STUDIA UBB EDUCATIO ARTIS GYMN., LXX, Special Issue 1, 2025, pp. 145-160
(RECOMMENDED CITATION)
DOI: 10.24193/subbeag.70.sp.iss.1.10

EFFECTS OF A MULTICOMPONENT BALANCE AND STRENGTH TRAINING PROGRAM ON POSTURAL STABILITY IN OLDER ADULTS: A REPEATED-MEASURES ANALYSIS

Alexandru-Valentin ENACHE[1], Daniela CHEPTĂNARU[2], Evelyne GEIGER[3], Anca-Lucia VĂDAN[4]*

ABSTRACT. Aging is characterized by a progressive decline in balance and mobility, leading to an increased risk of falls among older adults. This pilot study investigated the effects of a multicomponent balance and strength training program on postural control in community-dwelling older adults. Four participants (two men, two women; age 72–94 years, M = 79.0, SD = 9.9) completed a 6-week intervention consisting of thrice-weekly sessions (20–25 minutes, light-to-moderate intensity) including warm-up, progressive balance/strength exercises and cool-down. Postural stability was assessed using a BTS P-WALK baropodometric platform under six conditions: quiet standing and half-squat position with eyes open then closed, each on hard and soft surfaces. Thirty-six center-of-pressure variables (area, path length, velocity) were analyzed at three time points (baseline, intermediate, final). Given the small sample size (N = 4) and some non-normally distributed variables, Friedman's test was used. No statistically significant differences were found across time (all $p \geq .105$). However, descriptive trends indicated modest improvements in sway area, path length, and velocity under eyes-open and half-squat conditions, suggesting enhanced postural stability.

[1] Faculty of Physical Education and Sport, Department of Physiotherapy and Theoretical Disciplines, Babes-Bolyai University, Pandurilor street nr.7, 400376, Romania
[2] Faculty of Physical Education and Sport, Department of Physiotherapy and Theoretical Disciplines, Babes-Bolyai University, Pandurilor street nr.7, 400376, Romania
[3] Faculty of Physical Education and Sport, Department of Physiotherapy and Theoretical Disciplines, Babes-Bolyai University, Pandurilor street nr.7, 400376, Romania
[4] Faculty of Physical Education and Sport, Department of Physiotherapy and Theoretical Disciplines, Babes-Bolyai University, Pandurilor street nr.7, 400376, Romania
* Corresponding author: anca.vadan@ubbcluj.ro

Although underpowered, this study highlights the feasibility of implementing multicomponent balance training in older adults and suggests potential benefits for fall prevention. The absence of decline in postural stability itself may be clinically relevant. Future larger-scale trials with longer follow-up are needed to confirm these findings and to explore whether improvements in force-platform metrics translate into meaningful reductions in fall risk.

Keywords: Older adults; Balance training; Strength training; Postural control; Center of pressure (CoP); Half-squat position; Multicomponent exercise program; Fall prevention.

INTRODUCTION

As life expectancy has increased, so did the prevalence of falls among the elderly. A fall is the consequence (a symptom) of a disease. It is the leading cause of morbidity and mortality among older adults, so its prevention must be a public health priority (Rubenstein, 2006). Aging comes with frailty; it is a progressive decline in balance, mobility and strength. As people grow older, voluntary physical activity tends to decline, which is closely associated with reduced aerobic capacity, muscle strength and stamina. In recent years, researchers highlighted that regular physical exercise may help prevent frailty (Liu & Fielding, 2011). Chen et al. (2014), emphasized that the early detection of this fragility, together with timely evaluation and treatment, is central to delivering high-quality care for the expanding elderly population.

There is consistent evidence that structured exercise programs can lower both the number of falls and the incidence of individuals who experience them. The most effective strategies are multicomponent interventions that combine balance and strength training. Enhanced muscle activation, together with a reduction in the fear of falling, likely contributes to better functional outcomes, such as improved performance on the Timed Up and Go (TUG) test (Patar & Scheicher, 2014).

Previous studies have shown that increasing ankle mobility through different forms of physical activity, such as stretching, water exercise and Tai Chi may have some benefits in increasing balance in older people (Menz et al., 2005).

