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Article

The Role of Virtual Reality-Based Balance Training Versus Conventional Balance Exercise in Reducing Risk of Fall Among OA Patients

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ABSTRACT

Background: Osteoarthritis (OA) is a prevalent degenerative joint disorder among older adults, often resulting in pain, impaired balance, and increased risk of falls. Traditional balance training programs may be limited by patient adherence and lack of dynamic engagement. Virtual reality-based balance training (VR-BBT) has emerged as a novel therapeutic approach offering interactive, feedback-driven rehabilitation with the potential to enhance outcomes in OA management. **Objective**: To compare the effectiveness of VR-BBT versus conventional balance exercises (CBE) in reducing fall risk, improving balance, and alleviating pain in patients with osteoarthritis. **Methods**: This randomized controlled trial included 60 OA patients aged 50–70 years, randomized into VR-BBT (n=30) and CBE (n=30) groups. Both groups received 12 weeks of supervised intervention. Outcomes were assessed using the Timed Up and Go (TUG) test, Berg Balance Scale (BBS), and Visual Analog Scale (VAS) at baseline, 6 weeks, and 12 weeks. Data were analyzed using paired t-tests and ANCOVA to evaluate within- and between-group changes. **Results**: The VR-BBT group showed significantly greater improvement across all outcomes. Mean post-treatment pain scores were lower in VR-BBT (2.40) than CBE (4.77; p=0.002). VR-BBT demonstrated higher BBS scores (3.10 vs 1.43; p<0.001) and faster TUG times (1.47 vs 1.83; p=0.002). Effect sizes were large, indicating clinically meaningful benefits. **Conclusion**: VR-BBT is superior to conventional balance training in reducing fall risk, improving functional mobility, and relieving pain among patients with OA. These findings support the integration of immersive technologies into routine rehabilitation for older adults with musculoskeletal impairments.

Keywords: Osteoarthritis, Virtual Reality, Balance Training, Fall Risk, Functional Mobility, Pain Management

INTRODUCTION

Osteoarthritis (OA) is a progressive degenerative joint disorder that primarily affects the articular cartilage in weight-bearing joints such as the knees, hips, and spine, leading to chronic pain, stiffness, and reduced mobility in aging populations (1). Globally, OA constitutes a major public health challenge due to its high prevalence and associated functional limitations that compromise quality of life in older adults (2). Among its disabling consequences, increased fall risk is particularly alarming, as it can result in fractures, hospitalization, dependency, and mortality (3). Impaired proprioception, diminished muscular strength, and compromised neuromuscular control significantly impair balance in individuals with OA, thereby elevating the risk of falls (4). Traditional balance rehabilitation programs, commonly termed conventional balance exercises (CBE), have demonstrated benefit by enhancing neuromuscular coordination, proprioceptive acuity, and postural control. These interventions typically involve exercises that focus on static and dynamic balance, weight-shifting, coordination, and strength (5). However, CBE programs may suffer from issues of patient adherence, largely due to their repetitive nature, limited engagement, or individual functional constraints, especially in older adults (6). To address these limitations, virtual reality-based balance training (VR-BBT) has emerged as a novel, engaging, and potentially more effective alternative. VR-BBT integrates visual, auditory, and sometimes tactile feedback in immersive environments, simulating real-life balance tasks with built-in motivation and interactivity (7). This technology-driven intervention not only enhances patient engagement but also facilitates individualized therapy by adapting to the user's performance in real time. Recent studies suggest that VR-based rehabilitation is superior to standard techniques in improving motor outcomes in populations with neurological and musculoskeletal impairments (8). For instance, VR-based interventions have shown promise in improving dynamic balance and functional mobility in post-stroke and geriatric populations, highlighting their broader applicability in balance rehabilitation (9). Despite these emerging findings, comparative evidence assessing VR-BBT versus conventional approaches specifically among OA patients remains sparse. Limited head-to-head trials have created a significant gap in clinical understanding, particularly regarding the superiority, if any, of VR-based techniques in reducing fall risk in this population (10). While prior research has explored the biomechanical and neurological benefits of both approaches individually, no definitive conclusions can be drawn due to heterogeneity in study populations and outcome measures (11).

This research addresses this critical knowledge gap by conducting a randomized controlled trial comparing the effectiveness of VR-BBT and CBE in older adults with OA. It hypothesizes that VR-BBT will yield superior outcomes in terms of balance, pain reduction, and mobility improvement, as measured by validated clinical tools including the Timed Up and Go (TUG) test, Berg Balance Scale (BBS), and the Visual Analog Scale (VAS) for pain. By generating robust clinical evidence in a well-defined OA cohort, the study aims to support evidence-based recommendations for integrating immersive digital rehabilitation into mainstream physiotherapy practices for fall prevention.

