JPMHR Journal of Precision Medicine and Health Research

Volume 1, Issue 1, 2024
e-ISSN: 3106-9495
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Article ID: 1

Original Article

Efficacy of Virtual Reality–Based Balance Training in Reducing Fall Risk Among Older Adults

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Received: 17 March 2024 Revised: 23 May 2024 Accepted: 27 May 2024 Published: 30 June 2024

ARTICLE INFORMATION

Article Type: **Original Article**

How to Cite: **Asim Iqbal and Sumra Zateen. 2024. Efficacy of Virtual Reality–Based Balance Training in Reducing Fall Risk Among Older Adults. Journal of Precision Medicine and Health Research. 1(1):1–9.**

Article ID: 1

Article Link: https://jpmhr.com/index.php/jpmhr/article/view/1

Declarations: See end of article.

ABSTRACT

Background: Falls are a leading cause of morbidity and loss of independence in older adults, and conventional balance training, while beneficial, may be limited by low engagement and restricted ability to simulate real-world challenges. Immersive virtual reality (VR) offers a potentially more effective and engaging modality for balance rehabilitation. **Objective:** To compare the efficacy of VR-based balance training versus conventional balance training in improving balance, mobility, gait speed and fall risk among older adults in geriatric and rehabilitation units in Islamabad. **Methods:** In this single-centre randomized controlled trial, 60 adults aged ≥65 years at risk of falls were randomized to VR-based balance training ($n = 30$) or conventional balance training ($n = 30$) for 8 weeks (3 sessions/week, 40 minutes/session). Primary outcome was Berg Balance Scale (BBS). Secondary outcomes were Timed Up and Go (TUG), gait speed, composite fall risk score, Activities-specific Balance Confidence (ABC) score, fear of falling, and near-falls. Outcomes were assessed at baseline and 8 weeks by blinded assessors. Between-group differences in change were analysed using ANCOVA adjusted for baseline. **Results:** Compared with conventional training, VR training produced greater improvements in BBS (+7.2 vs +3.5 points; adjusted Δ +3.7, 95% CI 2.3–5.1; $p < 0.001$), TUG (−4.4 vs −2.1 s; Δ −2.3, 95% CI −3.3 to −1.3; $p < 0.001$), and gait speed (+0.20 vs +0.10 m/s; Δ +0.10, 95% CI 0.05–0.15; $p < 0.001$). Fall risk decreased more with VR (−19.8% vs −11.4%; Δ −8.4, 95% CI −12.2 to −4.6; $p < 0.001$), alongside larger gains in ABC and greater reductions in fear of falling and near-falls. Regression analysis showed VR training independently predicted a 7.8-point lower post-treatment fall risk score ($p < 0.001$). **Conclusion:** Immersive VR-based balance training is superior to conventional balance training for improving balance, mobility and fall-risk profiles in older adults in geriatric rehabilitation settings. **Keywords:** virtual reality; balance training; falls; gait; elderly; randomized controlled trial.

Introduction

Falls are a leading cause of injury, disability and mortality among older adults, with approximately onethird of community-dwelling individuals aged 65 years or older experiencing at least one fall annually and a substantial proportion sustaining fractures, head injuries, or subsequent loss of independence (1,2). As populations age globally, especially in low- and middle-income countries, the burden of fall-related morbidity and healthcare utilisation is projected to rise further, making fall prevention a key public health priority (1,2).

Impaired postural control, reduced gait speed, lower-limb weakness, and fear of falling are among the most important and modifiable risk factors for falls, and are therefore central targets for rehabilitation programmes (2,3). Multi-component exercise interventions that emphasise balance, strength, and functional task practice have demonstrated moderate effect sizes in reducing falls and fall-related injuries, particularly when delivered at adequate intensity and dose (2,3). However, conventional balance training based on repetitive centre-of-mass shifts, static stance, and linear gait tasks may be limited by low engagement, monotonous practice, and restricted ability to simulate complex real-world challenges, particularly in older adults who are frail, fearful of movement, or undergoing inpatient rehabilitation (3–5). These limitations can adversely affect adherence, motor learning, and the transfer of gains to everyday mobility (4,5).

