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Recreational Exercise as a Preventive Strategy for Balance Decline in Late Middle Age Adults

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Abstract

Age-related decline in balance may begin during late middle adulthood (55–65 years), increasing the risk of future falls and functional limitations. Evidence regarding recreational exercise as a preventive strategy in this population remains limited. This study aimed to evaluate the effects of a 12-week recreational exercise program on balance in adults aged 55–65 years. A quasi-experimental controlled pre–post design included 60 participants (experimental group: n=30; control group: n=30). The experimental group completed a supervised recreational exercise program four times per week for 12 weeks, while the control group maintained usual activities. Balance was assessed using Leonardo Mechanography during tandem and single-leg stance under eyes open and eyes closed conditions. Center of pressure variables included standard ellipse area, path length, and equilibrium index. Non-parametric statistical tests were applied. The experimental group demonstrated significantly greater improvements in all center of pressure parameters compared with the control group ($p<0.05$), particularly under eyes-closed and single-leg stance conditions. Large effect sizes indicated enhanced postural control, reduced sway magnitude, and improved sensory integration. The control group showed minimal changes or slight deterioration in several variables. A 12-week recreational exercise program significantly improved static and dynamic balance in adults aged 55–65 years, supporting its role as a preventive strategy for early postural decline.

Keywords: *balance, recreational exercise, postural control, center of pressure, middle-aged adults, fall prevention*

Introduction

Aging is associated with progressive declines in neuromuscular function, sensory integration, and postural control, contributing to reduced balance performance and increased risk of functional limitations (Álvarez-Bustos et al., 2025; Wang et al., 2024). These changes typically emerge during late middle adulthood (approximately 55–65 years), a critical transitional phase preceding the onset of frailty and disability (Cruz-Jentoft et al., 2010; Michel & Ecarnot, 2019). Even subtle impairments in balance at this stage are clinically relevant, as they are associated with reduced mobility, loss of independence, and increased future fall risk (Schneider et al., 2025; Xie et al., 2023).

Balance is a complex motor skill resulting from the integration of visual, vestibular, and proprioceptive inputs, combined with adequate muscular strength and central nervous system processing (Khan et al., 2025; Yosef et al., 2026). Age-related deterioration in these systems leads to increased postural sway, delayed neuromuscular responses, and reduced stability under challenging conditions such as single-leg stance or sensory deprivation (Abrahámová & Hlavačka, 2008; Alizadehsaravi et al., 2022). These deficits contribute not only to fall risk but also to gradual loss of functional autonomy and quality of life.

A substantial body of evidence demonstrates that structured exercise interventions can improve balance and reduce fall risk in older adults (Choudhary et al., 2026; Papalia et al., 2020). Multicomponent programs incorporating strength, balance, and coordination training have consistently shown beneficial effects on postural control and functional performance (Ekelund et al., 2019; Foster et al., 2018). Clinical programs such as the Otago Exercise Program have also demonstrated effectiveness in improving balance and reducing falls in older populations (Citozi et al., 2025; Zhang et al., 2026).

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However, these interventions are predominantly designed for older or frail individuals and are often delivered in supervised clinical settings, limiting their accessibility and scalability in the general population.

In contrast, structured recreational exercise programs may represent a more accessible and sustainable alternative for individuals in late middle adulthood who are still functionally independent but at risk of gradual decline. Such programs can integrate balance-challenging tasks within enjoyable, low-barrier formats, potentially improving adherence and long-term participation (Bauman et al., 2012; Cabo et al., 2025; World Health Organization, 2020). This distinction between recreational exercise and more performance or competition-oriented training modalities is consistent with evidence from fitness populations, where recreational gym users and female fitness competitors demonstrate systematically different health related behaviours, particularly in training structure, dietary regulation, supplementation practices, and body image outcomes (Jantal et al., 2026). However, despite these advantages, evidence regarding the effectiveness of structured recreational exercise programs on objectively measured balance outcomes in late middle aged adults remains limited and underexplored, particularly using laboratory-based postural assessment tools.

Moreover, most existing research has focused on populations aged 65 years and older, while the 55–65 age group remains relatively understudied despite representing a critical preventive window for intervention (Adams et al., 2023; Di Lorito et al., 2021). Recent work suggests that measurable declines in postural control and increased fall risk can already be observed in this age range, underscoring the need for targeted preventive strategies before the onset of frailty and disability (Adams et al., 2023; Nohelova et al., 2026; Wang et al., 2024). Addressing balance decline during this stage may delay functional deterioration, reduce future fall risk, and support healthy aging trajectories.

