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Original Article

Physiotherapy Section

Effectiveness of Virtual Reality-based Rehabilitation and High-intensity Exercise Program for Total Knee Arthroplasty Patients: A Randomised Controlled Trial

K NISHITHA[1], A ANITHA[2], D THAHEERA[3]

ABSTRACT

Introduction: Progression of articular cartilage loss and wear and strain are the usual causes of Osteoarthritis (OA), sometimes referred to as degenerative joint disease. India had roughly 200,000 knee arthroplasty procedures in 2020 in which nearly 72% were because of OA. Rebuilding the knee joint through knee arthroplasty is a great alternative for treating symptomatic OA in patients who have not responded to conservative treatment.

Aim: To determine the effect of Virtual Reality (VR)- based rehabilitation and high-intensity exercise program for Total Knee Arthroplasty (TKA).

Materials and Methods: In this double-blinded randomised controlled trial, 36 participants matched the inclusion criteria who underwent Total Knee Replacement (TKR) at the Department of Physiotherapy, Saveetha College of Physiotherapy, SIMATS, Chennai, Tamil Nadu, India. The study was started in the month of October 2023 and ended in January 2024. Then the participants were randomly allotted to an experimental group-VR (n=18) and a conventional group-high-intensity exercises (n=18). Outcome measures used are the Numeric Pain Rating Scale (NPRS) pain scale, knee range of motion, Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) and Timed Up and Go (TUG) test. A paired t-test was utilised to evaluate significant variations between the pre- and post-test measurements. In order to find any meaningful differences between the two groups, an unpaired t-test was employed.

Results: The average mean±Standard Deviation (SD) of age and Body Mass Index (BMI) was found to be 51.2±5.2 years and 28.3±2.0 kg/m². The experimental group and the conventional group both exhibited notable changes in terms of within-group differences. Numeric Pain Rating Scale (NPRS) significantly showed the same between the groups, but the range of motion showed better output in VR-based rehabilitation than indifferently supporting the pain outcome of the experimental group ($p\geq0.0001$). Balance, gait and functional activities were improved in the experimental group compared to the conventional group and in the VR-based rehabilitation, the functional independence of the patient was achieved in nine weeks compared to the High-intensity (HI) exercises.

Conclusion: The VR-based rehabilitation showed better outcomes in pain, range of motion, balance, gait and functional independence than a high-intensity exercise programme.

Keywords: Degenerative joint disease, Functional independence, Knee joint, Osteoarthritis, Virtual reality

INTRODUCTION

The OA is a prevalent condition marked by the progressive deterioration of the articular cartilage within the joint, along with subchondral bone remodelling, synovitis and the development of osteophytes- bony protuberances- at the joint borders. Also, it is the main factor contributing to progressive impairment. Primary and secondary OA are the two main categories in which knee OA is usually diagnosed. An overall estimate of the prevalence of knee OA in India was 28.7% [1].

Many variables, such as elderly status, female gender, obesity and overweight, knee traumas, frequent joint use, inadequate bone density, weakening of the muscles and flexibility of the joints, can lead to the occurrence of joint OA. Risk factors for OA can be identified and modified, especially in the weight-bearing joints, to lower the likelihood of the condition and avoid pain and disability later on. In accordance with body BMI, one of the most adjustable risk factors for OA is the mechanical pressures placed on the joints [2,3]. Indicator of symptomatic disease and consequent handicap include female gender, lower educational attainment, obesity and weak muscles [4].

According to the results of the current survey, 33.2% of people in big cities had primary knee OA overall; in smaller cities, it was 19.3%; in towns, it was 18.3%; and in villages, it was 29.2% and the sedentary lifestyles were led by 32.7% of people living in big cities, compared to 28.7% in villages and 18.1% in towns. In comparison to people living in cities and towns, approximately 44.5% of the villagers were employed in physically taxing jobs [5]. The prevalence rises with age, with women having a significantly greater prevalence (51%, range: 31.6-77) than men (33.09%, range: 28.1-61.5 years, higher rates in urban areas than in rural ones and higher rates among those with higher Body Mass Index (BMI) [6].

Higher rates are found in the lower socio-economic class [7]. These studies also show that persons with sedentary lifestyles and low levels of physical activity have higher rates of Knee Osteoarthritis (KOA) than people with active lifestyles and regular exercise [8]. Co-morbidities such as osteoporosis, diabetes mellitus and hypertension are commonly observed [9-11]. The prevalence and incidence of knee OA worldwide was 203 per 10,000 person-years reported in this study. Over the age of 40 years, knee OA remains prominent worldwide, in particular among women and the elderly [12]. An investigation revealed that among Indian patients undergoing primary Total Knee Replacement (TKR), Anteromedial Osteoarthritis (AMOA) was highly prevalent (46.94%) in US [13] and in India, 5 lac TKRs get carried out annually.