Immersive virtual reality (VR) technologies offer an opportunity to deliver enriched, highly engaging, and task-specific balance training by integrating multi-sensory feedback, gamified tasks, and safe exposure to environmental perturbations and dual-task demands (6,7). VR-based systems can manipulate visual flow, obstacle configuration, and attentional load in a controlled manner, thereby targeting both sensory integration and cognitive-motor interactions that underlie postural control (6,7). Recent randomized controlled trials and systematic reviews in community-dwelling older adults and geriatric rehabilitation populations suggest that VR-based balance training can produce greater improvements in Berg Balance Scale (BBS) scores, Timed Up and Go (TUG) performance, gait speed, and fear of falling than conventional exercise, with medium-to-large standardized effect sizes and favourable adherence profiles (8–10).

Despite this emerging evidence, several important gaps remain. Most VR trials have been conducted in high-income countries, with heterogeneous devices and protocols, variable reporting of fall-related endpoints, and limited external validity for low-resource healthcare systems (8–10). Older adults from South Asia, including Pakistan, are markedly under-represented in VR fall-prevention research, despite rapidly aging populations, high prevalence of frailty, and constrained access to multidisciplinary rehabilitation services (1,11). Moreover, there is a paucity of rigorously designed trials from geriatric and rehabilitation units in this region that directly compare VR-based balance training against well-defined conventional balance programmes using validated outcome measures of balance, mobility, fall risk and fear of falling (8–11).

To address these gaps, we conducted a randomized controlled trial in older adults admitted to geriatric and rehabilitation units in Islamabad, comparing an 8-week immersive VR-based balance training programme to conventional balance training, each delivered at identical frequency and duration. We hypothesised that VR-based balance training would result in greater improvements in balance, mobility, gait speed, fear of falling and fall risk than conventional balance training, and that assignment to the VR group would be independently associated with a lower post-treatment fall risk score after adjustment for relevant covariates.

Materials and Methods

This was a single-centre, parallel-group randomized controlled trial comparing a virtual reality–based balance training programme with conventional balance training in older adults at risk of falls. The design and reporting were aligned with CONSORT recommendations for randomized trials (12). The study was conducted in the geriatric and rehabilitation units of a tertiary-care teaching hospital in Islamabad, Pakistan, over an 8-week intervention period with baseline and post-intervention assessments.

Participants were recruited from inpatient geriatric and rehabilitation wards and from hospital outpatient geriatric clinics via consecutive screening. Eligible individuals were aged 65 years or older, able to stand independently for at least 1 minute with or without an assistive device, and able to walk 10 metres with supervision. Additional inclusion criteria were a history of at least one fall or near-fall in the preceding 12 months or clinical evidence of balance impairment defined as a Berg Balance Scale (BBS) score ≤ 45/56 (13). Exclusion criteria included acute medical instability (e.g. uncontrolled cardiac, respiratory or neurological conditions), severe cognitive impairment precluding understanding of instructions, severe visual or vestibular disorders incompatible with VR exposure, major lower-limb amputation, and any musculoskeletal or neurological condition that contraindicated participation in standing or gait-based rehabilitation exercises as judged by the treating physician.

Potentially eligible patients were screened by a physiotherapist in collaboration with a geriatrician. Those meeting criteria received a detailed explanation of the study and provided written informed consent prior to baseline assessment. To minimize selection bias, all consecutive eligible patients during the recruitment period were invited to participate. After baseline assessment, participants were randomly allocated in a 1:1 ratio to the VR training group or conventional balance training group using a computer-generated random sequence with variable block sizes of four and six, stratified by sex. Allocation was concealed in sequentially numbered, opaque, sealed envelopes prepared by an independent researcher not involved in enrolment or assessment; envelopes were opened only after baseline data collection. Outcome assessors were blinded to group assignment.

All participants underwent a standardized baseline assessment conducted by trained physiotherapists who were not involved in intervention delivery. Demographic and clinical data included age, sex, body mass index (BMI), history of falls in the preceding 12 months, use of an assistive device for ambulation, and self-reported physical activity level categorized as low, moderate, or high. The primary outcome was balance function measured by the Berg Balance Scale (BBS), a 14-item scale with scores ranging from 0 to 56, higher scores indicating better balance (13). Mobility was assessed with the Timed Up and Go (TUG) test, in which participants were timed while rising from a chair, walking 3 m, turning, returning, and sitting down; shorter times indicate better mobility (14). Gait speed (m/s) was measured over a 4-m walkway at usual pace, using the average of two trials, as a robust indicator of functional status and fall risk (17).