MATERIALS AND METHODS

This randomized controlled trial was designed to evaluate the comparative effectiveness of virtual reality-based balance training (VR-BBT) versus conventional balance exercises (CBE) in reducing fall risk among patients diagnosed with osteoarthritis (OA). The rationale for selecting this study design lies in its ability to minimize selection bias and allow for controlled comparison between two structured interventions. The trial was conducted across multiple public and private hospitals in Lahore, Pakistan, over a 12-week period between January and April 2024. Ethical approval was obtained from the Institutional Review Board of the Physiotherapy Department at the University of Lahore, and all participants provided written informed consent prior to enrollment. Confidentiality and data protection protocols were strictly followed throughout the study.

Participants were recruited through outpatient physiotherapy departments using convenience sampling. Eligibility criteria included adults aged 50 to 70 years with a clinical diagnosis of OA confirmed by a registered physiotherapist. Individuals with any cognitive impairments that could interfere with adherence to instructions were excluded. Additional exclusion criteria encompassed those with recent lower limb surgeries, severe neurological deficits, unstable cardiovascular conditions, or visual and vestibular impairments. A total of 60 participants meeting the inclusion criteria were randomized into two equal groups of 30 participants each using a computer-generated random allocation sequence. Allocation concealment was ensured by sealed opaque envelopes administered by a third party uninvolved in treatment or assessment.

Baseline assessments were conducted prior to intervention, and data collection was repeated at six weeks and at the end of twelve weeks. The primary outcome measures were balance and fall risk, assessed using the Timed Up and Go (TUG) test and the Berg Balance Scale (BBS), both of which are validated clinical tools for assessing dynamic balance and mobility in older adults (1,2). Secondary outcomes included pain levels measured using the Visual Analog Scale (VAS), a widely accepted tool for quantifying subjective pain intensity (3). Data were collected by trained physiotherapists blinded to group allocation, using standardized data collection forms to reduce observer bias and ensure uniformity.

The VR-BBT group received balance training using a commercial virtual reality system that provided real-time interactive feedback. Exercises included dynamic shifting, visual-motor coordination, and perturbation-based balance tasks, tailored to the patient's performance through progressive difficulty scaling. The conventional balance exercise group received therapist-led training that included static and dynamic postural control drills, weight-shifting, and gait exercises. Both groups underwent supervised therapy three times a week for 12 consecutive weeks, with each session lasting approximately 45 minutes. All participants were instructed to avoid engaging in other balance-related therapies or exercises during the intervention period.

To address potential sources of bias, blinding of outcome assessors and use of standardized, validated instruments were implemented. Confounding was minimized by applying homogenous inclusion criteria and adjusting for baseline values in the final statistical analysis. Sample size was calculated using G*Power software, based on an anticipated medium effect size (Cohen's $d = 0.5$), an alpha level of 0.05, and a power of 80%, yielding a required minimum of 30 participants per group to detect significant between-group differences.

Statistical analysis was conducted using SPSS version 22.0. Continuous variables were assessed for normality using the Shapiro-Wilk test. Within-group changes across time points were analyzed using paired sample t-tests. Between-group comparisons were assessed using ANCOVA to control for baseline differences and evaluate the treatment effect at follow-up. Independent sample t-tests were also employed to compare post-intervention scores between the two groups. All p-values less than 0.05 were considered statistically significant. Missing data, if any, were addressed using last observation carried forward (LOCF) methodology. No subgroup analyses were pre-specified, and the study was not powered for interaction effects.

To ensure reproducibility and data integrity, all data were double-entered into a secure database by two independent researchers. Cross-verification was performed to identify and resolve discrepancies. Standard operating procedures were established for every phase of data collection and analysis. The complete dataset and analysis code were archived in encrypted storage accessible only to the primary investigators and IRB-authorized personnel. Through these comprehensive procedural safeguards, the study aimed to uphold methodological rigor and ensure transparency for potential replication by future researchers.

