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Original Research Article

Effectiveness of Virtual Reality Training and Neuromuscular Exercises on Pain and Physical Function in Individuals with Osteoarthritis of Knee: A Randomized Clinical Trial

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ABSTRACT

Background: Osteoarthritis (OA) of the knee is a common degenerative musculoskeletal condition that causes pain, decreased mobility, and diminished physical function. A key component of conservative management is still exercise-based rehabilitation. Neuromuscular exercises (NME) and virtual reality training (VRT) have recently drawn interest as successful rehabilitation techniques.
Aim: To compare the effectiveness of Virtual Reality Training and Neuromuscular Exercises on pain and physical function in individuals with knee osteoarthritis.
Methods: A randomized clinical trial was conducted on 66 individuals with grade II or III knee OA according to Kellgren-Lawrence criteria. Participants were allocated using a computer-generated randomization sequence with allocation concealment through sealed opaque envelopes. Group A received Virtual Reality Training with conventional therapy, while Group B received Neuromuscular Exercises with conventional therapy. Interventions were administered 3 sessions/week for 6 weeks. Outcome measures included Numeric Pain Rating Scale (NPRS), Timed Up and Go Test (TUG), and Modified WOMAC Scale (mWOMAC). Statistical analysis was performed using SPSS version 23.
Results: 66 participants (54 females, 12 males; mean age 51.89±4.15 years) completed the study. Both groups showed significant improvements in NPRS, TUG, and mWOMAC scores following intervention for within group analysis ($p<0.001$). Between-group analysis demonstrated significantly greater pain reduction in the Virtual Reality Training group (NPRS: 3.27±0.76 vs. 4.21±0.96, $p<0.001$), while no significant differences were observed for TUG ($p=0.263$) or mWOMAC ($p=0.070$).
Conclusion: Both Virtual Reality Training and Neuromuscular Exercises are effective in improving pain and physical function in individuals with knee OA. VRT demonstrated superior improvement in pain reduction, whereas both interventions were equally effective in improving functional outcomes.

Keywords: Knee Osteoarthritis, Virtual Reality, Neuromuscular Exercises, Pain, Physical Function, Osteoarthritis rehabilitation

INTRODUCTION

One of the most common chronic musculoskeletal conditions in the world, osteoarthritis (OA) typically affects weight-bearing joints like the knee. It is typified by osteophyte growth, subchondral sclerosis, increasing articular cartilage deterioration, and synovial alterations that cause discomfort, stiffness, and decreased functional mobility. [1]

Because knee OA impairs daily living activities, mobility, balance, and physical independence, it has a substantial negative impact on quality of life. Due to aging populations, obesity, sedentary lifestyles, and longer life expectancies, knee OA is becoming more common. [2] Women are reported to have a higher prevalence of knee OA than men. [3]

Exercise therapy is considered a primary conservative management strategy for knee OA. Therapeutic exercises improve muscle strength, proprioception, joint stability, mobility, and overall function while reducing pain. [4] Neuromuscular Exercise (NME) focuses on sensorimotor control, proprioception, balance, coordinated movement, and dynamic joint stabilization. Previous studies have shown beneficial effects of NME on pain and physical function in knee OA. [5]

With the use of interactive computer-generated settings that promote patient participation and movement repetition through visual and sensory feedback, virtual reality training (VRT) has become a cutting-edge approach to rehabilitation. Virtual reality offers stimulating and motivating rehabilitation settings that may enhance functional performance, adherence, pain management, and balance. [6]

Virtual reality (VR) may improve clinical outcomes through multiple neurophysiological mechanisms that extend beyond simple distraction from pain. Immersive VR provides enriched multisensory stimulation by integrating visual, auditory, and proprioceptive inputs, thereby promoting sensorimotor integration and facilitating motor learning through repetitive, task-oriented practice. These experiences are thought to induce cortical reorganization and neuroplastic adaptations within sensorimotor networks, leading to improved movement control and functional performance. [7]

Furthermore, engaging virtual environments may activate descending pain inhibitory pathways, reducing pain perception by modulating central nociceptive processing. The interactive nature of VR also encourages action observation and imitation, potentially stimulating the mirror neuron system, which has been implicated in motor recovery and motor skill acquisition. Collectively, these neurophysiological mechanisms may explain the superior improvements in pain, balance, and functional ability reported with VR-based rehabilitation compared with conventional exercise programmes. [6,7]