The slow, deliberate movements of Tai Chi Chuan enhance focus and attention, promoting a sense of calm and relaxation even in stressful situations. Evidence from research indicates that practicing Tai Chi Chuan can significantly improve balance and reduce fear of falling among community-dwelling older adults (Hosseini et al., 2018).

The purpose of this study was to examine how a structured exercise program that integrates balance, strength, and coordination activities influences postural control in older adults. To capture these effects, center-of-pressure parameters—such as area, path length, and velocity—were measured on a baropodometric platform under different testing conditions, bipedalism and half-squat position with eyes open and closed, each once on hard and then on soft surfaces.

MATERIAL AND METHODS

Participants

Four community-dwelling older adults (two men and two women) participated in the 6-week study. The participants' ages ranged from 72 to 94 years (M = 79.0, SD = 9.9). The mean height was 167.0 cm (SD = 8.9), and the mean weight was 69.5 kg (SD = 16.1). All participants were able to ambulate independently without assistive devices and reported no acute musculoskeletal or neurological conditions that would limit their ability to participate in the exercise program.

The study was conducted in accordance with the ethical standards of the Declaration of Helsinki (World Medical Association, 2013).

All participants received a detailed explanation of the purpose, procedures, potential risks, and benefits of the study. Written informed consent was obtained from each participant prior to enrollment. Participants were informed of their right to withdraw from the study at any time without any consequences.

Procedure

Evaluation protocols

The evaluation was conducted once for each of the following protocols, each lasting 15 seconds. The subject assumed a bipodal orthostatic position with feet at shoulder width. The protocols were:

- Standing on a baropodometric plate (H) with eyes closed (EC).
- Standing on a baropodometric plate (H) with eyes open (EO).
- Standing on a baropodometric plate (H) covered with a 1.5 cm thick sponge (S), with eyes closed (EC).
- Standing on a baropodometric plate (H) covered with a 1.5 cm thick sponge (S), with eyes open (EO).

- In a half-squat position on the baropodometric plate (H) with arms extended forward and eyes open (EO).
- In a half-squat position on the baropodometric plate (H) with arms extended forward and eyes closed (EC).

The sequence allowed the subject to adapt to varying orthostatic positions. The half-squat was maintained for 15 seconds outside the orthostatic balance zone, enabling the evaluation of aerobic capacity while ensuring safety.

The Romberg test, typically performed with eyes open (EO) and eyes closed (EC) on a hard surface (H), was expanded to include new conditions: evaluation on a soft surface (S) and in a half-squat position (H-Sqt). The following parameters were evaluated:

- Soft Surface (S): Eyes closed (EC) and open (EO) measurements for barycenter area, length, and speed (left foot, right foot and body).
- Hard Surface (H): Eyes closed (EC) and open (EO) measurements for barycenter area, length, and speed (left foot, right foot and body), both in the standing and half-squat positions.

The assessments were conducted using the BTS P-WALK baropodometric platform, which consists of a 675x540x5 mm plate equipped with 2,304 resistive sensors (1x1 cm each), with a pressure range of 30-400 kPa, a sampling frequency of 100 Hz, and an AC/USB adapter power supply, weighing approximately 7 kg.

Materials

Each training session was performed three times per week, lasted 20–25 minutes at a low-to-moderate intensity, and was structured into three phases: a 5-minute warm-up (seated mobility exercises), 15 minutes of progressive balance and strengthening exercises, and a 3–5-minute cool-down with breathing and relaxation exercises.

Table 1. Exercise program

Exercise type	Objectives	Progression
Static isometric	Improving static balance through postural muscle activation	Hard surface versus unstable, eyes open versus closed
Dynamic balance	Increasing dynamic stability and walking safety	Simple walking versus over obstacle
Strength	Development of lower body and core muscle strength	Increasing elastic band resistance and the number of repetitions

Exercise type	Objectives	Progression
Proprioceptive and sensory system training	Proprioception, vestibular and visual control stimulation	Hard surface versus unstable
Functional (ADL-based)	Adapting exercises into ADL	Hand support versus no hand support
Coordination and stretching	Improvement of coordination and flexibility	Task complexity through interactive games

Data analysis

All statistical analyses were performed using IBM SPSS Statistics (Version XX; IBM Corp., Armonk, NY, USA). Descriptive statistics (means and standard deviations) were calculated for all 36 force-platform variables at the three measurement time points (initial, intermediate and final). Data were first screened for normality using the Shapiro–Wilk test. Although most variables were approximately normally distributed, several variables showed significant departures from normality ($p < .05$). Given the small sample size ($N = 4$) and the presence of non-normally distributed variables, a nonparametric approach was selected for inferential analysis.