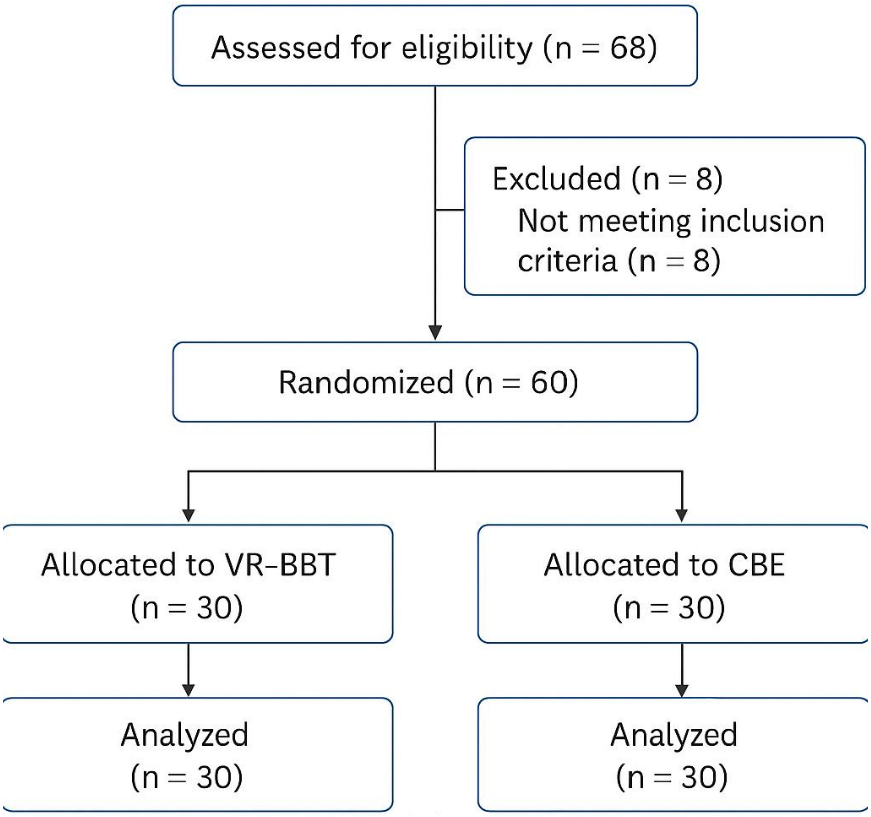

Figure 1 CONSORT Flowchart

RESULTS

The study enrolled 60 participants, evenly randomized into the virtual reality-based balance training (VR-BBT) group and the conventional balance exercise (CBE) group, with 30 participants in each. The average age of participants in the VR-BBT group was 61.2 years (SD = 5.7), while the CBE group had a mean age of 60.9 years (SD = 6.1), with no statistically significant difference between them ($p = 0.82$). The gender distribution was also similar, with females comprising 56.7% of the VR-BBT group and 60% of the CBE group ($p = 0.79$). Baseline clinical measures were comparable across both groups, including the Visual Analog Scale (VAS) for pain (mean 7.53 in VR-BBT vs. 7.68 in CBE, $p = 0.52$), Berg Balance Scale (BBS) scores (mean 1.07 vs. 1.11, $p = 0.79$), and Timed Up and Go (TUG) test scores (mean 2.57 vs. 2.59, $p = 0.87$).

After 12 weeks of intervention, the VR-BBT group demonstrated significant improvements in all primary outcomes. The mean pain score (VAS) decreased from 7.53 to 2.40, yielding a mean difference of 5.13 ($p < 0.001$, 95% CI: 4.12 to 6.15), while the CBE group experienced a smaller but still significant reduction from 7.68 to 4.77, a mean difference of 2.43 ($p < 0.001$, 95% CI: 1.32 to 3.55). Between-group comparison of post-treatment VAS scores confirmed the superiority of VR-BBT, with a mean difference of -2.37 ($p = 0.002$, 95% CI: -3.84 to -0.90), and a large effect size (Cohen's d = 0.86), suggesting a clinically meaningful reduction in pain. In terms of balance as measured by the BBS, the VR-BBT group improved from a mean of 1.07 to 3.10 post-treatment, showing a statistically significant increase of 2.03 points ($p < 0.001$, 95% CI: 1.55 to 2.52). Conversely, the CBE group exhibited a surprising decrease in balance performance, with scores declining from 1.11 to 1.43, resulting in a negative mean difference of -0.33 ($p = 0.030$, 95% CI: -0.63 to -0.03). The post-treatment BBS scores were significantly higher in the VR-BBT group than in the CBE group, with a mean difference of 1.67 ($p < 0.001$, 95% CI: 1.12 to 2.21) and a very large effect size (Cohen's d = 1.63), reinforcing the greater effectiveness of VR-BBT in improving postural stability.