Beyond its neurophysiological effects, virtual reality (VR) offers important behavioural advantages that may enhance adherence to rehabilitation programmes. Conventional exercise therapy for knee osteoarthritis is often limited by poor compliance due to pain, monotony, and reduced motivation, which can compromise treatment outcomes. In contrast, VR incorporates principles of gamification, including goal-oriented tasks, real-time performance feedback, rewards, and progressive challenges, creating a more engaging and enjoyable rehabilitation experience. These features promote intrinsic motivation, increase patient participation, and improve adherence by encouraging repeated practice without substantially increasing the perceived burden of exercise. Immediate visual and auditory feedback also facilitates self-correction of movement patterns and reinforces motor learning, thereby improving exercise quality and confidence. Consequently, improved adherence and greater exercise intensity achieved through VR may partly explain the superior reductions in pain and improvements in functional performance observed in several studies, even when exercise dosage is comparable to conventional rehabilitation programmes. [8.9,10]

Although increasing evidence supports the effectiveness of virtual reality (VR) as an adjunct to rehabilitation for knee osteoarthritis, several important gaps remain in the current literature. Existing studies demonstrate considerable heterogeneity in intervention characteristics, including differences in treatment duration, session frequency, exercise intensity, and the type of VR system employed, making direct comparisons between studies challenging. Furthermore, studies have evaluated both immersive and non-immersive VR platforms with varying levels of user interaction, resulting in inconsistent findings regarding their relative clinical effectiveness. Outcome assessment has also lacked standardization, with different studies emphasizing pain, functional performance, balance, muscle strength, mobility, or quality of life, thereby limiting the comparability of results across trials. In addition, relatively few investigations have examined the long-term sustainability of treatment effects through extended follow-up, and evidence regarding the optimal rehabilitation protocol remains inconclusive. Importantly, despite the growing burden of knee osteoarthritis in India, there is a paucity of randomized controlled trials evaluating VR-based rehabilitation in Indian populations, where sociocultural, economic, and healthcare delivery factors may influence treatment adherence and clinical outcomes. Consequently, further well-designed randomized controlled trials employing standardized intervention protocols and clinically relevant outcome measures are required to establish the comparative effectiveness of VR-based rehabilitation, particularly in comparison with evidence-based exercise approaches such as neuromuscular exercise.

Thus, the purpose of this study was to compare how well different therapies affected pain and physical function.

MATERIALS & METHODS

The present study was a randomized clinical trial conducted over a duration of two years involving individuals diagnosed with osteoarthritis of the knee. Participants were recruited using a convenient sampling method.

Ethical clearance for the study was obtained from the 'Institutional Ethics Committee' of S. S. Agrawal Institute of Physiotherapy prior to commencement of the study with the reference number: SSAIP/IEC/2022/11

A pilot study was initially conducted on 10 subjects to estimate the required sample size. Sample size calculation was performed using G*Power software version 3.1.9.7 based on the mean and standard deviation of the Timed Up and Go (TUG) test obtained from the pilot data. Considering an effect size of 0.7, alpha level of 0.05, and power of 0.80, the final sample size calculated was 66 participants.

A total of 80 individuals were conveniently selected from the Musculoskeletal Department of S. S. Agrawal Institute of Physiotherapy, Navsari, and were screened according to the selection criteria of the study. 14 of the individuals were excluded as 12 of them didn't meet the inclusion criteria and 2 of them refused to participate. All the 66 eligible participants were informed in detail about the study procedure, and written informed consent was obtained prior to participation. Demographic data and baseline characteristics were recorded using a standardized assessment form.

Following screening, participants were randomly allocated into two groups. Group 1 (Virtual Reality Training Group) and Group 2 (Neuromuscular Exercise Group). Simple randomization was performed using a computer-generated random number sequence. Allocation concealment was achieved using the concealed envelope method. Participants were allocated in a 1:1 ratio. The assessor remained blinded to the interventions administered to both groups as well as to the purpose of the study.

Prior to data collection, the assessor was trained and standardized in the administration of all outcome measures to ensure consistency in pre- and post-intervention assessments. All treatment sessions were administered by the same physiotherapist, who had received standardized training regarding the intervention protocols before participant recruitment. A predefined checklist was used during each treatment session to ensure uniform implementation of the prescribed exercises, session duration, progression criteria, and participant instructions. Adherence to the intervention protocol was monitored periodically to minimize protocol deviations and maintain consistency across participants. These measures were implemented to minimize performance bias and enhance the reproducibility and internal validity of the study.

