DOI: 10.48305/jrrs.2026.46757.1159 Published by Vesnu Publications

Effect of Adding Perturbation-Based Balance Training to a Falls Management Exercise Program on Reactive Balance in Older Women: A Quasi-experimental Trial

Yalda Beygi[1], Nader Rahnama[2], Ashraf Mahmoudzadeh[3]

Original Article

Abstract

Introduction: Falls are common among older adults, and impaired reactive balance may increase fall risk. This study investigated the effect of adding perturbation-based balance training to a falls management exercise program on reactive balance in older women.

Materials and Methods: This quasi-experimental trial included 40 women aged 60 years and older with a history of falls. Participants drew one of 40 identical, opaque, sealed envelopes containing 20 allocations for each group (1:1) and were assigned to either the falls management exercise or combined training. Both groups trained three times weekly for 8 weeks (24 sessions); the combined group additionally completed 15 minutes of perturbation-based balance training per session. The primary outcomes were the Gain and Phase Lag indices of the Fall Risk Assessment (Sinus) test using the Synapsys Posturography System under eyes-open and eyes-closed conditions. Complete-case analyses included 31 participants (n=15 and n=16) and used paired-samples t-tests and ANCOVA (alpha = 0.05).

Results: Both interventions significantly improved reactive-balance indices under eyes-open and eyes-closed conditions. Within-group effect sizes ranged from 0.60 to 1.52. After baseline adjustment, none of the between-group comparisons were significant (P = 0.096-0.951; partial eta squared = 0-0.096). Percentage improvements ranged from 15.2% to 33.6% in the falls management group and from 12.7% to 35.9% in the combined group.

Conclusion: Eight weeks of falls management exercise, with or without perturbation-based balance training, improved reactive-balance indices in older women. However, adding perturbation-based balance training did not provide a statistically significant additional benefit.

Keywords: Older adults; Falls; Reactive balance; Postural balance; Perturbation-based balance training; Falls management exercise

Citation: Beygi Y, Rahnama N, Mahmoudzadeh A. **Effect of Adding Perturbation-Based Balance Training to a Falls Management Exercise Program on Reactive Balance in Older Women: A Quasi-experimental Trial.** J Res Rehabil Sci 2025; 21.

Received date: 31.12.2024 Accept date: 04.02.2025 Published: 03.04.2025

Introduction

Population aging refers to the gradual shift in a population's age structure toward older age groups, driven mainly by declining fertility rates and increasing life expectancy (1). This phenomenon is widely recognized as one of the most significant demographic and social challenges of the twenty-first century, with far-reaching implications for health, care, and rehabilitation systems (2). According to United Nations reports, the proportion of older adults

1- Department of Sport Injuries and Corrective Exercises, School of Sport Sciences, University of Isfahan, Isfahan, Iran
2- Professor, Department of Sport Injuries and Corrective Exercises, School of Sport Sciences, University of Isfahan, Isfahan, Iran
3- Assistant Professor, Department of Physiotherapy, School of Rehabilitation Sciences, Isfahan University of Medical Sciences, Isfahan, Iran
Corresponding Author: Ashraf Mahmoudzadeh; Assistant Professor, Department of Physiotherapy, School of Rehabilitation Sciences, Isfahan University of Medical Sciences, Isfahan, Iran; Email: a.mahmodzadeh@rehab.mui.ac.ir

This is an open-access article distributed under the terms of the Creative Commons Attribution-NonCommercial 4.0 Unported License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

in the global population is expected to increase substantially in the coming decades, with the population aged 65 and older projected to reach approximately 16% of the world's population by 2050 (1, 3). In Iran, population aging is also occurring at a considerable pace; according to the National Aging Document, the population aged 60 and older is expected to reach approximately 13 million people, or about 14% of the country's population, by 2031 (1410 in the Iranian calendar) (4). Accordingly, growth in the older population can have major consequences, including increased fall risk, reduced functional independence, and a greater need for care and rehabilitation services.

According to the World Guidelines for Falls Prevention and Management in Older Adults, a fall is defined as an event in which a person unintentionally comes to rest on the ground, floor, or a lower surface, and it is considered one of the leading causes of injury and loss of independence among older adults (5). Reports indicate that approximately 30% of individuals aged 65 and older and about 50% of those aged 80 and older experience a fall each year (6, 7). Fall-related injuries occur in a considerable proportion of cases and can range from minor injuries such as bruising to more severe outcomes such as fractures and head injuries (6).

Reactive balance plays a crucial role in fall prevention because, when balance is lost, an individual must restore posture through rapid, appropriate responses, including reactive stepping strategies. Evidence shows that reactive balance capacity declines in older adults compared with younger individuals; after exposure to balance perturbations, older adults typically exhibit weaker stepping responses, including shorter step length and a lower stepping threshold (8). This reduced ability to recover balance not only increases fall risk but can also lead to psychological and behavioral consequences. In this regard, fear of falling is a common problem among older adults. It can result in restricted daily activities, reduced social participation, increased negative emotions, and lower levels of physical activity (9, 10).

Given the physical, psychological, and social consequences of falls, designing and implementing effective fall-prevention strategies for older adults is essential. Fall prevention education is a low-cost, feasible intervention that can increase older adults' awareness of risk factors and prevention strategies, thereby reducing fall risk (11). Studies show that exercise interventions combining strength, balance, and aerobic training can reduce fall risk in older adults, particularly healthy older adults (12, 13). However, researchers have not consistently reported the effectiveness of these exercises in frail older adults or those at higher risk of falling, and one possible reason is that many conventional exercises are not specifically tailored to the responses required for balance recovery during a fall (12). In contrast, an effective response to sudden perturbations requires mechanisms such as rapid expansion of the base of support, compensatory stepping, and compensatory rotations of body segments around the center of mass—mechanisms not specifically trained in conventional strength or balance exercises (14, 15). In contrast, perturbation-based balance training exposes individuals to conditions that demand rapid balance recovery and can lead to greater improvements in reactive balance and reduced fall risk (15).

