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Original Article

Effect of Virtual Reality–Based Balance Training vs. Conventional Balance Training in Elderly at Risk of Falls

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ABSTRACT

Background: Falls are a major cause of morbidity, mortality, and reduced independence in older adults, with balance impairment serving as a key modifiable risk factor. Conventional balance training (CBT) has demonstrated benefits but is limited by poor engagement and adherence. Virtual Reality–based Balance Training (VRBT) has emerged as an innovative, interactive modality that may enhance both adherence and rehabilitation outcomes. Objective: To compare the effectiveness of VRBT versus CBT in improving balance, functional mobility, postural stability, and fall-related self-efficacy among elderly individuals at risk of falls in Pakistan. Methods: A randomized controlled trial was conducted at Therapy Plus Clinic, Lahore, enrolling 80 participants aged ≥60 years with fall risk (Berg Balance Scale [BBS] ≤45). Participants were randomized to VRBT or CBT for 45-minute supervised sessions, three times weekly, over six weeks. Outcomes included BBS, Timed Up and Go (TUG), Functional Reach Test (FRT), and Falls Efficacy Scale–International (FES-I). Data were analyzed using repeated-measures ANOVA, with significance set at $p < 0.05$. Results: Both groups improved significantly; however, VRBT yielded greater gains across all outcomes. Between-group differences favored VRBT in BBS (+4.4 points, $p < 0.001$), TUG (–1.7 seconds, $p = 0.002$), FRT (+3.6 cm, $p < 0.001$), and FES-I (–3.2 points, $p = 0.004$). Effect sizes ranged from moderate to large. Conclusion: VRBT was more effective than CBT in enhancing balance, mobility, and confidence, offering a scalable and engaging intervention for fall prevention in older adults.
Keywords: Falls, Elderly, Balance Training, Virtual Reality, Rehabilitation, Fall Prevention.

INTRODUCTION

Falls are among the leading causes of injury-related morbidity and mortality in older adults, accounting for significant healthcare expenditures and functional decline worldwide. The World Health Organization reports that falls are the second leading cause of unintentional injury deaths, with adults over the age of 65 bearing the highest risk (1). Beyond mortality, falls frequently result in fractures, traumatic brain injuries, loss of independence, and heightened fear of falling, which together diminish quality of life in aging populations (2). In low- and middle-income countries, including Pakistan, limited geriatric services and rehabilitation resources amplify the socioeconomic burden of fall-related injuries on families and health systems (3). Consequently, developing accessible and effective fall prevention strategies remains an urgent priority for clinicians and policymakers.

Impaired balance is a central risk factor for falls in the elderly, arising from age-related declines in muscle strength, proprioception, vestibular function, and reaction time (4). Chronic conditions such as diabetes, hypertension, and stroke further exacerbate instability, compounding fall risk (5). Conventional balance training (CBT)—incorporating static and dynamic balance drills, gait retraining, muscle strengthening, and proprioceptive exercises—has long been the cornerstone of rehabilitation (6). Evidence supports that structured exercise programs reduce fall incidence and improve postural control; however, adherence is often limited due to monotonous routines and low patient motivation, particularly in older populations (7). This limitation has fueled the search for innovative modalities that improve engagement without compromising therapeutic efficacy.

Virtual Reality–based Balance Training (VRBT) has recently emerged as a promising intervention, integrating immersive environments with gamified rehabilitation. By simulating real-world tasks—such as negotiating obstacles, weight shifting, and reaching activities—VRBT provides patients with safe yet challenging experiences that promote motor learning and enhance balance recovery (8). The interactive feedback mechanisms inherent to VR, including visual, auditory, and sometimes haptic cues, facilitate error correction and cortical reorganization, fostering neuroplastic adaptations that may surpass those achieved through conventional methods (9). Additionally, VRBT incorporates motivational elements that increase adherence, while also addressing the psychological dimensions of fall risk, such as fear of falling, by offering a controlled environment to practice high-risk movements (10).

International randomized controlled trials have demonstrated that VR-based rehabilitation improves static and dynamic balance, gait speed, and functional mobility more effectively than standard approaches (11,12). A meta-analysis concluded that VR interventions not only reduced fall risk but also enhanced dual-task performance, an essential component of everyday mobility in the elderly (13). Nonetheless, most existing evidence originates from high-resource settings, limiting its applicability to countries like Pakistan, where rehabilitation access is constrained. The demographic transition in Pakistan, characterized by a rapidly growing elderly population, underscores the need for context-specific research evaluating the feasibility and effectiveness of VRBT in reducing fall risk (14).