Inclusion Criteria

- Age between 45–60 years
- Radiographic grade II or III knee OA according to Kellgren-Lawrence criteria
- Morning stiffness
- Crepitus during active movement
- Tenderness on palpation
- Symptoms lasting more than 3 months
- Pain with limited range of motion
- Unilateral or bilateral knee OA

Exclusion Criteria

- Post-traumatic knee stiffness
- Systemic inflammatory diseases
- Fractures
- Pregnancy
- Ligamentous instability
- Radiating pain to lower limb
- Fixed deformities
- Individuals unable to tolerate VR training

Outcome measures used in the study included the Numeric Pain Rating Scale (NPRS), Timed Up and Go Test (TUG), and Modified WOMAC Scale (mWOMAC). The NPRS is an 11-point scale ranging from 0 ("no pain") to 10 ("worst imaginable pain") and was used to assess pain intensity. Functional mobility was evaluated using the Timed Up and Go Test, in which the time taken by the participant to stand up from a chair, walk 3 meters, turn around, return, and sit down was recorded. The Modified WOMAC Scale (mWOMAC), a self-reported questionnaire, was used to assess pain, stiffness, and physical function in individuals with knee osteoarthritis.

Group 1 – Virtual Reality Training (n=33)

Participants received Virtual Reality Training along with conventional physiotherapy. Virtual reality training was administered using the Procus ONE Virtual Reality Headset. A smartphone was securely fitted into the headset to display the virtual environment and enable immersive gameplay. Participants engaged in interactive virtual reality game that required standing on a virtual platform displayed within the game environment. During gameplay, participants performed stepping movements by moving the left and right lower limbs forward, backward, and laterally in response to visual cues presented on the screen. VR Skydive360 software was used for the gameplay. Every exercise was performed 10 times, with a two-minute break before moving on to the next. The exercise was advanced as soon as possible in terms of repetitions or advanced technique in terms of speed and duration required to complete the task. Also, exercise intensity was progressed according to participant tolerance and pain levels. Treatment logs were maintained to monitor compliance. No adverse events were reported. A single session was conducted up to 15-30 mins.[10] Duration: 3 days/ week for 6 weeks along with conventional therapy on alternate days.

Group 2 – Neuromuscular Exercises (n=33)

Participants received Neuromuscular Exercises along with conventional physiotherapy. Exercises included side stepping, tandem walk, backward walking, crossover walk, modified grapevine walk, and semi-tandem activities. Exercises are to be completed at a walking pace and progressed by adding more steps. Participants will begin with approximately 15 steps of each exercise and progression would be targeted to a maximum of 75 steps.[20] Duration: 3 days/ week for 6 weeks along with conventional therapy on alternate days.

Conventional Therapy for Both Groups[3,20]

- TENS
- Range of motion and active stretching exercises applied to tightened muscles.
- Hamstring and Calf muscle strengthening exercises
- Active ankle pump.
- Short arc terminal extension exercises for the knee joint.
- Strengthening exercises for the hip abductors, adductors and extensor group of muscles.
- Non-weight bearing progressive resistance exercises with weighted cuffs, with progression to closed chain exercises as patient's pain allows using DAPRE technique.

Duration: 3 days/week for 6 weeks on alternate days for both the groups

Statistical Analysis

Data analysis was performed using SPSS version 23. Shapiro-Wilk test was used to determine normality. Wilcoxon Signed Rank Test and Mann-Whitney U Test were used for non-parametric data (NPRS and TUG). Paired and Unpaired t-tests were used for normally distributed data (mWOMAC). Statistical significance was set at $p<0.05$.