In recent years, perturbation-based balance training has received considerable attention as a task-specific approach for improving reactive balance and preventing falls (12, 15). By applying external, sudden, and repeated perturbations, this training exposes individuals to conditions that temporarily reduce stability and require a rapid, appropriate response to prevent falling (15). Therefore, training under perturbation conditions can better prepare individuals to cope with real-life balance-threatening situations, such as slipping, tripping, and sudden loss of balance (12, 15). Studies have shown that perturbation-based balance training can improve balance recovery responses and certain functional indicators related to fall prevention in older adults (12, 14, 15). Evidence from systematic reviews and meta-analyses also indicates that these exercises have considerable potential to reduce fall risk. However, training dose, perturbation type, participant characteristics, and the outcome measured can influence the magnitude of their effect (12, 13, 16).

A systematic review and network meta-analysis by Kim et al. (17), encompassing 39 randomized controlled trials and 1,388 older adults, showed that balance exercises with a reactive component had the highest probability of improving reactive balance. However, the authors emphasized that adaptations depend on the type, direction, intensity, and location of the applied perturbation, and that the transfer of effects to untrained reactive tasks may be limited (17). This principle reinforces the need to examine the effect of adding perturbation-based exercises to a structured fall management program and to evaluate this effect using an objective posturography test.

Despite the growing body of research on perturbation-based balance training, it remains unclear whether adding a short-term component of these exercises to structured fall management programs

produces a significant additional effect on reactive balance compared with performing fall management exercises alone. Some studies have examined combinations of training approaches such as Tai Chi, strength-balance training, or balance perturbations; however, evidence regarding the added effect of perturbation-based exercises alongside a fall management program—particularly in older women with a history of falls and using an objective posturography instrument—remains limited. Therefore, this study examined the effect of adding 15 minutes of perturbation-based balance training to fall management exercises on objective indicators of reactive balance in older women. The main hypothesis was that, after controlling for pre-test values, the combined-training group would show a greater reduction in gain and phase-delay indices than the group receiving fall management exercises alone.

Materials and Methods

The present study was a two-group, parallel-design, quasi-experimental trial with pre-test and post-test assessments, conducted from early January 2025 to late February 2025 (early Dey 1403 to early Esfand 1403). The Ethics Committee of the University of Isfahan approved the study protocol, and all participants signed a written informed consent form before enrollment. The study population consisted of women aged 60 years and older who participated in cultural programs at the Sobhan Cultural Center in Sepahanshahr, Isfahan, and we used convenience and purposive sampling methods.

Based on previous studies (18), we used a statistical power of 0.80 and an alpha level of 0.05. Using G*Power software (3.1.9.7, freeware released March 17, 2020, University of Düsseldorf, Düsseldorf, Germany) and calculations based on Cochran's formula, we estimated the appropriate sample size at 36 participants; accounting for potential dropout, we selected 40 individuals for this study. Inclusion criteria included being female, aged 60 years or older, in generally good health, having a history of falls, and being able to walk independently indoors and outdoors. Exclusion criteria included severe neurological, orthopedic, cardiovascular, or respiratory disease; uncorrected visual impairment; severe dizziness; cognitive impairment; absence from more than 20% of sessions; injury during the study; use of protein supplements; use of medications affecting muscle strength or balance; regular exercise outside the protocol; and withdrawal or failure to attend the post-test.

After completing the pre-test assessments, participants were assigned to two groups of 20 using restricted randomization with a 1:1 allocation ratio via a lottery method. The names of the two groups were written on 20 identical slips each, and the slips were placed in 40 identical, opaque, sealed envelopes. The envelopes were thoroughly shuffled before allocation began, and after each participant's definitive enrollment, one envelope was selected and opened; thus, allocation remained concealed until the envelope was opened. The principal investigator prepared and shuffled the envelopes and carried out the allocation procedure. Due to the nature of the intervention, blinding of participants and the trainer was not feasible. The researcher performed a reactive balance assessment and was aware of group allocation; however, the statistical analyst analyzed the coded data without knowing the meaning of the group codes.

Intervention Procedure

The training intervention was delivered to both groups for 8 weeks, with three sessions per week, for a total of 24 sessions. A trainer supervised the exercises. Each session began with a 5-minute warm-up of low- to moderate-intensity aerobic activities and ended with a 5-minute cool-down of stretching exercises. The fall management exercise group completed a program that included strength, balance, and floor-based exercises. This program was designed based on the fall management exercise model and included flexibility and mobility exercises, dynamic endurance, resistance exercises for the lower limbs and ankles, resistance exercises for the upper limbs and back, dynamic balance, backward walking, floor work, and a Tai Chi-style cool-down, and was carried out according to the program presented in Figure 1 (19). The intensity of the fall management exercises was progressively increased throughout the intervention period. Resistance exercises using elastic bands were implemented in three phases: a skill-acquisition phase in sessions 1 to 8, a training-load-progression phase in sessions 9 to 16, and a maintenance phase in sessions 17 to 24. At the beginning of each phase, participants started with the lightest appropriate resistance band. In the fourth session, each participant's 10RM band was determined so that the individual could perform 10 repetitions while maintaining correct form and reach fatigue on the tenth repetition. After 2 to 3 training sessions with the same band, if the participant could perform 12 repetitions with correct form, the training resistance was increased. In the twelfth session, the 8RM band was determined, and in sessions 18 to 20, the 6RM band was determined, with resistance increases based on the participant's ability to maintain correct exercise performance.

The combined-training group, in addition to the fall management exercises, also performed 15 minutes of perturbation-based balance training in each session.