Rebuilding a diseased damaged, or ankylosed joint is the goal of TKA. Modification of naturally occurring elements, artificial replacement, or a combination of the two can be used to achieve this. The procedure known as TKA involves cutting away the abnormal knee articular surfaces and resurfacing the area primarily with metal and polyethylene components [14]. When joint cartilage is destroyed due to OA, rheumatoid arthritis/inflammatory arthritis, posttraumatic degenerative joint disease, or osteonecrosis/joint collapse with cartilage destruction, TKA is used [15]. One of the best surgical procedures for improving functional recovery and pain reduction in people with advanced OA of the knee is TKR [16]. Between 2006 and 2019, the total number of TKRs reported to the registry climbed from 1019 to 27,000. OA knee was detected in the majority of patients (98.5%) [17].

By simulating real-world scenes and objects, VR is an artificially constructed setting that gives users the sensation that they are fully immersed in their surroundings. Immersion VR involves the user entirely submerging himself in a computer-generated, artificial three-dimensional world [18]. Non immersive VR is one type of it. While you can command specific people or activities in VR, the technology does not speak to you directly. Through a computer, you can engage with the virtual world.

High-intensity, progression-based rehabilitation was the focus of the HI intervention [19]. When evaluating pain, the Numeric Pain Rating Scale (NPRS) is frequently employed. It is an adult patients' uni-dimensional pain intensity assessment, including those who have rheumatic disease-related chronic pain [20]. A goniometer is a tool that allows an object to be rotated to a certain position or measures an angle. More so in orthopaedics, the first description fits. Goniometry is the art and science of measuring joint ranges in each joint plane. Patients with OA of the hip or knee are frequently assessed using the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) [21]. The physical function scale's validity has been questioned in earlier research [22]. A popular, quick and easy clinical performance-based assessment of lower extremity function, mobility and fall risk is the "TUG" test (TUG). The aim of the study was to determine the effect of VR-based rehabilitation and high-intensity exercise program for TKA.

The null hypothesis is no significant difference between the experimental and conventional group using TUG, WOMAC, NPRS and Range of Motion (ROM) and the alternate hypothesis is a significant difference between the experimental and conventional group using TUG, WOMAC, NPRS and ROM.

MATERIALS AND METHODS

A double-blind randomised control trial with a convenient random sample design was used and this study was conducted at the Department of Physiotherapy, Saveetha College of Physiotherapy, SIMATS, Chennai, Tamil Nadu, India. The study protocol was approved by the Indeterminate Sentence Review Board (ISRB) (072/03/2023/PSR/SCPT), comprised of 36 participants who underwent TKA, of whom 21 were female and 15 were male. The study started in the month of October 2023 and ended in January 2024.

The participants' were divided into two groups randomly: the VR-based rehabilitation group with conventional exercises (n=18) and the high-intensity exercise programme group (n=18). Additionally, each participant gave their informed consent.

Inclusion criteria: Both men and women with age group from 45 to 65 years and people with unilateral TKA were included in the study.

Exclusion criteria: People with unstable disease, people with previous orthopaedics pathologies on same side, cataract surgery/vision loss, Hearing loss, other medical conditions like Parkinson's, vertigo, cardiorespiratory co-morbidities, over-weight >30 years according to BMI: (BMI ≤18.5 kg/m^2), normal weight (BMI >18.5 and ≤25 kg/m^2 100), overweight (BMI >25 and ≤30 kg/m^2), obese (BMI >30 and ≤40 kg/m^2) and morbidly obese (BMI >40 kg/m^2 101) [23], TKR because of tumour and trauma were excluded from the study [24].

Study Procedure

Under the guidance of an experienced physiotherapist who was blind to the study, participants in the VR-based rehabilitation completed a twelve-week program with three sessions each week.

Intervention: The VR-based rehabilitation: In order to receive real-time visual and audible feedback, participants were instructed to stand upright on the VR-based rehabilitation balance board and interact with objects in serious games that represented their personal centre of pressure. The artificial setting and visuals demonstrating the accuracy of task execution made up the visual Brain Fold (BF). When the visual, a sound stimulus activated the auditory BF, whereas other sounds indicated incorrect or poor exercise execution. The difficulty of the game steadily rose. This is done four days per week- 40 minutes per day with each 7-minute break. The games are loaded from game engine software.

