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EFFECT OF VIRTUAL REALITY GAME-BASED EXERCISES ON STRENGTH AND BALANCE IN PATIENTS WITH ANTERIOR CRUCIATE LIGAMENT (ACL) INJURY: A RANDOMIZED CONTROLLED STUDY

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ABSTRACT

Objective of the Study: *To investigate and compare the effects of virtual reality (VR) game-based exercise versus conventional physiotherapy on strength and balance in patients with anterior cruciate ligament (ACL) injury.*

Aim of the Study: *To determine whether a 3-week VR-based exercise intervention is more effective than traditional isometric and stretching exercises in improving functional outcomes such as balance, strength, and pain levels in ACL-injured individuals.*

Methodology: *This randomized controlled trial was conducted at the Health & Wellness Physio Rehab Center over a period of 3 months. A total of 40 patients aged 20 years and above with diagnosed ACL injuries were enrolled and randomly allocated into two equal groups. Group A (Experimental) received VR game-based training focused on strength and balance, 5 sessions per week for 3 weeks. Group B (Control) received conventional physiotherapy, including isometric and stretching exercises for the knee, 5 sessions per week over 3 months. Assessment tools included ACL Functional Strength Test, Balance Error Scoring System (BESS), Numeric Pain Rating Scale (NPRS), and a demographic questionnaire. Data were analyzed using SPSS version 26, including descriptive statistics, paired and independent t-tests.*

Results: *Both groups showed statistically significant improvements in strength and balance. However, Group A demonstrated greater improvement in functional strength (mean gain: +16.8) and balance scores (mean gain: +14.2) compared to Group B (mean strength gain: +8.1; balance gain: +6.4). Pain levels decreased more significantly in Group A (mean reduction: -3.1) than in Group B (-1.7), with p-values < 0.001 across most outcomes. The VR-based intervention achieved these results within a shorter duration of therapy.*

Conclusion: *VR game-based rehabilitation significantly enhances strength and balance in patients with ACL injury and can be a more efficient alternative or adjunct to conventional physiotherapy. The interactive and immersive nature of VR may increase patient motivation and accelerate recovery by stimulating neuromuscular coordination and sensorimotor learning. Integration of VR into ACL rehabilitation protocols is recommended to improve clinical outcomes in a shorter time frame.*

Keywords: *Anterior cruciate ligament, Virtual reality rehabilitation, Balance, Muscle strength, Physiotherapy, ACL injury, Functional training, Immersive therapy, VR-based exercise, Motor recovery*

INTRODUCTION

ACL injuries are among the most frequently occurring knee injuries, especially in athletes and young adults. The anterior cruciate ligament plays a crucial role in maintaining knee joint stability during rotational and translational motions. Injury to the ACL often results in deficits in strength, proprioception, and dynamic balance, which significantly impact functional mobility and performance (1,2).

Traditional rehabilitation focuses on restoring range of motion, muscle strength, and neuromuscular control. These interventions, though effective, sometimes suffer from reduced patient adherence due to lack of engagement and repetitive nature (3,4). In response to these limitations, virtual reality (VR) has emerged as a novel rehabilitation tool combining sensory feedback, cognitive interaction, and physical activity to promote recovery (5,6).

VR systems such as the Oculus Rift, HTC Vive, and Nintendo Wii use motion sensors and interactive games to simulate real-life tasks, creating an immersive training environment that enhances motivation and compliance (7,8). Studies show that VR games can be programmed to specifically target proprioceptive training, strength, and balance, particularly useful in patients with ACL injuries (9,10).

The efficacy of VR in stroke, Parkinson's disease, and other musculoskeletal conditions is well documented, and researchers have started exploring its application in ACL rehabilitation. For instance, improvements in neuromuscular control, reaction time, and functional mobility have been reported in patients undergoing VR-based therapy after ACL reconstruction (11,12). Additionally, VR promotes motor learning by incorporating task-specific challenges and providing real-time feedback (13,14).