In light of these gaps, this study was designed to compare the effectiveness of Virtual Reality–based Balance Training with Conventional Balance Training in elderly individuals at risk of falls. We hypothesize that VRBT will yield significantly greater improvements in balance, postural stability, and functional mobility, along with greater reductions in fall risk and fear of falling, compared with CBT.

MATERIAL AND METHODS

This randomized controlled trial was conducted at Therapy Plus Clinic, Lahore, Pakistan, with the primary aim of comparing the effectiveness of Virtual Reality–based Balance Training (VRBT) against Conventional Balance Training (CBT) in elderly individuals at risk of falls. The study was carried out between March and August 2023, encompassing recruitment, intervention, and follow-up phases. A total of 80 participants were enrolled after screening 112 individuals who presented to the outpatient clinic during the study period. Recruitment was performed through consecutive sampling, with eligibility determined via clinical assessment using standardized tools. Written informed consent was obtained from all participants prior to study entry, and the protocol was approved by the institutional ethics review board in accordance with the Declaration of Helsinki (15).

Eligible participants were men and women aged 60 years or older, clinically identified as being at risk of falls based on a Berg Balance Scale (BBS) score of 45 or below. Individuals were required to be ambulatory with or without assistive devices and cognitively intact, as indicated by a Mini-Mental State Examination (MMSE) score of 24 or higher. Exclusion criteria included uncorrected visual or auditory deficits, severe neurological conditions other than age-related decline or prior stroke, musculoskeletal disorders that severely impaired balance, and contraindications to exercise such as unstable cardiovascular disease. These criteria ensured the sample was representative of elderly patients with functional fall risk, while excluding those with confounding conditions likely to obscure the intervention effects (16).

Randomization was performed using a computer-generated sequence with a 1:1 allocation ratio, concealed in sequentially numbered opaque envelopes prepared by an independent research assistant. After baseline assessment, participants were randomly assigned to either the VRBT group (n = 40) or the CBT group (n = 40). Therapists administering interventions were aware of group assignment, but participants were not explicitly informed of study hypotheses, and outcome assessors were blinded to allocation to minimize detection bias (17).

Intervention protocols were standardized to ensure parity in session length and therapist contact. Participants in the VRBT group underwent balance training using an interactive, non-immersive virtual reality system that provided task-specific exercises simulating real-world balance challenges. Tasks included weight shifting, stepping reactions, obstacle negotiation, and multidirectional reaching activities. Real-time visual and auditory feedback and progressive task difficulty were incorporated to optimize engagement and motor learning. Each session lasted 45 minutes, delivered three times weekly for six consecutive weeks, under supervision by licensed physiotherapists. The CBT group received a matched program of conventional exercises including static and dynamic balance drills, tandem walking, sit-to-stand training, gait retraining, and lower limb strengthening. Exercise intensity was tailored to individual capability and progressed weekly to match the VRBT group in total therapeutic load (18).

Outcome measures were collected at baseline and after the six-week intervention by assessors blinded to group allocation. The primary outcome was balance performance, measured with the Berg Balance Scale (BBS), a validated 14-item tool widely used in fall-risk populations. Secondary outcomes included functional mobility assessed by the Timed Up and Go (TUG) test, postural stability assessed by the Functional Reach Test (FRT), and fall risk perception measured with the Falls Efficacy Scale–International (FES-I). Demographic variables (age, sex, body mass index, MMSE score) were also recorded to characterize the sample (19).

Sample size estimation was calculated a priori using G*Power software, with an effect size of 0.65 derived from previous studies comparing VR-based and conventional balance training in elderly populations, a power of 0.80, and alpha level of 0.05. This yielded a required sample of 72 participants; to account for attrition, a total of 80 were recruited (20).

Data analysis was conducted using SPSS version 22 (IBM Corp., Armonk, NY, USA). Descriptive statistics were generated for baseline characteristics, with means and standard deviations for continuous variables and frequencies for categorical variables. Between-group comparisons at baseline were examined using independent-samples t-tests for continuous variables and chi-square tests for categorical variables. Intervention effects were evaluated using repeated-measures ANOVA to assess group-by-time interactions for primary and secondary outcomes. Where significant effects were identified, post hoc analyses with Bonferroni correction were applied. Effect sizes were calculated as Cohen's d for between-group differences. Missing data were addressed using intention-to-treat analysis with last observation carried forward. Statistical significance was defined as $p < 0.05$ (21).