Therefore, the aim of this study was to evaluate the effectiveness of a 12-week structured recreational exercise training program on static and dynamic balance in adults aged 55–65 years. By focusing on a healthy, community-dwelling late middle-aged population and assessing balance with validated laboratory-based postural measures, the present study seeks to extend existing evidence on exercise-based fall prevention beyond older and frail adults and to clarify the preventive role of recreational exercise in this transitional life stage. We hypothesized that participants engaged in the recreational training program would demonstrate significantly greater improvements in laboratory-based and functional balance measures compared to a non-intervention control group.

Materials and methods

Research design

This study employed a quasi-experimental, controlled, pre–post intervention design to evaluate the effects of a structured recreational exercise training program on balance performance in adults aged 55–65 years. Participants were allocated to either an experimental group (EG) or a control group (CG), with assessments conducted at baseline (T1) and after the 12-week intervention period (T2).

Group allocation was performed consecutively at the time of recruitment, with eligible participants assigned to EG or CG based on their availability to attend the supervised training sessions and to avoid mixing participants from the same recreational centers within different groups. This procedure was chosen to minimize contamination between groups and to maintain comparable baseline characteristics in terms of age, sex distribution, and anthropometric variables.

Although randomization was not implemented due to logistical constraints, baseline comparability between groups was verified statistically and descriptively prior to the intervention. This procedure was intended to reduce, although not eliminate, the risk of selection bias inherent to quasi-experimental designs. The control group did not participate in any structured exercise intervention and was instructed to maintain their usual daily activities throughout the study period.

Participants

A total of 60 community-dwelling adults aged 55–65 years were recruited from Tirana, Albania, through local community announcements and recreational centers. Participants allocated to an experimental group (EG; n=30) and a control group (CG; n=30). The overall sample included 31 women (51.7%) and 29 men (48.3%), with sex distribution balanced across groups. Baseline characteristics indicated comparable groups, with the control group presenting a mean age of 58.43±3.46 years, height of 174.83±7.90 cm, and body mass of 78.53±15.12 kg, while the experimental group had a mean age of 58.93±3.88 years, height of 170.97±7.99 cm, and body mass of 74.97±14.33 kg.

Participants self-reported their habitual physical activity level using a brief questionnaire, and those engaging in structured balance or resistance training more than once per week were excluded. The remaining sample consisted of individuals with low-to-moderate, primarily recreational physical activity patterns, such as walking or light group exercise classes.

Eligibility criteria were defined to ensure a relatively homogeneous and healthy sample. Inclusion criteria were as follows: (1) age between 55 and 65 years; (2) ability to walk independently without assistive devices; (3) absence of diagnosed neurological, vestibular, or severe musculoskeletal disorders affecting balance; (4) medical clearance for participation in moderate-intensity physical activity; and (5) no engagement in structured balance or resistance training programs within the previous 6 months.

Exclusion criteria included: (1) recent lower-limb injury or surgery within the past 6 months; (2) presence of severe cardiovascular or metabolic conditions contraindicating exercise; (3) cognitive impairment limiting the ability to follow instructions; and (4) participation in other structured exercise interventions during the study period.

Participants were instructed to maintain their usual lifestyle and to refrain from initiating new exercise routines outside the study protocol throughout the intervention period.

All participants provided written informed consent prior to participation. The study protocol was approved by the institutional ethics committee (Approval No. 2934/1 Prot; December 15, 2025) and was conducted in accordance with the principles of the Declaration of Helsinki.

Procedures and outcome measures

All participants underwent assessments at two time points: baseline (T1) and immediately after the 12-week intervention period (T2). Testing was conducted under standardized laboratory conditions, at the same time of day for each participant, to minimize circadian variability. Participants were instructed to avoid strenuous physical activity 24 hours prior to testing.

Balance performance was assessed using the Leonardo Mechanography platform (Novotec Medical GmbH, Pforzheim, Germany; software version 4.2), a validated system for measuring ground reaction forces and center-of-pressure (COP) displacement during static postural tasks (Wiegmann et al., 2019). All assessments were performed by the same experienced examiner, who was blinded to group allocation with respect to data processing and statistical analysis; however, complete blinding during testing could not be guaranteed because participants were aware of their group assignment.

Testing procedures followed the standardized protocol recommended by the manufacturer (Leonardo Mechanography – Basic Analysis System, BAS). Participants performed a series of balance tasks under different sensory conditions, including tandem stance with eyes open (Tandem EO), tandem stance with eyes closed (Tandem EC), single-leg stance with eyes open (SL-EO), and single-leg stance with eyes closed (SL-EC).

The primary outcome variables derived from COP analysis were: (1) standard ellipse area (cm^2), representing postural sway magnitude; (2) relative path length (mm/s), indicating sway velocity; (3) absolute path length (mm), reflecting total COP displacement; (4) ellipse angle (°), describing sway orientation; and (5) equilibrium index (anteroposterior direction), representing postural control efficiency.