I. Immersive Virtual Reality (VR)

Paddle boat [23]: The participants were asked to lie down in supine position, sensors were inserted into their limbs, 3D-head-mounted glasses were utilised and an immersive VR rowing boat game was executed. Then, these game exercises were performed every three days for 30 minutes, with an interval of seven minutes between each 10 minutes. Participants were requested to use knee flexion (VR interaction) to paddle a boat in an immersive virtual world [Table/Fig-1].

[Table/Fig-1]: Paddle boat: Knee flexion is activated in this as a primary exercise to initiate the movement in the knee. As paddling the boat in immersive VR reduces the pain sensation by distracting it and by the concentration of the game.

II. Non immersive Virtual Reality (VR) [24,25]

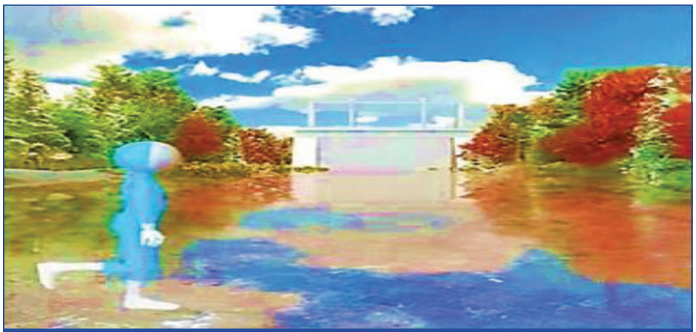
1. Cave game: The participants were asked to be seated in a chair. Now, the participants were asked to concentrate on the bird by flexing and extending their knees. The participant can move the avatar, a bird in particular, upwards and downwards to gather as many bugs as they can [Table/Fig-2].

[Table/Fig-2]: Cave game: By holding the leg in straight position (to reach the bugs), helps in the activation of the quadriceps muscle.

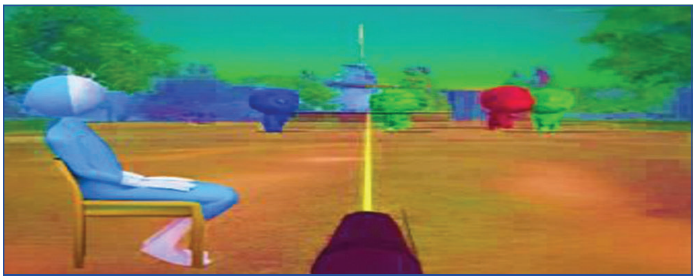
2. Rowing game: The participant was asked to stand on a single leg and the goal is to get to the gate before it closes by rowing the boat (knee flexion) [Table/Fig-3].

3. Intruders: The participants were asked to be seated in a chair and then the participants were asked to extend their knee to blast zombies and flex their knee to load the cannon. The cannon are aimed with movements of the hand [Table/Fig-4].

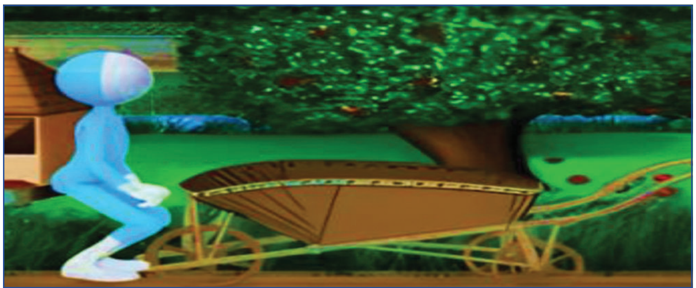
4. Pick-up: The participants were asked to be in standing and the player manipulates the girl avatar in the garden to make her pick up veggies and toss them into the wheelbarrow by squatting (down and up) [Table/Fig-5].



[Table/Fig-3]: Rowing game- Improves knee flexion as the boat moves as fast, which depends on the level and a holding time of knee flexion.



[Table/Fig-4]: Intruders: It improves knee extension as fast as the zombies come, the contraction of the shooting should be, which helps in the hamstring and quadriceps muscles.



[Table/Fig-5]: Pick-up: Initiate the movement of squatting and balancing, as the participant's action of picking the fruit should be without any support.

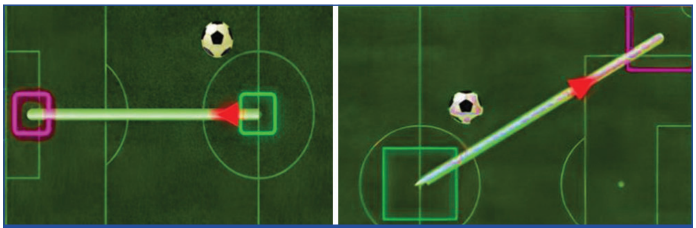
5. Squat-Pong: The participants were asked to be in a standing position. The participants were asked to play tennis against the computer by pushing the racket upward (squat; rise to toes) and downward (squat; down) [Table/Fig-6].

