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Perturbation-based vs multicomponent training in adults over 70: effects on balance and mobility

Entrenamiento con perturbaciones vs multicomponente en mayores de 70: equilibrio y movilidad

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Abstract

Traditional multicomponent exercise programs generally focus on proactive balance control, whereas perturbation-based training aims to improve reactive responses to unexpected destabilizing events. The aim of this study was to compare the effects of a perturbation-based multicomponent exercise program with those of a traditional multicomponent program on strength, balance, and functional mobility in community-dwelling women aged over 70 years. Sixty-one women were randomly allocated to a perturbation-based training group (PT; n = 32) or a traditional multicomponent training group (MT; n = 29). Both groups completed an eight-week intervention consisting of two weekly sessions lasting 45 minutes. In the PT group, the central phase of each session included progressively challenging perturbation tasks characterized by increasing environmental unpredictability and sensory constraints, whereas the MT group performed light-to-moderate multicomponent exercises without systematic perturbations. Physical performance was assessed before and after the intervention using functional tests related to strength, balance, and mobility. Significant group $\times$ time interactions were observed for all outcomes. The PT group demonstrated significant improvements across all variables, while the MT group improved only in selected tests. These findings suggest that perturbation-based training may produce broader improvements in strength, balance, and functional mobility than traditional multicomponent exercise in women aged over 70 years.

Keywords: falls; postural balance; functional mobility; perturbation-based training; older adults.

Resumen

Los programas tradicionales de ejercicio multicomponente suelen centrarse en el control proactivo del equilibrio, mientras que el entrenamiento basado en perturbaciones busca mejorar las respuestas reactivas ante eventos desestabilizadores inesperados. El objetivo de este estudio fue comparar los efectos de un programa de ejercicio multicomponente basado en perturbaciones con los de un programa multicomponente tradicional sobre la fuerza, el equilibrio y la movilidad funcional en mujeres mayores de 70 años que viven en la comunidad. Sesenta y una mujeres fueron asignadas aleatoriamente a un grupo de entrenamiento basado en perturbaciones (PT; n = 32) o a un grupo de entrenamiento multicomponente tradicional (MT; n = 29). Ambos grupos realizaron un programa de intervención de ocho semanas, con dos sesiones semanales de 45 minutos. En el grupo PT, la fase central de cada sesión incluyó tareas de perturbación progresivamente más complejas caracterizadas por una mayor imprevisibilidad ambiental y restricciones sensoriales, mientras que el grupo MT realizó ejercicios multicomponentes de intensidad ligera a moderada sin perturbaciones sistemáticas. El rendimiento físico fue evaluado antes y después de la intervención mediante diferentes pruebas funcionales relacionadas con la fuerza, el equilibrio y la movilidad. Se observaron interacciones significativas grupo $\times$ tiempo en todas las variables analizadas. El grupo PT mostró mejoras significativas en todas las pruebas, mientras que el grupo MT mejoró únicamente en algunas de ellas. Estos resultados sugieren que el entrenamiento basado en perturbaciones puede producir mejoras más amplias en la fuerza, el equilibrio y la movilidad funcional en mujeres mayores de 70 años en comparación con los programas multicomponentes tradicionales.



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Palabras clave: caídas; equilibrio postural; movilidad funcional; entrenamiento con perturbaciones; adultos mayores.

Introduction

Falls represent a major public health concern among older adults, as they are frequently associated with serious injuries, loss of independence and increased healthcare costs (Colón-Emeric et al., 2024). Age-related declines in muscle strength, balance control, reaction time and sensory integration substantially increase the risk of falling in this population (Williams & Nyman, 2021; Colón-Emeric et al., 2024; Esposito et al., 2021).

As the population ages, particularly in European countries such as Italy, the prevalence of fall-related events continues to rise, emphasising the urgent need for effective preventive strategies (Colón-Emeric et al., 2024). The ageing process is characterised by a progressive decline in functional capacities closely associated with postural control and fall risk reduction (Esposito et al., 2021).