To compare repeated measures across the three time points, Friedman's test was conducted for each variable. This test is the nonparametric alternative to repeated-measures ANOVA and evaluates whether the median ranks differ across related samples. When significant main effects were observed, post hoc pairwise comparisons were planned using Wilcoxon signed-rank tests with Bonferroni correction to control for Type I error. No significant Friedman tests were found, so post hoc tests were not performed. The level of significance was set at $p = .05$ for all tests.

RESULTS

The distribution of each variable at all three time points (initial, intermediate, and final) was examined using the Shapiro–Wilk test. Most variables were normally distributed ($p > .05$), suggesting approximate normality. However, several variables—including H_EC_LSF at baseline ($p = .017$), INTERIM_S_EO_LSF ($p = .017$), INTERIM_H_EO_Aria_R_HalfSquat ($p = .030$), and FINAL_H_EO_Aria_B ($p = .012$)—significantly deviated from normality. Given the very small sample size ($N = 4$), even minor departures from normality could bias parametric analyses.

To ensure a conservative and robust analysis, we therefore used Friedman's test, the nonparametric equivalent of repeated-measures ANOVA, which does not require normally distributed data and is suitable for comparing three related measurements within subjects.

Table 2. Friedman Test results for variables obtained in the upright position on a hard surface with eyes open

Pair	Variable Name	N	Mean	Std. Deviation	Minimum	Maximum	Friedman Test (p)
	H_EO_Aria_L	4	10.23	4.39	6.1	15.65	
1	INTERIM_H_EO_Aria_L	4	9.6	6.22	2.28	15.43	0.779
	FINAL_H_EO_Aria_L	4	9.12	10.06	1.35	23.5	
	H_EO_Aria_B	4	47.48	29.1	18.14	85.47	
2	INTERIM_H_EO_Aria_B	4	19.27	11.92	10.2	36.61	0.105
	FINAL_H_EO_Aria_B	4	22.4	12.89	14.73	41.68	
	H_EO_Aria_R	4	16.1	11.2	4.78	28.44	
3	INTERIM_H_EO_Aria_R	4	6.8	2.85	4.25	10.04	0.174
	FINAL_H_EO_Aria_R	4	5.73	1.93	3.57	8.26	
	H_EO_L	4	91.35	27.17	60.7	118.9	
4	INTERIM_H_EO_L	4	86.4	11.6	74.4	99.2	0.779
	FINAL_H_EO_L	4	76.6	23.07	49.3	96.9	
	H_EO_Vit	4	6.08	1.83	4	7.9	
5	INTERIM_H_EO_Vit	4	5.78	0.75	5	6.6	0.779
	FINAL_H_EO_Vit	4	5.13	1.54	3.3	6.5	
	H_EO_LSF	4	2.28	0.78	1.4	3.3	
6	INTERIM_H_EO_LSF	4	5.83	3.27	2.2	9.7	0.105
	FINAL_H_EO_LSF	4	3.95	1.87	2.3	6.6	

(mm^2) = millimiter square; mm (millimeter); (mm/s) millimeter/seconds; SD = standard deviation; Hard surface Eyes Open Area Left (H_EO_Area_L, mm^2); Interim Hard surface Eyes Open Area Left (Interim_H_EO_Area_L, mm^2); Final Hard surface Eyes Open Area Left (Final_H_EO_Area_L, mm^2); Hard surface Eyes Open Area Body (H_EO_Area_B, mm^2); Interim Hard surface Eyes Open Area Body (Interim_H_EO_Area_B, mm^2); Final Hard surface Eyes Open Area Body (Final_H_EO_Area_B, mm^2); Hard surface Eyes Open Area Right (H_EO_Area_R, mm^2); Interim Hard surface Eyes Open Area Right (Interim_H_EO_Area_R, mm^2); Final Hard surface Eyes Open Area Right (Final_H_EO_Area_R, mm^2); Hard surface Eyes Open Length (H_EO_L, mm); Interim Hard surface Eyes Open Length (Interim_H_EO_L, mm); Final Hard surface Eyes Open Length (Final_H_EO_L, mm); Hard surface Eyes Open Speed (H_EO_Vit, mm/s), Interim Hard surface Eyes Open Speed (Interim_H_EO_Vit, mm/s); Final Hard surface Eyes Open Speed (Final_H_EO_Vit, mm/s); Hard surface Eyes Open LSF (H_EO_LSF); Interim Hard surface Eyes Open LSF (Interim_H_EO_LSF); Final Hard surface Eyes Open LSF (Final_H_EO_LSF).