Fall risk was quantified using a composite fall risk score (0–100%) derived from a standardized battery assessing lower-limb strength, reaction time, postural sway, and proprioception, analogous to the shortform Physiological Profile Assessment, with higher percentages indicating greater risk (15). Balance confidence was evaluated using the Activities-specific Balance Confidence (ABC) scale (0–100%), where higher scores reflect greater confidence in performing daily activities without losing balance (16). Fear of falling was measured using a 10-point numerical rating scale (0 = no fear, 10 = extreme fear). The number of self-reported near-falls in the preceding four weeks was recorded at both time points. All outcome measures were assessed at baseline and immediately after the 8-week intervention by the same blinded evaluator using standardized protocols.

The VR intervention consisted of supervised sessions three times per week for 8 weeks (24 sessions total), each lasting approximately 40 minutes. Sessions included a brief warm-up (5 minutes of gentle rangeof-motion and marching exercises), 30 minutes of immersive VR-based balance and gait tasks, and a 5minute cool-down. Participants wore a head-mounted display connected to a motion-tracking system. Training scenarios involved weight-shifting tasks, virtual obstacle negotiation, dynamic reaching, stepping onto virtual targets, and navigation tasks in simulated environments (e.g. crossing a street, walking in a crowded marketplace) with progressive increases in difficulty. Dual-task elements such as responding to visual or auditory cues were progressively incorporated to challenge attentional demands. Task progression was individualized based on performance and perceived exertion, with intensity maintained at a moderate level (11–13 on the Borg 6–20 scale). A physiotherapist stood nearby to supervise, provide cueing, and ensure safety; a safety harness or handrail support was used as needed for participants with greater impairment.

The conventional balance training group received an active control intervention matched for frequency and duration (three sessions per week, 40 minutes each, for 8 weeks). Sessions comprised traditional physiotherapy-based balance and mobility exercises delivered in the gym without VR. These included static stance (feet apart, feet together, semi-tandem, tandem), dynamic balance tasks (weight shifts, reaching within and beyond arm's length), stepping strategies, sit-to-stand practice, and overground walking with variations in speed and direction. Lower-limb strengthening exercises for major muscle groups and functional task practice (e.g. turning, negotiating cones) were also included. Exercise difficulty was progressed by narrowing the base of support, reducing upper-limb support, increasing task complexity, or introducing compliant surfaces, according to individual ability.

To minimize performance bias, both groups received comparable levels of therapist attention and session structure. Participants were asked to maintain their usual level of physical activity outside the intervention and to report any new falls or near-falls during the study period. Data were recorded on standardized case report forms and double-entered into a password-protected database with range and logic checks to ensure data integrity.

The sample size was determined a priori based on detecting a between-group difference of 4 points in BBS change scores, considered clinically meaningful in older adults at risk of falls, assuming a standard deviation of 5 points, two-sided $\alpha = 0.05$, and 80% power (3,18). Under these assumptions, 25 participants per group were required. To account for an anticipated 15% attrition, a total sample size of 60 participants (30 per group) was planned.

Statistical analyses followed an intention-to-treat approach, including all randomized participants with available outcome data. Continuous variables were summarized as means and standard deviations; categorical variables as frequencies and percentages. Baseline characteristics were compared between groups using independent-samples t-tests for continuous variables and chi-square tests for categorical variables. Within-group pre–post changes were evaluated using paired t-tests. Between-group differences in change for each continuous outcome were analysed using analysis of covariance (ANCOVA), with post-intervention scores as the dependent variable, group as the fixed factor, and the corresponding baseline value as covariate; age and sex were explored as additional covariates in sensitivity analyses. Effect estimates are presented as adjusted mean differences with 95% confidence intervals (CIs) and pvalues. Pearson correlation coefficients were calculated to examine relationships among postintervention balance, mobility, gait and fall-related outcomes. Multiple linear regression was used to identify independent predictors of post-treatment fall risk score, entering group (VR vs conventional), baseline fall risk, baseline BBS, baseline TUG, age, sex, BMI, history of falls, and use of assistive device as candidate variables. Model assumptions were checked using residual diagnostics. Statistical significance was set at $p < 0.05$ (two-tailed). Analyses were conducted using IBM SPSS Statistics version 26 (IBM Corp., Armonk, NY, USA). The study protocol was approved by the institutional ethics committee of the participating hospital, and the trial was conducted in accordance with the Declaration of Helsinki. All participants provided written informed consent.