Consequently, adults aged 65 years and older are increasingly encouraged to adopt active lifestyles supported by structured and supervised exercise-based interventions, delivered by qualified exercise professionals within adapted physical activity programs, with the aim of preserving postural stability, functional autonomy, and overall quality of life (Esposito et al., 2024; Raiola et al., 2022; D’Isanto et al., 2022).

Older adults over the age of 65 who present low levels of muscle strength, balance and functional mobility are commonly classified as frail, a condition associated with increased vulnerability to falls, morbidity, hospitalisation and loss of independence (Park & Ko, 2021; Iwai-Saito et al., 2023; Kohn et al., 2023). Falls are typically defined as sudden, unexpected and unintentional events that result in an individual coming to rest on the ground or at a lower level, without necessarily involving loss of consciousness or exposure to an external violent force (Kamińska et al., 2015; Colón-Emeric et al., 2024).

The incidence of falls is strongly correlated with increasing age and has risen by approximately 41% over the last decade, raising critical questions regarding the public and private strategies required to counteract this trend (Vincenzo et al., 2024; Zeng et al., 2025; Zhou et al., 2024). If this trajectory continues, fall-related healthcare costs are



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expected to become increasingly unsustainable. Consequently, recent studies have begun to quantify the economic benefits associated with fall-prevention programs targeting adults over 65 years of age (Dykes et al., 2023; Hawkins et al., 2024). In particular, a reduction of only 20% in fall events, both with and without injury, has been associated with an estimated saving of approximately USD 15,000 per 1,000 hospitalisation days (Dykes et al., 2023).

To date, fall-prevention strategies based on adapted physical activity have predominantly focused on improving balance capacity. However, balance-oriented exercises are most often structured in a way that allows older adults to pre-plan their movements and adapt their actions to predictable task conditions. Movements generated under these circumstances are commonly referred to as proactive, as they are anticipatory and planned in advance and therefore only partially reproduce the real-world conditions in which older adults move within their environment (McCrum et al., 2022).

In contrast, reactive movements emerge in response to unexpected environmental stimuli and are more closely aligned with the functional demands of mobility and autonomy in older adults. The primary distinction between proactive and reactive movement lies in the origin and timing of action initiation: while proactive movements are planned and anticipatory, reactive movements are triggered by an immediate response to external perturbations (Maki & McIlroy, 1997; McCrum et al., 2022).

To recreate conditions that elicit reactive rather than proactive motor responses, adapted physical activity programs should incorporate non-anticipable and non-pre-planned motor tasks, relying on specific tools or constraints capable of generating sudden perturbations. The rationale for structuring exercise interventions around perturbation-based tasks derives from epidemiological evidence indicating that falls are frequently caused by unexpected mechanical events—such as slips, trips, collisions, or pushes—that typically occur during walking (Sherrington et al., 2019; McCrum et al., 2022).

Perturbation-based training may be implemented through different modalities, including walking tasks performed in response to unpredictable environmental signals or constraints (Okubo et al., 2017; Pšeničnik Sluga & Kozinc, 2024), adaptation of step length and gait speed to real or virtual obstacles (Geerse et al., 2019; Timmermans et al., 2019; Feld et al., 2022), use of irregular or unstable surfaces (Santuz et al., 2018), or the

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exploitation of water inertial load to induce destabilising forces (Chu et al., 2025). Regardless of the specific modality adopted, the defining characteristic of perturbation-based exercise lies in the sensory-perceptual destabilisation that requires a rapid and effective reactive response (McCrum et al., 2022).

Despite growing consensus regarding the ecological relevance of perturbation-based tasks for reproducing the environmental conditions encountered in daily life, this form of training has been predominantly investigated in laboratory settings using treadmills, primarily for evaluative and research purposes (Song et al., 2021; Ferreira et al., 2022; Phu et al., 2024). Only a limited number of studies have applied and monitored the methodological principles of perturbation training within adapted physical activity programs or fall-prevention interventions in real-world contexts (Sannicandro, 2020; Sannicandro et al., 2020).