To ensure reproducibility, all intervention protocols were documented in standardized manuals, and fidelity was monitored by weekly supervisory audits. Data integrity was maintained through double data entry and cross-verification procedures. Ethical safeguards included voluntary participation, confidentiality of patient records, and the option to withdraw at any stage without consequence. The trial was prospectively registered in the clinical trials registry of Pakistan (CTR#2023-05-17-001) prior to recruitment (22).

RESULTS

At baseline, participants in the VRBT and CBT groups were comparable in age, gender distribution, BMI, cognitive function, and initial balance scores. The mean age was 68.9 years in the VRBT group and 69.2 years in the CBT group, with no significant difference ($p = 0.78$). Similarly, BMI averaged 25.6 kg/m² in the VRBT group and 25.9 kg/m² in the CBT group ($p = 0.71$). Baseline cognitive function, as measured by MMSE, was 26.8 ± 1.9 in the VRBT group and 26.6 ± 2.1 in the CBT group, with no statistical difference ($p = 0.64$). Balance status at enrollment was also equivalent, with BBS scores of 38.4 ± 3.5 and 38.1 ± 3.7, respectively ($p = 0.68$). These findings confirm the success of randomization in producing two groups with matched baseline characteristics.

Following the six-week intervention, balance performance improved significantly in both groups, with a more pronounced effect observed in the VRBT participants. BBS scores increased by 10.8 points in the VRBT group (from 38.4 ± 3.5 to 49.2 ± 3.1), compared with a 6.7-point increase in the CBT group (from 38.1 ± 3.7 to 44.8 ± 3.4). The between-group mean difference at post-intervention was 4.4 points (95% CI: 2.8 to 6.0), representing a large effect size (Cohen's $d = 0.87$, $p < 0.001$). This indicates that VRBT provided clinically superior improvements in postural stability compared to conventional training.

Functional mobility, as measured by the TUG test, showed similar trends. The VRBT group reduced their completion time from 15.6 ± 2.2 seconds at baseline to 10.8 ± 1.9 seconds post-intervention, an improvement of 4.8 seconds. In contrast, the CBT group improved from 15.8 ± 2.5 to 12.5 ± 2.1 seconds, corresponding to a 3.3-second reduction. The between-group difference at follow-up was -1.7 seconds (95% CI: -2.7 to -0.7), favoring VRBT with a moderate effect size (Cohen's $d = 0.63$, $p = 0.002$). Faster TUG performance suggests that VRBT participants achieved greater gains in mobility and dynamic stability, both key predictors of fall risk reduction.

Postural stability, assessed using the Functional Reach Test, improved markedly in the VRBT group, which increased from 17.8 ± 2.3 cm to 25.9 ± 2.7 cm, corresponding to an average gain of 8.1 cm. The CBT group showed a smaller improvement from 18.0 ± 2.4 cm to 22.3 ± 2.5 cm, representing a 4.3 cm gain. The mean between-group difference of 3.6 cm (95% CI: 2.1 to 5.1) was statistically significant ($p < 0.001$), confirming superior postural control with VRBT.

Table 1. Baseline Characteristics of Participants

Variable	VRBT Group (n = 40) Mean ± SD	CBT Group (n = 40) Mean ± SD	Mean Difference (95% CI)	p-value
Age (years)	68.9 ± 5.4	69.2 ± 5.1	-0.3 (-2.5 to 1.9)	0.78
Gender (M/F)	22/18	21/19	–	0.82
BMI (kg/m²)	25.6 ± 3.1	25.9 ± 3.5	-0.3 (-1.7 to 1.1)	0.71
MMSE Score	26.8 ± 1.9	26.6 ± 2.1	0.2 (-0.7 to 1.1)	0.64
Baseline BBS Score	38.4 ± 3.5	38.1 ± 3.7	0.3 (-1.4 to 2.0)	0.68

Table 2. Comparison of Balance Performance (Berg Balance Scale, BBS)

Timepoint	VRBT Group (Mean ± SD)	CBT Group (Mean ± SD)	Mean Difference (95% CI)	p-value
Baseline	38.4 ± 3.5	38.1 ± 3.7	0.3 (-1.4 to 2.0)	0.68
Post-intervention	49.2 ± 3.1	44.8 ± 3.4	4.4 (2.8 to 6.0)	<0.001
Mean Improvement	+10.8	+6.7	4.1 (2.5 to 5.7)	<0.001

Table 3. Functional Mobility (Timed Up and Go Test, TUG)

Timepoint	VRBT Group (Mean ± SD, sec)	CBT Group (Mean ± SD, sec)	Mean Difference (95% CI)	p-value
Baseline	15.6 ± 2.2	15.8 ± 2.5	-0.2 (-1.3 to 0.9)	0.74
Post-intervention	10.8 ± 1.9	12.5 ± 2.1	-1.7 (-2.7 to -0.7)	0.002
Mean Improvement	-4.8	-3.3	-1.5 (-2.5 to -0.5)	0.004