Table 3. Friedman Test results for variables obtained in the upright position on a soft surface with eyes open

Pair	Variable Name	N	Mean	Std. Deviation	Minimum	Maximum	Friedman Test (p)
	S_EO_Aria_L	4	12.34	10.61	2.46	27.07	
1	INTERIM_S_EO_Aria_L	4	37.56	29.32	4.92	75.3	0.174
	FINAL_S_EO_Aria_L	4	33.27	18.36	11.85	55.98	
	S_EO_Aria_B	4	91.55	41.28	43.43	141.06	
2	INTERIM_S_EO_Aria_B	4	151.49	97.54	15.01	242.32	0.472
	FINAL_S_EO_Aria_B	4	122.09	60.4	51.11	176.17	
	S_EO_Aria_R	4	30.09	27.79	3.43	65.97	
3	INTERIM_S_EO_Aria_R	4	27.13	27.37	3.11	66.27	0.472
	FINAL_S_EO_Aria_R	4	19.32	12.89	11.08	38.51	
	S_EO_L	4	99.95	20.22	74	120.3	
4	INTERIM_S_EO_L	4	104.58	30.84	64.9	134.3	0.779
	FINAL_S_EO_L	4	116.78	20.42	92	141.6	
	S_EO_Vit	4	6.33	1.61	4.9	8	
5	INTERIM_S_EO_Vit	4	6.98	2.09	4.3	9	0.282
	FINAL_S_EO_Vit	4	7.78	1.36	6.1	9.4	
	S_EO_LSF	4	1.53	0.28	1.2	1.8	
6	INTERIM_S_EO_LSF	4	1.55	1.84	0.4	4.3	0.42
	FINAL_S_EO_LSF	4	1.2	0.79	0.5	2.3	

(mm^2) = millimiter square; mm (millimeter); (mm/s) millimeter/seconds; SD = standard deviation; Soft surface Eyes Open Arial Left (S_EO_Aria_L, mm^2); Interim Soft surface Eyes Open Arial Left (Interim_S_EO_Aria_L, mm^2); Final Soft surface Eyes Open Arial Left (Final_S_EO_Aria_L, mm^2); Soft surface Eyes Open Arial Body (S_EO_Aria_B, mm^2); Interim Soft surface Eyes Open Arial Body (Interim_S_EO_Aria_B, mm^2); Final Soft surface Eyes Open Arial Body (Final_S_EO_Aria_B, mm^2); Soft surface Eyes Open Arial Right (S_EO_Aria_R, mm^2); Interim Soft surface Eyes Open Arial Right (S_EO_Aria_R, mm^2); Final Soft surface Eyes Open Arial Right (S_EO_Aria_R, mm^2); Soft surface Eyes Open Lenght (S_EO_L, mm); Interim Soft surface Eyes Open Lenght (Interim_S_EO_L, mm); Final Soft surface Eyes Open Lenght (Final_S_EO_L, mm); Soft surface Eyes Open Speed (S_EO_Vit, mm/s); Interim Soft surface Eyes Open Speed (Interim_S_EO_Vit, mm/s); Final Soft surface Eyes Open Speed (Final_S_EO_Vit, mm/s); Soft surface Eyes Open LSF (S_EO_LSF); Interim Soft surface Eyes Open LSF (Interim_S_EO_LSF); Final Soft surface Eyes Open LSF (Final_S_EO_LSF).