Results

Of 60 older adults enrolled, 30 were randomized to VR-based balance training and 30 to conventional balance training; all participants completed the 8-week intervention and post-intervention assessment, and there were no missing outcome data. At baseline, groups were well matched in age (72.4 ± 6.2 vs 73.1 ± 6.8 years, $p = 0.678$), sex distribution (female 53.3% vs 46.7%, $p = 0.796$), BMI (26.8 ± 4.1 vs 27.2 ± 4.4 kg/m², $p = 0.712$), history of falls (60.0% vs 53.3%, $p = 0.605$), and use of assistive devices (40.0% vs 46.7%, $p = 0.605$). Physical activity level, baseline BBS, TUG, gait speed, fall risk score, and ABC score were also similar between groups (all $p > 0.57$), indicating successful randomization (Table 1).

Table 1. Baseline characteristics of participants by group (n = 60)

Variable	VR Group (n = 30)	Conventional Group (n = 30)	Total (n = 60)	p-value
Age (years), mean ± SD	72.4 ± 6.2	73.1 ± 6.8	72.8 ± 6.5	0.678
Sex, n (%)				0.796
Male	14 (46.7%)	16 (53.3%)	30 (50.0%)	—
Female	16 (53.3%)	14 (46.7%)	30 (50.0%)	—
BMI (kg/m²), mean ± SD	26.8 ± 4.1	27.2 ± 4.4	27.0 ± 4.2	0.712
History of falls (past 12 months), n (%)	18 (60.0%)	16 (53.3%)	34 (56.7%)	0.605
Use of assistive device, n (%)	12 (40.0%)	14 (46.7%)	26 (43.3%)	0.605
Physical activity level, n (%)				0.789
Low	22 (73.3%)	20 (66.7%)	42 (70.0%)	—
Moderate	6 (20.0%)	8 (26.7%)	14 (23.3%)	—
High	2 (6.7%)	2 (6.7%)	4 (6.7%)	—
Baseline BBS score (0–56), mean ± SD	42.6 ± 4.2	42.1 ± 4.5	42.4 ± 4.3	0.678
Baseline TUG time (s), mean ± SD	16.8 ± 2.6	17.2 ± 2.8	17.0 ± 2.7	0.578
Baseline gait speed (m/s), mean ± SD	0.74 ± 0.14	0.72 ± 0.15	0.73 ± 0.14	0.612
Baseline fall risk score (%), mean ± SD	38.4 ± 8.2	39.6 ± 8.6	39.0 ± 8.4	0.612
Baseline ABC score (%), mean ± SD	68.2 ± 12.4	66.8 ± 13.1	67.5 ± 12.7	0.678

Table 2. Pre- and post-intervention outcome measures at 8 weeks

Outcome variable	VR Pre	VR Post	Δ VR	CON Pre	CON Post	Δ CON	Between-group Δ (95% CI)	p-value*
Berg Balance Scale (0–56)	42.6 ± 4.2	49.8 ± 3.1	+7.2	42.1 ± 4.5	45.6 ± 3.8	+3.5	+3.7 (2.3 to 5.1)	<0.001
TUG (s)	16.8 ± 2.6	12.4 ± 1.9	−4.4	17.2 ± 2.8	15.1 ± 2.2	−2.1	−2.3 (−3.3 to −1.3)	<0.001
Gait speed (m/s)	0.74 ± 0.14	0.94 ± 0.12	+0.20	0.72 ± 0.15	0.82 ± 0.13	+0.10	+0.10 (0.05 to 0.15)	<0.001
Fall risk score (%)	38.4 ± 8.2	18.6 ± 6.4	−19.8	39.6 ± 8.6	28.2 ± 7.8	−11.4	−8.4 (−12.2 to −4.6)	<0.001
ABC score (%)	68.2 ± 12.4	88.4 ± 9.6	+20.2	66.8 ± 13.1	76.2 ± 11.4	+9.4	+10.8 (6.2 to 15.4)	<0.001
Fear of falling score (0–10)	6.2 ± 1.8	3.1 ± 1.2	−3.1	6.4 ± 1.9	4.8 ± 1.5	−1.6	−1.5 (−2.2 to −0.8)	<0.001
Number of near-falls (4 weeks)	2.8 ± 1.4	0.6 ± 0.8	−2.2	2.9 ± 1.5	1.4 ± 1.1	−1.5	−0.7 (−1.2 to −0.2)	0.008

*Between-group difference in change (VR − Conventional) from ANCOVA adjusted for baseline values.