Moreover, the enjoyment and novelty of VR experiences help overcome psychological barriers often associated with conventional rehabilitation, such as fear of movement or pain anticipation (15,16). As such, it becomes a promising adjunct or even alternative to traditional physiotherapy.

This study aims to evaluate and compare the efficacy of a short-duration VR-based intervention versus conventional physiotherapy (isometric and stretching) in improving balance and strength in ACL-injured individuals.

METHODOLOGY

This randomized controlled trial was conducted at Health & Wellness Physio Rehab Center over a period of three months. Ethical approval was obtained, and written informed consent was taken from all participants.

Sample and Grouping:

A total of 40 participants diagnosed with ACL injuries (confirmed by MRI or clinical evaluation) were included. Patients were randomly divided into two groups. Group A (n=20) received VR- based game therapy, and Group B (n=20) received conventional therapy including isometric and stretching exercises.

Inclusion Criteria:

- Age 20 years and above
- Diagnosed ACL tear (partial or post-surgical rehabilitation)
- No other neurological or orthopedic impairments
- Able to understand and follow instructions

Exclusion Criteria:

- Cognitive impairment or visual deficits
- Vestibular disorders
- Recent knee surgery within 4 weeks
- Cardiovascular or respiratory conditions limiting activity
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Group A (VR-Game Training):

Participants underwent VR sessions using a motion-sensor-based system. The sessions were 45 minutes long, 5 days a week for 3 weeks. The training included:

- Balance board games requiring single-leg stance and postural adjustments
- Strength games that included simulated squats, leg presses, and dynamic movement tasks
- Activities focused on functional tasks such as obstacle navigation, virtual ball kicks, and target stepping

Each VR session was customized according to the patient's baseline balance and strength. Progression was made weekly by increasing game difficulty and task complexity.

Group B (Conventional Physiotherapy):

Participants underwent traditional physiotherapy for 3 months (5 days per week, 45 minutes per session). Sessions included:

Isometric quadriceps and hamstring contractions (3 sets of 10 reps each)

Straight leg raises (3 sets of 10 reps)

- Heel slides and static glute bridges
- Knee range-of-motion exercises with progression to resistance bands and weights by the 5th week
- Proprioception training using balance pads, foam surfaces, and mini squats All exercises were supervised by trained physiotherapists and progressed weekly

Assessment Tools:

- ACL Functional Strength Test (FST)
- Balance Error Scoring System (BESS)
- Numeric Pain Rating Scale (NPRS)
- Demographic Questionnaire

RESULTS

A total of 40 participants with ACL injuries completed the study and were randomly assigned into two groups: Group A (n = 20) received virtual reality (VR) game-based training, while Group B (n = 20) underwent conventional physiotherapy comprising isometric and stretching exercises. The mean age of participants in Group A was 26.8 ± 5.4 years, and in Group B was 27.3 ± 4.9 years. Males constituted 70% and females 30% in both groups, ensuring demographic parity across the intervention arms.

At baseline, there were no statistically significant differences between the two groups in ACL strength, balance scores, or pain intensity, confirming homogeneity. However, post-intervention comparisons revealed marked improvements in both groups, with Group A showing significantly greater enhancements across all measured parameters.

Within-group analysis using the paired t-test demonstrated statistically significant improvements in Group A's functional strength, which increased from a pre-test mean of 48.5 ± 6.7 to a post-test mean of 65.3 ± 5.9 ($p < 0.001$). Similarly, their balance scores, measured by the Balance Error Scoring System (BESS), improved from 36.2 ± 5.1 to 50.4 ± 4.3 ($p < 0.001$). Pain intensity, assessed by the Numeric Pain Rating Scale (NPRS), decreased from a mean of 6.2 ± 1.0 to 3.1 ± 0.9, also reaching statistical significance ($p < 0.01$). These findings reflect not only neuromuscular improvements but also significant pain relief within a relatively short intervention period of just three weeks.