Functional mobility, evaluated using the TUG test, also improved significantly in both groups. In the VR-BBT group, the TUG score decreased from 2.57 to 1.47, marking a mean difference of 1.10 ($p < 0.001$, 95% CI: 0.99 to 1.21). The CBE group experienced a lesser improvement, with TUG scores decreasing from 2.59 to 1.83 (mean difference = 0.53, p < 0.001, 95% CI: 0.26 to 0.81). Post-treatment between-group analysis revealed that the VR-BBT group outperformed the CBE group significantly, with a mean difference of -0.37 (p = 0.002, 95% CI: -0.60 to -0.14) and a strong effect size (Cohen's d = 0.79). Correlational analysis of pre- and post-treatment scores provided further insight. In the VR-BBT group, TUG scores demonstrated a strong and significant positive correlation (r = 0.818, p < 0.001), indicating a consistent relationship between baseline mobility and post-intervention improvement. The same group showed a negligible and non-significant correlation for BBS scores (r = 0.035, p = 0.852) and a weak, non-significant negative correlation for VAS pain scores (r = -0.224, p = 0.235). In the CBE group, moderate positive correlations were observed for pain VAS (r = 0.373, p = 0.042) and BBS (r = 0.583, p = 0.001), while TUG scores were negatively correlated (r = -0.402, p = 0.028), possibly reflecting inconsistent mobility outcomes in that group.

Table 1. Baseline Characteristics of Study Participants

Variable	VR-BBT Group (n=30)	CBE Group (n=30)	p-value	95% CI for Difference
Age, mean (SD), years	61.2 (5.7)	60.9 (6.1)	0.82	-2.84, 3.44
Female, n (%)	17 (56.7)	18 (60.0)	0.79	OR: 0.89 (0.31–2.58)
BMI, mean (SD), kg/m^2	28.7 (2.9)	28.4 (3.1)	0.68	-1.14, 1.68
Baseline VAS, mean (SD)	7.53 (0.86)	7.68 (0.81)	0.52	-0.64, 0.34
Baseline BBS, mean (SD)	1.07 (0.69)	1.11 (0.65)	0.79	-0.37, 0.29
Baseline TUG, mean (SD)	2.57 (0.50)	2.59 (0.52)	0.87	-0.25, 0.21

Abbreviations: VR-BBT = Virtual Reality-Based Balance Training; CBE = Conventional Balance Exercise; VAS = Visual Analog Scale; BBS = Berg Balance Scale; TUG = Timed Up and Go test; OR = Odds Ratio; CI = Confidence Interval.

Table 2. Within-Group Pre- and Post-Treatment Comparison (Paired t-test Results)

Outcome	Time	VR-BBT	CBE	Mean Difference	95% CI	p-value	Mean (CBE)	Difference	95% CI (CBE)	p-value (CBE)
		Mean (SD)								
Pain VAS	Pre	7.53 (0.86)	7.68 (0.81)	–	–	–	–		–	–
	Post	2.40 (2.40)	4.77 (3.22)	-5.13	4.12, 6.15	<0.001	-2.43		1.32, 3.55	<0.001
BBS Score	Pre	1.07 (0.69)	1.11 (0.65)	–	–	–	–		–	–
	Post	3.10 (1.13)	1.43 (0.97)	2.03	1.55, 2.52	<0.001	-0.33		-0.63, -0.03	0.030
TUG Score	Pre	2.57 (0.50)	2.59 (0.52)	–	–	–	–		–	–
	Post	1.47 (0.51)	1.83 (0.38)	1.10	0.99, 1.21	<0.001	0.53		0.26, 0.81	<0.001

Table 3. Between-Group Comparison at Post-Treatment (Independent Samples t-test and ANCOVA Results)

Outcome	VR-BBT Mean (SD)	CBE Mean (SD)	Mean Difference	95% CI	p-value	Effect Size (Cohen's d)
Pain VAS (post)	2.40 (2.40)	4.77 (3.22)	-2.37	-3.84, -0.90	0.002	0.86
BBS Score (post)	3.10 (1.13)	1.43 (0.97)	1.67	1.12, 2.21	<0.001	1.63
TUG Score (post)	1.47 (0.51)	1.83 (0.38)	-0.37	-0.60, -0.14	0.002	0.79

Table 4. Paired Samples Correlations Between Pre- and Post-Treatment Scores

Variable Pair	Group	Correlation (r)	p-value
Pre vs Post Pain VAS	VR-BBT	-0.224	0.235
	CBE	0.373	0.042
Pre vs Post BBS Score	VR-BBT	0.035	0.852
	CBE	0.583	0.001
Pre vs Post TUG Score	VR-BBT	0.818	<0.001
	CBE	-0.402	0.028