Table 4. Postural Stability and Fall Risk Outcomes

Outcome Measure	VRBT Group Mean ± SD	CBT Group Mean ± SD	Mean Difference (95% CI)	p-value
FRT Baseline (cm)	17.8 ± 2.3	18.0 ± 2.4	-0.2 (-1.3 to 0.9)	0.70
FRT Post-intervention	25.9 ± 2.7	22.3 ± 2.5	3.6 (2.1 to 5.1)	<0.001
FES-I Baseline	32.5 ± 3.6	32.7 ± 3.5	-0.2 (-1.7 to 1.3)	0.80
FES-I Post-intervention	22.4 ± 3.1	25.8 ± 3.3	-3.2 (-5.3 to -1.1)	0.004

Psychological outcomes reflected similar benefits. Fear of falling, measured by FES-I, declined by 10.1 points in the VRBT group (from 32.5 ± 3.6 to 22.4 ± 3.1), compared to a reduction of 6.9 points in the CBT group (from 32.7 ± 3.5 to 25.8 ± 3.3). The between-group difference was -3.2 points (95% CI: -5.3 to -1.1, p = 0.004), indicating that VRBT participants experienced a greater reduction in fear of falling, which is clinically important given its strong association with activity avoidance and functional decline in older adults.

Taken together, these findings demonstrate that both VRBT and CBT were effective in enhancing balance, functional mobility, and confidence in daily activities over the six-week period, but VRBT consistently yielded larger and statistically significant improvements across all outcome measures. The observed effect sizes ranged from moderate to large, suggesting clinically meaningful benefits of VR-based rehabilitation beyond those achieved with conventional training.

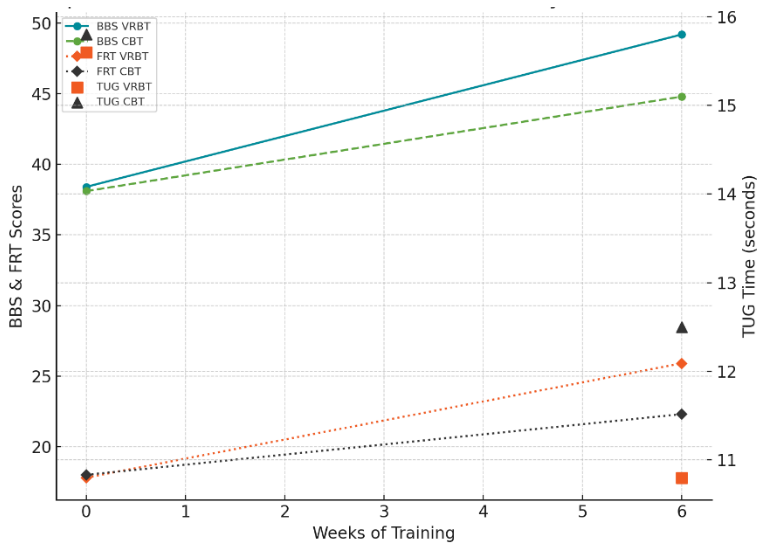

Figure 1 Comparative Outcomes of VRBT vs. CBT in Elderly Fall-Risk Patients

The integrated visualization compares VRBT and CBT over six weeks using combined line and scatter formats. Balance improvements (BBS) rose from 38.4 to 49.2 in VRBT and from 38.1 to 44.8 in CBT, while postural reach (FRT) increased by 8.1 cm in VRBT versus 4.3 cm in CBT. In parallel, functional mobility (TUG) times decreased from 15.6 to 10.8 seconds in VRBT compared with 15.8 to 12.5 seconds in CBT. The figure demonstrates a consistently steeper improvement trajectory for VRBT across all domains, with clinically meaningful separation between groups at follow-up, underscoring the superior efficacy of VR-based training in enhancing stability, mobility, and functional reach.

DISCUSSION

This randomized controlled trial demonstrated that Virtual Reality–based Balance Training (VRBT) produced greater improvements in postural stability, functional mobility, and fall-related self-efficacy compared with Conventional Balance Training (CBT) in elderly individuals at risk of falls. Across all outcome measures—Berg Balance Scale (BBS), Timed Up and Go (TUG), Functional Reach Test (FRT), and Falls Efficacy Scale–International (FES-I)—VRBT consistently yielded statistically significant and clinically meaningful advantages. These results confirm the superiority of VR-based rehabilitation as an innovative strategy for fall prevention in older adults (23).