Table 4. Friedman Test results for variables obtained in the upright position on a hard surface with eyes close

Pair	Variable Name	N	Mean	Std. Deviation	Minimum	Maximum	Friedman Test (p)
	H_EC_Arial_L	4	9.68	6.74	3.01	17.41	
1	INTERIM_H_EC_Aria_L	4	19.35	20.16	0.71	44.41	0.779
	FINAL_H_EC_Aria_L	4	17.45	15.84	0.76	34.12	
	H_EC_Aria_B	4	52.89	36.74	6.1	95.9	
2	INTERIM_H_EC_Aria_B	4	92.32	90.33	6.74	173.09	0.472
	FINAL_H_EC_Aria_B	4	59.96	67.66	5.72	158.74	
	H_EC_Aria_R	4	21.68	19.35	4.57	49.33	
3	INTERIM_H_EC_Aria_R	4	15.36	15.07	2.36	33.79	0.779
	FINAL_H_EC_Aria_R	4	17.32	25.67	1.82	55.72	
	H_EC_L	4	114.88	55.79	65.4	186.7	
4	INTERIM_H_EC_L	4	110.9	52.07	56.4	167.1	1
	FINAL_H_EC_L	4	136.18	113.38	45.7	302.1	
	H_EC_Vit	4	7.65	3.68	4.4	12.4	
5	INTERIM_H_EC_Vit	4	7.38	3.44	3.8	11.1	1
	FINAL_H_EC_Vit	4	9.05	7.55	3	20.1	
	H_EC_LSF	4	4.1	4.42	1.4	10.7	
6	INTERIM_H_EC_LSF	4	3.45	3.54	0.8	8.4	0.779
	FINAL_H_EC_LSF	4	3.8	2.83	1.9	8	

(mm^2) = millimiter square; mm (millimeter); (mm/s) millimeter/seconds; SD = standard deviation; Hard surface Eyes Close Arial Left (H_EC_Aria_L); Interim Hard surface Eyes Close Arial Left (Interim_ H_EC_Aria_L, mm^2); Final Hard surface Eyes Close Arial Left (Final_H_EC_Aria_L, mm^2); Hard surface Eyes Close Arial Body (H_EC_Aria_B, mm^2); Interim Hard surface Eyes Close Arial Body (Interim_H_EC_Aria_B, mm^2); Final Hard surface Eyes Close Arial Body (Final_ H_EC_Aria_B, mm^2); Hard surface Eyes Close Arial Right (H_EC_Aria_R, mm^2); Interim Hard surface Eyes Close Arial Right (Interim_H_EC_Aria_R, mm^2); Final Hard surface Eyes Close Arial Right (Final_H_EC_R, mm^2); Hard surface Eyes Close Lenght (H_EC_L, mm); Interim Hard surface Eyes Close Lenght (Interim_H_EC_L, mm); Final Hard surface Eyes Close Lenght (Final_H_EC_L, mm); Hard surface Eyes Close Speed (H_EC_Vit, mm/s); Interim Hard surface Eyes Close Speed (Interim_H_EC_Vit, mm/s); Final Hard surface Eyes Close Speed (Final_H_EC_Vit, mm/s); Hard surface Eyes Close LSF (H_EC_LSF); Interim Hard surface Eyes Close LSF (Interim_H_EC_LSF); Final Hard surface Eyes Close Speed (Final_H_EC_LSF).

Table 5. Friedman Test results for variables obtained in the upright position on a soft surface with eyes close

Pair	Variable Name	N	Mean	Std. Deviation	Minimum	Maximum	Friedman Test (p)
	S_EC_Aria_L	4	23.9	13.67	11.64	38.24	
1	INTERIM_S_EC_Aria_L	4	14.66	3.63	10.79	19.17	0.368
	FINAL_S_EC_Aria_L	4	44.47	37.82	7.41	97.24	
	S_EC_Aria_B	4	108.21	44.49	64.17	164.9	
2	INTERIM_S_EC_Aria_B	4	94.65	36.14	62	143.67	0.472
	FINAL_S_EC_Aria_B	4	161.96	114.82	48.84	311.63	
	S_EC_Aria_R	4	29.61	14.95	10.44	44.6	
3	INTERIM_S_EC_Aria_R	4	15.95	7.78	9.42	27.24	0.779
	FINAL_S_EC_Aria_R	4	35.37	40.92	7.02	95.83	
	S_EC_L	4	154.63	53.56	90.4	216	
4	INTERIM_S_EC_L	4	106.45	18.87	87.5	132.1	0.174
	FINAL_S_EC_L	4	144.8	54.74	88.7	215.1	
	S_EC_Vit	4	10.3	3.59	6	14.4	
5	INTERIM_S_EC_Vit	4	7.08	1.27	5.8	8.8	0.174
	FINAL_S_EC_Vit	4	9.63	3.64	5.9	14.3	
	S_EC_LSF	4	2.48	1.34	1.3	4.4	
6	INTERIM_S_EC_LSF	4	1.28	0.54	0.6	1.8	0.165
	FINAL_S_EC_LSF	4	1.28	0.81	0.4	2.1	

