RESEARCH ARTICLE

Comparing VR-Based Exercises and Routine Physical Therapy Effects on Pain, Kinesiophobia, and Functional Abilities in Non-Specific Chronic Low Back Pain Patients "A Randomized Clinical Trial"

Fatimah Khalifeh, Ph.D Candidate; Noureddin Karimi, Ph.D ; Mohammad Hassan Azarsa, Ph.D; Somayeh Mohammadi, Ph.D; Samaneh Hosseinzade, Ph.D; Saeed Behzadipour, Ph.D; Pezhman Masoudi, Ph.D

Research performed at Rufeidah rehabilitation hospital, Tehran, Iran

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Abstract

Objectives: To compare the effects of Virtual Reality (VR)-based exercises and routine physical therapy on pain, kinesiophobia, and functional abilities in patients with Non-Specific Chronic Low Back Pain (NSCLBP).

Methods: Twenty-eight participants aged 20 to 55 were included and randomly assigned to two groups, ensuring single blinding. Both groups received routine physical therapy, which included transcutaneous electrical nerve stimulation (TENS), ultrasound therapy, and infrared light, along with identical exercise programs. The intervention group also engaged in additional exercises using VR technology. Participants had been experiencing NSCLBP for three months or longer.

Results: The intervention group showed significant improvements in pain (P=0.001), disability index, quality of life (QoL) (P=0.004), range of motion (ROM) in flexion and extension (P=0,008, P=0.002), and both left and right sided balance (P=0.001, P=0.013) compared to the control group. However, no significant differences were observed in the Tampa Scale of Kinesiophobia (P=0.148) and strength in flexion and extension (P=0.370, P=0.09).

Conclusion: VR-based therapeutic exercises significantly improved pain, disability, quality of life, and balance in NSCLBP patients compared to routine physical therapy interventions.

Level of evidence: I

Keywords: Kinesiophobia, Low Back Pain, Physical Therapy Modalities, Virtual Reality, Wearable Electronic Devices

Introduction

Chronic Low Back Pain (CLBP) is defined as pain in the lower back that persists for more than three months. It can significantly interfere with daily activities, work productivity, and social responsibilities, including family life.[1] CLBP is also increasingly contributing to rising healthcare costs. [2] Its prevalence tends to rise steadily from the third decade of life until around the age of 60 and is more commonly observed in females.[3]

There is a lack of robust evidence supporting the efficacy and appropriateness of many spinal surgeries and interventions.[4] Treatment options for CLBP include pharmacological and surgical interventions, but there is

Corresponding Author: Noureddin KARIMI, Department of Physiotherapy, University of Social Welfare and Rehabilitation Sciences, Tehran, Iran

Email: karimi@uswr.ac.ir

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moderate evidence for the short-term efficacy of opioids in treating CLBP pain, so a multidisciplinary approach is initially recommended. [5] This approach includes exercise, stress reduction, relaxation therapy, spinal manipulation, and electrical stimulation. [6] Several factors can hinder recovery, such as cognitive impairments, low motivation, and catastrophic thinking, which can lead to prolonged disability. [7] Psychological therapies for chronic pain vary in scope, duration, and goals, showing different patterns of effectiveness.[8] The fear-avoidance model suggests that individuals with high fear of CLBP avoid movements they perceive as threatening, particularly lumbar spine flexion [7] Exercise therapy is the most commonly used conservative treatment for low back pain, with proven effectiveness in improving function and work capacity .[9] Virtual reality (VR) is an interactive, computer-generated technology that immerses users in a simulated three-dimensional environment, often delivered through head-mounted displays or other wearable devices. Unlike traditional rehabilitation methods, VR enables patients or even doctors to actively engage with customized tasks and real-time feedback in a safe and controlled setting.[10] By combining elements of gaming, movement simulation, and biofeedback, VR not only enhances patient motivation and adherence but also provides clinicians with precise tools to monitor performance and progress. These unique features make VR a promising adjunct to conventional physical therapy, particularly in the management of chronic musculoskeletal conditions such as low back pain in different areas of body. [11, 12] Additionally, a systematic review has shown that virtual reality (VR) exercises can be effective in managing low back pain, improving functional abilities, and increasing patient motivation. These benefits may contribute to reduced workday losses and support more effective physical rehabilitation outcomes. The review further indicated that VR interventions for chronic low back pain are generally safe and feasible, with preliminary evidence suggesting improvements in quality of life and reductions in pain levels. However, evidence for functional improvements remains limited and inconsistent, and most available studies have methodological shortcomings, small sample sizes, and short-term outcome assessments. The review highlighted the need for more robust randomized controlled trials with larger sample sizes, standardized treatment protocols, and long-term follow-up to better define the role of virtual reality (VR) in managing chronic low back pain. [13] In direct response to these limitations, the present study was carefully designed with a rigorous methodological framework, an adequate sample size, and standardized, validated outcome measures. These measures encompassed variables that had previously been examined in isolation—such as pain intensity, functional disability, (QoL), kinesiophobia, (ROM), and muscular strength. Additionally, the study incorporated extended follow-up assessments to evaluate both short- and long-term effects. As virtual reality adds new features to exercise therapy that help participants progress more precisely and concretely through rehabilitation programs, this study aims to evaluate the effectiveness of two intervention strategies—routine physical therapy (RPT) and VR exercises (VREs)—on pain intensity, functional disability, QoL, kinesiophobia, ROM, and muscular strength in the lumbar area of patients with CLBP.[11]

Materials and Methods

Study Design

This study was a single-blind randomized controlled trial (RCT) with a 1:1 allocation ratio. The trial compared the effects of Virtual Reality (VR)-based exercises and routine physical therapy on patients with Non-Specific Chronic Low Back Pain (NSCLBP). It was conducted at Rufaidah Rehabilitation Hospital, Tehran, Iran, from February to August 2024, following ethical approval by the University of Social Welfare and Rehabilitation Sciences Ethics Committee (IR.USWR.REC.1401.256). The health, dignity, and integrity of the participants were ensured and the objectives, procedures, potential risks and benefits of the study were clearly communicated to them. Participation in this study was completely voluntary, and all participants were informed that they could withdraw at any time without consequence. They were assured that their personal information and data would remain confidential and would not be disclosed or published in any form, including abbreviations. Informed consent was obtained from all participants, and their rights were protected in accordance with the principles outlined in the Declaration of Helsinki.