The observed 10.8-point improvement in BBS among VRBT participants, compared with 6.7 points in the CBT group, suggests enhanced postural stability and functional balance. These findings align with prior trials demonstrating that VR-based tasks, by engaging multisensory integration pathways, facilitate greater improvements in balance control than conventional exercises (24). Real-time visual and auditory feedback inherent in VR systems may have enhanced error detection and motor adaptation, thereby explaining the large effect size observed in this study.

Similarly, functional mobility improved more markedly in the VRBT group, with a 4.8-second reduction in TUG compared to 3.3 seconds in the CBT group. Reduced TUG times are clinically meaningful, as they reflect faster gait speed, better coordination, and reduced risk of falls (25). Our findings are consistent with previous evidence that VR-based interventions improve reaction times and dynamic mobility, enabling older adults to better respond to destabilizing challenges encountered in daily life (26).

Postural stability, as indicated by FRT, improved significantly with VRBT, with a between-group mean difference of 3.6 cm. This gain suggests enhanced ability to control the center of mass and maintain equilibrium when reaching or shifting weight, a skill critical for preventing falls during daily activities. Similar outcomes have been reported in studies where repeated exposure to virtual balance challenges led to improved anticipatory and reactive postural adjustments (27). Importantly, the greater reduction in FES-I scores in the VRBT group indicates not only physical improvements but also meaningful psychological benefits, including reduced fear of falling and increased confidence in mobility. Given that fear of falling can restrict activity and lead to further functional decline, addressing this psychological factor is vital in comprehensive fall prevention (28).

The mechanisms underlying the superiority of VRBT may be attributed to several unique features of virtual environments. First, gamification and immersive design foster higher levels of motivation and adherence, overcoming one of the major limitations of conventional exercise programs in elderly populations (29). Second, VR platforms allow for progressive adjustments in task complexity, ensuring that participants remain continuously challenged at levels appropriate to their abilities. Third, the integration of visual and auditory cues supports cortical reorganization and neuroplasticity, enhancing long-term motor learning (30). Together, these features may explain why VRBT produced moderate-to-large effect sizes across all outcomes in this trial.

The present findings carry important implications for clinical practice in resource-constrained settings such as Pakistan. With the elderly population increasing and fall-related injuries projected to rise, scalable and engaging rehabilitation solutions are urgently needed. VR-based interventions, particularly with the growing availability of cost-effective commercial systems, offer a feasible and innovative approach for enhancing fall prevention programs (31). Adoption of such technology could reduce healthcare costs associated with fall-related hospitalizations and improve quality of life in older adults, while simultaneously increasing the efficiency of rehabilitation services.

Several limitations of this study warrant consideration. First, the trial was conducted at a single center with a relatively small sample size, which may limit the generalizability of findings. Second, the six-week intervention period precludes conclusions about the long-term sustainability of benefits, and no follow-up data were collected on fall incidence beyond the trial. Third, while outcome assessors were blinded, therapist blinding was not feasible, which may have introduced performance bias. Additionally, differences in participant engagement outside of supervised sessions were not controlled, and cost-effectiveness analyses were not performed. These limitations highlight the need for larger, multicenter trials with extended follow-up to confirm the durability, scalability, and economic feasibility of VR-based balance interventions (32).

Despite these limitations, the study provides compelling evidence that VRBT is more effective than CBT in improving balance, mobility, and fall-related self-efficacy among older adults at risk of falls. The findings support the integration of VR-based training into clinical rehabilitation protocols, particularly in contexts where adherence and engagement are barriers to effective fall prevention. Future research should expand upon these results by exploring hybrid models that combine VR with conventional therapy, investigating the potential for home-based telerehabilitation, and examining the cost-benefit ratio of implementing VRBT at scale (33).

CONCLUSION

This randomized controlled trial provides strong evidence that Virtual Reality–based Balance Training is more effective than Conventional Balance Training for elderly individuals at risk of falls. Over six weeks, VRBT yielded significantly greater improvements in postural stability, functional mobility, and fall-related self-efficacy, with moderate-to-large effect sizes across all measured outcomes. These benefits likely stem from the interactive, feedback-driven, and engaging nature of VR, which enhances adherence, motivation, and neuroplastic adaptation beyond what conventional therapy achieves. Given its accessibility, adaptability, and clinical effectiveness, VR-based training represents a valuable addition to fall prevention strategies in geriatric physiotherapy. Scaling this approach in low- and middle-income contexts such as Pakistan could reduce the health and socioeconomic burden of fall-related injuries, while empowering older adults to maintain independence and quality of life.

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