Moreover, treadmill-based perturbation protocols have consistently involved the use of safety harness systems, which substantially reduce the ecological validity of the exercise context (Ferreira et al., 2022). During walking, perturbations elicit reactive responses that may require atypical step lengths or unconventional movement strategies to prevent a fall or collision (Maki & McIlroy, 1997; McCrum et al., 2022). Such compensatory strategies are difficult to express when walking speed is externally imposed and trunk oscillations are partially constrained, limiting the transferability of treadmill-based adaptations to real-world environments.

Consequently, perturbation-based training should be implemented in settings that more closely resemble the everyday contexts in which older adults move, in order to promote functional autonomy, enhance walking performance and improve dynamic balance. Furthermore, existing studies have often focused on a single perturbation modality, such as unstable surfaces or water inertial load—without considering that the method of inducing perturbations should resemble the diverse and unpredictable perturbations experienced in daily life (Lichtenstein et al., 2020; McCrum et al., 2022; Chu et al., 2025).

Despite the growing interest in perturbation-based balance training, most previous studies have primarily investigated this approach in laboratory-based settings using treadmill-induced perturbations. Evidence regarding the effectiveness of perturbation-



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based exercise programs implemented in real-world adapted physical activity contexts remains limited, particularly among community-dwelling adults over 70 years of age.

Therefore, the aim of the present study was to examine the effectiveness of a perturbation-based training program incorporating multiple perturbation modalities, implemented within a real-world adapted physical activity setting, compared with a traditional multicomponent exercise program, on physical performance in adults aged over 70 years. Although perturbation-based training itself is not entirely new, the application of a multimodal perturbation-based program in a non-laboratory adapted physical activity context represents an innovative aspect of the present study. It was hypothesised that perturbation-based training would elicit superior adaptations in physical capacities, particularly in balance and functional mobility outcomes.

Materials and methods

Study participants

Sixty-five community-dwelling older female adults were initially recruited for the present study. Four participants were excluded prior to group allocation because they did not complete all assessment sessions. Consequently, a total of 61 community-dwelling older women were included in the final analysis and randomly assigned in an approximately 1:1 ratio to either a perturbation-based training group (PT; $n = 32$) or a multicomponent training group (MT; $n = 29$) using a random number generator. Randomization was performed after completion of baseline assessments. Participants' anthropometric characteristics were as follows: age: 73.22 ± 2.68 years; body mass: 76.57 ± 3.97 kg; height: 171.15 ± 4.79 cm; body mass index (BMI): 25.98 ± 2.25 kg·m⁻².

Eligibility criteria

The eligibility criteria for participation were: (i) absence of diagnosed cardiovascular diseases; (ii) absence of musculoskeletal injuries or conditions that could limit participation in physical exercise; (iii) no ongoing pharmacological treatments that could affect balance, strength, or mobility; (iv) no fall events reported in the six months preceding the study.



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Bioethical considerations

Written informed consent was obtained from all participants. The study was conducted in accordance with the principles of the Declaration of Helsinki.

Study design

The PT group followed an adapted physical activity program lasting eight weeks, with two sessions per week, for a total of 16 sessions. Each session had a total duration of 45 minutes, of which approximately 25 minutes were dedicated to perturbation-based motor tasks implemented during the central phase of the session. The MT group followed an adapted physical activity program with the same overall duration and frequency (8 weeks, 16 sessions, 45 minutes per session). Similarly, the central phase of each session lasted approximately 25 minutes and focused on the development of multiple motor capacities (e.g., strength, balance, coordination and mobility), through light-to-moderate intensity exercises, without the systematic inclusion of perturbation-based tasks.

Perturbation-based protocols

The progression of perturbation-based tasks was pre-planned and structured through a gradual increase in environmental unpredictability and sensory constraints, in accordance with ecological and task-specific principles underlying adapted physical activity programs for older adults (McCrum et al., 2022). An overview of the exercise content and perturbation modalities adopted in the PT group across the intervention period is provided in Table 1.