Participants

A total of 44 participants were assessed for eligibility. Sixteen participants were excluded for the following reasons: 14 did not meet the inclusion criteria, and 2 declined to participate. The remaining 28 participants were randomized into two groups: 14 were assigned to the routine physical therapy (control) group, and 14 to the VR-based exercise (intervention) group. All participants received the allocated interventions and were analyzed for the study outcomes.

Participants were recruited using purposive sampling from the Rufaidah hospital's patient registry. They were informed about the study's objectives, risks, and benefits before providing written informed consent .[14, 15]

Inclusion and exclusion criteria

Participants were between 20 and 55 years old, of either gender, and had experienced non-specific chronic low back pain (NSCLBP) for at least three months. Their educational backgrounds ranged from diploma-level to higher education. Exclusion criteria included congenital deformities, traumatic injuries, systemic or neurological diseases, spinal or lower extremity fractures, corticosteroid use, pregnancy, and missing more than two treatment sessions. [4, 15, 16] participants were examined by the physician and a multiple approach of physical examination combining imaging and VAS pain self-reporting were used to ensure the diagnosis of CNLBP. [16]

After participant selection, consent forms outlining the study's objectives, procedures, and conditions were provided to each individual. The ethical guidelines mentioned above were strictly adhered to throughout the research. Ethical approval for the study was granted by the

Ethics Committee of the University of Social Welfare and Rehabilitation Sciences (Approval ID: IR.USWR.REC.1401.256). This study was registered in the Iranian Registry of Clinical Trials (ID: IRCT20230411057885N1, registered on 15/05/2023) and adhered to the CONSORT guidelines for randomized controlled trials. Participant allocation and dropouts are illustrated in the study flowchart [Figure 1].

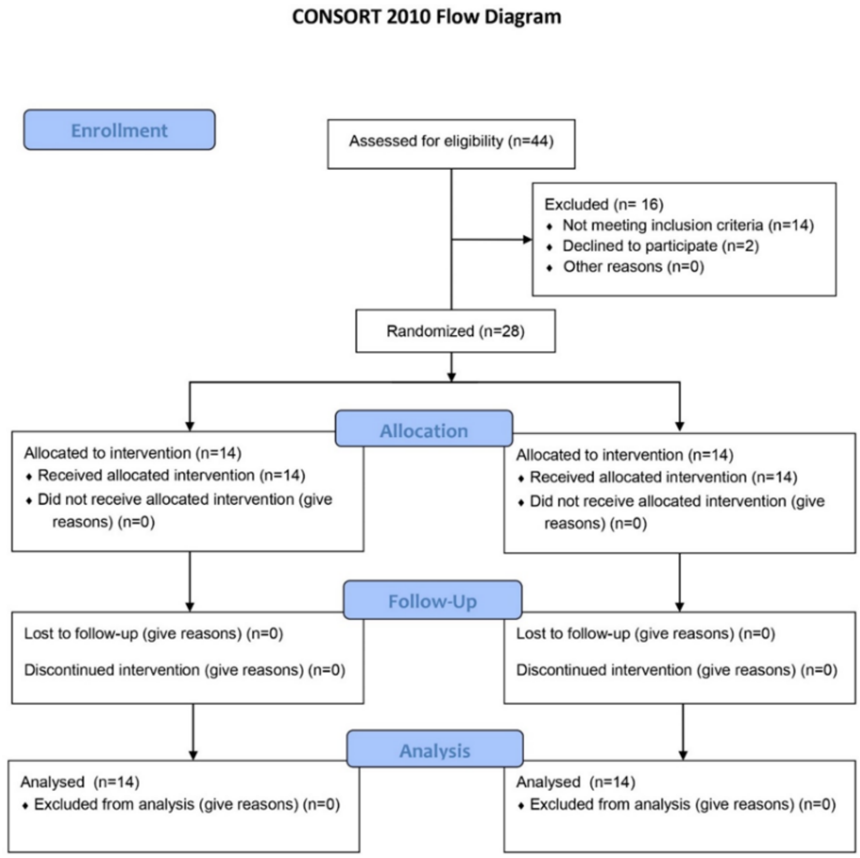

Fig 1. Participant flow diagram showing the recruitment, allocation, and follow-up of participants

Randomization and Allocation

After obtaining informed consent, participants were randomly assigned to either the routine group or the VR group using a simple random stratified method. To ensure gender homogeneity, the following procedure was used for group allocation.

1. **Random Assignment:**

The first sample was randomly assigned to one of the two intervention groups.

This randomization was achieved using sealed envelopes, each containing a sheet of paper indicating the assigned intervention (VR-based or non-VR exercise).

2. **Gender Pairing:**

Subsequent samples of the same gender are then placed in the opposite group.

This approach balances the distribution of male and female participants across both intervention arms.

Evaluations were conducted before the first session, immediately after the 10th treatment session, and at the two-week follow-up check. [16]

Blinding

This trial utilized a single-blind design. Outcome assessors and data analysts were blinded to group assignments, while the physiotherapist responsible for administering the interventions was not involved in participant recruitment, randomization, or data analysis.