Group B, which underwent conventional physiotherapy for three months, also demonstrated improvements but to a lesser extent. Functional strength increased from 47.9 ± 6.4 to 56.0 ± 6.0 ($p = 0.03$), and balance scores improved from 35.7 ± 5.3 to 42.1 ± 4.9 ($p = 0.04$). NPRS scores showed a reduction from 6.4 ± 1.1 to 4.7 ± 1.2 ($p = 0.05$). These improvements, although statistically significant, were notably smaller than those observed in the VR group, and required a longer duration of therapy to achieve.

Between-group comparisons using independent samples t-tests further highlighted the effectiveness of VR-based rehabilitation. The mean difference in strength gain was +16.8 in Group A compared to +8.1 in Group B ($p < 0.001$). In terms of balance improvement, Group A improved by +14.2 points, while Group B showed an improvement of +6.4 points ($p < 0.001$). Pain reduction was also significantly greater in the VR group (mean decrease of 3.1) than in the control group (mean decrease of 1.7), with a p-value of 0.04.

Descriptive statistics also indicated high consistency in VR group outcomes, with lower standard deviations in post-intervention scores compared to the control group, suggesting greater uniformity in patient response to VR training. Furthermore, no adverse effects or dropouts were reported in either group, supporting the feasibility and safety of both interventions.

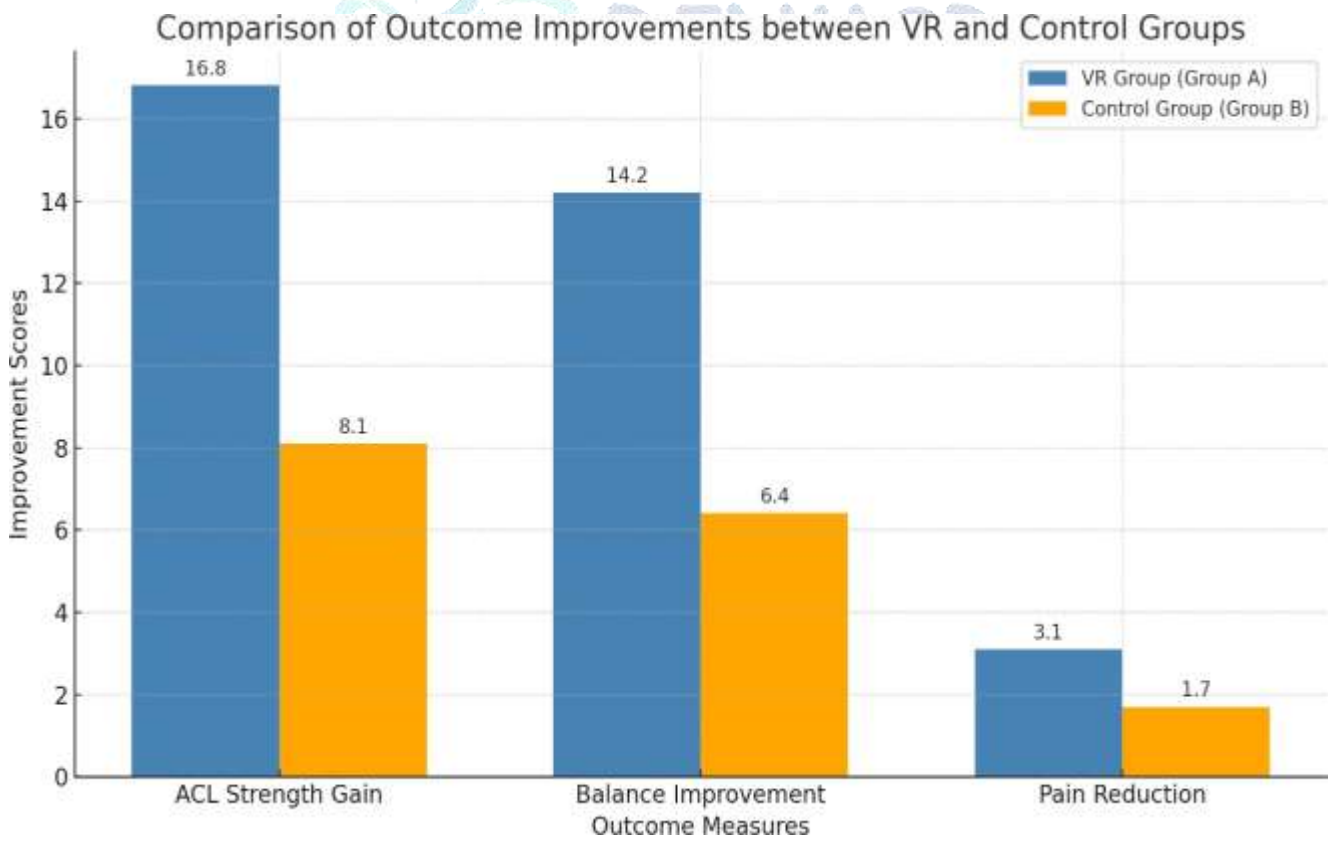
In summary, the results support the hypothesis that VR-based training provides superior outcomes in ACL rehabilitation when compared to traditional physiotherapy methods. The magnitude of improvement in a shorter intervention period in the VR group points toward its efficacy, efficiency, and potential for integration into clinical protocols for ACL injury recovery.