(mm^2) = millimiter square; mm (millimeter); (mm/s) millimeter/seconds; SD = standard deviation; Soft surface Eyes Close Arial Left (S_EC_Aria_L, mm^2); Interim Soft surface Eyes Close Arial Left (Interim_S_EC_Aria_L, mm^2); Final Soft surface Eyes Close Arial Left (Final_S_EC_Aria_L, mm^2); Soft surface Eyes Close Arial Body (S_EC_Aria_B, mm^2); Interim Soft surface Eyes Close Arial Body (Interim_S_EC_Aria_B, mm^2); Final Soft surface Eyes Close Arial Body (Final_S_EC_Aria_B, mm^2); Soft surface Eyes Close Arial Right (S_EC_Aria_R, mm^2); Interim Soft surface Eyes Close Arial Right (Interim_S_EC_Aria_R, mm^2); Final Soft surface Eyes Close Arial Right (Final_S_EC_Aria_R, mm^2); Soft surface Eyes Close Lenght (S_EC_L, mm); Interim Soft surface Eyes Close Lenght (Interim_S_EC_L, mm); Final Soft surface Eyes Close Lenght (Final_S_EC_L, mm); Soft surface Eyes Close Speed (S_EC_Vit, mm/s); Interim Soft surface Eyes Close Speed (Interim_S_EC_Vit, mm/s); Final Soft surface Eyes Close Speed (Final_S_EC_Vit, mm/s); Soft surface Eyes Close LSF (S_EC_LSF); Interim Soft surface Eyes Close LSF (Interim_S_EC_LSF); Final Soft surface Eyes Close LSF (Final_S_EC_LSF).

Table 6. Friedman Test results for variables obtained in the HalfSquat position on a hard surface with eyes open

Pair	Variable Name	N	Mean	Std. Deviation	Minimum	Maximum	Friedman Test (p)
	H_EO_Aria_L_HalfSquat	4	40.47	21.84	12.48	57.92	
1	INTERIM_H_EO_Aria_L_HalfSquat	4	64.15	33.71	17.04	96.81	0.174
	FINAL_H_EO_Aria_L_HalfSquat	4	55.5	49.91	10.44	126.55	
	H_EO_Aria_B_HalfSquat	4	159.41	119.14	34.43	318.8	
2	INTERIM_H_EO_Aria_B_HalfSquat	4	133.41	56.99	49.31	169.91	0.472
	FINAL_H_EO_Aria_B_HalfSquat	4	197.08	146.5	86.83	412.88	
	H_EO_Aria_R_HalfSquat	4	33.67	19.92	5.51	52.41	
3	INTERIM_H_EO_Aria_R_HalfSquat	4	36.39	18.17	9.46	47.38	0.368
	FINAL_H_EO_Aria_R_HalfSquat	4	39.14	16.72	16.1	54.17	
	H_EO_L_HalfSquat	4	159.08	63.81	65.6	20.8	
4	INTERIM_H_EO_L_HalfSquat	4	149.48	62.43	65	215.5	0.779
	FINAL_H_EO_L_HalfSquat	4	153.73	54.43	77.3	205.9	
	H_EO_Vit_HalfSquat	4	10.6	4.23	4.4	13.9	
5	INTERIM_H_EO_Vit_HalfSquat	4	9.95	4.19	4.3	14.4	0.627
	FINAL_H_EO_Vit_HalfSquat	4	10.25	3.6	5.2	13.7	
	H_EO_LSF_HalfSquat	4	1.33	0.59	0.6	1.9	
6	INTERIM_H_EO_LSF_HalfSquat	4	1.15	0.19	0.9	1.3	0.282
	FINAL_H_EO_LSF_HalfSquat	4	0.93	0.31	0.5	1.2	