[Table/Fig-6]: Squat-pong: Initiate the movement from standing to half squat, which actively strengthens the quadriceps, hamstring and calf muscle activation.

6. Lateral weight shift exercise: The participants were asked to be in standing position and in horizontal and diagonal way ask them to move their weight in the direction of the goal (the green area) without shifting their feet. Once you're done, return to the beginning location [Table/Fig-7].

7. Bubble-runner: The participants were asked to be in standing position and attempts to pop balloons by striking them while moving the avatar, which is a humanoid inside a bubble, with weight transfer [Table/Fig-8].

8. Cannon: The participants were asked to sit on a chair and asked to place the cannon to shoot targets while extending the knee that was operated on. Hand motions are used to aim and fire the cannon [Table/Fig-9].



[Table/Fig-7]: Lateral weight shift -Moving their weight without moving the foot helps in the coordination and balance.

[Table/Fig-8]: Bubble-runner: -Weight transfer is done by moving the body according to the position of the balloon.

[Table/Fig-9]: Cannon--Knee extension is strengthened while aiming the target.

9. Hiking: The participants were asked to be in standing position and asked to walk in the terrain path by raising their knees as per the gaming [Table/Fig-10].

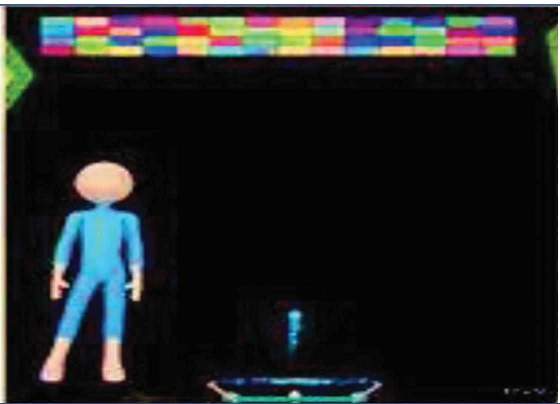
[Table/Fig-10]: Hiking- Walking by, overcoming the obstacles.

10. Toy-Golf: When playing golf, the player was instructed to control the avatar, or golfer, by shifting their weight from side to side (targeting) and making golf swings with their hands then the participants were asked to move things on the track, such as spinning the windmill to accelerate the golf ball, the player also squats [Table/Fig-11].

11. Brick breaker: The participants were instructed to stand erect, then they were instructed transfer their weight from side to side. Afterwards the player bounces the ball inside the trampoline until it smashes through the top bricks. Additionally, the player can catch falling fruit onto the trampoline [Table/Fig-12].

12. Hat-trick: The participant was asked to be in a standing position and moves the avatar (figure with sombrero) by weight transfer from side to side and, with hands, tries to grasp the objects falling from the straps and throw them into a sombrero [Table/Fig-13].

[Table/Fig-11]: Toy-golf exercise: Improves balance by weight shifting from side to side.



[Table/Fig-12]: Brick breaker improves balance by weight shifting from side to side.

[Table/Fig-13]: Hat-trick: Weight transferring from side to reach the object and to throw it again.

Progressive protocol of Virtual Reality (VR): This is done four days per week- 40 minutes per day with each seven minutes break for 12 weeks [24,25].

Week 0-1:

- Immersive VR: Paddle boat.
- Cave game
- Rowing game (S)
- Bubble runner
- Cannon

Week 2-3:

- Cave game
- Rowing game (M)
- Bubble runner
- Cannon

Week 4:

- Cave game
- Rowing game (F)
- Bubble runner
- Cannon

Week 5 and 6:

- Cave game
- Intruders (S)
- Pick-up
- Cannon
- Hat-trick (S)
- Lateral weight shift exercise.

Week 7 and 8:

- Intruders (M)
- Pick-up
- Hat-trick (M and F)
- Hiking

Week 9:

- Intruders (F)
- Cave game
- Squat pong (S)
- Brick breaker
- Toy golf

Week 10, 11 and 12:

Participants can select:

- Cave game
- Intruder (F)
- Rowing game (F)
- Pick-up
- Squat pong (S)
- Bubble runner
- Brick breaker
- Hat-trick
- Cannon
- Hiking
- Toy golf.

High-intensity exercise program [26]- 4 days per week for 12 weeks.

Phase 1 (Weeks 0-2)

- Heel glides in a supine knee flexion.
- Knee extensions in a short arc.
- Bilateral squats while standing.
- External rotation of the hips while resting on the side, flexing the hips to 45° and the knees to 90° (clams).
- Plantar and dorsiflexion of the ankle in a supine position (ankle pumps).
- Progress: ROM >15°-80°; NPRS at rest, <5/10; when able to perform 2×8 repetitions without tiredness.