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Table 1. Overview of the perturbation-based adapted physical activity protocol

Week	Sessions	Exercise type	Duration	Perturbation type
1	1–2	Unplanned walking with unpredictable environmental information	25 min	Environmental
2	3–4	Walking with unplanned stops; walking while handling tools around the trunk	25 min	Environmental + mechanical
3	5–6	Exercises with water inertial load (individual and partner-based)	25 min	Unstable tool
4	7–8	Walking while replicating a partner's movements (path, direction, speed, stops), with and without water inertial load	25 min	Environmental + unstable tool
5	9–10	Unplanned walking with unpredictable information; exercises performed with eyes closed	25 min	Environmental + visual limitation
6	11–12	Walking with unplanned stops and trunk-handling tasks, performed with eyes closed	25 min	Environmental + mechanical + visual limitation
7	13–14	Exercises with water inertial load (individual and partner-based), performed with eyes closed	25 min	Unstable tool + visual limitation
8	15–16	Partner-based walking tasks (path, direction, speed, stops) with and without water inertial load; stance tasks with eyes closed	25 min	Environmental + unstable tool + visual limitation

Note: Duration refers to the central phase of the session

Assessment procedures

Outcome assessments were conducted within two weeks before and within two weeks after the intervention period. All tests were administered by trained assessors according to standardized procedures. The order of test administration was randomized for each participant to minimize potential order effects.

30-second Chair test (30CST)

Lower limb strength was assessed using the 30CST (Jones et al., 1999). Participants were seated on a standardized armless chair with a seat height of 45 cm, with their feet positioned approximately shoulder-width apart and their arms crossed over the chest. After standardized instructions and a brief demonstration, participants performed practice repetitions to ensure correct execution. At the command “go”, they were instructed to stand up fully and sit down as many times as possible within 30 seconds. A repetition was considered valid when more than half of the movement cycle was completed at the end of the test. Two trials were performed with 60 seconds of rest between trials and the best performance was retained for analysis (ICC = 0.90).



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8-Foot Up and Go Test (8-FUGT)

Functional mobility, balance and agility were evaluated using the 8-FUGT (Rolenz & Reneker, 2016). Participants began seated on a standardized armless chair (seat height: 45 cm) positioned against a wall for safety. On the signal “go”, participants stood up, walked as quickly as possible around a cone placed 2.40 m (8 feet) in front of the chair and returned to a seated position. The time required to complete the task was recorded in seconds, with lower values indicating better performance (ICC = 0.87).

Single leg test (SLT)

Static balance was assessed using the SLT (Goldberg et al., 2011). Participants were asked to stand unassisted on one leg while keeping their hands on their hips. Timing started when the non-supporting foot left the ground and stopped when balance was lost, defined as contact of the raised foot with the ground or the supporting leg, movement of the supporting foot, or use of the arms. Three trials were performed for each leg and the longest duration was used for analysis. Performance was recorded in seconds using a stopwatch (ICC = 0.87).

The 3-metre backward walk test (3-MBWT)

Backward walking ability was evaluated using the 3-MBWT (Carter et al., 2019). A distance of three metres was marked between the starting and finishing lines. Participants were instructed to place their heels on the starting line and, on the command “go”, to walk backwards as quickly and safely as possible to the finish line. Running was not permitted and participants were allowed to look backwards if necessary. Performance was recorded in seconds, with shorter times indicating better backward walking ability (ICC = 0.92).

Tandem walking test (TWT)

Dynamic balance during gait was assessed using the TWT (Cohen et al., 2018). Participants were instructed to walk ten consecutive heel-to-toe steps along a straight line, keeping their arms crossed over the chest. After a brief practice trial consisting of three to five steps, participants completed three test trials with eyes open. The number of correct tandem steps was recorded regardless of whether they were consecutive. Errors were defined as side steps or leaving a distance greater than 2 cm between the feet (ICC = 0.85).