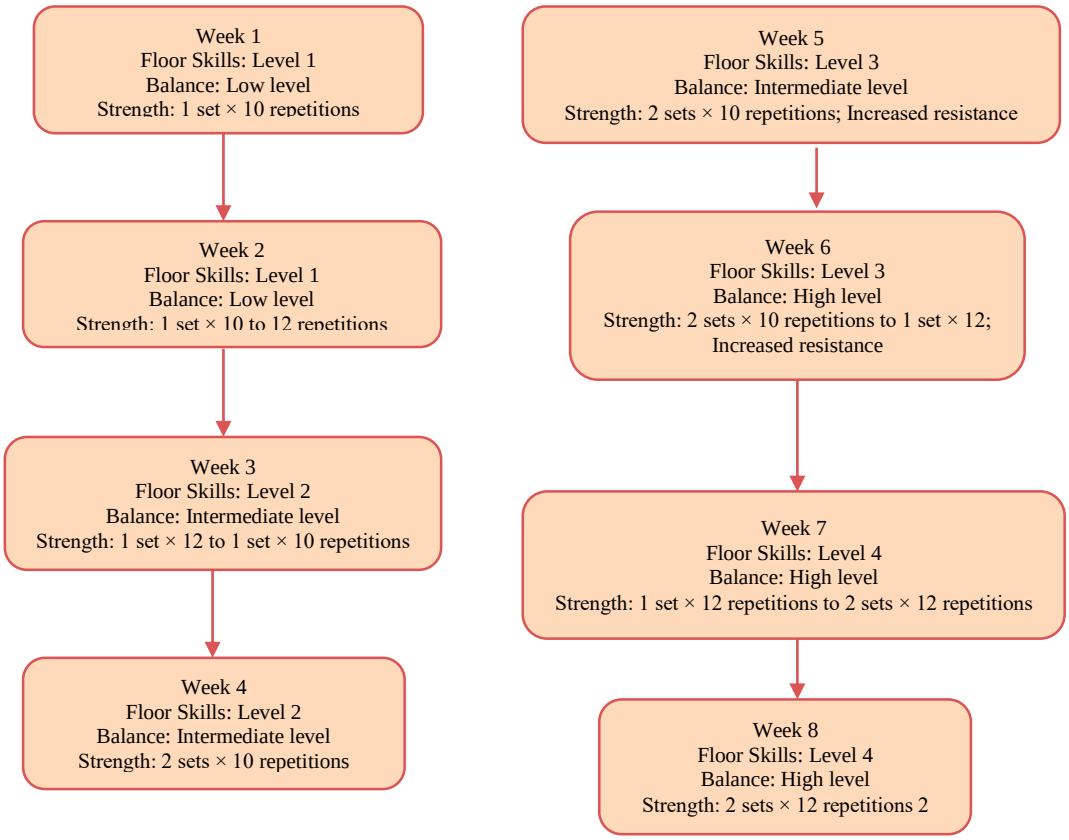


Figure 1. The eight-week progression of the modified fall management program
Both groups completed three sessions per week, for a total of 24 sessions. The program included warm-up, flexibility and joint mobility, dynamic endurance, limb strengthening with resistance bands, dynamic balance, backward walking, floor-based skills, and cool-down. Resistance progressed according to individual repetition-maximum principles and the maintenance of correct technique.

These exercises were designed to challenge dynamic stability mechanisms, including expansion of the base of support and compensatory rotation of body segments around the center of mass, under unstable conditions. The perturbation-based exercises consisted of four components—standing, lunging, walking, and jumping on a cushion ball and BOSU ball—and were performed according to the program presented in Figure 2 (14). The intensity and difficulty of the exercises were progressively increased throughout the intervention period. By the end of the program, all participants in the combined-training group had reached the highest predetermined exercise level.

Adherence to the intervention was defined as attendance at least 80% of the 24 training sessions. All participants who completed the intervention period attended all 24 sessions; therefore, the mean number of sessions attended in both groups was 24±0, and the adherence rate among participants who completed the study was 100%. During the intervention period, five participants from the fall management group and four from the combined-training group withdrew from the study for reasons including insufficient participation, absenteeism, illness, family issues, relocation, or failure to attend the post-test. We excluded data from these individuals from the final analysis, which was based on participants who completed both the intervention and the post-test assessment.

Instruments and Data Collection Procedure

Reactive balance was assessed using the Fall Risk Assessment (Sinus) test on the Synapsys Posturography System (Synapsys, Marseille, France). This test recorded two indices—Gain and Phase Lag. Gain was defined as the ratio of the postural response amplitude to the platform's sinusoidal stimulus amplitude and was reported as a dimensionless value. Phase Lag was defined as the phase angle difference between the platform's sinusoidal stimulus and the postural response and was reported in degrees.