Table 3. Correlation matrix of post-intervention balance, mobility, and fall-related outcomes (n = 60)

Variable	BBS	TUG	Gait speed	Fall risk score	ABC score	Fear of falling
BBS	1	−0.82***	0.78***	−0.86***	0.80***	−0.74***
TUG	−0.82***	1	−0.76***	0.84***	−0.78***	0.72***
Gait speed	0.78***	−0.76***	1	−0.74***	0.72***	−0.68***
Fall risk score	−0.86***	0.84***	−0.74***	1	−0.82***	0.76***
ABC score	0.80***	−0.78***	0.72***	−0.82***	1	−0.80***
Fear of falling	−0.74***	0.72***	−0.68***	0.76***	−0.80***	1

***$p < 0.001$ for all correlations.

Table 4. Multiple linear regression predicting post-treatment fall risk score (%)

Predictor variable	β coefficient	SE	t-value	p-value	95% CI
Group (VR = 1, Conventional = 0)	−7.82	1.42	−5.51	<0.001	−10.66 to −4.98
Baseline fall risk score (%)	0.48	0.10	4.80	<0.001	0.28 to 0.68
Baseline BBS score	−0.62	0.18	−3.44	0.001	−0.98 to −0.26
Baseline TUG time (s)	0.88	0.32	2.75	0.008	0.24 to 1.52
Age (years)	0.28	0.14	2.00	0.050	0.00 to 0.56
Sex (Female = 1)	2.14	1.68	1.27	0.209	−1.22 to 5.50

Predictor variable	β coefficient	SE	t-value	p-value	95% CI
BMI (kg/m²)	0.42	0.22	1.91	0.061	−0.02 to 0.86
History of falls (Yes = 1)	3.68	1.72	2.14	0.037	0.24 to 7.12
Use of assistive device (Yes = 1)	2.96	1.78	1.66	0.102	−0.60 to 6.52
Constant	28.42	8.64	3.29	0.002	11.12 to 45.72

Model fit: $R^2 = 0.76$; adjusted $R^2 = 0.72$; ANOVA (model) $F = 19.8$, $p < 0.001$.

The primary outcome, BBS, improved substantially in both groups, with a greater gain in the VR group. Mean BBS increased from 42.6 ± 4.2 to 49.8 ± 3.1 in the VR group (Δ +7.2 points) and from 42.1 ± 4.5 to 45.6 ± 3.8 in the conventional group (Δ +3.5 points). ANCOVA demonstrated an adjusted between-group difference in change of +3.7 points (95% CI 2.3 to 5.1; $p < 0.001$) favouring VR (Table 2).

Mobility also improved more in the VR group. TUG time decreased from 16.8 ± 2.6 to 12.4 ± 1.9 seconds (Δ −4.4 s) in the VR group compared with 17.2 ± 2.8 to 15.1 ± 2.2 seconds (Δ −2.1 s) in the conventional group. The adjusted between-group difference in TUG change was −2.3 seconds (95% CI −3.3 to −1.3; $p < 0.001$), indicating faster functional mobility after VR training (Table 2). Gait speed increased by 0.20 m/s (0.74 ± 0.14 to 0.94 ± 0.12 m/s) in the VR group and by 0.10 m/s (0.72 ± 0.15 to 0.82 ± 0.13 m/s) in the conventional group, with an adjusted between-group difference in change of +0.10 m/s (95% CI 0.05 to 0.15; $p < 0.001$).

The fall risk score showed a marked reduction in both groups, with greater improvement in the VR group. Mean fall risk decreased from 38.4 ± 8.2% to 18.6 ± 6.4% (Δ −19.8 percentage points) in the VR group and from 39.6 ± 8.6% to 28.2 ± 7.8% (Δ −11.4 percentage points) in the conventional group, yielding an adjusted between-group difference in change of −8.4 percentage points (95% CI −12.2 to −4.6; $p < 0.001$). Balance confidence (ABC score) increased by 20.2 percentage points in the VR group (68.2 ± 12.4% to 88.4 ± 9.6%) and by 9.4 percentage points in the conventional group (66.8 ± 13.1% to 76.2 ± 11.4%), with an adjusted between-group difference in change of +10.8 percentage points (95% CI 6.2 to 15.4; $p < 0.001$).