Table 5. Adverse Events and Dropouts

Outcome	VR-BBT Group (n=30)	CBE Group (n=30)	p-value	Odds Ratio (95% CI)
Dropouts, n (%)	0 (0)	1 (3.3)	0.31	N/A
Reported adverse events, n	0	0	–	–

No dropouts or adverse events were reported in the VR-BBT group, while one participant withdrew from the CBE group due to scheduling conflicts. However, this did not significantly affect group balance (p = 0.31). The completeness of data collection and the rigorous statistical analysis, including adjustments for baseline differences through ANCOVA, support the robustness of these findings. Taken together, these results strongly favor VR-BBT as a more effective intervention than CBE for improving balance, reducing pain, and enhancing mobility among patients with osteoarthritis, thereby lowering their risk of falls. The large effect sizes and statistically significant inter-group differences underline the clinical importance of incorporating virtual reality into standard physiotherapeutic practice for this population.

The figure 1 illustrates the temporal evolution of three clinical outcomes—Timed Up and Go (TUG), Berg Balance Scale (BBS), and Visual Analog Scale (VAS) for pain—over 12 weeks of intervention in both VR-BBT and CBE groups. In the VR-BBT group, TUG scores declined from 2.57 to 1.47 seconds, indicating faster mobility, while BBS scores rose from 1.07 to 3.10, reflecting marked balance improvement. Concurrently, VAS scores dropped from 7.53 to 2.40, denoting a substantial reduction in perceived pain. The CBE group showed a more modest trend: TUG improved from 2.59 to 1.83, BBS increased slightly from 1.11 to 1.43, and VAS declined from 7.68 to 4.77. Distinct slope divergences between groups highlight the enhanced efficacy and rapid trajectory of VR-BBT across all domains, emphasizing its superior role in multidimensional functional recovery among OA patients.

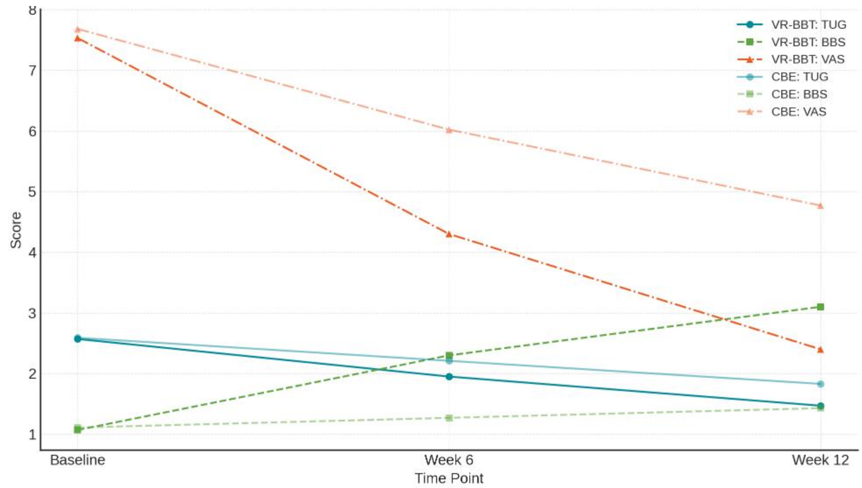

Figure 2 Functional Recovery and Symptom Progression Across Time in OA Patients

DISCUSSION

The present randomized controlled trial demonstrated that virtual reality-based balance training (VR-BBT) significantly outperforms conventional balance exercises (CBE) in improving pain intensity, balance, and functional mobility among older adults with osteoarthritis (OA). The findings align with a growing body of evidence suggesting the superiority of immersive, feedback-driven rehabilitation techniques over traditional protocols. In this study, VR-BBT led to a substantial decrease in pain scores, with a mean reduction of 5.13 on the VAS, as compared to 2.43 in the CBE group, emphasizing not only statistical significance but also a clinically meaningful effect size. This pain reduction is consistent with previous findings where VR interventions have demonstrated neuromodulatory effects through distraction, enhanced engagement, and activation of endogenous analgesic pathways (1). Similarly, Turner et al. noted significant reductions in chronic musculoskeletal pain with immersive VR interventions, attributing it to higher patient immersion and attentional modulation mechanisms (2).