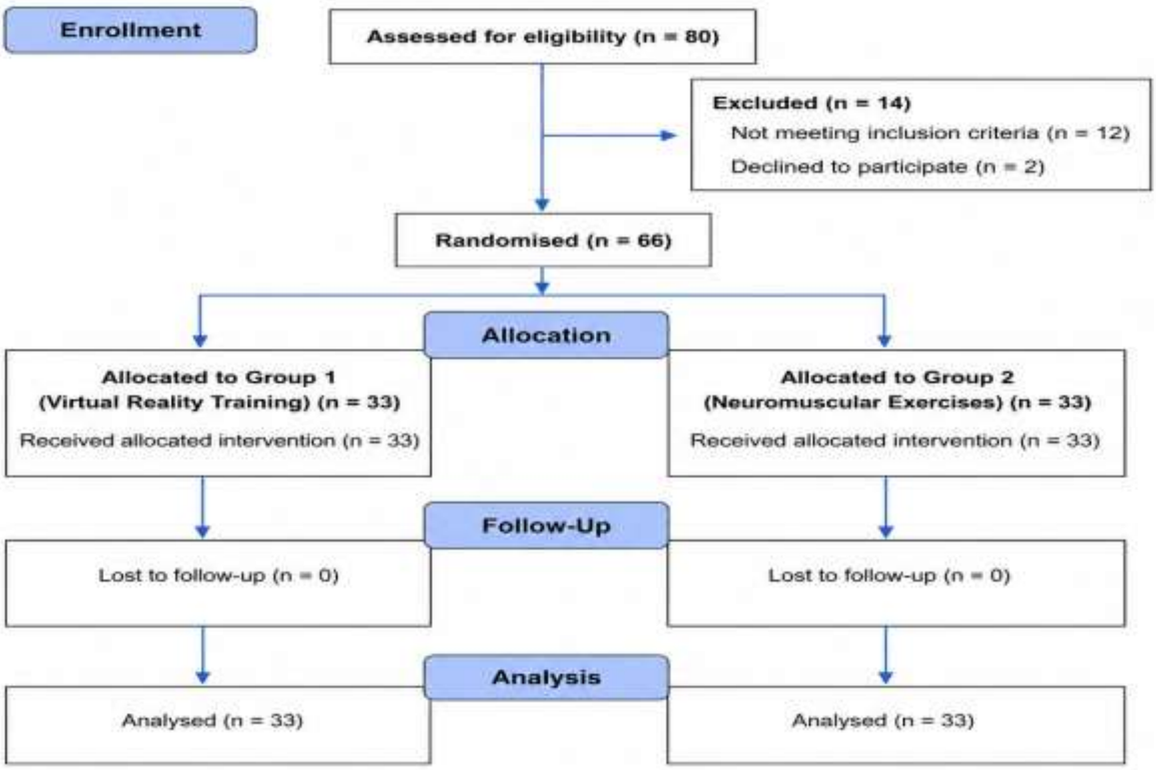

Figure 1. CONSORT flow diagram of participant recruitment, allocation, follow-up and analysis. A total of 80 participants were assessed for eligibility, of whom 14 were excluded (12 did not meet the inclusion criteria and 2 declined to participate). 66 participants were randomized and equally allocated to Group 1 (Virtual Reality Training) and Group 2 (Neuromuscular Exercises), with 33 participants in each group. All participants received the allocated intervention. There were no losses to follow-up, and all 66 participants were included in the final analysis.

RESULT

Demographic Characteristics

A total of 66 participants were included in the study.
The demographic characteristics and gender distribution of the participants are presented in Table 1.

Table 1. Demographic Characteristics and Gender Distribution of Participants (N=66)

Variable	Value
Age (years), Mean ± SD	51.89 ± 4.15
Height (cm), Mean ± SD	163.51 ± 5.54
Weight (kg), Mean ± SD	66.12 ± 8.11
BMI (kg/m²), Mean ± SD	24.81 ± 3.49
Female, n (%)	54 (81.8%)
Male, n (%)	12 (18.2%)

Table 1 shows that the participants had a mean age of 51.89 ± 4.15 years, mean height of 163.51 ± 5.54 cm, mean weight of 66.12 ± 8.11 kg, and mean BMI of 24.81 ± 3.49 kg/m². The study population consisted predominantly of females (81.8%), while males constituted 18.2% of the sample.

Within-Group Comparison

Group 1 – Virtual Reality Training

The pre-treatment and post-treatment comparison of outcome measures in the Virtual Reality Training group is presented in Table 2.

Table 2. Within-Group Comparison of Outcome Measures in Group 1 (Virtual Reality Training)

Outcome Measure	Pre-treatment Mean ± SD	Post-treatment Mean ± SD	p-value
NPRS	6.76 ± 0.90	3.27 ± 0.76	<0.001*
TUG (seconds)	14.67 ± 1.63	11.42 ± 0.70	<0.001*
mWOMAC	66.42 ± 4.71	47.88 ± 7.31	<0.001*

*Statistically significant at $p < 0.05$.