Intervention protocol

The experimental group participated in a 12-week structured recreational exercise training program designed to improve balance and functional stability. Training sessions were conducted four times per week, with each session lasting 50–60 minutes, resulting in a total weekly training volume of approximately 200–240 minutes.

Each session consisted of a warm-up phase, a main balance training phase, and a cool-down phase. The program included progressively challenging static and dynamic balance exercises, with systematic progression achieved through modifications in task complexity, base of support, and sensory conditions (e.g., eyes open vs. eyes closed).

Training intensity was maintained at low-to-moderate levels in accordance with current recommendations for older adults, ensuring both safety and feasibility for long-term adherence (Foster et al., 2018). All sessions were supervised by qualified instructors, and participant attendance was recorded to monitor adherence throughout the intervention period. Mean adherence in the experimental group was 83.3±10.4% of planned sessions, with most participants attending at least 75% of the scheduled training sessions. No adverse events related to the intervention were reported. A detailed overview of the training structure, progression model, and exercise prescription is presented in Table 1. Across the 12 week period, task difficulty was increased in three broad phases (weeks 1–4, 5–8, and 9–12), starting with wider bases of support and predominantly eyes open conditions and progressing to narrower stances, longer hold times, and more frequent eyes closed and simple dual task elements.

Table 1. Structure of the Recreational Exercise Training Program

Component	Description
Total Duration	12 weeks
Frequency	4 sessions per week
Session Duration	50–60 minutes
Weekly Volume	200–240 minutes
Session Structure	(1) Warm-up; (2) Main balance training; (3) Cool-down
Warm-up	10–12 minutes of low-intensity mobility and activation exercises (e.g., joint mobility, dynamic stretching, light walking)
Main Training Component	30–40 minutes of balance-oriented exercises
Exercise Types	Static and dynamic balance tasks, including: single-leg stance, tandem stance and walking, backward walking, heel-to-toe walking, step-ups, coordination drills
Exercise Selection per Session	2–3 exercises per session, rotated progressively across sessions
Sets and Repetitions	3–4 sets of 15–20 repetitions or time-based holds (depending on exercise type)
Intensity	Low to moderate intensity, adapted to individual capacity

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Table 1. Structure of the Recreational Exercise Training Program

Component	Description
Progression Strategy	Gradual increase in difficulty through: (1) reduced base of support; (2) increased movement complexity; (3) introduction of dynamic and eyes-closed conditions
Cool-down	5–10 minutes of stretching and recovery exercises
Supervision	All sessions supervised by qualified instructors
Adherence Monitoring	Attendance recorded at each session

Note. Values describe the structure and prescription of the recreational exercise training program. Intensity was maintained at low-to-moderate levels and progression was achieved by systematically increasing task complexity, reducing base of support, and introducing sensory challenges (eyes closed conditions). All sessions were supervised, and adherence was monitored through attendance records.

Statistical analysis

Descriptive statistics were calculated for all variables and are presented as mean ± standard deviation (SD). The normality of data distribution was assessed using the Shapiro–Wilk test. As several outcome variables violated the assumption of normality, non-parametric statistical procedures were applied for all inferential analyses. Within-group differences between baseline (T1) and post-intervention (T2) were analyzed using the Wilcoxon signed-rank test. Between-group differences in change scores (Δ=T2−T1) were evaluated using the Mann–Whitney U test. Hodges–Lehmann median differences and corresponding 95% confidence intervals were used to estimate effect magnitude and precision. An a priori power analysis was performed using G*Power (Version 3.1; Heinrich-Heine University, Düsseldorf, Germany) (Faul et al., 2007) for a two-group comparison of change scores in a primary COP outcome (two-tailed t test, α=0.05, power =0.80). Based on previous physical activity intervention studies in community-dwelling older adults, which typically report moderate-to-large standardized mean differences in clinically relevant functional outcomes (Cohen's d=0.4–0.8) (Chase, Phillips, & Brown, 2017), we considered a medium-to-large clinically relevant effect (d=0.7). Under these assumptions, the required sample size was estimated at 25 participants per group; our final sample of 30 participants per group exceeded this target. Statistical significance was set at p<0.05. All statistical analyses were performed using IBM SPSS Statistics (Version 31.0; IBM Corp., Armonk, NY, USA).

Results

Baseline demographic and anthropometric characteristics of the two groups are presented in Table 2. The control and experimental groups showed similar age, height, weight, and BMI values, with comparable variability across all measures, indicating adequate group homogeneity at baseline (see Table 2).