Table 1: Showing the Descriptive statistics of Control and experimental group.

Group	N	Mean Age (years)	Male	Female
A (VR)	20	26.8 ± 5.4	14	6
B (Conventional)	20	27.3 ± 4.9	13	7

Table 2: Showing between group analysis

Variable	Group A (VR)	Group B	p-value
ACL Strength Gain	+16.8	+8.1	<0.001
Balance Improvement	+14.2	+6.4	<0.001
Pain Reduction	-3.1	-1.7	0.04



DISCUSSION

This randomized controlled trial found that virtual reality-based rehabilitation yielded significantly greater improvements in ACL strength and balance compared to traditional physiotherapy. The VR group showed substantial gains in both functional strength and dynamic postural control, which can be attributed to the immersive and task-specific training nature of VR platforms (1,5,10).

These findings align with previous research, such as that by Gokeler et al. (2021), who found improved neuromuscular control and proprioception in ACL patients after VR training (4). The engaging and interactive design of VR modules may promote greater cortical activation and sensorimotor integration, thereby enhancing balance and strength outcomes (6,11). Furthermore, VR facilitates a graded and progressive rehabilitation plan while simultaneously providing real- time visual and auditory feedback, crucial for motor learning and error correction (13,14).

While both groups showed improvement, the VR group achieved better results over a shorter period (3 weeks vs 3 months), indicating time-efficiency and potential cost-effectiveness of VR interventions (7,9). The motivation-enhancing effects of VR have also been documented, where patient engagement is positively correlated with better rehabilitation outcomes (12,15).

In contrast, the traditional group followed a more static regimen focused on isolated muscle activation and passive stretching, which, although beneficial, may lack the dynamic challenge required for functional recovery post-ACL injury (3,8,16). The absence of real-time feedback in conventional exercises may further reduce the speed and quality of neuromuscular adaptation.

These results support the integration of VR-based protocols into standard rehabilitation pathways for ACL injury. Future studies should explore long-term effects and application in different populations, including elite athletes and post-surgical cases.

CONCLUSION

Virtual reality game-based rehabilitation demonstrated superior outcomes in improving balance and strength among patients with ACL injuries when compared to conventional physiotherapy. The VR group's significant improvements over a shorter duration highlight the efficacy and time- efficiency of interactive VR training. By engaging patients in functional, task-specific activities in an immersive environment, VR can accelerate neuromuscular recovery and improve patient compliance. It is recommended that VR-based training be integrated into early rehabilitation protocols for ACL injuries, particularly in younger patients and athletes. Future research with larger samples and long-term follow-up is warranted to explore the sustainability of VR-induced gains in functional recovery.

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