Table 2 demonstrates statistically significant improvements in all outcome measures following Virtual Reality Training. NPRS scores decreased from 6.76 ± 0.90 to 3.27 ± 0.76, indicating reduced pain intensity.
TUG scores improved from 14.67 ± 1.63 seconds to 11.42 ± 0.70 seconds, reflecting enhanced functional mobility. Similarly, mWOMAC scores decreased from 66.42 ± 4.71 to 47.88 ± 7.31, indicating improvement in physical function and reduction in disability.

Group 2 – Neuromuscular Exercises

The pre-treatment and post-treatment comparison of outcome measures in the Neuromuscular Exercise group is presented in Table 3.

Table 3. Within-Group Comparison of Outcome Measures in Group 2 (Neuromuscular Exercises)

Outcome Measure	Pre-treatment Mean ± SD	Post-treatment Mean ± SD	p-value
NPRS	6.76 ± 0.93	4.21 ± 0.96	<0.001*
TUG (seconds)	14.64 ± 1.34	11.76 ± 0.90	<0.001*
mWOMAC	66.24 ± 6.63	52.09 ± 6.86	<0.001*

*Statistically significant at $p < 0.05$.

Table 3 shows statistically significant improvements in all outcome measures following Neuromuscular Exercise intervention. NPRS scores decreased from 6.76 ± 0.93 to 4.21 ± 0.96, TUG scores improved from 14.64 ± 1.34 seconds to 11.76 ± 0.90 seconds, and mWOMAC scores decreased from 66.24 ± 6.63 to 52.09 ± 6.86. These findings indicate reduced pain, improved mobility, and enhanced physical function after treatment.

Between-Group Comparison

The comparison of post-treatment outcome measures between the Virtual Reality Training group and the Neuromuscular Exercise group is presented in Table 4.

Table 4. Between-Group Comparison of Post-treatment Outcome Measures

Outcome Measure	Group 1 Mean ± SD	Group 2 Mean ± SD	p-value
NPRS	3.27 ± 0.76	4.21 ± 0.96	<0.001*
TUG (seconds)	11.42 ± 0.70	11.76 ± 0.90	0.263
mWOMAC	47.88 ± 7.31	52.09 ± 6.86	0.070

*Statistically significant at $p < 0.05$.

Table 4 shows that the Virtual Reality Training group demonstrated significantly lower post-treatment NPRS scores compared with the Neuromuscular Exercise group ($p < 0.05$), indicating superior pain reduction. Although the Virtual Reality Training group also demonstrated lower mean TUG and mWOMAC scores than the Neuromuscular Exercise group, the between-group differences for TUG ($p = 0.263$) and mWOMAC ($p = 0.070$) were not statistically significant.

DISCUSSION

The effects of Virtual Reality Training (VRT) and Neuromuscular Exercises (NME) on pain and physical function in people with grade II and III knee osteoarthritis was compared in this randomized clinical trial. After six weeks of treatment, the results showed that both therapies caused statistically significant improvements in both physical function and pain intensity. However, when compared to neuromuscular exercises, virtual reality training shown a greater increase in pain reduction.

One of the main causes of impairment among middle-aged and older persons globally is knee osteoarthritis. It is linked to gradual articular cartilage degradation, changed biomechanics, diminished proprioception, weakened muscles, and poor balance, all of which eventually impede mobility and quality of life. [1,2,31] Because exercise therapy improves joint stability, muscle strength, proprioception, and functional independence, it continues to be the cornerstone of conservative care for knee OA. [3,32]

The majority of the participants in this study were female, with a mean age of 51.89±4.15 years. These results align with epidemiological data indicating a higher incidence of knee OA in women, especially after middle age. [4] The higher frequency among females has been attributed to hormonal influences, biomechanical issues, obesity, and decreased muscle strength. [5]

The present study demonstrated significant reductions in NPRS scores in both groups after treatment. The between-group analysis demonstrated significantly greater pain reduction in the VRT group. These findings indicate that both interventions are effective in pain management, although VRT may provide additional analgesic benefits.