Table 2. Baseline Characteristics of Study Participants

Group		N	Min	Max	Mean	SD	CV
Control	Age (years)	30	55	65	58.43	3.46	5.92
	Height (cm)	30	164	201	174.83	7.90	4.52
	Weight (kg)	30	50.70	114.80	78.53	15.12	19.26
	BMI (kg/m²)	30	18.40	33.90	25.54	3.70	14.52
Experimental	Age (years)	30	55	65	58.93	3.88	6.59
	Height (cm)	30	150	188	170.97	7.99	4.68
	Weight (kg)	30	55.20	108.30	74.97	14.33	19.11
	BMI (kg/m²)	30	19.60	31.40	25.50	3.51	13.76

Note. Values are presented as number of participants (N), minimum (Mini), maximum (Maxi), mean, standard deviation (SD), and coefficient of variation (CV). BMI = body mass index. Control and experimental groups each included 30 participants. Baseline demographic and anthropometric characteristics were comparable between groups, indicating initial group homogeneity.

Pre- and post-intervention mean ± SD values for COP variables in tandem and single-leg stance under eyes-open and eyes-closed conditions are presented in Table 3.

Table 3. Pre- and post-intervention mean ± SD values for COP variables in tandem stance under eyes-open (EO) and eyes-closed (EC) conditions

Condition	Variable	Group	T1 Mean ± SD	T2 Mean ± SD
TanEO	Standard Ellipse (cm²)	CG	3.54±2.05	5.15±3.11
		EG	4.24±3.27	2.65±0.94
	Ellipse Angle (°)	CG	-0.38±22.05	2.78±18.78
		EG	-0.97±18.97	-7.50±11.86
	Relative Pathlength (mm/s)	CG	54.95±10.87	64.43±26.49
		EG	58.45±10.32	50.66±6.53
	Absolute Pathlength (mm)	CG	260.59±69.27	332.16±120.62
		EG	335.78±141.89	314.62±130.81
	Equilibrium Index (AP)	CG	87.00±2.66	82.24±4.95
		EG	86.16±2.19	91.05±1.98
TanEC	Standard Ellipse (cm²)	CG	11.32±5.32	22.12±10.79
		EG	13.40±4.81	11.90±8.20
	Ellipse Angle (°)	CG	-1.28±25.71	-7.75±24.87
		EG	-1.97±29.51	9.02±11.03
	Relative Pathlength (mm/s)	CG	104.52±46.59	112.45±47.35
		EG	105.50±46.26	76.75±35.72
	Absolute Pathlength (mm)	CG	1045.37±465.97	1101.06±476.27
		EG	1051.98±456.62	723.63±294.99
	Equilibrium Index (AP)	CG	70.75±7.78	70.01±8.97
		EG	70.18±10.01	79.46±7.33
SL EO	Standard Ellipse (cm²)	CG	13.12±15.25	7.06±3.24
		EG	10.39±8.47	4.98±1.99
	Ellipse Angle (°)	CG	8.35±44.59	6.25±43.06
		EG	4.93±36.82	2.95±18.31
	Relative Pathlength (mm/s)	CG	115.26±61.81	92.38±32.62
		EG	101.49±37.57	79.14±26.96
	Absolute Pathlength (mm)	CG	576.28±309.06	505.00±164.60
		EG	506.79±187.51	427.88±147.15
	Equilibrium Index (AP)	CG	77.53±15.90	83.67±3.59
		EG	81.66±5.15	87.15±3.45
SL EC	Standard Ellipse (cm²)	CG	20.74±9.96	20.43±7.75
		EG	20.37±8.22	14.15±9.20
	Ellipse Angle (°)	CG	-2.09±48.77	5.26±47.34
		EG	0.82±52.05	1.25±37.75
	Relative Pathlength (mm/s)	CG	141.60±42.01	150.03±41.29
		EG	139.87±38.61	112.5±38.22
	Absolute Pathlength (mm)	CG	708.48±211.09	765.83±202.46
		EG	691.26±190.26	606.66±186.94
	Equilibrium Index (AP)	CG	73.77±8.37	73.28±6.66
		EG	76.85±8.92	80.69±8.46

Note. TanEO = tandem stance, eyes open; TanEC = tandem stance, eyes closed; SL EO = single-leg stance, eyes open; SL EC = single-leg stance, eyes closed; CG = control group; EG = experimental group. Values represent pre-intervention (T1) and post-intervention (T2) mean ± SD for each COP variable.

To confirm baseline comparability, group differences in COP variables at pre-test were assessed using the Mann-Whitney U test. No significant differences were found between the control and experimental groups for any COP variable across tandem or single-leg stance conditions (all p>0.05), indicating that the two groups were comparable before the intervention (see Table 4).