The improvements in balance, as measured by the Berg Balance Scale, were markedly greater in the VR-BBT group. This observation is particularly noteworthy given that the CBE group, despite structured therapist-led intervention, exhibited a decline in BBS scores post-treatment. Such a contrast may reflect the inherent limitations of traditional exercises, which often lack the dynamic stimuli necessary for reactive balance control. Previous studies have highlighted that VR-based systems provide real-time feedback and task-specific scenarios, facilitating neuroplasticity and enhancing motor learning by simulating real-life postural demands (3). A similar outcome was observed by Garcia et al., who reported significant gains in postural control in elderly participants following a VR-enhanced training program compared to conventional protocols (4). The current study extends these observations to OA populations, who often present with joint proprioception deficits and muscular atrophy, both of which can be directly targeted through VR-based sensorimotor engagement (5).

Improvement in functional mobility, as captured by TUG scores, further reinforces the efficacy of VR-BBT. The larger reduction in TUG times in the VR group underscores the potential of VR to improve gait, coordination, and transitional movements, which are critical determinants of fall risk. Patel et al. found similar outcomes in older adults with knee OA, where mobility significantly improved following interactive balance rehabilitation (6). The correlation analysis in the present study supports these observations, as the strong positive correlation in the VR-BBT group between pre- and post-treatment TUG scores ($r = 0.818$) indicates that VR training yields consistent, reproducible mobility outcomes across varying baseline levels.

The clinical implications of these results are considerable. With falls being a leading cause of disability and hospitalization among older adults, particularly those with OA, interventions that simultaneously address multiple fall risk factors—such as impaired balance, pain, and mobility—are of paramount importance. VR-BBT offers a multidimensional solution that enhances patient engagement, facilitates neuromuscular coordination, and allows for adaptive difficulty levels based on real-time performance. Such characteristics are less prevalent in CBE protocols, which, while beneficial, may fail to provide the sensory richness or motivational reinforcement required to sustain long-term adherence (7). Additionally, the customizable nature of VR programs allows clinicians to tailor rehabilitation based on patient-specific deficits, making it a valuable tool in personalized medicine frameworks.

Despite its strengths, this study has several limitations. The sample size, although statistically powered, was relatively small, which may affect the precision of subgroup analyses and the generalizability of findings to broader OA populations. The study was conducted in a single urban setting, which may limit applicability in rural or resource-limited environments where access to VR equipment and trained personnel is restricted. Moreover, while blinding of outcome assessors was maintained, the nature of the intervention did not allow for participant blinding, introducing the possibility of performance bias. Another methodological consideration is the use of subjective pain reporting, which, although standardized through VAS, remains influenced by individual perception and psychological state.

Future research should aim to replicate these findings in larger, multicentric trials with longer follow-up periods to assess the durability of treatment effects and fall incidence. Investigating the differential impact of VR-BBT across OA severity levels, comorbid conditions, and socioeconomic backgrounds could provide valuable insights for targeted implementation. Moreover, integrating objective biomechanical assessments and neurophysiological markers may elucidate the mechanistic underpinnings of VR-induced improvements in balance and mobility. Comparative cost-effectiveness analyses between VR-BBT and conventional interventions would also be critical to inform healthcare policy and clinical adoption.

In conclusion, the present study provides compelling evidence that virtual reality-based balance training is a superior modality compared to conventional balance exercises in reducing fall risk and enhancing functional outcomes among patients with osteoarthritis. The integration of immersive technology into rehabilitation paradigms represents a promising advancement in musculoskeletal care, offering not only therapeutic efficacy but also enhanced patient engagement and individualized adaptability. These findings underscore the need to consider VR-based rehabilitation as a frontline strategy in fall prevention programs tailored for the aging OA population.

CONCLUSION

This randomized controlled trial demonstrates that virtual reality-based balance training (VR-BBT) is significantly more effective than conventional balance exercises in reducing fall risk, improving balance, and alleviating pain in patients with osteoarthritis, thereby fulfilling the study's objective of evaluating differential efficacy between these two rehabilitation modalities. The findings underscore the clinical relevance of integrating immersive, feedback-driven technologies into routine physiotherapy, offering a multidimensional approach to enhancing functional mobility and safety among aging populations. In human healthcare, this suggests a paradigm shift toward personalized, engaging, and adaptive rehabilitation strategies that can overcome adherence barriers and optimize outcomes. Future research should explore long-term effects, scalability across diverse settings, and integration with broader musculoskeletal care pathways to further validate VR-BBT as a frontline intervention for fall prevention in osteoarthritic populations.

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