(mm^2) = millimiter square; mm (millimeter); (mm/s) millimeter/seconds; SD = standard deviation; Hard surface Eyes Open Arial Left HalfSquat (H_EO_Aria_L_HalfSquat, mm^2); Interim Hard surface Eyes Open Arial Left HalfSquat (Interim_H_EO_Aria_L_HalfSquat, mm^2); Final Hard surface Eyes Open Arial Left HalfSquat (Final_H_EO_Aria_L_HalfSquat, mm^2); Hard surface Eyes Open Arial Body HalfSquat (H_EO_Aria_B_HalfSquat, mm^2); Interim Hard surface Eyes Open Arial Body HalfSquat (Interim_H_EO_Aria_B_HalfSquat, mm^2); Final Hard surface Eyes Open Arial Body HalfSquat (Final_H_EO_Aria_B_HalfSquat, mm^2); Hard surface Eyes Open Arial Right HalfSquat (H_EO_Aria_R_HalfSquat, mm^2); Interim Hard surface Eyes Open Arial Right HalfSquat (Interim_H_EO_Aria_R_HalfSquat, mm^2); Final Hard surface Eyes Open Arial Right HalfSquat (Final_H_EO_Aria_R_HalfSquat, mm^2); Hard surface Eyes Open Lenght HalfSquat (H_EO_L_HalfSquat, mm); Interim Hard surface Eyes Open Lenght HalfSquat (Interim_H_EO_L_HalfSquat, mm); Final Hard surface Eyes Open Lenght HalfSquat (Final_H_EO_L_HalfSquat, mm); Hard surface Eyes Open Speed HalfSquat (H_EO_Vit_HalfSquat, mm/s); Interim Hard surface Eyes Open Speed HalfSquat (Interim_H_EO_Vit_HalfSquat, mm/s); Final Hard surface Eyes Open Speed HalfSquat (Final_H_EO_Vit_HalfSquat, mm/s); Hard surface Eyes Open LSF HalfSquat (H_EO_LSF_ HalfSquat); Interim Hard surface Eyes Open LSF HalfSquat (Interim_H_EO_LSF_ HalfSquat); Final Hard surface Eyes Open LSF HalfSquat (Final_H_EO_LSF_ HalfSquat).

Table 7. Friedman Test results for variables obtained in the HalfSquat position on a hard surface with eyes close

Pair	Variable Name	N	Mean	Std. Deviation	Minimum	Maximum	Friedman Test (p)
	H_EC_Aria_L_HalfSquat	4	77.86	39.71	39.51	133.61	
1	INTERIM_H_EC_Aria_L_HalfSquat	4	172.15	66.79	128.86	271.08	0.174
	FINAL_H_EC_Aria_L_HalfSquat	4	160.22	121.26	16.89	269.14	
	H_EC_Aria_B_HalfSquat	4	261.63	122.24	98.65	390.36	
2	INTERIM_H_EC_Aria_B_HalfSquat	4	505.83	87.56	418.73	627.33	0.368
	FINAL_H_EC_Aria_B_HalfSquat	4	559.09	493.28	84.06	1213.65	
	H_EC_Aria_R_HalfSquat	4	61.96	50.21	13.81	120.97	
3	INTERIM_H_EC_Aria_R_HalfSquat	4	134.26	135.87	54.97	336.7	0.174
	FINAL_H_EC_Aria_R_HalfSquat	4	99.17	58.65	27.23	170.82	
	H_EC_L_HalfSquat	4	237.95	108.93	105.4	363.5	
4	INTERIM_H_EC_L_HalfSquat	4	264.83	111.85	132.2	392.7	0.368
	FINAL_H_EC_L_HalfSquat	4	234.65	110.35	81.1	344	
	H_EC_Vit_HalfSquat	4	15.85	7.25	7	24.2	
5	INTERIM_H_EC_Vit_HalfSquat	4	17.65	7.46	8.8	26.2	0.368
	FINAL_H_EC_Vit_HalfSquat	4	15.63	7.35	5.4	22.9	
	H_EC_LSF_HalfSquat	4	0.93	0.13	0.8	1.1	
6	INTERIM_H_EC_LSF_HalfSquat	4	0.53	0.21	0.3	0.8	0.174
	FINAL_H_EC_LSF_HalfSquat	4	0.7	0.48	0.2	1.2	