Table 4. Pre-intervention group comparisons — Mann-Whitney U test

Condition	Variable	Mann-Whitney U	Z	p	Sig.
TanEO	Standard Ellipse (cm²)	483.00	- 0.488	0.626	NS
	Ellipse Angle (°)	551.50	1.501	0.133	NS
	Relative Pathlength (mm/s)	564.00	1.685	0.092	NS
	Absolute Pathlength (mm)	581.00	1.937	0.053	NS
	Equilibrium Index (AP)	377.500	-1.072	0.284	NS
TanEC	Standard Ellipse (cm²)	440.5	-0.140	0.888	NS
	Ellipse Angle (°)	443.0	-0.103	0.918	NS
	Relative Pathlength (mm/s)	445.0	-0.074	0.941	NS
	Absolute Pathlength (mm)	433.0	-0.251	0.802	NS
	Equilibrium Index (AP)	388.5	-0.909	0.363	NS
SL-EO	Standard Ellipse (cm²)	388.5	-0.909	0.363	NS
	Ellipse Angle (°)	400.0	-0.133	0.894	NS
	Relative Pathlength (mm/s)	403.0	-0.695	0.487	NS
	Absolute Pathlength (mm)	400.5	-0.732	0.464	NS
	Equilibrium Index (AP)	491.5	0.614	0.539	NS
SL-EC	Standard Ellipse (cm²)	493.0	0.36	0.525	NS
	Ellipse Angle (°)	478.0	0.414	0.679	NS
	Relative Pathlength (mm/s)	428.0	-0.325	0.745	NS
	Absolute Pathlength (mm)	419.0	-0.458	0.647	NS
	Equilibrium Index (AP)	552.50	1.516	0.130	NS

Note. TanEO = tandem stance, eyes open; TanEC = tandem stance, eyes closed; SL-EO = single-leg stance, eyes open; SL-EC = single-leg stance, eyes closed. Mann-Whitney U test used to compare control and experimental groups at pre-intervention (T1). Significance level set at p<0.05. "Significant" indicates p<0.05, whereas "NS" indicates p≥0.05.

Significant between-group differences were observed in tandem postural balance outcomes under both eyes-open (EO) and eyes-closed (EC) conditions. In the EO condition, all Δ variables showed statistically significant differences (p≤0.013), indicating greater improvements in the experimental group compared with the control group. In the EC condition, significant between-group differences were also identified for all variables (p≤0.015). Greater improvements were particularly observed for area ellipse, absolute pathlength, and equilibrium index, suggesting enhanced postural stability and better anteroposterior balance control in the experimental group. Overall, the experimental group demonstrated superior improvements in tandem balance performance under both visual conditions (see Table 5).

Table 5. Between-Group Comparisons of Tandem Postural Balance Changes (Δ values) Under Eyes-Open and Eyes-Closed Conditions

Condition	Variable	Mann-Whitney U	Z	p	Sig.	Hodges–Lehmann Median Difference (95% CI)
TanEO	Standard Ellipse (cm²)	232.00	-3.22	0.001	Significant	2.27 (0.84–3.81)
	Ellipse Angle (°)	281.50	-2.49	0.013	Significant	8.44 (2.31–14.70)
	Relative Pathlength (mm/s)	44.00	-6.00	<0.001	Significant	57.83 (43.61–75.18)
	Absolute Pathlength (mm)	207.00	-3.59	<0.001	Significant	90.65 (36.20–133.50)
	Equilibrium Index (AP)	877.00	6.31	<0.001	Significant	-11.30 (-14.50–-8.70)

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Table 5. Between-Group Comparisons of Tandem Postural Balance Changes (Δ values) Under Eyes-Open and Eyes-Closed Conditions

Condition	Variable	Mann-Whitney U	Z	p	Sig.	Hodges–Lehmann Median Difference (95% CI)
TanEC	Standard Ellipse (cm²)	188.00	-3.874	<0.001	Significant	12.675 (6.370–19.480)
	Ellipse Angle (°)	615.00	2.440	0.015	Significant	-11.385 (-18.480–-3.460)
	Relative Pathlength (mm/s)	196.00	-3.755	<0.001	Significant	34.485 (14.450–51.340)
	Absolute Pathlength (mm)	188.00	-3.874	<0.001	Significant	384.450 (194.900–561.800)
	Equilibrium Index (AP)	708.00	3.815	<0.001	Significant	-8.500 (-12.900–-4.400)

Note. Δ represents change scores (Δ=T2 − T1). Independent-Samples Mann–Whitney U tests were used to compare the control group (CG) and experimental group (EG) under tandem eyes-open (EO) and tandem eyes-closed (EC) conditions. p-values less than 0.05 were considered statistically significant. "Significant" indicates p<0.05, whereas "NS" indicates p≥0.05. Hodges–Lehmann median differences with 95% confidence intervals (CI) indicate the magnitude and direction of between-group differences. Positive values indicate greater improvements in the experimental group, whereas negative values indicate greater improvements in the control group.

Significant between-group differences were observed in most single-leg postural balance Δ variables under both eyes-open (SL-EO) and eyes-closed (SL-EC) conditions. In the SL-EO condition, all variables showed significant differences except standard ellipse area (p=0.469), with the experimental group demonstrating greater improvements in sway velocity, path length, and equilibrium index. In the SL-EC condition, significant differences were found for all variables except ellipse angle (p=0.929), indicating superior improvements in postural stability and sway magnitude parameters in the experimental group (see Table 6).