Interventions

For both groups, routine physiotherapy modalities were applied consistently prior to exercise. Continuous ultrasound with a frequency of 3 MHz was administered for 8 minutes (4 minutes on each side). The ultrasound application targeted the lower back area between the first and fifth lumbar vertebrae, specifically between the spinous and transverse processes on both the right and left sides. [13] The second step involved 15 minutes of electrical stimulation using the NORM continuous current mode of TENS applied to the lower back (L1-L5) with two channels and four electrodes (10 cm x 10 cm) placed around the painful area, set to a frequency of 20 Hz and a pulse width of 10 milliseconds. [16]This was conducted in conjunction with 15 minutes of infrared heat applied at a distance of 30 cm from the lower back area. [17] In the third step of the exercise regimen, patients received comprehensive training on how to perform each exercise. Each session included four distinct exercises that targeted various aspects of rehabilitation: stretching, strengthening, sensory-motor activities, and dynamic goals.

Treatment Schedule:

Patients receive treatment every other day, totaling 10 sessions.

Each session occurs once a day at the clinic. Notably, there is no home exercise program included in this protocol.

Both the VR and control groups performed identical exercise protocols, with the main distinction being that the VR group used the system's stopwatch to regulate duration, while the control group followed timing with a standard handheld stopwatch. Each movement, including lateral bending, was maintained for 5 seconds per repetition. Training began with 5 repetitions and was gradually increased to 20 across sessions, with exercise intensity adjusted according to individual tolerance. The only exception was the lunge exercise, which was standardized using a green Thera Band to provide consistent resistance. The number of targets was standardized across groups. In the VR system, participants were instructed to reach a hypothetical ball that was visually aligned with the intended limb or body point (e.g., for lateral bending, the ball was positioned at knee level). When the participant successfully reached the target, the ball would "explode," providing visual feedback. In the control group, participants performed the same reaching task toward the designated body point without the virtual feedback.

Control Group:

Participants performed routine exercises targeting flexibility, strength, and balance without additional VR components.

Intervention Group:

Participants performed the same exercises using a VR system (Sena), incorporating real-time visual and auditory feedback. The VR system included a Kinect camera for motion detection, a processing unit, and a 32-inch monitor.[17, 18, 19]

Outcome Measures:

The primary outcomes assessed were pain, measured using the Visual Analogue Scale (VAS), and functional disability, evaluated with the Modified Oswestry Disability Index (MODI). Secondary outcomes included quality of life (assessed via the SF-12 questionnaire), lumbar range of motion (ROM) in flexion and extension using a goniometer, muscular strength measured with a dynamometer, balance assessed through the single-leg stand test, and kinesiophobia evaluated using the Tampa Scale for Kinesiophobia (TSK).[20, 21, 22]

VR-system used explanation:

The Sena system provides the ability to perform exercises in various fields of rehabilitation. The system used by the Kinect camera (it is a motion detection system based on photography); It records movement data from the movements of the patient's limbs and then analyzes motion data by a pre-processing unit. In addition to the Kinect camera and the processing unit, which is a small computer, this system; also uses a 32-inch monitor, which is installed in order to show the virtual space to the patient and give suitable audio and visual feedbacks in each exercise. The sensor is able to recognize a person from a distance of 5.1 to 5.3 meters and track his body movements. This sensor can also see up to a height of 2 meters without error.

This VR system uses both auditory and visual feedbacks. [13, 14] As for real-time auditory feedback where motor movements are monitored, production errors are detected and corrected, the part of the body to be trained (left or right, upper or lower limb, head or shoulders), the number of repetitions, stating errors in posture and performance, motivation and rewards, will be orally declared without using any headphones, providing multiple auditory inputs and assessing position of the eyes and head with respect to the body.

[15, 17] Visual feedbacks are summarized by using targets to emphasize movement, changeable colors to maintain the exact training maneuvers (green for correct movements, red for errors), postural monitoring by avatar control, multiple perimeters that are close to reality (work location, home, gym, sea shore) without using any type of headset to maintain better understanding of the surrounding, thus avoiding falls, seizures, headaches. [19]

Sample Size:

Sample size was calculated using the formula for comparing means. Based on a previous study, the standard deviation for the Tampa Scale of Kinesiophobia (TSK) was 8.6 for males and 7.9 for females (2). Assuming a 10-point difference between groups, with 95% confidence (z=1.96) and 80% power (z=0.85), the required sample size was 11 participants per group. To account for potential dropouts, 14 participants per group were included, totaling 28 participants. [2]

$$n = \frac{2(z_{1-\alpha/2} + z_{1-\beta})^2 \, SD^2}{d^2}$$

Statistical Analysis:

Data were analyzed using SPSS-27. Continuous variables were summarized as means and standard deviations. Normality was assessed using the Shapiro-Wilk test. Repeated measures ANOVA was used for within-group comparisons, and independent t-tests for between-group differences. P-values <0.05 were considered statistically significant. [22]

Results

Out of 28 patients, there were 14 (50%) in each of the two groups. The distribution included 14 (50%) males and 14 (50%) females. The mean age in the control group was 35 years (SD= 6.34), while in the intervention group it was 39 years (SD=7.12). T-test showed that mean of age, height, weight, and BMI didn't differ significantly between two groups [Table 1].

The normality of the main variables was assessed using the Shapiro-Wilk test at three different stages. All variables, except for right-side and left-side balance, were normally distributed (P > 0.05). The intervention group demonstrated significant improvements compared to the control group in several variables measured at the 10th session and follow-up.