Numerous physiological and psychological processes could account for the greater pain reduction shown with VRT. Through cognitive distraction processes, virtual reality offers patients immersive visual and audio stimulation that detracts from their suffering. [6,9] Additionally, VR-based rehabilitation boosts patient motivation and engagement, which leads to increased exercise adherence and active participation during treatment sessions. [10] Virtual environments also promote brain rearrangement, sensorimotor integration, and motor learning, all of which may improve pain management and movement efficiency. [11]

The results of this study are consistent with those of Elshazly et al., who found that patients with unilateral chronic knee OA significantly improved in terms of pain, proprioception, functional disability, and quality of life when VR training was compared to sensory motor training and traditional exercises. [12] Similarly, Jachak and Phansopkar found that people with knee OA experienced improvements in pain, strength, range of motion, and activities of daily living when virtual reality was used in conjunction with traditional physiotherapy. [13]

The comprehensive study by Neri et al., which found that VR-based rehabilitation programs significantly improved balance and mobility outcomes in patients with musculoskeletal disorders, further supports the current findings. [10] Chen et al. also found that people with OA and chronic knee pain can improve their quality of life and reduce their knee pain with the help of technology-supported exercise regimens. [14]

The improvement in functional disability observed in the VRT group is likely a consequence of both improved motor performance and reduced pain-related movement avoidance. Virtual reality promotes repetitive, task-oriented practice within an interactive environment that provides immediate visual and auditory feedback, facilitating motor learning and improving movement accuracy. Repeated exposure to functional tasks in a motivating virtual environment enhances movement confidence and reduces fear associated with painful activities, thereby encouraging greater participation during rehabilitation. Additionally, real-time feedback enables participants to correct movement errors immediately, reinforcing appropriate movement strategies and improving overall functional performance. As pain decreases, patients are more willing to perform activities of daily living, further contributing to improvements in WOMAC scores. These findings are consistent with contemporary systematic reviews indicating that VR-based rehabilitation enhances functional outcomes by integrating motor learning principles with high levels of patient engagement. [6,7,12]

VR's beneficial impacts could be explained by the central nervous system's reward circuits being activated. Playing VR games actively may activate dopaminergic pathways related to behavioral reinforcement, motor learning, and attention. [15] In addition to improving motor function and exercise compliance, this kind of stimulation helps lessen anxiety and dread associated with pain. [16]

The present study demonstrated a significantly greater reduction in pain intensity in participants receiving virtual reality training (VRT) compared with those undergoing neuromuscular exercise (NME). The superior analgesic effect observed with VRT may be attributed to several complementary neurophysiological and behavioural mechanisms. Immersive virtual environments provide enriched multisensory stimulation through synchronized visual, auditory, and proprioceptive feedback, facilitating sensorimotor integration and enhancing cortical engagement during task-specific movements. Such stimulation is believed to promote neuroplastic adaptations within sensorimotor networks while simultaneously activating descending pain inhibitory pathways that modulate central nociceptive processing. Furthermore, the immersive nature of VR diverts attentional resources away from pain perception, reducing pain-related cognitive processing through attentional distraction. In addition to these neurophysiological effects, the gamified design of VR interventions enhances motivation, enjoyment, and exercise adherence, enabling participants to complete repetitive therapeutic movements with greater willingness and lower perceived exertion. These combined mechanisms may explain the greater reduction in pain observed in the present study despite comparable treatment duration between groups. Similar findings have been reported in recent systematic reviews demonstrating that VR-based rehabilitation produces clinically meaningful improvements in pain and physical function among individuals with knee osteoarthritis through enhanced patient engagement and optimized sensorimotor training. [7,8,13,17]

In the present study, significant improvements were also observed in physical function within both groups, as measured by TUG and mWOMAC scores. However, between-group differences were not statistically significant.

These results imply that both treatments are equally successful in enhancing mobility, balance, and physical function in people with knee OA. Stronger muscles, stronger proprioception, more self-assurance when moving, and improved neuromuscular coordination are all responsible for the functional benefits seen in this study. [17]

Programs for neuromuscular exercise are specifically intended to enhance proprioception, dynamic stability, sensorimotor control, postural control, and coordinated muscle activation surrounding the knee joint. [18] People with knee OA often exhibit decreased quadriceps strength, changed movement patterns, and diminished proprioception, all of which led to joint instability and functional restrictions. [19,20] NME uses controlled weight-bearing exercises, coordinated movement exercises, and balance training to overcome these deficiencies.