Table 6. Between-Group Comparisons of Single-Leg Postural Balance Changes (Δ values) Under Eyes-Open and Eyes-Closed Conditions

Condition	Variable	Mann-Whitney U	Z	p	Sig.	Hodges–Lehmann Median Difference (95% CI)
SL-EO	Standard Ellipse (cm²)	401.0	-0.724	0.469	NS	0.915 (−1.800 – 3.410)
	Ellipse Angle (°)	281.5	-2.491	0.013	Significant	8.435 (2.310 – 14.700)
	Relative Pathlength (mm/s)	44.0	-6.002	<0.001	Significant	57.830 (43.610 – 75.180)
	Absolute Pathlength (mm)	207.0	-3.593	<0.001	Significant	90.650 (36.200 – 133.500)
	Equilibrium Index (AP)	877.0	6.313	<0.001	Significant	−11.300 (−14.500 – −8.700)
SL-EC	Standard Ellipse (cm²)	183.5	−3.94	<0.001	Significant	10.17 (5.58 – 13.84)
	Ellipse Angle (°)	444.0	0.09	0.929	NS	0.50 (−16.19 – 17.77)
	Relative Pathlength (mm/s)	157.0	−4.33	<0.001	Significant	32.90 (22.83 – 44.10)
	Absolute Pathlength (mm)	182.0	3.96	<0.001	Significant	122.05 (78.30 – 167.40)
	Equilibrium Index (AP)	645.5	2.89	0.004	Significant	−3.15 (−5.90 – −1.30)

Note. Between-group comparisons of single-leg postural balance change scores (Δ = post-intervention minus baseline) were analyzed using the Independent-Samples Mann–Whitney U test under both eyes-open (SL-EO) and eyes-closed (SL-EC) conditions. Hodges–Lehmann estimates with 95% confidence intervals (CI) indicate the magnitude and direction of median group differences.

Within-group analyses using the Wilcoxon Signed-Rank Test revealed clear and condition-specific patterns of adaptation (see Table 7). In the TanEO condition, the control group showed significant increases in sway-related parameters accompanied by reduced equilibrium control, indicating a deterioration in postural stability over time. In contrast, the experimental group demonstrated significant improvements across all parameters (predominantly p<0.001), reflected by reduced sway magnitude and enhanced anteroposterior control.

Under TanEC conditions, no significant changes were observed in the control group, whereas the experimental group exhibited marked improvements in sway-related parameters and the equilibrium index (all p≤0.001), indicating enhanced postural control under visual deprivation.

For the SL-EO condition, the control group showed partial improvements limited to selected parameters, while the experimental group demonstrated consistent and statistically significant enhancements across all key balance outcomes.

In the most demanding condition, SL-EC, no significant changes were identified in the control group, whereas the experimental group exhibited robust and uniform improvements across all sway-related parameters (all p<0.001), re-

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flecting substantial gains in postural stability under increased task difficulty.

Overall, these findings indicate that the intervention induced consistent and meaningful improvements in balance performance across all conditions, particularly under increased postural and sensory demands, whereas the control group showed minimal or no adaptive changes.

Table 7. Within-Group Temporal Changes in Postural Balance Performance across Testing Conditions

Condition	Group	Variable	Z	p-value	Direction of change
TanEO	Control	Standard Ellipse (cm²)	−2.232	0.026*	Increase
		Ellipse Angle (°)	−0.504	0.614	No change
		Relative Pathlength (mm/s)	−2.149	0.032*	Increase
		Absolute Pathlength (mm)	−2.622	0.009**	Increase
		Equilibrium Index (AP)	−3.261	0.001**	Increase
	Experimental	Standard Ellipse (cm²)	−2.437	0.015*	Decrease
		Ellipse Angle (°)	−3.569	<0.001***	Decrease
		Relative Pathlength (mm/s)	−4.720	<0.001***	Decrease
		Absolute Pathlength (mm)	−4.782	<0.001***	Decrease
		Equilibrium Index (AP)	−4.782	<0.001***	Decrease
TanEC	Control	Standard Ellipse (cm²)	−0.792	0.428	No change
		Ellipse Angle (°)	−0.668	0.504	No change
		Relative Pathlength (mm/s)	−0.956	0.339	No change
		Absolute Pathlength (mm)	−0.792	0.428	No change
		Equilibrium Index (AP)	−0.082	0.934	No change
	Experimental	Standard Ellipse (cm²)	−4.700	<0.001***	Decrease
		Ellipse Angle (°)	−3.240	0.001**	Increase
		Relative Pathlength (mm/s)	−4.782	<0.001***	Decrease
		Absolute Pathlength (mm)	−4.782	<0.001***	Decrease
		Equilibrium Index (AP)	−4.782	<0.001***	Increase
SL-EO	Control	Standard Ellipse (cm²)	−3.116	0.002**	Decrease
		Ellipse Angle (°)	−0.010	0.992	No change
		Relative Pathlength (mm/s)	−2.828	0.005**	Decrease
		Absolute Pathlength (mm)	−0.668	0.504	No change
		Equilibrium Index (AP)	−2.520	0.012*	Increase
	Experimental	Standard Ellipse (cm²)	−3.260	0.001**	Decrease
		Ellipse Angle (°)	−0.607	0.544	No change
		Relative Pathlength (mm/s)	−4.762	<0.001***	Decrease
		Absolute Pathlength (mm)	−3.065	0.002**	Decrease
		Equilibrium Index (AP)	−4.682	<0.001***	Increase