Table 1: Demographic variables in two groups

Variables	Intervention group(n=14) Mean (SD)	Control group(n=14) Mean (SD)	T-test	
			value	P-value
Age (year)	39.43 (7.12)	35.07 (6.34)	1.709	0.099
Weight (Kg)	77.93 (13.64)	75.57 (12.07)	0.473	0.640
Height (cm)	172.57 (12.66)	173.50 (13.07)	0.927	0.850
Body Mass Index	26.02 (1.84)	25.07 (2.35)	1.182	0.248
Sex	Male: 7(50%)	Male: 7(50%)		
	Female: 7(50%)	Female: 7(50%)		

Visual Analogue Scale of Pain (VAS):

A reduction in mean of pain was observed in the intervention group at the 10th session (mean = 0.71, SD = 1.06) and follow-up (mean = 0.29, SD = 0.46) compared before stage (mean = 4.0, SD = 1.88). T-test showed that mean of pain in intervention and control groups were significantly different at 10th session and follow-up stages (P<0.05) [Table 2].

Table 2: Comparing means of mail variables in two groups at each stage

Variables	**Stage**	Intervention group(n=14) Mean (SD)	Control group(n=14) Mean (SD)	T-test value	P-value
Visual Analogue Scale of Pain	Baseline	4.00 (1.88)	5.21 (1.18)	2.042	0.051
	10th session	0.71 (1.06)	2.36 (1.15)	3.914	**0.001**
	Follow up	0.29 (0.46)	1.86 (0.94)	5.554	**0.001**
Disability Index	Baseline	29.57 (16.68)	34.86(14.81)	1.038	0.299
	10th session	19.14(8.54)	28.29(12.09)	2.309	**0.029**
	Follow up	13(6.91)	25.71(12.22)	2.895	**0.004**
Quality of Life (QoL)	Baseline	30.14(6.75)	28.07(7.22)	76.000	0.329
	10th session	38.07(6.66)	32.68(7.17)	2.060	**0.049**
	Follow up	42.21(6.27)	35.29(6.51)	2.867	**0.008**
ROM (Flexion)	Baseline	7.07(1.24)	7.65(5.56)	-1.477	0.140
	10th session	8.92(0.88)	7.28(1.85)	2.978	**0.008**
	Follow up	9.85(1.14)	7.60(2)	3.639	**0.002**
ROM (Extension)	Baseline	23.13(7.15)	28.68(41.58)	-1.730	0.084
	10th session	27.01(7.39)	20.68(10.01)	1.904	0.068
	Follow up	28.85(6.82)	21.37(10.23)	2.275	**0.031**
Balance (Left)*	Baseline	13.67(4.36)	10.89(4.10)	-1.772	0.076
	10th session	17.77(2.66)	14.01(3.62)	-2.816	**0.005**
	Follow up	18.66(2.20)	15.28(2.99)	-3.284	**0.001**
Balance (Right)*	Baseline	13.83(5.20)	11.52(5.06)	-1.035	0.301
	10th session	17.44(3.47)	14.23(4.33)	-1.978	**0.048**
	Follow up	19.21(1.05)	16.27(3.49)	-2.497	**0.013**

*U Mann-Whitney test

Repeated-measures ANCOVA showed that baseline pain significantly influenced subsequent pain scores ($P<0.05$; $\eta^2=0.46$). After adjusting for baseline, the intervention had a significant effect on pain ($P<0.05$; $\eta^2=0.48$). Specifically, pain was lower in the intervention group than in the control group at both the 10th session (mean difference = −1.07; $P<0.05$; $\eta^2=0.27$) and follow-up (mean difference = −1.28; $P<0.05$; $\eta^2=0.47$), indicating moderate to-large intervention effects. [Table 3]

Table 3. results of repeated measurements ANCOVA (before stage as a covariate variable) and group variable's coefficients of the model

	ANOVA analysis						Coefficient of group (baseline=control)			
variable			F value	P -value	effect size, Etha	stage	beta	t-value	P-value	effect size, Etha
Visual Analogue Scale of Pain	Between groups	Time	1.039	0.318	0.04	10th session	-1.078	3.108	**0.005**	0.27
		Time*group	0.285	0.598	0.01	Follow up	-1.280	4.768	**0.000**	0.47
		Time*before	3.770	0.064	0.13					
	Within groups	Group	23.052	**0.000**	0.48					
		before	21.961	**0.000**	0.46					
Disability Index	Between groups	Time	4.405	**0.046**	0.15	10th session	-6.330	2.583	**0.016**	0.21
		Time*group	4.145	0.052	0.14	Follow up	-9.916	4.714	**0.000**	0.47
		Time*before	0.002	0.962	0.00					
	Within groups	Group	14.863	**0.001**	0.37					
		before	60.422	**0.000**	0.70					

Table 3. Continued

Quality of Life (QoL)	Between groups	Time	7.540	**0.011**	0.23	10th session	3.630	2.633	**0.014**	0.21
		Time*group	2.817	0.106	0.10	Follow up	5.369	3.798	**0.001**	0.36
		Time*before	1.669	0.208	0.06					
	Within groups	Group	12.045	**0.002**	0.32					
		before	71.230	**0.000**	0.74					
ROM (Flexion)	Between groups	Time	0.11	0.919	0.000	10th session	0.899	3.084	**0.005**	0.27
		Time*group	3.812	0.062	0.132	Follow up	1.438	4.129	**0.000**	0.40
		Time*before	0.883	0.356	0.034					
	Within groups	Group	16.239	**0.000**	0.394					
		before	84.574	**0.000**	0.772					
ROM (Extension)	Between groups	Time	4.937	**0.036**	0.16	10th session	0.804	0.843	0.407	0.02
		Time*group	4.082	0.054	0.14	Follow up	2.107	1.862	0.074	0.12
		Time*before	0.600	0.446	0.02					
	Within groups	Group	2.139	0.156	0.07					
		before	292.362	**0.000**	0.92					

Disability Index:

A reduction in the disability index was observed in the intervention group at the 10th session (mean = 19.14, SD = 8.54) and follow-up (mean = 13.00, SD = 6.91) compared to the baseline stage (mean = 29.57, SD = 16.68). Independent T-test showed significant differences between the intervention and control groups at both the 10th session (P=0.029) and follow-up (P=0.004) [Table 2].