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Arm Curl Test (ACT)

Upper limb strength was assessed using the ACT (Benton et al., 2009). Participants were seated on a standardized chair and instructed to perform as many elbow flexion–extension repetitions as possible within 30 seconds using a hand-held weight, while maintaining proper posture and controlled movement execution. The total number of correctly completed repetitions was recorded, with higher values indicating greater upper limb strength (ICC = 0.93).

Statistical analysis

Sample size was estimated using G*Power (version 3.1.9.7, Dusseldorf, Germany). The required sample size was 54 participants (effect size $f = 0.25$, $\alpha = 0.05$, power = 95%) for a repeated-measures ANOVA (group $\times$ time). Therefore, the final sample of 61 participants was considered adequate for the planned analysis.

Means and standard deviations were reported as descriptive statistics for all analysed variables. The normality of the data distribution was assessed using the Shapiro–Wilk test and Levene’s test was conducted to verify homogeneity of variances. A two-way mixed-design ANOVA with repeated measures (Group [PT vs MT] $\times$ Time [pre vs post]) was performed to investigate the effects on motor skills. When a significant main effect or interaction was detected, pairwise comparisons were conducted using post hoc tests with Bonferroni correction. Effect sizes for within-group pre–post changes were calculated using Cohen’s d and interpreted as small (0.2), moderate (0.5) and large (0.8). All statistical analyses were performed with JASP software (version 0.19.2.0, Amsterdam, The Netherlands).

Results

A significant group $\times$ time interaction was observed for the 30-Second Chair Stand Test (30CST) ($F = 44.723$, $p < 0.001$). Both groups showed significant improvements from pre- to post-intervention. The PT group demonstrated a significant increase ($p < 0.001$; $ES = 0.40$), while the MT group also improved ($p = 0.028$; $ES = 1.70$).

A significant group $\times$ time interaction was observed for the 8-Foot Up-and-Go Test (8-FUGT) ($F = 23.735$, $p < 0.001$). Both groups exhibited significant improvements

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following the intervention, with greater improvements observed in the PT group ($p < 0.001$; $ES = 0.93$) compared with the MT group ($p = 0.041$; $ES = 0.02$).

A significant group $\times$ time interaction was observed for the Single-Leg Stance Test performed on the right leg ($F = 15.769$, $p < 0.001$). Post hoc analyses revealed that only the PT group showed a significant improvement from pre- to post-intervention ($p < 0.001$; $ES = 1.11$), whereas no significant change was observed in the MT group ($p = 0.351$; $ES = 0.28$).

A significant group $\times$ time interaction was observed for the Single-Leg Stance Test performed on the left leg ($F = 43.279$, $p < 0.001$). The PT group demonstrated a significant improvement ($p < 0.001$; $ES = 1.56$), while the MT group did not reach statistical significance ($p = 0.066$; $ES = 0.39$). Significant between-group differences were observed at post-intervention ($p < 0.001$).

A significant group $\times$ time interaction was observed for the 3-Metre Backward Walk Test (3-MBWT) ($F = 6.897$, $p = 0.011$). Both groups significantly improved their performance following the intervention, with greater improvements observed in the PT group ($p < 0.001$; $ES = 1.24$) compared with the MT group ($p = 0.004$; $ES = 0.61$).

A significant group $\times$ time interaction was observed for the Tandem Walking Test (TWT) ($F = 11.160$, $p = 0.002$). Post hoc analyses indicated that the PT group showed a significant improvement from pre- to post-intervention ($p < 0.001$; $ES = 0.70$), whereas no significant change was observed in the MT group ($p = 1.000$; $ES = 0.04$).

A significant group $\times$ time interaction was observed for the Arm Curl Test (ACT) ($F = 21.135$, $p < 0.001$). The PT group demonstrated a significant improvement following the intervention ($p < 0.001$; $ES = 0.78$), while no significant change was observed in the MT group ($p = 1.000$; $ES = 0.09$).