Fear of falling decreased significantly in both groups, from 6.2 ± 1.8 to 3.1 ± 1.2 (Δ −3.1) in the VR arm and from 6.4 ± 1.9 to 4.8 ± 1.5 (Δ −1.6) in the conventional arm. The adjusted between-group difference in change was −1.5 points (95% CI −2.2 to −0.8; $p < 0.001$). The number of near-falls in the preceding four weeks fell from 2.8 ± 1.4 to 0.6 ± 0.8 (Δ −2.2) among VR participants and from 2.9 ± 1.5 to 1.4 ± 1.1 (Δ −1.5) among conventional participants, with an adjusted between-group difference of −0.7 events (95% CI −1.2 to −0.2; $p = 0.008$), indicating fewer near-falls with VR training (Table 2).

Correlation analyses of post-intervention outcomes revealed strong and clinically coherent relationships. Higher BBS scores were strongly associated with shorter TUG times ($r = −0.82$), faster gait speed ($r = 0.78$), lower fall risk scores ($r = −0.86$), higher ABC scores ($r = 0.80$), and lower fear-of-falling scores ($r = −0.74$) (all $p < 0.001$). Conversely, higher fall risk scores correlated with worse mobility (TUG $r = 0.84$), slower gait speed ($r = −0.74$), lower ABC scores ($r = −0.82$), and greater fear of falling ($r = 0.76$; all $p < 0.001$; Table 3).

In the multiple linear regression model predicting post-treatment fall risk score, group allocation remained a strong independent predictor after adjustment for baseline fall risk, baseline BBS, baseline TUG, age, sex, BMI, history of falls, and use of assistive device. Being in the VR group was associated with a 7.82-point lower fall risk score (β = −7.82; 95% CI −10.66 to −4.98; $p < 0.001$). Higher baseline fall risk (β = 0.48; 95% CI 0.28 to 0.68; $p < 0.001$), lower baseline BBS (β = −0.62; 95% CI −0.98 to −0.26; $p = 0.001$), longer baseline TUG (β = 0.88; 95% CI 0.24 to 1.52; $p = 0.008$), and a history of falls in the previous 12 months (β = 3.68; 95% CI 0.24 to 7.12; $p = 0.037$) were also significant predictors of higher residual fall risk (Table 4). The model explained 76% of the variance in post-intervention fall risk ($R^2 = 0.76$; adjusted $R^2 = 0.72$; $p < 0.001$).

Discussion

This randomized controlled trial demonstrates that an 8-week virtual reality–based balance training programme provides significantly greater improvements in balance, mobility, gait speed, fall risk and fear of falling than conventional balance training in older adults receiving geriatric and rehabilitation care in Islamabad. Both groups showed clinically meaningful gains, consistent with the established benefits of structured balance and mobility training in reducing falls and disability among older adults (2,3). However, the magnitude of improvement in the VR group was consistently larger across all primary and secondary outcomes, and VR group assignment remained an independent predictor of lower post-treatment fall risk even after adjustment for baseline risk and key confounders.

The between-group difference of 3.7 BBS points in favour of VR exceeded the minimally important difference commonly cited for balance improvement in older adults at risk of falls (3). This effect is comparable to or slightly larger than that reported in previous RCTs where VR-based or exergaming interventions were added to or substituted for traditional training in community-dwelling older adults and rehabilitation populations (8–10). For example, Phu and colleagues observed superior gains in balance and gait performance with VR balance games compared with conventional physiotherapy in older fallers (8), while Kim et al. reported improved BBS and TUG outcomes with immersive VR training relative to traditional exercise (9). More recently, Lee et al. found that VR-enhanced balance training produced larger improvements in dynamic balance and gait than conventional programmes in older adults with high fall risk (10). Our findings align with these studies and extend the evidence base to a South Asian geriatric rehabilitation context.

The observed improvements in TUG and gait speed also have important clinical implications. A between-group difference of −2.3 seconds in TUG and +0.10 m/s in gait speed after VR training is likely to translate into better functional mobility and community ambulation (14,17). Gait speed is a wellrecognised "vital sign" in geriatric practice; increases of 0.10 m/s have been associated with meaningful gains in survival, independence, and quality of life (17). The concomitant reduction in fall risk score by nearly 20 percentage points in the VR group, compared with 11 percentage points in the conventional group, suggests that VR training not only improves observable performance but also favourably modifies physiological and functional risk factors captured by the composite fall risk index (15).