Phase 2 (Weeks 2-4)

- Bilateral calf rises while standing*.
- Side-lying hip abduction*.
- Straight leg raise*.
- Simultaneous sitting single-leg knee extension.
- Consistent transfers from sitting to standing.
- Lunging forward or standing on one leg.
- One-way stepping is multidirectional.
- Along with phase 1 exercises.
- Progress: ROM, >15°-90°; NPRS at rest, <5/10; achieved when 2×8 repetitions may be executed without fatigue.

Phase 3 (Weeks 4-6)

- Sitting single-leg knee extension and flexion*.
- Calf press*.
- Standing hip extension, flexion, abduction and adduction*.
- Wall slides to a 90° flexion of the knee.
- Step-downs; side step-ups.
- Front lunging.
- Tilt board squats.
- Stability ball supine hip extension.
- Along with phase 2 exercises.
- Progress: NPRS at rest of less than 3/10; ROM, more than 10°-100°; and when 2×8 repetitions can be performed without exhaustion.

Phase 4 (Weeks 6-12)

- Flexion (eccentric) and extension (eccentric) of the knee while seated individually.
- The quirky single-leg press.
- Single-leg eccentric calf press
- Abduction, adduction, flexion and extension of the hips when standing
- Step-downs, side step-ups and step-ups
- Lunging in several directions.
- Wall slides that have endurance hold of five to ten seconds at 90°.
- Along with phase three exercises.

Outcome measures

NPRS: Numerical pain rating scale: The outcome measure, the NPRS, is an ordinal and subjective, one-dimensional gauge of pain severity. "No pain" is represented by a score of '0' on the 11-point numerical scale, while "pain as bad as you can imagine" or "worst pain imaginable" are represented by a score of '10' [27].

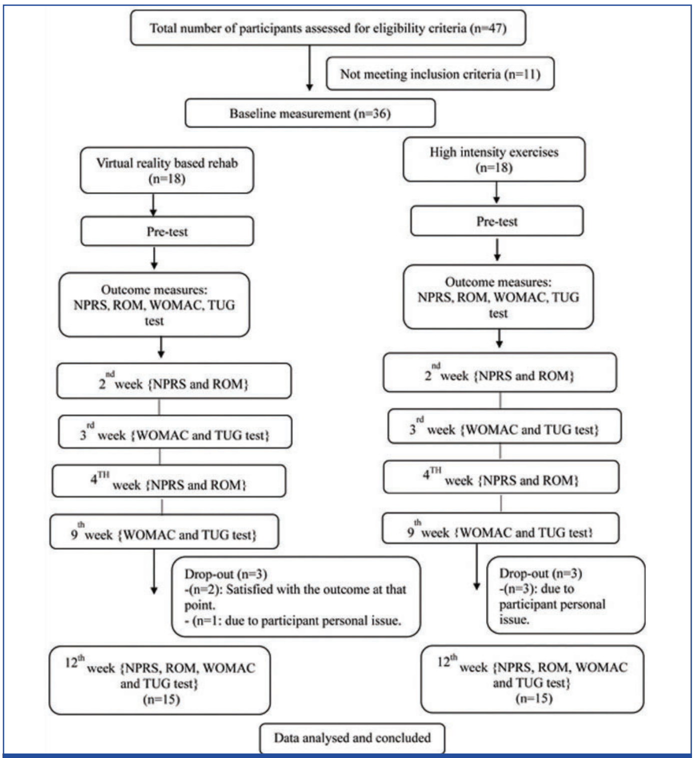
WOMAC: A self-report questionnaire designed specifically for measuring the symptoms of OA in the knees is known as the WOMAC OA Index. It is reliable, dependable and responsive to modifications in the health state of individuals suffering from OA. For each item, the authors employed the 3.1 Likert version with five answer levels, which stood for various levels of severity (none, mild, moderate, severe, or extreme) and were scored from 0 to 4. The final score of WOMAC was calculated by the sum of the overall pain, stiffness and function values. For the overall WOMAC, scores ranges from 0 to 96, with 0 being the highest potential health state and 96 the worst. The function gets worse the higher the score. Thus, lowering the total score resulted in an improvement [28,29].

Range of motion: Person lying down in supine position with their knee extended in a 0° extended, abducted position. This is a ratio scale and it is objective.

- Axis: the femur's lateral epicondyle.
- Stationary arm: the length of the femur to the greater trochanter.
- Arm movement: via the fibula to the lateral malleolus [30].

Timed Up and Go (TUG) test: The TUG test calculates how long it takes a participant to get up from a chair, go three metres, turn around, return to the chair and seat down in terms of seconds and <10 seconds indicates normal [31].