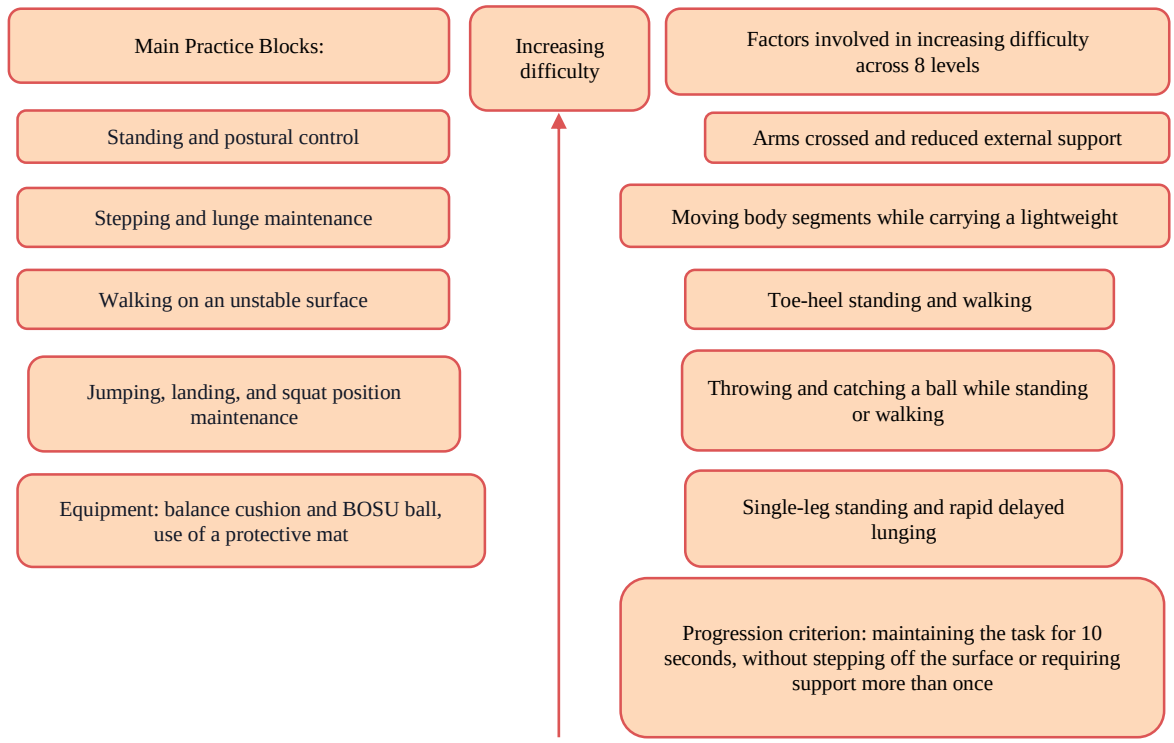


Figure 2. Concept and progression of perturbation-based dynamic stability training in the combined-training group

In addition to the fall management program, the combined-training group received an extra 15 minutes of training in each session. Participants performed tasks on a balance cushion and a BOSU ball, with increasing challenge through greater instability, task complexity, and reduced external support. All exercises were performed under close supervision and on a protective mat. The overall structure was based on dynamic stability training under perturbation and was adapted for the present study.

In the eyes-open condition, participants fixated on a stationary plus sign at the center of the screen, and the test was repeated in the eyes-closed condition. In both conditions, the platform moved slowly and sinusoidally at 0.25 Hz in the anterior-posterior direction, and participants were required to maintain their balance without moving their feet.

Each test lasted 20 seconds, and the device continuously recorded center-of-pressure displacement. Although the platform stimulus was applied only in the anterior-posterior direction, we analyzed the center-of-pressure response along both the anterior-posterior and medial-lateral components. Within this protocol framework, a decrease in gain indicates a reduced response amplitude relative to a constant stimulus, and a decrease in phase lag indicates that the response timing is more closely aligned with the stimulus (20, 21).

We performed statistical analyses using SPSS (IBM Corp., 2019; IBM SPSS Statistics for Windows, Version 27.0; Armonk, NY, USA) at a significance level of 0.05. Quantitative data were reported as mean ± standard deviation, and the primary analysis used complete cases. We assessed data normality using the Kolmogorov-Smirnov test. Given that the assumption of homogeneity of regression slopes was met, along with the assumption of homogeneity of variances, which was assessed using Levene's test, independence of observations was considered satisfied based on the study design, as each participant was assigned to only one group and each individual was analyzed as an independent unit. We used analysis of covariance (ANCOVA), controlling for pre-test values as a covariate, for between-group comparisons following the intervention. We used a paired t-test for within-group comparisons. Within-group effect size was reported using Cohen's d, and between-group effect size was reported using partial eta squared (partial η^2).

Results

Of the 60 women invited, 40 were found eligible after screening and were randomly allocated to either the fall management group (n=20) or the combined-training group (n=20). During the intervention, five

participants from the fall management group and four from the combined-training group did not complete the post-test assessment; therefore, post-test data for 9 individuals were unavailable, and the final analysis was based on complete cases, comprising 15 participants in the fall management group and 16 participants in the combined-training group. For the 31 participants included in the analysis, no additional missing data were observed for the primary outcomes, and no imputation was performed. No adverse events or injuries related to the training interventions were reported. Table 1 presents the participants' demographic characteristics, and Figure 3 presents the flow of enrollment, allocation, follow-up, and analysis.

We used paired t-tests to examine within-group changes in reactive balance indices. After eight weeks of intervention, both groups showed significant improvements in the gain and phase lag indices across the anterior-posterior and medial-lateral response components, under both eyes-open and eyes-closed conditions. Within-group effect sizes ranged from 0.60 to 1.52 (Tables 2 and 3).

Table 1. Demographic characteristics of participants

Variable	Fall management group	Combined-training group	P
Age (years)	64.5 ± 6.4	63.7 ± 4.0	0.903
Weight (kg)	67.2 ± 11.4	65.5 ± 8.0	0.638
Height (cm)	155.2 ± 6.2	158 ± 5.7	0.183

Data are reported as mean ± standard deviation. We used independent t-tests for between-group comparisons.

In the eyes-open condition, the G index improved by 23.7% in the fall management group and 12.7% in the combined-training group. Similarly, the P.L index improved by 29.2% and 30.3% in the same condition, respectively. In the medial-lateral component under the eyes-open condition, the G index improved by 25.6% in the fall management group and 27.2% in the combined-training group. The P.L index improved by 33.6% and 35.9% in this condition, respectively.

In the eyes-closed condition, the G index in the anterior-posterior component improved by 22.9% in the fall management group and 21.1% in the combined-training group.