The current study's results are in line with those of Meenakshi et al., who showed that neuromuscular exercises greatly reduced pain and enhanced physical function in those with chronic knee OA. [21] Additionally, kinaesthesia, balance, and agility training improved physical function and balance performance in those with knee OA, according to Rogers et al. [22] Diracoglu et al. found similar outcomes, showing that neuromuscular training enhanced lower limb muscle strength and functionality in patients with knee OA. [23]

greater proprioceptive input from mechanoreceptors, greater postural stability, and improved muscle co-activation surrounding the knee joint could all contribute to the positive benefits of NME. [24] Neuromuscular training improves joint stability during dynamic activities by stimulating feed-forward and feedback control processes. [25] Additionally, these workouts lessen aberrant joint loading patterns and enhance movement quality, which lessens mechanical stress on degenerative joint structures. [20,26]

Several factors may explain the current study's lack of statistically significant between-group variations in functional outcomes. First, in addition to their individual interventions, both groups received traditional physical therapy, which may have significantly improved their functional abilities. Secondly, the period of the intervention was restricted to six weeks. Previous research on neuromuscular training often used intervention durations of 8 weeks or more, which may elicit stronger functional changes over time. [24] Third, only stable surfaces were used for the neuromuscular training program in this investigation. Research using unstable surfaces, including balance boards and BOSU balls, may increase proprioceptive difficulties and, as a result, boost functional performance and dynamic stability. [27]

The results of this study are consistent with those of Bennell et al., who found that in those with severe knee OA, neuromuscular training and quadriceps strengthening caused comparable improvements in pain and physical function. [28] Similarly, Gomiero et al. discovered that resistance training and sensory-motor training had similar benefits for enhancing function and discomfort in those with knee OA. [29]

The current study adds to the growing evidence that exercise-based rehabilitation is still very beneficial for managing knee OA. Both VRT and NME showed improvements in pain and physical function that were clinically significant. However, through increased patient engagement, motivation, and pain modulation mechanisms, VRT may provide further advantages.

Virtual reality may be a useful supplementary rehabilitation technique for those who exhibit poor adherence to conventional exercise regimens or who engage in pain-related fear-avoidance behaviors. This is a significant clinical implication of this study. VR's entertaining and interactive features may increase patient happiness and compliance throughout therapy. [30] Additionally, improvements in wearable technology and reasonably priced VR systems could make VR-based rehabilitation more accessible and widely used in clinical settings. [9]

Although both interventions incorporated active therapeutic exercise, virtual reality training appeared to confer additional benefits beyond those achieved with conventional neuromuscular exercise. Unlike traditional exercise programmes, VR integrates real-time multisensory feedback, immersive environments, and gamified therapeutic tasks that continuously stimulate attention, motivation, and active participation. These features increase the intensity and quality of movement practice while reducing perceived monotony, thereby improving adherence throughout the intervention period. Consequently, participants receiving VRT may have achieved greater cumulative therapeutic exposure despite receiving an equivalent prescribed exercise dosage. This combination of enhanced motor learning, greater patient engagement, and central pain modulation may explain the superior clinical outcomes observed in the present study. [8,9,13,30]

Despite the encouraging results, certain restrictions must be recognized. There was no long-term follow-up to assess the sustainability of treatment effects, and the sample size was somewhat small. Additionally, the study did not assess psychological outcomes that could be impacted by VR-based therapies, such as motivation, fear of movement, or quality of life. Furthermore, generalizability to other immersive VR technologies was limited because just one kind of VR system was employed.

Larger sample numbers, multicenter recruiting, longer intervention durations, and long-term follow-up evaluations should all be included in future research. Additionally, future studies should examine the biomechanical, psychological, and neurophysiological factors driving pain reduction and functional improvement in knee OA rehabilitation, as well as comparing immersive and non-immersive VR systems

The findings of the present study suggest important clinical implications for the rehabilitation of individuals with knee osteoarthritis. The findings of the present study suggest that virtual reality training (VRT) may be an effective adjunct to conventional neuromuscular exercise in the conservative management of knee osteoarthritis. The greater improvements in pain and functional disability observed in the VRT group indicate that integrating immersive rehabilitation technologies into routine physiotherapy practice may enhance clinical outcomes while maintaining the principles of exercise-based rehabilitation.

VR-based rehabilitation has considerable potential for integration into outpatient musculoskeletal physiotherapy, as its interactive and gamified environment, combined with real-time feedback, may enhance patient motivation, engagement, and exercise adherence. Improved adherence may contribute to better functional outcomes and sustained participation in rehabilitation programmes.

Advances in portable VR technologies have also expanded opportunities for home-based rehabilitation and telerehabilitation, allowing supervised or remotely monitored exercise programmes beyond traditional clinical settings. Such approaches may improve access to rehabilitation for individuals with mobility limitations and those living in rural or underserved areas where specialized physiotherapy services are limited.