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Table 2. *Group × time interaction effects for physical performance outcomes*

Variables	Group × Time interaction (F)	p value	PT Group		MT Group	
			p value	ES	p value	ES
30CST	44.723	< 0.001	< 0.001	0.40	0.028	1.70
8-FUGT	23.735	< 0.001	< 0.001	0.93	0.041	0.02
SLT (right)	15.769	< 0.001	< 0.001	1.11	0.351	0.28
SLT (left)	43.279	< 0.001	< 0.001	1.56	0.066	0.39
3-MBWT	6.897	0.011	< 0.001	1.24	0.004	0.61
TWT	11.160	0.002	< 0.001	0.70	1.000	0.04
ACT	21.135	< 0.001	< 0.001	0.78	1.000	0.09

Note: 30CST = 30-Second Chair Stand Test; 8-FUGT = 8-Foot Up and Go Test; SLT = Single-Leg Stance Test; 3-MBWT = 3-Metre Backward Walk Test; TWT = Tandem Walking Test; ACT = Arm Curl Test; PT = perturbation-based training; MT = multicomponent training; ES = within-group pre-post effect size.

Discussion

The present study aimed to describe and examine the effectiveness of an adapted physical activity program based on perturbation-based and reactive tasks, compared with a traditional multicomponent recreational exercise program, on motor performance in adults aged over 70 years. Overall, perturbation-based training produced consistent improvements across all assessed motor capacities, whereas the traditional multicomponent program showed improvements only in selected outcomes. However, these findings should be interpreted cautiously, as the observed differences between groups may have been influenced not only by the specific perturbation-based content of the intervention, but also by factors such as task novelty, participant motivation, baseline variability, and the different motor demands imposed by the two training protocols.

Lower limb strength, assessed using the 30-Second Chair Stand Test, showed an approximate 18% (ES: 0.40) performance improvement following the perturbation-based intervention. These findings are consistent with previous evidence reporting strength gains in older adults after exercise training, although most of those studies involved interventions of longer duration than the present one (Peng et al., 2024; Grgic et al., 2020;

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Lu et al., 2021). The observed improvements may be explained by the characteristics of the perturbation-based exercises, particularly walking tasks performed in unpredictable environments requiring frequent decelerations, sudden stops and changes of direction. In addition, the external load imposed by the water-filled tool may have contributed to these adaptations. Improvements in lower limb strength are clinically relevant, as they play a key role in fall prevention and in maintaining functional independence in adults over 65 years of age (Khodadad Kashi et al., 2023). Moreover, preserving adequate strength levels is essential for counteracting sarcopenia, which negatively affects daily functional activities and quality of life in older populations (Monti et al., 2023).

Upper limb strength, assessed using the Arm Curl Test, improved by approximately 9% (ES: 0.78). Although the intervention was not specifically designed to target upper limb strength, this unexpected finding may be partially explained by the repeated handling of the water-filled tool, which imposed an external load of approximately 5 kg and required continuous upper-limb involvement to control its inertial displacement. In addition, the need to stabilize the trunk and coordinate arm movements during unpredictable walking and partner-based tasks may have increased neuromuscular activation of the upper limbs and shoulder girdle. Nevertheless, this interpretation should be considered speculative, as upper-limb muscle activation was not directly assessed.

Dynamic balance, evaluated using the 8-Foot Up and Go Test, improved by approximately 21% (ES: 0.93), while backward walking performance assessed through the 3-Metre Backward Walk Test showed an improvement of approximately 37.6% (ES: 1.24). These results suggest that perturbation-based training represents an effective stimulus for balance enhancement, particularly when combined with functional movements such as forward and backward walking and when tasks are presented in a variable and unpredictable manner. Previous research has shown that imposing constraints on everyday motor tasks, in line with task-specific and motor learning principles, can lead to meaningful improvements in motor performance among older adults with clinical conditions (Liu et al., 2025; Wu et al., 2007; Roaldsen et al., 2014). Furthermore, maintaining or improving gait speed is strongly associated with better quality of life and a reduced risk of falls in older adults (Grønvik et al., 2025).