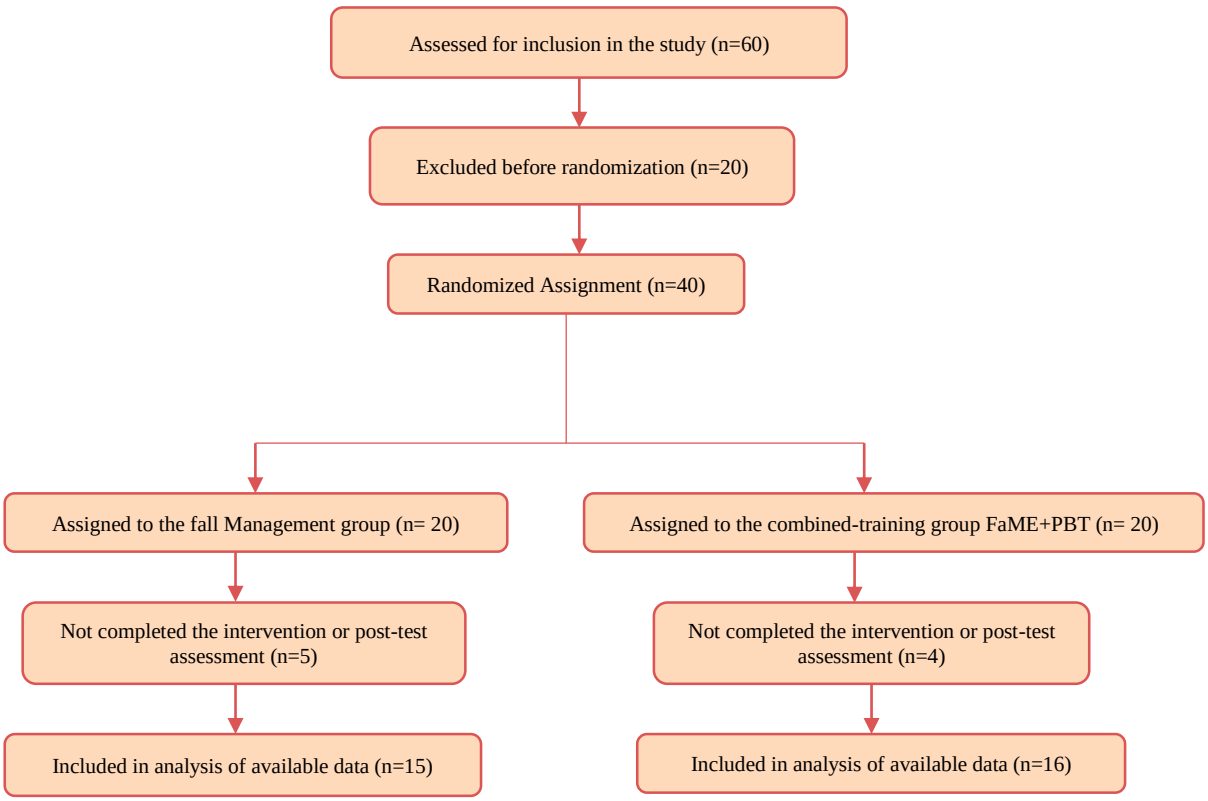


Figure 3. Flow diagram of participant recruitment, allocation, follow-up, and analysis
Of the 60 women invited, 40 were enrolled after screening and randomized in a 1:1 ratio. The final analysis was based on complete cases: 15 participants in the fall management group and 16 in the combined-training group. Post-test data were unavailable for 9 participants.

http://jrrs.mui.ac.ir

Table 2. Within-group and between-group comparisons of reactive balance indices in the eyes-open condition

Open-eye	Groups	Fall management		Within-group comparison		Combined		Within-group comparison		Between-group comparison	
	Stages	Pre-test (mean ± SD)	Post-test (mean ± SD)	p	Effect Size	Pre-test (mean ± SD)	Post-test (mean ± SD)	p	Effect Size	p	Effect Size
Anterior-posterior	G	1.01±0.29	0.77±0.27	0.001	1.16	1.02±0.29	0.89±0.27	0.013	0.704	0.096	0.096
	P.L (degree)	84.53±27.82	59.8±28.2	0.006	0.837	98.4±43.15	68.5±41.64	0.029	0.603	0.758	0.003
Medial-lateral	G	0.39±0.11	0.29±0.07	0.001	1.38	0.44±0.14	0.32±0.09	0.001	1.15	0854	0.001
	P.L (degree)	114.5±50.9	76.07±55.48	0.014	0.723	124.5±52.3	79.8±38.12	0.001	0.993	0.951	0.000

G: Gain, the ratio of postural response amplitude to platform sinusoidal stimulus amplitude, reported as a unitless index; P.L: Phase Lag, the phase angle difference between the sinusoidal stimulus and the postural response, reported in degrees. A decrease in either index indicates improvement. Within-group comparisons were performed using the paired t-test, and between-group comparisons were performed using analysis of covariance (ANCOVA) after controlling for pre-test values.

Table 3. Within-group and between-group comparisons of reactive balance indices in the eyes-closed condition

Open-eye	Groups	Fall management		Within-group comparison		Combined		Within-group comparison		Between-group comparison	
	Stages	Pre-test (mean ± SD)	Post-test (mean ± SD)	p	Effect Size	Pre-test (mean ± SD)	Post-test (mean ± SD)	p	Effect Size	p	Effect Size
Anterior-posterior	G	1.96±0.47	1.51±0.41	0.001	1.25	1.94±0.63	1.53±0.44	0.001	1.33	0.732	0.004
	P.L (degree)	81.5±17.6	69.1±18.3	0.001	1.27	79.1±13.9	66.6±12.7	0.001	1.52	0.859	0.001
Medial-lateral	G	0.57±0.07	0.40±0.16	0.001	1.06	0.58±0.15	0.47±0.15	0.005	0.804	0.253	0.046
	P.L (degree)	99.8±44.7	72.4±23.8	0.010	0.767	100.5±43.1	65.6±14.9	0.001	0.914	0.258	0.045

G: Gain, the ratio of postural response amplitude to platform sinusoidal stimulus amplitude, reported as a unitless index; P.L: Phase Lag, the phase angle difference between the sinusoidal stimulus and the postural response, reported in degrees. A decrease in either index indicates improvement. Within-group comparisons were performed using the paired t-test, and between-group comparisons were performed using analysis of covariance (ANCOVA) after controlling for pre-test values.

Likewise, the P.L. index in this condition decreased by 15.2% and 15.8%, respectively. In the medial-lateral component under the eyes-closed condition, the improvement in the G index was 29.8% in the fall management group and 18.9% in the combined-training group. In addition, the P.L index improved by 27.4% and 34.7%, respectively.

Overall, the greatest percentage improvement was observed in the medial-lateral component of the P.L index under the eyes-open condition in the combined-training group, with a 35.9% decrease. The smallest percentage improvement was observed for the G index in the anterior-posterior component under the eyes-open condition in the combined-training group, which showed a 12.7% decrease.