Repeated-measures ANCOVA indicated that baseline disability significantly influenced subsequent scores (P<0.001; η^2=0.70). After adjusting for baseline, the intervention had a significant effect on disability (P=0.001; η^2=0.37). Specifically, disability was lower in the intervention group compared to the control group at the 10th session (mean difference = −6.33; P=0.016; η^2=0.21) and at follow-up (mean difference = −9.92; P<0.001; η^2=0.47), reflecting moderate-to-large intervention effects [Table 3].

Quality of Life (QoL):

An improvement in mean QoL was observed in the intervention group at the 10th session (mean = 38.07, SD = 6.66) and follow-up (mean = 42.21, SD = 6.27) compared to the baseline stage (mean = 30.14, SD = 6.75). Independent T-test showed significant differences between the intervention and control groups at both the 10th session (P=0.049) and follow-up (P=0.008) [Table 2].

Repeated-measures ANCOVA revealed that baseline QoL significantly influenced subsequent QoL scores (P<0.001; η^2=0.74). After adjusting for baseline, the intervention had a significant effect on QoL (P=0.002; η^2=0.32). Specifically, QoL was higher in the intervention group compared to the control group at the 10th session (mean difference = +3.63; P=0.014; η^2=0.21) and at follow-up (mean difference = +5.37; P=0.001; η^2=0.36), indicating moderate-to-large intervention effects [Table 3].

Tampa Scale of Kinesiophobia (TSK):

No significant differences were found between groups across all time points.

Range of Motion (ROM)

Improvements in ROM were observed in the intervention group across both flexion and extension movements. For flexion, mean values increased from baseline (mean = 7.07, SD = 1.24) to the 10th session (mean = 8.92, SD = 0.88) and follow-up (mean = 9.85, SD = 1.14). For extension, mean values increased from baseline (mean = 23.13, SD = 7.15) to the 10th session (mean = 27.01, SD = 7.39) and follow-up (mean = 28.85, SD = 6.82). T-test results showed significant between-group differences at the 10th session and follow-up for flexion (P=0.008 and P=0.002, respectively), and at follow-up for extension (P=0.031) [Table 2].

Repeated-measures ANCOVA revealed that baseline ROM significantly influenced subsequent flexion scores (P<0.001; η^2=0.77), while the effect for extension was also significant (P<0.001; η^2=0.92). After adjusting for baseline, the intervention demonstrated significant effects on ROM flexion (P<0.001; η^2=0.39), but less consistent effects on extension (P=0.156; η^2=0.07). Specifically, flexion was greater in the intervention group compared to the control group at the 10th session (mean difference = +0.90; P=0.005; η^2=0.27) and follow-up (mean difference = +1.44; P<0.001; η^2=0.40). For extension, the differences were not significant at the 10th session (mean difference = +0.80; P=0.407; η^2=0.02) or follow-up (mean difference = +2.11; P=0.074; η^2=0.12), suggesting stronger intervention effects for flexion than for extension [Table 3].

Strength and Balance:

Left balance

An increasing mean of left balance was observed in the intervention group at the 10th session (mean = 17.77, SD =

2.66) and follow-up (mean = 18.66, SD = 2.20) compared before stage (mean = 13.67, SD = 4.36). Mann-Whitney test showed that mean of left balance in intervention and control groups were significantly different at 10th session and follow-up stages (P<0.05) [Table 2].

The GEE model indicated that baseline balance score had a significant effect on left-side balance at both 10th session and follow-up (P<0.05). After controlling for baseline, the group effect was significant, showing an overall difference in left-side balance between the two groups (P<0.05). Based on the Bonferroni test, in the intervention group there was no significant difference between 10th session and follow-up scores (P=0.167), whereas in the control group a significant difference was observed between these two stages. Between groups, right-side balance differed significantly at the 10th session stage but not at follow-up, indicating that although baseline balance strongly influenced outcomes, the intervention improved left-side balance only immediately after treatment, with no sustained effect at follow-up [Table 4].

Right balance

An increasing mean of right balance was observed in the intervention group at the 10th session (mean = 17.44, SD = 3.47) and follow-up (mean = 19.21, SD = 1.05) compared before stage (mean = 13.83, SD = 5.20). Mann-Whitney test showed that mean of right balance in intervention and control groups were significantly different at 10th session and follow-up stages (P<0.05) [Table 2].

The GEE model indicated that baseline balance score had a significant effect on right-side balance at both 10th session and follow-up (P<0.05). After controlling for baseline, the group effect was significant, showing an overall difference in right-side balance between the two groups (P<0.05). Based on the Bonferroni test, in the intervention group there was no significant difference between 10th session and follow-up scores (P=0.052, approaching significance), whereas in the control group a significant difference was observed between these two stages. Between groups, right-side balance differed significantly at the 10th session stage but not at follow-up, indicating that although baseline balance strongly influenced outcomes, the intervention improved right-side balance only immediately after treatment, with no sustained effect at follow-up. Strength measurements did not show significant differences between groups [Table 4, Figure 2].