Condition	Group	Variable	Z	p-value	Direction of change
SL-EC	Control	Standard Ellipse (cm²)	−0.237	0.813	No change
		Ellipse Angle (°)	−0.257	0.797	No change
		Relative Pathlength (mm/s)	−0.833	0.405	No change
		Absolute Pathlength (mm)	−1.286	0.199	No change
		Equilibrium Index (AP)	−0.010	0.992	No change
	Experimental	Standard Ellipse (cm²)	−4.782	<0.001***	Improvement
		Ellipse Angle (°)	−0.216	0.829	No change
		Relative Pathlength (mm/s)	−4.782	<0.001***	Improvement
		Absolute Pathlength (mm)	−4.782	<0.001***	Improvement
		Equilibrium Index (AP)	−4.784	<0.001***	Improvement

Note. TanEO = tandem stance, eyes open; TanEC = tandem stance, eyes closed; SL-EO = single-leg stance, eyes open; SL-EC = single-leg stance, eyes closed. Wilcoxon Signed-Rank Test comparing T2 vs. T1 within each group. *p<0.05; **p<0.01; ***p<0.001. Decreases in sway-related variables indicate improved postural stability, whereas increases in the Equilibrium Index (AP) indicate improved anteroposterior control. For Ellipse Angle (°), "Increase" or "Decrease" refers strictly to numerical change in sway orientation and does not necessarily indicate improved or worsened postural control.

Discussion

This study aimed to evaluate the effectiveness of a 12-week structured recreational exercise training program on static and dynamic balance in late middle-aged adults (55–65 years) using laboratory-based postural assessment. The main findings supported our hypothesis, showing that participants who engaged in the recreational exercise program demonstrated significantly greater improvements in balance performance compared with the control group across nearly all testing conditions. Improvements were especially pronounced in tandem stance and single-leg stance tasks performed under eyes-closed conditions, suggesting that participation in the recreational exercise program was associated with better balance control under increased sensory and postural demands. Beyond statistical significance, the magnitude and consistency of these changes appear clinically relevant. Across the most demanding conditions, particularly tandem and single-leg stance with eyes closed, the experimental group showed substantial reductions in sway area and path length together with meaningful increases in equilibrium index compared with the control group, as reflected in the pre- and post-intervention values reported in Table 3. Overall, such combined improvements in multiple COP parameters are generally interpreted as indicating more stable posture and a lower likelihood of balance loss during everyday tasks that challenge sensory integration, although definitive causal conclusions cannot be drawn from this quasi-experimental design.

The most relevant improvements were observed in center-of-pressure (COP) variables, including standard ellipse area, relative path length, and absolute path length, together with significant enhancement of the equilibrium index. Reduced sway magnitude and sway velocity indicate better postural regulation, improved neuromuscular coordination, and more efficient integration of vestibular, visual, and proprioceptive inputs (Cui et al., 2024; Wang et al., 2024).

In the present study, these interpretations are based on indirect evidence from COP outcomes, because neuromuscular activation and sensory integration were not directly assessed and should therefore be regarded as plausible explanations rather than established causal effects.

These findings are consistent with previous systematic reviews showing that balance-focused and multicomponent exercise interventions significantly improve postural stability and reduce fall risk in aging populations (Choudhary et al., 2026; Papalia et al., 2020; Sherrington et al., 2019).

A particularly important finding was the superior improvement observed under eyes-closed conditions (TanEC and SL-EC). Since visual input was removed during these tasks, participants relied primarily on vestibular and somatosensory mechanisms to maintain stability. The experimental group showed significant improvements across nearly all variables, whereas the control group demonstrated little or no adaptation. This suggests that the intervention enhanced sensory reweighting capacity and postural adaptability, both of which are known to decline progressively with aging (Alizadehsaravi et al., 20224; Cui et al., 2024; Liu et al., 2024). Similar findings have been reported in interventions involving standing balance training, where repeated exposure to unstable conditions improved postural control under sensory deprivation (Caña-Pino & Marín-Rubio, 2025; Pšeničnik Sluga & Kozinc, 2024).