To compare the effectiveness of the two interventions, analysis of covariance (ANCOVA) was used to control for pre-test values. After controlling for the pre-test effect, no significant difference was observed between the two groups in any of the reactive balance indices (P = 0.096–0.951). The between-group effect size ranged from 0.000 to 0.096; therefore, the added effect of perturbation-based balance training compared with fall management exercises alone was estimated to range from negligible to moderate (Tables 2 and 3).

Discussion

The present study aimed to examine the effect of eight weeks of fall management exercises and combined fall management plus perturbation-based balance training on reactive balance in older women. The results showed that both training programs produced significant within-group improvements in the gain and phase lag indices across the anterior-posterior and medial-lateral components, under both eyes-open and eyes-closed conditions. However, after controlling for pre-test values, no statistically significant difference was observed between the two groups in any of the reactive balance indices; therefore, adding 15 minutes of perturbation-based balance training to the fall management exercise program did not demonstrate a statistically significant advantage over fall management exercises alone under the conditions of the present study.

The interpretation of effect sizes supports this same pattern. The effect size for within-group changes across the various indices ranged from 0.60 to 1.52, indicating moderate to large changes in both training programs. In contrast, the between-group effect size after controlling for pre-test values ranged from 0.000 to 0.096. The largest between-group effect size was observed for the gain index in the anterior-posterior component under the eyes-open condition (partial $\eta^2 = 0.096$; P = 0.096), but this comparison was also not statistically significant. For the other outcomes, the between-group effect sizes were predominantly negligible to small; thus, within-group improvement was considerable, but evidence for an additional effect of the combined program was limited.

These findings are consistent with prior evidence on the positive effect of structured balance and fall-prevention programs on postural control in older adults. Brüll et al. (2023), comparing two models of perturbation-based balance training—treadmill-based perturbation training and training on unstable surfaces—showed that both approaches can improve reactive balance and fall-risk-related indices; however, the training effects were largely task-dependent, and an overall superiority of one method over the other was not consistently observed. Similarly, Hezel et al. (23) reported that both perturbation-based balance training methods were favorable for older adults in terms of safety, acceptance, and feasibility. However, individual characteristics and the nature of the exercise may influence the magnitude of the training response. These results are consistent with the findings of the present study, as the combined training was also feasible and produced within-group improvements in reactive balance indices. However, no statistically superior effect over fall management exercises was observed.

Existing evidence suggests that the effect of perturbation-based balance training may be influenced by the characteristics of the studied population, the dose and duration of the intervention, and the type of task or outcome assessed (12, 15, 17). Petrovic et al. (24) showed that a brief reactive balance training protocol on a perturbation treadmill could improve certain physical performance indices in hospitalized older patients. However, the direct effect on fall risk reduction was inconclusive. Nørgaard et al. (25) also reported that perturbation-based balance training improves reaction time and dual-task walking speed in the short term. However, some of these effects diminish at 6- to 12-month follow-up. This phenomenon could be explained by a ceiling effect in healthier older adults or by reduced persistence of training-induced responses. Furthermore, Gerards et al. (26) showed that adding perturbation-based balance training to usual care did not produce a significant difference in clinical balance scores compared with usual care alone. This evidence may partly account for the lack of a significant difference between the two groups observed in the present study.

In contrast, some studies have reported an additive effect of perturbation-based training. For example,

Desai et al. showed that combining perturbation-based balance training with the Otago strengthening program not only improved within-group indices such as the Timed Up and Go test and center-of-pressure displacement, but also showed significant superiority in between-group comparisons relative to the Otago program alone (27). The discrepancy between the findings of the present study and those of Desai et al. (27) may stem from differences in the type of base intervention, the intensity and volume of perturbation exercises, the assessment instruments, participant characteristics, and outcome measures. Additionally, Van Wouwe et al. (28) reported that a three-week period of perturbation training can improve reactive balance in a standing position. However, this effect does not necessarily generalize to balance during walking. This finding underscores the principle of training specificity and indicates that the transfer of perturbation training effects to different motor tasks or contexts is not always guaranteed.

In the present study, improvement in reactive balance was interpreted as a reduction in the two indices—gain and phase lag—in the sinusoidal test on the posturography device. A decrease in gain indicates that, after the intervention, participants generated smaller, more controlled body sway in response to the external perturbation; in other words, their postural response was more proportionate and less exaggerated. Conversely, a decrease in phase lag indicates a shorter time interval between the applied sinusoidal stimulus and the body's response, suggesting a faster, more coordinated neuromuscular response to the perturbation. The simultaneous improvement in these two indices suggests that both training programs enhanced the efficiency of older women's postural responses to external perturbations. This interpretation is consistent with the report by Ghulyan and Paolino (20), who considered posturography and body-response-to-perturbation indices useful for assessing fall risk in older adults with instability.

Another notable finding in the present study was a significant improvement in reactive balance indices under both eyes-open and eyes-closed conditions in both training groups. Balance control in the eyes-open condition partly depends on visual information, and vision helps regulate postural responses by providing information about the body's position relative to the environment. The balance control system adjusts the relative contributions of visual, proprioceptive, and vestibular inputs based on each input's availability and reliability, a process known as "sensory reweighting" (29, 30). In the eyes-closed condition, visual input is removed, and balance control must rely more heavily on proprioceptive and vestibular information and neuromuscular responses; therefore, the improvement of reactive balance indices in both conditions indicates that both the fall management exercises and the combined training were able to improve postural control in older adults, both in the presence of and under restricted visual information. This finding is practically important, since many real-world fall situations, such as moving in low light, sudden changes in the base of support, or loss of balance in unfamiliar environments, require appropriate reweighting of sensory information and rapid reactive responses (15, 29, 30).

However, the absence of a significant difference between the two groups in both the eyes-open and eyes-closed conditions indicates that adding 15 minutes of perturbation-based balance training under the conditions of the present study did not produce a clear additional effect on vision-dependent or vision-independent reactive balance control compared with fall management exercises alone.