Table 4: Results of GEE analysis (before stage as a covariate variable) and Bonferroni pair test

Variable	Independent variables	GEE analysis Wald value	P-value	Bonferroni pair test First variable	Compared the two levels of the second variable	Different means	SE	P-value
Balance (Right)	Time	23.007	**0.000**	Intervention	10th session & follow up	-1.77	0.40	0.052
	Time*groups	0.117	**0.733**	control	10th session & follow up	-2.04[a]	0.33	**0.000**
	Groups	11.971	**0.001**	10th session	Intervention & control	1.94[a]	0.48	**0.009**
	before	68.278	**0.000**	Follow up	Intervention & control	1.67	0.72	0.100
Balance (Left)	Time	16.982	**0.000**	Intervention	10th session & follow up	-0.88	0.40	0.167
	Time*groups	0.543	0.461	control	10th session & follow up	-1.27[a]	0.33	**0.001**
	Groups	12.313	**0.000**	10th session	Intervention & control	2.15[a]	0.48	**0.000**
	before	50.617	**0.000**	Follow up	Intervention & control	1.76	0.72	0.090

Fig 2. Chart results for some variables

Discussion

The results of this study demonstrate that virtual reality (VR)-based exercises are a highly effective intervention for managing non-specific chronic low back pain (NSCLBP). Participants in the VR group exhibited significantly greater reductions in pain intensity and functional disability, as well as notable improvements in quality of life and postural balance, compared to those who received standard physical therapy alone. These findings suggest that immersive VR environments may exert analgesic effects through several interrelated mechanisms. First, VR provides multisensory engagement—combining visual, auditory, and proprioceptive feedback—which can modulate pain perception via attentional distraction and competition for cortical processing resources. By directing attention toward interactive and rewarding virtual tasks, the brain's focus is shifted away from nociceptive input, leading to reduced activation of pain-related networks such as the anterior cingulate cortex and insula. This attentional modulation is supported by the gate control theory of pain, wherein non-nociceptive sensory input can inhibit pain signal transmission at both spinal and supraspinal levels. Beyond simple distraction, VR may also influence neuroplastic and sensorimotor mechanisms. The visual representation of movement within a virtual environment can activate mirror neuron systems and motor-related cortical areas, even when real movement is limited. This activation may enhance motor relearning and cortical reorganization, counteracting the maladaptive neural patterns often seen in chronic pain. Through repeated exposure to pain-free, virtual movement experiences, VR promotes graded motor imagery and fear extinction. Psychologically, the sense of presence and immersion experienced during VR sessions contributes to emotional engagement and intrinsic motivation, enhancing adherence and perceived enjoyment of therapy. Positive affective states induced by VR are linked to increased dopaminergic activity and reduced stress-related responses, which can further modulate pain sensitivity. Over time, these processes lead to improvements in functional performance, self-efficacy, and overall psychological well-being. Collectively, these mechanisms explain how VR serves not merely as a distraction tool but as a comprehensive neurorehabilitative platform, simultaneously targeting sensory, motor, and emotional dimensions of chronic pain. This multidimensional interaction underscores the potential of VR as a transformative adjunct to conventional rehabilitation, facilitating both physical recovery and psychosocial adaptation in individuals with NSCLBP.

Comparison with Previous Studies:

Visual Analogue Scale (Pain)

Our findings are consistent with and build upon previous research examining the effectiveness of VR-based interventions for chronic low back pain (CLBP). In agreement with Wu et al. 23, this study demonstrated significant reductions in pain intensity and functional disability in the VR intervention group, reinforcing the analgesic and rehabilitative benefits of immersive VR exercises. From a physiological perspective, the observed reduction in pain may be related to modulation of central pain processing and neuroplastic adaptations within the somatosensory cortex. Immersive VR experiences engage multiple sensory pathways, which can alter the excitability of nociceptive networks and enhance descending inhibitory control, thereby reducing the perception of pain. From a psychological viewpoint, the immersive and interactive nature of VR creates a sense of presence and cognitive engagement that diverts attention away from pain-related sensations. This attentional shift supports the "distraction hypothesis," reducing activity within pain-associated brain regions such as the insula and anterior cingulate cortex. Moreover, the gamified context of VR enhances motivation, self-efficacy, and emotional well-being, which are key factors in sustaining long-term pain relief. From a motor control perspective, VR training facilitates more efficient motor planning and coordination by providing immediate visual feedback and sensorimotor reinforcement. This process may reduce aberrant muscle co-contraction patterns and restore balanced activation of trunk stabilizers, ultimately decreasing mechanical stress on pain-sensitive structures. Finally, from an anatomical standpoint, VR-based movements can promote optimal activation of deep spinal stabilizers such as the multifidus and transversus abdominis muscles. Improved recruitment of these muscles enhances lumbopelvic stability, supports spinal alignment, and reduces compensatory loading of superficial musculature. Over time, this adaptive response leads to an improved energy consumption strategy that enables the musculoskeletal system to tolerate mechanical loads more effectively. Collectively, these mechanisms provide a comprehensive explanation for the significant pain reduction observed in this study, highlighting VR's capacity to simultaneously influence neurophysiological, psychological, and biomechanical aspects of chronic low back pain.

Quality of Life and Postural balance:

Unlike the findings of Wu et al., our study demonstrated significant improvements not only in pain and disability but also in quality of life and postural balance, providing a more comprehensive understanding of functional recovery. Similarly, Zhang et al. 22 reported that VR-based training effectively reduced pain, disability, and pain-related fear immediately after intervention, although they emphasized the absence of long-term outcomes and the need for high-quality trials. Addressing these limitations, the present study included follow-up assessments that revealed sustained improvements across nearly all measured variables, suggesting that VR-based exercises have durable therapeutic effects in the management of NSCLBP.