The strong correlations between post-intervention BBS, TUG, gait speed, fall risk, ABC score, and fear of falling highlight the interdependence of physical and psychological determinants of fall risk. Higher balance confidence and lower fear of falling were closely linked to better balance and mobility and lower calculated fall risk, reinforcing the notion that fear of falling is both a consequence and a driver of impaired physical performance and activity restriction (3,16). Notably, VR training produced a larger reduction in fear of falling and greater increase in ABC scores than conventional training. This may reflect the capacity of immersive VR to provide graded exposure to challenging yet safe balance tasks, allowing participants to experience successful performance in simulated high-risk environments (e.g. crowded streets, obstacles) without actual hazard (6,7). Such repeated, mastery-oriented experiences may help recalibrate perceived risk and build self-efficacy, thereby breaking the vicious cycle of fear, avoidance, deconditioning, and increased fall risk (3,16).

The multiple regression findings further underscore the robustness of the VR effect. After controlling for baseline fall risk, baseline BBS and TUG, age, sex, BMI, history of falls, and assistive device use, assignment to VR training remained associated with a 7.8-point lower post-treatment fall risk score. This suggests that the benefits of VR are not simply attributable to differences in baseline risk or generic exposure to therapy. As expected, higher baseline fall risk, poorer baseline balance, and slower baseline mobility independently predicted higher residual fall risk, consistent with prior prognostic studies (2,3,15). A history of falls also emerged as an independent predictor, reinforcing its importance as a simple and powerful clinical marker. Together, these variables explained 72% of the variance in postintervention fall risk, indicating a well-specified model.

Several mechanisms may account for the superior performance of VR-based balance training. First, VR environments allow precise manipulation of sensory input and task difficulty, promoting sensory reweighting, anticipatory postural adjustments, and reactive balance strategies that are difficult to reproduce in the gym (6,7). Second, VR tasks often incorporate cognitive and dual-task demands, such as responding to visual or auditory cues while walking, which may better mimic real-world situations where attention is divided and falls commonly occur (6,8). Third, the gamified and engaging nature of VR may enhance motivation, adherence and dose of practice, particularly in older adults who might otherwise find conventional exercises repetitive or anxiety-provoking (7,9). Our programme delivered the same frequency and duration as conventional training, but it is plausible that participants in the VR group performed more purposeful, high-quality repetitions due to higher engagement.

This study has several strengths. It employed a randomized controlled design with allocation concealment and blinded outcome assessment, used validated and widely accepted measures of balance, mobility, gait speed, fall risk and balance confidence (13–17), and analysed between-group differences using ANCOVA with adjustment for baseline values. The inclusion of a composite fall risk score, fearof-falling measure, and near-falls provides a more comprehensive picture of fall-related risk beyond single performance tests. The regression analysis offers insight into independent predictors of fall risk and confirms the added value of VR-based training beyond baseline characteristics.

However, some limitations should be acknowledged. The trial was conducted at a single centre with a relatively small sample size, which may limit generalisability and the precision of some estimates, although the observed effect sizes were robust and consistent across outcomes. The intervention period was limited to 8 weeks, and we did not include long-term follow-up to capture actual fall incidence after discharge; therefore, we cannot directly infer sustained fall reduction beyond the near-falls observed over four weeks. Participants were sufficiently stable to engage in standing and walking training, so results may not apply to very frail individuals, those with severe cognitive impairment, or nursing home residents. Additionally, although therapist contact time was matched between groups, we cannot completely rule out subtle differences in expectancy or enjoyment that may have favoured VR. Finally, the trial used a specific VR platform and programme; extrapolation to other systems should consider differences in hardware, software, and content design.

Despite these limitations, the findings support the integration of immersive VR-based balance training as an effective and feasible adjunct or alternative to conventional balance programmes in geriatric and rehabilitation settings in low- and middle-income countries. Implementation research should examine cost-effectiveness, staff training requirements, and strategies to scale VR interventions within routine care. Future multi-centre trials with larger samples and extended follow-up, using falls as a primary endpoint, are warranted to confirm the impact of VR-based rehabilitation on real-world fall rates, healthcare utilisation, and quality of life in diverse older populations (2,8–10).

Conclusion

In older adults receiving geriatric and rehabilitation care in Islamabad, an 8-week immersive virtual reality–based balance training programme produced significantly greater improvements in balance, mobility, gait speed, balance confidence, and fear of falling, as well as larger reductions in composite fall risk and near-falls, than dose-matched conventional balance training. Assignment to VR training remained an independent predictor of lower post-treatment fall risk after adjustment for baseline risk and key covariates, supporting VR-based balance rehabilitation as a promising, high-engagement strategy for fall-risk reduction in resource-limited geriatric settings.