Regarding the possible underlying mechanism, fall management exercises likely improved older adults' balance strategies by strengthening lower-limb muscles, improving postural control, increasing familiarity with near-fall situations, and practicing floor-based tasks. In the combined-training group, perturbation-based balance exercises created unstable and unpredictable conditions that challenged the neuromuscular system to respond more rapidly and more coordinatedly to environmental changes. Training under such conditions can improve the ability to rapidly adjust the base of support, inter-joint coordination, and compensatory body strategies. Findings by Milte and colleagues have also shown that aging can be associated with a decline in the quality of postural responses to continuous rotational perturbations and with impaired coordination between body segments, particularly in axial and lateral movements; this reinforces the need for interventions that specifically target reactive responses (31).

Nevertheless, the absence of a significant difference between the two groups in the present study may have several explanations. First, it is possible that the fall management program alone provided sufficient training stimulus to improve reactive balance, and that adding 15 minutes of perturbation-based training per session, in terms of duration and training volume, did not constitute a sufficient additional load to produce a significant incremental effect relative to fall management exercises. Second, the participants in the present study were relatively healthy older adults with independent walking ability; therefore, a ceiling effect may have been present in some balance indices. Third,

perturbation-based balance training is inherently task-specific, and its effects may be more apparent in tasks similar to the trained task than in those that generalize broadly across all balance tests. Fourth, the relatively small sample size may have reduced the study's statistical power to detect between-group differences.

Despite no statistically significant difference between the two groups, reductions in gain and phase lag in both interventions indicate that, after training, participants' postural responses to the platform's sinusoidal stimulus were characterized by smaller amplitudes and greater temporal coordination (20, 21). From a theoretical standpoint, improved reactive balance capacity may be important for recovering stability when facing sudden perturbations; however, adaptations in reactive balance are largely dependent on the type, direction, intensity, and conditions of the trained perturbation, and their transfer to different tasks may be limited (15, 17); therefore, the present findings support improvement in laboratory-based indices of postural control, but the relationship between these changes and a reduction in actual falls was not assessed in the present study.

Limitations

The present study had several limitations that should be considered when interpreting the results. These limitations include the dropout of 9 participants, the use of complete-case analysis, the limited final sample size, convenience sampling, the absence of a follow-up period to assess the persistence of training effects, the lack of assessment of actual fall incidence after the intervention, the restriction of the sample to older women with independent walking ability, the limited volume of perturbation-based balance training to 15 minutes per session, and the lack of blinding of the assessor to group allocation; therefore, generalization of the results to older men, older adults with more severe mobility impairments, or training programs with a different dose should be made with caution. Future studies are recommended to use larger sample sizes, longer follow-up periods, assessor blinding, examination of different doses of perturbation-based balance training, and assessment of clinical outcomes such as the actual number of falls.

Recommendations

It is recommended that future research examine the effect of adding perturbation-based balance training at different volumes and intensities, in larger samples, and with longer follow-up periods. In addition, assessing outcomes such as the actual number of falls, fear of falling, balance confidence, dual-task walking performance, and quality of life could help determine the clinical applicability of this type of training in rehabilitation programs for older adults.

Conclusion

Eight weeks of fall management exercises and a combined program of fall management plus perturbation-based balance training were both associated with improvements in reactive balance indices in older women. However, after controlling for pre-test values, sufficient statistical evidence for the superiority of the combined program over fall management exercises alone was not observed. Larger studies with follow-up periods, assessment of actual falls, and examination of different doses of perturbation exercises are necessary to determine the added value of this type of training.

Acknowledgments

The authors express their gratitude and appreciation to all the participants in this research whose valuable cooperation made the conduct of this study possible.

Authors' Contribution

Project design and conceptualization: Yalda Beygi
Securing project funding: Yalda Beygi
Project support, execution, and operational services: Yalda Beygi
Provision of equipment and study samples: Yalda Beygi
Data collection: Yalda Beygi
Data analysis and interpretation: Yalda Beygi, Nader Rahnama
Specialized statistical services: Yalda Beygi, Nader Rahnama
Manuscript preparation: Yalda Beygi, Nader Rahnama, Ashraf Mahmoudzadeh
Expert evaluation of the manuscript (scientific concepts): Yalda Beygi, Nader Rahnama, Ashraf Mahmoudzadeh
Approval of the final manuscript for submission to the journal: Yalda Beygi, Nader Rahnama, Ashraf Mahmoudzadeh
Responsibility for study integrity (from inception to publication) and addressing reviewers' comments: Yalda Beygi, Nader Rahnama, Ashraf Mahmoudzadeh

Funding

This article is derived from the author's master's thesis at the University of Isfahan. The research was conducted with the approval of the University of Isfahan's Research Ethics Committee (Ethics Code: IR.UI.REC.1403.125). This study received no

financial support from any specific organization, institution, or center.

Conflict of Interest

The authors did not have a conflict of interest.