From a physiological perspective, immersive VR environments may facilitate sensorimotor integration by simultaneously engaging visual, vestibular, and proprioceptive systems. This multimodal stimulation enhances neural connectivity between the somatosensory cortex and cerebellum, leading to improved postural control and balance regulation. Furthermore, repeated exposure to pain-free movement within the virtual environment may downregulate hyperactivity of pain-related cortical regions and restore normal central nervous system function.

From a psychological viewpoint, VR offers a powerful tool for reducing pain catastrophizing and fear-avoidance behaviors. The engaging and game-like features of VR increase enjoyment, motivation, and adherence to therapy, which are often challenging in chronic pain rehabilitation. By promoting a sense of presence and accomplishment, VR positively influences emotional well-being and self-efficacy—key components of enhanced quality of life.

From a motor control perspective, real-time visual and auditory feedback allows patients to correct movement and postural errors immediately, improving motor learning and coordination. This feedback-driven practice promotes symmetrical weight distribution, better control of trunk and pelvic movements, and smoother muscle activation patterns during functional tasks.

Finally, from an anatomical standpoint, the repetitive, guided movements within VR scenarios may optimize activation of core stabilizing muscles such as the multifidus, transversus abdominis, and gluteal muscles, which are often inhibited in NSCLBP. Strengthening these deep stabilizers improves segmental spinal control, reduces compensatory overuse of superficial muscles, and enhances postural balance and movement efficiency.

Collectively, these physiological, psychological, and biomechanical mechanisms explain the observed improvements in both balance and quality of life. The immersive nature of VR therefore represents not merely a motivational tool but a multidimensional neuromotor intervention capable of promoting sustainable physical and psychosocial recovery in individuals with chronic low back pain.

Range of Motion (ROM) and Tampa Scale of Kinesiophobia (TSK):

Sadeghi et al. [23] reported that VR exercises, when integrated with targeted rehabilitation programs, produced significant improvements in pain, disability, and range of motion—findings that align closely with the results of our study. Notably, the inclusion of balance assessments in our research extends the existing literature by demonstrating VR's additional benefits for postural stability, offering a more comprehensive evaluation of its rehabilitative potential. The observed improvements in lumbar flexion and extension ROM can be attributed to the immersive and interactive nature of VR-based exercises, which often incorporate these trunk movements into dynamic, goal-oriented tasks. The visual immersion and task-driven engagement provided by VR encourage participants to move their spine more freely and repeatedly, promoting muscle elasticity, joint mobility, and motor learning. Physiologically, repetitive, controlled trunk motions enhance circulatory flow and soft-tissue flexibility, reducing stiffness in paraspinal and hamstring muscles. This in turn facilitates smoother, pain-free movement of the lumbar segments.

From a motor control perspective, VR exercises provide continuous real-time visual and proprioceptive feedback, enabling patients to adjust their posture and movement accuracy during performance. This feedback-driven training enhances coordination between deep stabilizing muscles—such as the multifidus and transversus abdominis—and larger global movers like the erector spinae and gluteal muscles. Improved activation of these stabilizers contributes to better segmental spinal control and kinematic efficiency, directly supporting increases in range of motion. Psychologically, the immersive and gamified nature of VR fosters motivation and engagement, helping patients overcome the fear of pain during movement. This may partially explain the observed improvements in movement amplitude and flexibility. However, the limited improvement in kinesiophobia found in this study likely reflects the deep psychological roots of this condition. Fear of movement often arises from maladaptive pain beliefs, anxiety, and previous negative pain experiences, which cannot be fully addressed through physical interventions alone. While VR can temporarily reduce pain perception through distraction and enhanced self-efficacy, these effects may not be sufficient to produce sustained cognitive or emotional changes. Long-term reduction in kinesiophobia generally requires cognitive-behavioral strategies, graded exposure, or education-based interventions integrated with physical therapy to address fear-avoidance beliefs at both psychological and behavioral levels.

Overall, the combination of neurophysiological activation, motor learning, and psychological engagement offered by VR appears to play a pivotal role in improving spinal flexibility and functional performance. Nevertheless, future studies should explore integrating VR-based movement training with cognitive-behavioral components to achieve more lasting improvements in fear-related and psychosocial domains of chronic low back pain rehabilitation.

Disability Index:

