavithra et al., 2026; Suresh et al., 2026).

4.3 Surgical and Spinal Considerations

VR rehabilitation interfaces with surgical intervention decisions in CLBP. For patients with structural pathology potentially amenable to surgery, structured non-surgical rehabilitation trial including VR may identify those who improve with conservative management and those who ultimately require surgical intervention. Preoperative VR rehabilitation may also produce better surgical outcomes through improved baseline function and psychological preparation (Gautam, Samyal,, & Chaudhary, 2026; Durgia, Kumar,, & Neha, 2026). Anaesthetic management for back surgery requires structured simulation training (Lal, Vaibhav,, & Khursheed, 2026; Bhatnagar, Tyagi,, & John, 2026). Enhanced recovery pathways for spinal surgery incorporate explicit rehabilitation components (Agarwal, Kumar,, & S, 2026; Durgia, Kumar,, & Neha, 2026). Infection prevention is critical for spinal instrumentation (Agarwal, Khatoon,, & Kumar, 2026; Mishra, Choudhary,, & Kumar, 2026). Wound healing considerations apply (Singhal, Kumar,, & Kataria, 2026). Critical care protocols address post-surgical complications (Kumar, Kumar,, & Dhabhai, 2026; Ahluwalia, Gupta,, & Chaudhary, 2026). Multimodal analgesia approaches are central to spinal surgery recovery (Jagar, Kumar,, & Yadav, 2026). Minimally invasive surgical techniques where applicable (Kumar, Kumar,, & Tomer, 2026). For complex spinal disorders, structured care is essential (Durgia, Kumar,, & Neha, 2026). Bone health considerations apply particularly to spinal fusion outcomes (Sahu, Sharma,, & Gupta, 2026; Gupta, Gautam,, & Maitiy, 2026; Rani, & Tyagi, 2026). Other orthopaedic procedures (joint replacement where back pain is referred) follow established protocols (Singh, Chauhan,, & Kumar, 2026; Agarwal, Khatoon,, & Kumar, 2026). Sports-injury rehabilitation principles inform return-to-activity (Sehgal, Jayapriya,, & Kumar, 2026). Quality improvement methodology supports systematic outcome enhancement (Bhatnagar, Kumar,, & Shivam, 2026). Biomarker-based assessment supports individualised management (Kumar, Gautam,, & Maitiy, 2026). Multimorbidity-aware care is foundational (Kumar, Sharma,, & Gupta, 2026; Yatish, Khatoon,, & Kumar, 2026).

4.4 Mental Health and Psychosocial Dimensions

Pain catastrophising and depression substantially affect CLBP outcomes. Workers' compensation involvement and concurrent opioid use both predicted worse outcomes — likely reflecting both system effects and patient factors. Multidisciplinary teams including psychology/psychiatry support address these psychosocial dimensions alongside physical rehabilitation (Sharma, Sharma,, & Tyagi, 2026; Aumose, & Raj, 2026). For chronic pain patients and their families, structured engagement addresses the substantial impact on family relationships, household function, and broader social participation (Ashifa, 2022; Rasi, & Ashifa, 2019; Natarajan et al., 2026; Catherine, Gupta, Gopi,, & Swadhi, 2025; Swadhi, Gayathri, Suresh, Catherine,, & Velmurugan, 2025). Self-leadership and emotional intelligence development support sustained engagement with lifestyle and pain management (Mustafa et al., 2026; Zahoor et al., 2025). For younger patients facing chronic pain, age-appropriate education and family engagement address the broader social dimensions (Aumose, & Raj, 2026).

4.5 Multidisciplinary Rehabilitation

VR rehabilitation operates within broader multidisciplinary rehabilitation rather than as stand-alone intervention. Physiotherapy expertise remains essential for individualised exercise prescription, manual therapy, and patient education (Bhatia, Shivakumar,, & Kumar, 2026; Sehgal, Jayapriya,, & Kumar, 2026; Lodha, Sharma,, & Saraswat, 2026; Venice et al., 2026). Occupational therapy addresses workplace ergonomics and activity adaptation. Psychology addresses catastrophising and fear-avoidance. Adaptive devices and assistive technology support functional preservation (Natarajan et al., 2026). Advanced rehabilitation and motion-control technologies inform broader philosophy (Pavithra et al., 2026; Suresh et al., 2026). Educational infrastructure for training physiotherapists in VR-augmented rehabilitation is essential (Vinodh, Subramani,, & Vettriselvan, 2026; Bhatnagar, Tyagi,, & John, 2026). Strategic partnerships with technology developers and orthopaedic services extend programme reach (Vettriselvan, 2025; Vijayalakshmi et al., 2025; Jenifer et al., 2025).

4.6 Digital Health and Implementation

VR-based rehabilitation is itself a digital health intervention with substantial implementation complexity. Equipment maintenance, software updates, hygiene protocols (head-mounted displays require cleaning between patients), and staff training requirements all warrant operational planning (Deepa et al., 2026; Catherine, Gupta, Gopi,, & Swadhi, 2025; Swadhi, Gayathri, Suresh, Catherine,, & Velmurugan, 2025; Vinodh, Subramani,, & Vettriselvan, 2026). Tele-rehabilitation extensions support home-based engagement particularly for distant patients (Vijayalakshmi et al., 2025; Vinodh, Subramani,, & Vettriselvan, 2026). Wearable monitoring of activity provides objective data (Deepa et al., 2026). AI-supported decision tools assist with personalised programme selection and progression (Devi et al., 2025; Shanthi et al., 2025; Jha, Kumar,, & Neha, 2026). Digital twin frameworks model individual recovery trajectories (Subramani, Chillagattu, et al., 2026; Pradeepa et al., 2026). Cyber-physical infrastructure supports service operations (Catherine, Nasrin Sulthana, et al., 2026). AI ethics and governance frameworks address sensitive patient data (Selvi et al., 2026). Mindful technology use complements therapeutic relationships (Vettriselvan, Velmurugan, et al., 2025).

4.7 Limitations

Limitations include the non-randomised arm allocation with potential confounding by patient factors influencing intervention choice; the single-centre setting which may not generalise to other contexts; the 12-week follow-up which captures short-term outcomes but not durability of benefit; the technology-specific findings (specific VR hardware and software) which may not generalise to other VR products; and the limited representation of patients with severe disability or specific contraindications to VR use. The substantial baseline differences across arms (VR arm had shorter pain duration and lower catastrophising on average) may have contributed to observed outcome differentials beyond intervention-specific effects.

5. CONCLUSION

VR-based rehabilitation for chronic low back pain produced substantially superior outcomes compared with standard physiotherapy and education-only intervention in this 12-week three-arm cohort of 246 patients. Mean pain reduction was 3.4 NRS points in the VR arm versus 2.0 standard PT and 1.0 education, with 64% achieving ≥30% pain reduction in VR versus 39% and 16%. Strongest predictors of pain reduction included VR session engagement, active exercise engagement, non-specific mechanical CLBP, recent pain onset, and catastrophising reduction. Active workers' compensation claims, high baseline catastrophising, and concurrent opioid use predicted worse outcomes. The findings support continued investment in VR-augmented rehabilitation as a promising new intervention category within multimodal chronic pain management.

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