- <10 seconds indicates normal.
- <20 seconds indicates good mobility; able to go outside without assistance.
- Less than 30 seconds results in balance and walking issues; requires walking assistance when walking outside. Flowchart of the procedure is presented in [Table/Fig-14].



[Table/Fig-14]: Flowchart of the procedure.

STATISTICAL ANALYSIS

The following methodologies for statistical analysis were employed when analysing the data. Descriptive statistics were used to describe the sample characteristics. Baseline differences between groups were studied with paired t-test. Adherence was defined as the proportion of participants who completed all sessions according to the protocol. The treatment effect was assessed using paired and unpaired t-test. The level of significance was found to be less than 0.001.

RESULTS

The mean values and standard deviations of the outcome variables (pain levels, range of motion, balance, gait and functional outcomes) were presented using descriptive statistics at the end of the second, fourth and 12th weeks for pain and range of motion and the end of the third, ninth and 12th weeks for both groups for balance, gait and functional outcomes, before and after the intervention.

The demographic data of the participants is presented in [Table/Fig-15]. The average mean±SD of age and BMI was found to be 51.2±5.2 and 28.3±2.0 kg/m^2 (according to BMI of Asia) [23]. The male and female count was 15 and 21.

Demographic details	Value
Gender	Female: 21
	Male: 15
Age (in years)	51.2±5.2
BMI (kg/m^2)	28.3±2.0

[Table/Fig-15]: Demographic details.
BMI: According to BMI of Asia

The VR group pretest values of NPRS and ROM mean were 8.56 and 12.56 and the post-test values were 3.39 and 62.28 at the end of the 2nd week, 2.50 and 81.28 at the end of the 4th week and 1.47 and 105 at the end of the 12th week is presented in [Table/Fig-16]. The mean value for High-intensity exercise group pretest values of NPRS and ROM was 8.44 and 13.11, and the post-test values were 3.78 and 40.28 at the end of the 2nd week, 3.33 and 74.06 at the end of the 4th week, and 2.27 and 94.27 at the end of the 12th week.

The VR group pretest values of the WOMAC and TUG test mean were 71.22 and 36.61 and the post-test values were 51.17 and

Outcome	Week	VR-based rehabilitation				T-value	p-value	High-intensity exercises				T-value	p-value
		Pretest		Post-test				Pretest		Post-test			
		Mean	SD	Mean	SD			Mean	SD	Mean	SD		
NPRS	2	8.56	0.51	3.39	0.50	27.89	<0.0001	8.44	0.51	3.78	0.43	33.32	<0.0001
	4	3.39	0.50	2.50	0.51	6.468	<0.0001	3.78	0.43	3.33	0.49	3.062	<0.0001
	12	2.53	0.52	1.47	0.52	5.870	<0.0001	3.33	0.49	2.27	0.46	6.959	<0.0001
ROM [Flexion]	2	12.56	1.29	62.28	2.47	79.52	<0.0001	13.11	0.83	40.28	4.07	30.14	<0.0001
	4	62.28	2.47	81.28	3.43	17.76	<0.0001	40.28	4.07	74.06	4.09	25.88	<0.0001
	12	81.80	3.51	105.0	4.23	16.55	<0.0001	73.13	3.83	94.27	3.10	16.37	<0.0001

[Table/Fig-16]: Comparison of pre and post-test values of the VR- rehabilitation and HI exercise for pain and range of motion.
VR: Virtual reality; HI: High-intensity; NPRS: Numerical pain rating scale; ROM: Range of motion; p-value: Probability value using paired t-test

23.22 at the end of the 3rd week, 17.00 and 10.89 at the end of the 9th week and 14.93 and 8.60 at the end of the 12th week is presented in [Table/Fig-17]. Here in the high-intensity exercise programme, the pretest values of the WOMAC and TUG test mean were 71.00 and 35.83 and the post-test values were 62.06 and 28.72 at the end of the 3rd week, 31.39 and 16.22 at the end of the 9th week and 12.07 and 12.07 at the end of the 12th week.

The post-test values of VR-based rehabilitation for pain were 3.39, 2,50 and 1.47 and ROM (flexion) was 62.28, 81.28 and 105.00 in the 2nd, 4th and 12th weeks is presented in [Table/Fig-18]. Along with functional activity, WOMAC was 51.17, 17.00 and 14.93 and the TUG test was 23.22, 10.89 and 8.60 in the 3rd, 9th and 12th weeks. The post-test values of high-intensity exercises for pain were 3.78, 3.33 and 2.27 and ROM (flexion) was 40.28, 74.06 and 94.27 in the 2nd, 4th and 12th weeks. Along with functional activity, WOMAC was 62.06, 31.39 and 19.00 and the TUG test was 28.72, 16.22 and 12.07 in the 3rd, 9th and 12th weeks.