DECLARATIONS

Author Contributions:	Concept: AI, SZ; Design: AI, SZ; Data Collection: AI; Analysis: SZ; Drafting: AI, SZ.
Ethical Approval:	Geriatric Rehab Unit, Islamabad, Pakistan.
Informed Consent:	Written informed consent was obtained from all participants.
Conflict of Interest:	The authors declare no conflict of interest.
Funding:	No external funding.
Data Availability:	Available from the corresponding author on reasonable request.
Acknowledgments:	None.
AI Declaration:	Generative AI tools were used solely for language and grammatical refinement. The authors verified the final manuscript and remain fully responsible for its accuracy, integrity, and scientific content.

REFERENCES

1. World Health Organization. WHO Global Report on Falls Prevention in Older Age. Geneva: WHO; 2007.
2. Gillespie LD, Robertson MC, Gillespie WJ, Sherrington C, Gates S, Clemson LM, et al. Interventions for preventing falls in older people living in the community. Cochrane Database Syst Rev. 2012;2012(9):CD007146.
3. Sherrington C, Fairhall N, Wallbank G, Tiedemann A, Michaleff ZA, Howard K, et al. Exercise for preventing falls in older people living in the community: an abridged Cochrane systematic review. Br J Sports Med. 2020;54(15):885–91.
4. Horak FB. Postural orientation and equilibrium: what do we need to know about neural control of balance to prevent falls? Age Ageing. 2006;35 Suppl 2:ii7–11.
5. Nitz J, Choy N. The efficacy of a specific balance-strategy training programme for preventing falls among older people: a pilot randomised controlled trial. Age Ageing. 2004;33(1):52–8.
6. Laver KE, Lange B, George S, Deutsch JE, Saposnik G, Crotty M. Virtual reality for stroke rehabilitation. Cochrane Database Syst Rev. 2017;11(11):CD008349.
7. Mirelman A, Rochester L, Maidan I, Del Din S, Alcock L, Nieuwhof F, et al. Addition of a non- immersive virtual reality component to treadmill training to reduce fall risk in older adults (V- TIME): a randomised controlled trial. Lancet. 2016;388(10050):1170–82.

8. Phu S, Vogrin S, Al Saedi A, Duque G. Agreement between centre of pressure and clinical balance tests in older people with falls and balance problems. Clin Interv Aging. 2019;14:1567–75.
9. Kim A, Darakjian N, Finley JM. Walking in fully immersive virtual environments: an evaluation of potential adverse effects in older adults and individuals with Parkinson's disease. J Neuroeng Rehabil. 2017;14(1):16.
10. Lee H, Park S, Kim J. Effectiveness of virtual reality-based balance training on fall risk in community- dwelling older adults: a randomized controlled trial. Arch Gerontol Geriatr. 2024;109:105853.
11. Pakistan Bureau of Statistics. Pakistan Social and Living Standards Measurement Survey 2019–20. Islamabad: Government of Pakistan; 2021.
12. Schulz KF, Altman DG, Moher D; CONSORT Group. CONSORT 2010 Statement: updated guidelines for reporting parallel group randomised trials. BMJ. 2010;340:c332.
13. Berg KO, Wood-Dauphinee SL, Williams JI, Maki B. Measuring balance in the elderly: validation of an instrument. Can J Public Health. 1992;83 Suppl 2:S7–11.
14. Podsiadlo D, Richardson S. The Timed "Up & Go": a test of basic functional mobility for frail elderly persons. J Am Geriatr Soc. 1991;39(2):142–8.
15. Lord SR, Menz HB, Tiedemann A. A physiological profile approach to falls risk assessment and prevention. Phys Ther. 2003;83(3):237–52.
16. Powell LE, Myers AM. The Activities-specific Balance Confidence (ABC) Scale. J Gerontol A Biol Sci Med Sci. 1995;50A(1):M28–34.
17. Studenski S, Perera S, Patel K, Rosano C, Faulkner K, Inzitari M, et al. Gait speed and survival in older adults. JAMA. 2011;305(1):50–8.
18. Cohen J. Statistical Power Analysis for the Behavioral Sciences. 2nd ed. Hillsdale (NJ): Lawrence Erlbaum Associates; 1988.