Gunay and Barakat investigated the role of immersive gamification in educational contexts and concluded that the use of a VR headset did not confer additional benefits beyond those achieved through gamified learning alone. Although their study was conducted in a non-clinical, educational setting, their findings raise an important question regarding the necessity of immersion for added therapeutic value. This perspective invites further examination of whether the immersive qualities of VR are essential for enhancing rehabilitation outcomes, or whether structured, gamified engagement by itself may be sufficient to induce change. In contrast to these findings from educational research, our study demonstrated that immersive VR-based exercises produced meaningful clinical improvements in pain intensity, functional disability, quality of life, and postural balance among patients with non-specific chronic low back pain (NSCLBP). These outcomes suggest that immersion may play a more critical role in rehabilitation contexts, where multisensory feedback, embodiment, and real-time interaction directly influence motor control and functional recovery. Supporting this interpretation, Afzal et al. [reference] conducted a direct comparison between VR-based exercises and routine physical therapy, reporting significant reductions in both pain and disability in the VR group—findings that align closely with those of the present study. The observed reduction in disability index following VR-based intervention may be explained through an integration of physiological, motor control, and behavioral mechanisms. Physiologically, VR training encourages active and repetitive trunk movements, which improve spinal mobility, muscle elasticity, and joint lubrication. This reduces stiffness in the lumbar and paraspinal muscles, facilitating smoother, pain-free movement patterns. Enhanced motor control and coordination of the deep stabilizing muscles—such as the multifidus, transversus abdominis, and pelvic floor—further promote spinal stability and balanced load distribution across vertebral segments, thereby reducing strain on pain-sensitive structures. From a neuroscientific standpoint, immersive VR environments engage cortical regions involved in movement planning and proprioception, including the primary motor cortex and posterior parietal cortex. Continuous visual and auditory feedback facilitates sensorimotor integration, improving the brain's ability to anticipate and correct postural errors. Over time, these processes contribute to neuroplastic adaptations that enhance both movement precision and postural control. Behaviorally and psychologically, the interactive and motivational design of VR fosters patient engagement and adherence, key determinants of successful rehabilitation. The immersive environment captures attention and distracts from pain-related thoughts, thereby lowering pain perception through attentional modulation and descending inhibitory pathways. Moreover, as patients experience movement without exacerbated pain, their movement confidence increases, reducing protective muscle co-contraction and promoting smoother, more natural motion patterns. Although kinesiophobia did not demonstrate a significant reduction in our study—likely due to it's deeply rooted psychological nature—VR may nonetheless serve as a facilitative tool that indirectly alleviates fear-related avoidance by improving functional ability and reducing pain. Lasting changes in fear-avoidance beliefs, however, typically require the integration of cognitive-behavioral or exposure-based interventions alongside physical training. Importantly, this study extends previous research by employing a broader and more integrated set of validated outcome measures, encompassing pain, and disability, range of motion, quality of life, balance, and kinesiophobia. This multidimensional framework allows for a more holistic understanding of VR's rehabilitative effects, emphasizing that the benefits of immersion are not limited to distraction or engagement alone, but also involve complex physiological and neuropsychological mechanisms that underpin functional recovery in NSCLBP [Table 2,3]. [24, 25]

Findings and Interpretation

Our study demonstrates that integrating VR-based exercises with routine physiotherapy can significantly enhance clinical outcomes in individuals with non-specific chronic low back pain (NSCLBP). Participants in the VR group experienced substantial reductions in pain and disability, along with marked improvements in quality of life and postural balance. These results align with existing literature supporting the therapeutic potential of VR, which appears to facilitate pain relief and functional recovery through mechanisms such as immersive distraction, increased engagement, and improved motor control. The findings underscore the value of VR as a complementary tool in rehabilitation programs for NSCLBP.[16,17,20,26] Although no significant changes were observed in kinesiophobia, improvements in range of motion were evident, particularly in lumbar flexion and extension. Strength outcomes showed a positive trend, though changes were not statistically significant, indicating that VR may be more effective for flexibility and coordination than for direct strength gains.[25,26]

Taken together, these results suggest that VR provides an engaging, immersive platform that facilitates proprioceptive feedback and motor learning. By enhancing segmental coordination and muscular activation patterns, VR interventions likely support central nervous system adaptation, reducing pain and mechanical load on the lumbar spine.[27,28,29] This highlights the potential of VR as a complementary tool to conventional physiotherapy in the management of NSCLBP.[30]

Conclusion

This randomized controlled trial demonstrates that VR-based therapeutic exercises significantly improve pain intensity, QoL, ROM, and balance in patients with NSCLBP compared to routine physical therapy alone. The intervention group showed notable improvements in pain reduction, disability scores, and QoL, highlighting the potential of VR to enhance patient outcomes in rehabilitation settings. While ROM for flexion and extension improved significantly, muscle strength did not show statistically significant differences between the groups. This suggests that VR-based exercises may be more effective in enhancing flexibility and functional movements rather than strength. Potential confounding factors, such as differences in educational levels and sports activity between groups, may have influenced the outcomes. Furthermore, limitations, including the small sample size and single-blind design, should be addressed in future research. Overall, VR-based therapeutic exercises offer a promising adjunct to routine physical therapy for NSCLBP patients.

This article has been written according to CONSORT checklist.

Limitations and Future Research

Despite the promising results, this study has several limitations. Future research should focus on larger, more diverse populations and investigate the long-term sustainability of VR-based interventions over a year or more. Moreover, exploring the mechanisms underlying the observed improvements could provide deeper insights into how VR influences pain perception and functional outcomes possibly by adding electromyography or imaging procedures.

Abbreviations

NSCLBP: non-specific chronic low back pain
Quality of life: QoL
Virtual reality: VR
Range of motion: ROM
PPS: Pulse Per Second
SD: Standard Deviation
ROM: Range of Motion
TSK: Tampa Scale of Kinesiophobia
CM: Centimeter

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Authors Contribution:

Authors who conceived and designed the analysis: Noureddin Karimi, Mohammad Hassan Azarsa. Authors who collected the data: fatimah khalifeh. Authors who contributed data or analysis tools: Mohammad Hassan Azarsa, Saeed Behzadipour. Authors who performed the analysis: Fatimah Khalifeh. Authors who wrote the paper: Fatimah Khalifeh. Other contribution: Samaneh Hossein zade was responsible for statistical tests. Pezhman Masoudi edited the paper.

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Declaration of Informed Consent: There is no information in the submitted manuscript that can be used to identify patients, such as names, initials, hospital identification numbers, or photographs. If identifiable information is included and deemed essential for scientific purposes, written informed consent has been obtained from the patient (or their parent/guardian) and submitted along with the manuscript.

Fatimah khalifeh [1]
Noureddin Karimi*[1]
Somayeh Mohammadi [1]
Mohammad Hassan Azarsa [1]
Samaneh Hosseinzade [2]
Saeed Behzadipour [3]
Pezhman Masoudi [1]

1 Neuromusculoskeletal Rehabilitation Research Center, University of Social Welfare and Rehabilitation Sciences, Tehran, Iran

2 School of Public Health, Iran University of Medical Sciences, Tehran, Iran

3 Mechanical Engineering, Sharif University Of Technology, Tehran, Iran

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