The study's findings offer strong proof that VR-assisted physical rehabilitation is a more successful rehabilitation approach for those with TKR than high-intensity exercise regimens. The results show that both groups significantly improved, but the VR group continuously outperformed the other group on a number of outcome measures.

DISCUSSION

Through a comparative analysis of VR-based rehabilitation and high-intensity exercise programmes, the present study adds significant knowledge to the body of literature on rehabilitation strategies and their effects on patient outcomes in patients who have had TKA. The findings of this investigation add to the growing corpus of knowledge on the effectiveness of VR as a rehabilitation strategy by demonstrating the superiority of VR-based rehabilitation over high-intensity exercise efforts in promoting quicker recovery and improving outcomes for people with TKR.

Outcome	Week	VR-based rehabilitation				T-value	p-value	HI-intensity exercises				T-value	p-value
		Pretest		Post-test				Pretest		Post-test			
		Mean	SD	Mean	SD			Mean	SD	Mean	SD		
WOMAC	3	71.22	0.81	51.17	1.34	46.49	<0.0001	71.00	0.77	62.06	1.55	21.50	<0.0001
	9	51.17	1.34	17.00	2.54	47.17	<0.0001	62.06	1.55	31.39	1.55	66.03	<0.0001
	12	17.20	2.57	14.93	0.96	2.807	<0.0001	31.33	1.05	19.00	1.96	20.32	<0.0001
TUG test	3	36.61	1.04	23.22	1.59	27.93	<0.0001	35.83	1.29	28.72	1.27	22.79	<0.0001
	9	23.22	1.59	10.89	0.76	29.35	<0.0001	28.72	1.27	16.22	0.81	39.59	<0.0001
	12	10.93	0.76	8.60	1.12	7.320	<0.0001	16.22	0.81	12.07	0.88	15.02	<0.0001

[Table/Fig-17]: Pre and Post-test values of VR rehabilitation and HI exercise for functional activities.
VR: Virtual reality; HI: High-intensity; WOMAC: Western Ontario and McMaster Universities Arthritis Index; TUG test: Timed up and go test; p-value: Probability value using paired t-test

Outcome	Week	VR based rehabilitation		High-intensity exercises		T-value	p-value
		Mean	SD	Mean	SD		
NPRS	2	3.39	0.50	3.78	0.43	2.5026	0.0173
	4	2.50	0.51	3.33	0.49	5.000	<0.0001
	12	1.47	0.52	2.27	0.46	4.4900	<0.0001
ROM (Flexion)	2	62.28	2.47	40.28	4.07	19.607	<0.0001
	4	81.28	3.43	74.06	4.09	5.7393	<0.0001
	12	105.00	4.23	94.27	3.10	7.9278	<0.0001
WOMAC	3	51.17	1.34	62.06	1.55	22.535	<0.0001
	9	17.00	2.54	31.39	0.98	22.3988	<0.0001
	12	14.93	0.96	19.00	1.96	7.2032	<0.0001
TUG test	3	23.22	1.59	28.72	1.27	11.4405	<0.0001
	9	10.89	0.76	16.22	0.81	20.4128	<0.0001
	12	8.60	1.12	12.07	0.88	9.4047	<0.0001

[Table/Fig-18]: Comparison of post-test values between the groups for pain, Range of motion and functional activities.
VR: Virtual reality; HI: High-intensity; NPRS: Numerical pain rating scale; ROM: Range of motion; WOMAC: Western Ontario and McMaster Universities Arthritis Index; TUG test: Timed up and go test; p-value: Probability value using unpaired t-test

Effectiveness of VR-based rehabilitation in comparison to high-intensity exercise programmes: This study's findings support other research carried out in a variety of healthcare settings, suggesting that VR-based rehabilitation leads to more improvements in functional outcomes, pain levels, Range of motion, balance and gait than high-intensity exercise programme techniques. As an example, researches states that Pain lowers the quality of life and has a detrimental effect on social, psychological and physical functioning. Shahrbanian S et al., states that VR has been used more and more in the last ten years for pain management in particular as well as general rehabilitation [32]. Huang Q et al., concluded that acute pain can be adequately relieved by VR and with the introduction of more reasonably priced gadgets like head-mounted displays, VR has grown in viability and popularity in recent years. In contrast to many analgesics, which interfere with the C-fibre channel that sends nociceptive signals to the brain, VR modifies pain perception by affecting focus, attention and emotions. By increasing non painful brain signalling, the immersive environment produced by VR lessens the perception of pain [33]. It is also proved that in OA patients undergoing TKA, the clinical application of VR intervention can facilitate rehabilitation, lessen postoperative discomfort and enhance functional recovery.