The improvements observed in single-leg stance performance are also clinically meaningful. Single-leg stance is considered a sensitive marker of fall risk, mobility limitations, and future functional decline because it reflects the ability to maintain postural control during gait transitions, obstacle negotiation, and stair climbing (Yosef et al., 2026; Xie et al., 2023). The significant gains observed in both SL-EO and especially SL-EC conditions suggest that recreational exercise may contribute to preserving independence and delaying age-related functional deterioration during late middle adulthood. In addition, the pattern of changes observed in single-leg tasks characterized by reductions in sway magnitude and path length together with improvements in equilibrium index in the experimental group and minimal change or deterioration in the control group, supports the view that the intervention produced changes of a magnitude likely to translate into better stability during real-life situations such as negotiating uneven surfaces or recovering from minor perturbations.

These findings align with previous evidence supporting multicomponent exercise interventions such as the Otago Exercise Program, which has demonstrated strong effects on balance and fall prevention in older adults (Citozi et al., 2025; Wang & Kim, 2025; Zhang et al., 2026). However, unlike Otago, which is frequently applied in rehabilitation or frail populations, the present intervention targeted healthy, community-dwelling adults before major functional decline had occurred. This preventive approach may be particularly valuable because intervention before the onset of frailty is associated with better long-term outcomes and greater behavioral adherence (Michel & Ecarnot, 2019; World Health Organization, 2020).

Another relevant finding was the lack of improvement, and in some variables, deterioration, observed in the control group, particularly during tandem stance. Increased sway over time in adults without intervention supports the concept that measurable balance decline may already begin during late middle adulthood, even in apparently healthy individuals (Adams et al., 2023; Nohelova et al., 2026; Wang et al., 2024). This reinforces the importance of early preventive exercise rather than waiting until clinically significant instability or falls occur. Nevertheless, alternative explanations such as unmeasured changes in lifestyle, health status, or physical activity outside the intervention period cannot be excluded and may have contributed to the observed patterns in both groups, as these factors were not monitored systematically.

The recreational nature of the intervention also deserves attention. Exercise adherence remains one of the greatest challenges in preventive health programs, particularly among middle-aged and older adults. Programs perceived as enjoyable, socially engaging, and low burden are associated with better long-term participation than highly medicalized exercise prescriptions (Bauman et al., 2012; Franco et al., 2015). Therefore, recreational exercise may offer a more sustainable public health strategy compared with purely therapeutic interventions.

Importantly, this study contributes to the limited literature focusing specifically on adults aged 55–65 years. Most balance intervention studies focus on populations older than 65 years, despite evidence showing that neuromuscular decline, reduced postural control, and early fall risk begin much earlier (Adams et al., 2023; Di Lorito et al., 2021). Addressing balance decline during this transitional stage may delay frailty progression, reduce healthcare costs, and support healthy aging trajectories.

Practical implications

The present findings suggest that recreational balance-oriented exercise can be used as a simple, low-cost, and accessible strategy for preventing early balance decline in adults aged 55–65 years. Because the program required only moderate intensity and simple exercises, it can be easily implemented in community centers, recreational clubs, workplace wellness programs, and public health initiatives. Early intervention during late middle adulthood may help to reduce future fall risk, preserve independence, and support healthier aging trajectories (Liu-Ambrose et al., 2019).

Limitations

This study has several limitations. First, the quasi-experimental design without full randomization may introduce selection bias. Second, the relatively small sample size and single-city recruitment may limit generalizability. Third, the intervention lasted only 12 weeks and no follow-up assessment was performed, so long-term effects remain unclear. Finally, fall incidence, quality of life, and physical activity outside the intervention were not assessed, which may limit clinical interpretation.

Future research

Future studies should use randomized controlled designs with larger and more diverse samples to improve external validity. Longer interventions and follow-up assessments are needed to examine whether balance improvements are maintained over time and reduce fall risk. Future research should also compare recreational exercise with established programs such as the Otago Exercise Program and include additional outcomes such as fear of falling, balance confidence, and quality of life.

Conclusions

Late middle adulthood represents a critical window for preventing age-related balance decline before the onset of frailty and functional dependence. The findings of this study suggest that structured recreational exercise can serve as an effective, accessible, and sustainable strategy for preserving postural control and functional stability in adults aged 55–65 years.

Rather than waiting for balance impairment and falls to occur, early implementation of balance-oriented recreational programs may support healthier aging trajectories, reduce future fall risk, and help maintain independence. Recreational exercise should therefore be viewed not only as a leisure activity, but also as an important preventive tool in community health and active aging strategies.

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Conflict of interests
The authors declare no conflicts of interest related to this study.

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