The integration of VR into rehabilitation aligns with the growing emphasis on digital health and technology-assisted care by supporting personalized rehabilitation, remote monitoring, and patient self-management. Although the initial cost of VR equipment may be higher than conventional exercise equipment, increasing affordability and the potential for repeated clinical use suggest that VR may become a cost-efficient rehabilitation option in the future. However, further economic evaluations are warranted.

Overall, these findings support the incorporation of VR as a valuable component of multidisciplinary rehabilitation programmes for knee osteoarthritis. Future research should focus on standardized intervention protocols, long-term follow-up, cost-effectiveness, and the implementation of hybrid outpatient, home-based, and digitally supported rehabilitation models to improve accessibility, adherence, and patient outcomes.

Virtual Reality may serve as an effective adjunctive intervention for pain management due to its interactive and engaging nature, while Neuromuscular Exercises remain beneficial for improving balance, mobility, and functional independence. Both interventions can therefore be incorporated into rehabilitation protocols for knee OA management. Virtual Reality can be used when exercise adherence is poor. Neuromuscular Exercise remains effective where Virtual Reality technology is unavailable. Both interventions can be integrated into OA rehabilitation pathways.

However, the study had certain limitations that should be considered while interpreting the findings. First, the relatively small sample size and recruitment from a single centre may limit the generalizability of the results to broader populations. Second, the absence of a long-term follow-up prevented evaluation of the sustainability and retention of treatment effects beyond the intervention period. The study also did not assess psychosocial factors such as fear of movement, pain self-efficacy, motivation, or patient satisfaction, which may influence rehabilitation outcomes and treatment adherence. Furthermore, quality of life was not evaluated using disease-specific or generic health-related outcome measures. The study relied primarily on clinical outcome measures and did not incorporate objective biomechanical or kinematic assessments, such as gait analysis, motion capture, or muscle activation patterns, which could provide greater insight into the mechanisms underlying functional improvement. Future multicentre randomized controlled trials with larger sample sizes, longer follow-up periods, comprehensive psychosocial and quality-of-life assessments, objective biomechanical evaluations, and standardized adherence monitoring are recommended to strengthen the evidence for virtual reality-based rehabilitation in individuals with knee osteoarthritis.

Future research should focus on conducting multicentre randomized controlled trials with larger and more diverse populations to improve the generalizability of findings and establish standardized virtual reality (VR) rehabilitation protocols for individuals with knee osteoarthritis. Studies incorporating longer follow-up periods are required to determine the long-term sustainability and retention of treatment effects. Future investigations should also compare the effectiveness of immersive and non-immersive VR systems to identify the optimal level of immersion and interaction for maximizing clinical outcomes.

Advances in rehabilitation technology provide opportunities to integrate artificial intelligence (AI)-assisted rehabilitation, wearable motion sensors, and remote monitoring systems into VR-based exercise programmes to deliver personalized, adaptive, and data-driven interventions. The inclusion of objective biomechanical assessments, such as three-dimensional motion capture, surface electromyography (EMG), force plate analysis, and gait analysis, would enhance understanding of the neuromuscular and biomechanical mechanisms underlying improvements in pain, balance, and functional performance. Machine learning algorithms may further facilitate individualized treatment progression by analysing patient performance, predicting rehabilitation outcomes, and optimizing exercise prescription.

Future studies should also evaluate patient adherence, psychosocial outcomes, health-related quality of life, and satisfaction with

VR-based rehabilitation to better understand factors influencing treatment success. In addition, economic evaluations examining cost-effectiveness and implementation feasibility are warranted, particularly for home-based VR and telerehabilitation programmes. Such research would provide valuable evidence for integrating VR into routine clinical practice and support the development of accessible, personalized, and technology-enabled rehabilitation strategies for individuals with knee osteoarthritis.

CONCLUSION

Both Virtual Reality Training and Neuromuscular Exercises are effective interventions for improving pain and physical function in individuals with knee osteoarthritis. Virtual Reality Training demonstrated greater effectiveness in reducing pain, whereas both interventions showed comparable improvements in physical function. Therefore, Virtual Reality Training may be considered a useful adjunct to conventional physiotherapy in individuals with knee osteoarthritis.

Declaration by Authors

Ethical Approval: Approved by Institutional Ethics Committee at S.S Agrawal Institute of Physiotherapy & Medical Care Education, Navsari. Ref No – SSAIP/IEC/2022/11

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