References

1. United Nations Department of Economic and Social Affairs, Population Division. World Population Prospects 2024: Summary of Results. New York: United Nations; 2024.
2. United Nations Population Fund, HelpAge International. Ageing in the Twenty-First Century: A Celebration and a Challenge. New York: United Nations Population Fund; 2012.
3. United Nations Department of Economic and Social Affairs, Population Division. World Population Ageing 2019: Highlights. New York: United Nations; 2019.
4. National Council of the Elderly. National Document on Older Persons [Internet]. Tehran: National Council of the Elderly; 2021 [cited 2026 Jul 31]. Available from: https://snce.ir/?page_id=23369. [In Persian].
5. Montero-Odasso M, van der Velde N, Martin FC, Petrovic M, Tan MP, Ryg J, et al. World guidelines for falls prevention and management for older adults: a global initiative. Age Ageing. 2022; 51(9): afac205.
6. Rubenstein LZ, Josephson KR. The epidemiology of falls and syncope. Clin Geriatr Med. 2002; 18(2): 141-58.
7. O'Loughlin JL, Robitaille Y, Boivin JF, Suissa S. Incidence of and risk factors for falls and injurious falls among the community-dwelling elderly. Am J Epidemiol. 1993; 137(3): 342-54.
8. Hsiao-Wecksler ET, Robinovitch SN. The effect of step length on young and elderly women's ability to recover balance. Clin Biomech (Bristol, Avon). 2007; 22(5): 574-80.
9. Landers MR, Oscar S, Sasaoka J, Vaughn K. Balance confidence and fear of falling avoidance behavior are most predictive of falling in older adults: prospective analysis. Phys Ther. 2016; 96(4): 433-42.
10. Hicks GE. Addressing balance, mobility, and falls: are we moving the needle on fall prevention? J Gerontol A Biol Sci Med Sci. 2019; 74(9): 1487-8.
11. Ong MF, Soh KL, Saimon R, Wai MW, Mortell M, Soh KG. Fall prevention education to reduce fall risk among community-dwelling older persons: a systematic review. J Nurs Manag. 2021; 29(8): 2674-88.
12. Gerards MHG, McCrum C, Mansfield A, Meijer K. Perturbation-based balance training for falls reduction among older adults: current evidence and implications for clinical practice. Geriatr Gerontol Int. 2017; 17(12): 2294-303.
13. Devasahayam AJ, Farwell K, Lim B, Morton A, Fleming N, Jagroop D, et al. The effect of reactive balance training on falls in daily life: an updated systematic review and meta-analysis. Phys Ther. 2023; 103(1): pzac154.
14. Bohm S, Mandla-Liebsch M, Mersmann F, Arampatzis A. Exercise of dynamic stability in the presence of perturbations elicit fast improvements of simulated fall recovery and strength in older adults: a randomized controlled trial. Front Sports Act Living. 2020; 2: 52.
15. McCrum C, Bhatt TS, Gerards MHG, Karamanidis K, Rogers MW, Lord SR, et al. Perturbation-based balance training: principles, mechanisms and implementation in clinical practice. Front Sports Act Living. 2022; 4: 1015394.
16. Sharma S, Szabo IZ, Danielsen MB, Andersen S, Nørgaard JE, Lord SR, et al. Perturbation-based balance training reduces falls and fall injuries in older people: insights on mechanisms and training parameters from a systematic review. J Am Med Dir Assoc. 2026; 27(8): 106316.
17. Kim Y, Vakula MN, Bolton DAE, Dakin CJ, Thompson BJ, Slocum TA, et al. Which exercise interventions can most effectively improve reactive balance in older adults? A systematic review and network meta-analysis. Front Aging Neurosci. 2022; 13: 764826.
18. Alhamashi F, Rahnama N, Sadeghi M. Investigating the effect of eight weeks of reactive neuromuscular training (RNT) on body control, muscle strength and quality of life of older adults. J Sport Exerc Physiol. 2023; 16(2): 67-79. [In Persian].
19. Skelton D, Dinan S, Campbell M, Rutherford O. Tailored group exercise (Falls Management Exercise--FaME) reduces falls in community-dwelling older frequent fallers: an RCT. Age Ageing. 2005; 34(6): 636-9.
20. Ghulyan V, Paolino M. Posturography for evaluating risk of falls in elderly unstable patients. French Otorhinolaryngol. 2005; 88: 97-103.
21. Fawzan S, Kozou H, Baki F, Asal S. Fall risk assessment and effect of vestibular rehabilitation in the elderly population. Egypt J Otolaryngol. 2022; 38: 88.
22. Brüll L, Hezel N, Arampatzis A, Schwenk M. Comparing the effects of two perturbation-based balance training paradigms in fall-prone older adults: a randomized controlled trial. Gerontology. 2023; 69(7): 910-22.
23. Hezel N, Brüll L, Arampatzis A, Schwenk M. Acceptability of two perturbation-based balance training paradigms: perturbation treadmill versus dynamic stability training in the presence of perturbations. Gerontology. 2024; 70(6): 661-8.
24. Petrovic A, Wirth R, Klimek C, Lueg G, Daubert D, Giehl C, et al. Impact of reactive balance training on a perturbation treadmill on physical performance in geriatric patients: results of a single-center, assessor-blinded randomized controlled trial. J Clin Med. 2024; 13(19): 5790.
25. Nørgaard JE, Andersen S, Ryg J, Andreasen J, Oliveira ASC, Stevenson AJT, et al. Perturbation-based balance training of older adults and effects on physiological, cognitive and sociopsychological factors: a secondary analysis from a randomised controlled

trial with 12-month follow-up. BMJ Open. 2024; 14(8): e080550.
26. Gerards M, Marcellis R, Senden R, Poeze M, de Bie R, Meijer K, et al. The effect of perturbation-based balance training on balance control and fear of falling in older adults: a single-blind randomised controlled trial. BMC Geriatr. 2023; 23(1): 305.
27. Desai P, Kaur T, Dsouza P, Shah MR. Effectiveness of perturbation based balance training in an older individuals: a randomized clinical trial. Int J Health Sci Res. 2018; 8(7): 122-34.
28. Van Wouwe T, Afschrift M, Dalle S, Van Roie E, Koppo K, De Groote F. Adaptations in reactive balance strategies in healthy older adults after a 3-week perturbation training program and after a 12-week resistance training program. Front Sports Act Living. 2021; 3: 714555.
29. Schmidt D, Carpes FP, Milani TL, Germano AMC. Different visual manipulations have similar effects on quasi-static and dynamic balance responses of young and older people. PeerJ. 2021; 9: e11221.
30. Assländer L, Peterka RJ. Sensory reweighting dynamics following removal and addition of visual and proprioceptive cues. J Neurophysiol. 2016; 116(2): 272-85.
31. Mileti I, Taborri J, Rossi S, Del Prete Z, Paoloni M, Suppa A, et al. Reactive postural responses to continuous yaw perturbations in healthy humans: the effect of aging. Sensors (Basel). 2020; 20(1): 63.