In the present study, the VR based rehabilitation shows positive effect on functional activity. According to Pournajaf S et al., concluded that for TKR patients, equilibrium training using non immersive VR-based Series games can enhance gait, postural and clinical results [34]. Both the immersive and non immersive VR based rehabilitation were used in this study as immersive acts as a best route to reduce the pain sensation due to the complete immersion of mind and it was also concluded by VR combined with exercise helps lower pain, kinesiophobia and pain catastrophising in the early post-TKA phase and improves functional results [35] and non immersive virtual based rehabilitation is effective in range of motion and in functional activity. In 2023 Garcia-Sanchez M et al., also concluded that, in contrast to Computed Tomography (CT), Virtual Reality-based Rehabilitation (VRBR) is a useful therapy for knee pain, knee function, dynamic balance, knee flexion range of motion and knee extension strength in patients who undergone TKA based on the particular VRBR modality, immersive VBRV is better suited for enhancing knee pain and ROM, whereas non immersive VRBR is best for enhancing dynamic balance and knee extension strength. Both immersive and non immersive VRBR improved knee function in a comparable way [36].

When compared to a rehabilitation programme with a lesser intensity, an HI programme produces better results in terms of strength and functional performance both in the short and long term but the time taking can reduce the interest of the participants. According to Lee M et al., VR games have the potential to be a useful tool for patients recovering from knee surgery in terms of motivational rehabilitation [37]. However, depending on the severity of each patient's knee injury, it can be helpful to design a VR programme with varying degrees of difficulty in order to best match their needs. Furthermore, extreme pain or physical dysfunction may serve as a recommendation for VR-based therapy rather than a disqualifier [36].

Iwata states that there was no discernible change in gait speed at three weeks following TKI, but it was considerably lower at one and two weeks following the procedure but, here continuous TUG training using the exercise and VR-intervention maintains the activity strength of muscle and it was not measured after the period of rehabilitation. About half of the patients showed improvements above their preoperative scores (TUG, 55%) and gait speed, 50%. According to the research, a potential benchmark for monitoring the early stages of postoperative recovery following TKA could be reaching preoperative mobility within three weeks [38].

Here in the present study, it shows that the VR-based rehabilitation is superior to the high-intensity exercise program, which shows that there is a significant difference between the VR-based rehabilitation and the high-intensity exercise program. The p-value of <0.0001 indicates that there is a statistically significant difference between the groups and shows that there is rejection of the null hypothesis (H0). This states that the acceptance of alternate hypothesis (H1) and the null hypothesis has been rejected.

Limitation(s)

The limitation of the present study was that first-time users found the VR therapy to be somewhat uncomfortable and problems with immersion could affect how well the rehabilitation goes. Compatibility problems between different devices could also crop up. The confounding factors include the technical issues, where the VR equipment or software problems may affect the treatment delivery sometimes and also the age group differences between the participants, where the older adults may have different responses to VR-based rehabilitation. Additionally, a lot of users of VR systems reported side-effects that are important to consider because they affect how well rehabilitation goes. And HI exercises caused pain in the first few weeks, so some modality like wax can be applied to reduce that if the exercises were prescribed separately. Recommendations were large volumes of data are typically processed by VR systems, necessitating a lot of processing and storage power.

CONCLUSION(S)

The VR-based rehabilitation showed better outcomes in pain, ROM, balance, gait and functional independence than a high-intensity exercise programme. NPRS significantly showed the same between the groups, but the range of motion shows better output in VR-based rehabilitation than indifferently supporting the pain outcome of the experimental group. Balance, gait and functional activities are enhanced in the experimental group than conventional group. In the VR-based rehabilitation, the functional independence of the patient is achieved in nine weeks compared to the high-intensity exercises.

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PARTICULARS OF CONTRIBUTORS:
1. Postgraduate Student, Saveetha College of Physiotherapy, SIMATS, Chennai, Tamil Nadu, India.
2. Associate Professor, Saveetha College of Physiotherapy, SIMATS, Chennai, Tamil Nadu, India.
3. Postgraduate Student, Saveetha College of Physiotherapy, SIMATS, Chennai, Tamil Nadu, India.

NAME, ADDRESS, E-MAIL ID OF THE CORRESPONDING AUTHOR:
Dr. K Nishitha,
Postgraduate, Saveetha College of Physiotherapy, SIMATS, Saveetha Nagar, Thandalam, Chennai-602105, Tamil Nadu, India.
E-mail: nishithak2711@gmail.com

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