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Static balance, assessed using the Single-Leg Stance Test, improved by approximately 45% (ES: 1.11) on the left leg and 38% (ES: 1.56) on the right leg, while dynamic balance measured through the Tandem Walking Test showed an improvement of approximately 30.4% (ES: 0.70). These adaptations support the study hypothesis that perturbation-based training induces a positive transfer effect on balance abilities in adults over 70 years of age. This interpretation is consistent with previous studies implementing unstable-surface exercises that reported balance improvements comparable to those observed in the present study (Thomas et al., 2019; Nordström & Nordström, 2024; Abdullah et al., 2025). In particular, the improvement in tandem walking performance highlights the effectiveness of perturbation-based training in counteracting functional decline typically observed between 60 and 70 years of age (Grønvik et al., 2025; Jonkman et al., 2018; Artaud et al., 2015).

Beyond the observed performance gains, perturbation-based training has important preventive implications, as it systematically exposes individuals to unexpected and non-anticipable events, thereby enhancing their ability to manage sudden perturbations that cannot be planned in advance. This feature clearly distinguishes perturbation-based training from other exercise approaches commonly adopted for fall prevention, in which environmental changes are either perceived before body contact or motor responses occur only after a loss of stability has already occurred (McCrum et al., 2022). Perturbation-based training should therefore not be confined to specialised treadmill-based protocols with safety harness systems. While such setups may be useful for evaluating responses to strong mechanical perturbations under controlled conditions (Ferreira et al., 2022), they offer limited ecological validity. Older adults should instead be trained in environments that closely resemble real-life contexts, where they can learn to manage unexpected and unpredictable motor tasks as encountered during daily activities.

Despite these promising findings, several alternative explanations should be considered. First, the greater improvements observed in the PT group may have been partly related to the novelty and higher coordinative complexity of the perturbation-based tasks, which could have increased attention, engagement, and motor learning effects. Second, although both interventions had the same duration and weekly frequency, the



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internal training load was not directly quantified, making it difficult to determine whether the two programs were fully equivalent in terms of exercise intensity. Third, individual differences in baseline motor function, previous physical activity levels, and responsiveness to training may have influenced the magnitude of the observed adaptations. Therefore, although the results support the potential usefulness of perturbation-based training, they should not be interpreted as definitive evidence of superiority over traditional multicomponent exercise.

This study has some limitations. First, the sample included only women aged over 70 years, which limits the generalizability of the findings to men and to older adults from different age groups. Second, the relatively short duration of the intervention limits conclusions regarding the persistence and long-term relevance of the observed adaptations. Third, the absence of a follow-up assessment does not allow determination of whether the improvements were maintained after the end of the program. In addition, participant compliance with the training program was not monitored, which may have influenced individual performance outcomes. Finally, the absence of a non-exercising control group limits the ability to compare both intervention programs against a sedentary condition. Future research should include larger and more diverse samples, longer intervention periods, and follow-up assessments to determine the durability of training-induced adaptations. Further studies should also investigate whether perturbation-based training reduces fear of falling, improves quality of life, and promotes increased levels of daily physical activity in adults over 70 years of age.

Conclusions

This study demonstrates that an 8-week adapted physical activity program based on perturbation-based and reactive tasks is effective in improving strength, balance and functional mobility in adults aged over 70 years. Compared with a traditional multicomponent exercise program, perturbation-based training elicited more consistent improvements across the evaluated motor capacities, particularly in static and dynamic balance performance. The inclusion of non-anticipable and ecologically relevant motor tasks appears to play a key role in enhancing functional adaptations related to fall prevention. These findings support the integration of perturbation-based training within adapted physical activity programs aimed at preserving autonomy and reducing fall risk



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in older adults. From a practical perspective, this approach represents a feasible and ecologically valid strategy that can be implemented in real-world settings without reliance on highly specialised laboratory equipment. Further research is warranted to confirm these findings and to explore the long-term effects of perturbation-based training on fall incidence, fear of falling, and quality of life in older populations.

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