(mm^2) = millimiter square; mm (millimeter); (mm/s) millimeter/seconds; SD = standard deviation; Hard surface Eyes Close Arial Left HalfSquat (H_EC_Aria_L_ HalfSquat, mm^2); Interim Hard surface Eyes Close Arial Left HalfSquat (Interim_H_EC_Aria_L_ HalfSquat, mm^2); Final Hard surface Eyes Close Arial Left HalfSquat (Final_H_EC_Aria_L_ HalfSquat, mm^2); Hard surface Eyes Close Arial Body HalfSquat (H_EC_Aria_B_ HalfSquat, mm^2); Interim Hard surface Eyes Close Arial Body HalfSquat (Interim_H_EC_Aria_B_ HalfSquat, mm^2); Final surface Eyes Close Arial Body HalfSquat (Final_H_EC_Aria_B_ HalfSquat, mm^2); Hard surface Eyes Close Arial Right HalfSquat (H_EC_Aria_R_ HalfSquat, mm^2); Interim Hard surface Eyes Close Arial Right HalfSquat (Interim_H_EC_Aria_R_ HalfSquat, mm^2); Final Hard surface Eyes Close Arial Right HalfSquat (Final_H_EC_Aria_R_ HalfSquat, mm^2); Hard surface Eyes Close Lenght HalfSquat (H_EC_L_ HalfSquat, mm); Interim Hard surface Eyes Close Lenght HalfSquat (Interim_H_EC_L_ HalfSquat, mm); Final Hard surface Eyes Close Lenght HalfSquat (Final_H_EC_L_ HalfSquat, mm); Hard surface Eyes Close Speed HalfSquat (H_EC_Vit_ HalfSquat, mm/s); Interim Hard surface Eyes Close Speed HalfSquat (Interim_H_EC_Vit_ HalfSquat, mm/s); Final Hard surface Eyes Close Speed HalfSquat (Final_H_EC_Vit_ HalfSquat, mm/s); Hard surface Eyes Close LSF HalfSquat (H_EC_LSF_ HalfSquat); Interim Hard surface Eyes Close LSF HalfSquat (Interim_H_EC_LSF_ HalfSquat); Final Hard surface Eyes Close LSF HalfSquat (Final_H_EC_LSF_ HalfSquat).

To evaluate potential changes across three measurement sessions (initial, intermediate, final), Friedman's tests were performed separately for 36 force-platform variables. The analyses revealed no statistically significant differences across time for any of the variables, $\chi^2(2)$ range = 0.00–4.50, all p ≥ .105. This indicates that, within this small sample, the distributions of these measurements did not differ significantly across sessions.

For example, several measures of sway area (e.g., H_EO_Aria_B, S_EO_Aria_B, H_EC_Aria_B_HalfSquat) decreased slightly, while others showed mild increases.

H_EO_Aria_L, H_EO_Aria_B, H_EO_Aria_R:

Mean values for the eyes-open area variables showed slight decreases from initial to intermediate measurements, followed by small rebounds at the final measurement.

H_EO_L, H_EO_Vit, H_EO_LSF:

These parameters (related to sway path length and velocity) exhibited subtle reductions across time.

H_EC_Aria_L, H_EC_Aria_B, H_EC_Aria_R, H_EC_L, H_EC_Vit, H_EC_LSF: With eyes closed, area and velocity measures showed mixed trends, some increasing slightly.

S_EO and S_EC Variables:

Under semitandem stance, COP areas and velocities followed similar patterns, with moderate fluctuations but no clear directional change.

Half-Squat Conditions (H_EO_Aria_L_HalfSquat, H_EO_Aria_B_HalfSquat, etc.):

In half-squat postures, several variables showed decreases in mean sway area and path length by the final assessment.

DISCUSSION

The present study aimed to investigate the effects of a multicomponent balance and strength training program on postural control in older adults, using force-platform parameters. Thirty-six variables reflecting center-of-pressure (COP) behavior, surface area, velocity and other kinetic indicators were assessed at three time points: initial, intermediate and final. Friedman's nonparametric tests indicated no statistically significant differences across time for any variables (all

$p \geq .105$). Nonetheless, descriptive analyses revealed meaningful patterns in the evolution of mean values that merit discussion in light of the intervention content.

Across most variables, mean values exhibited small-to-moderate directional changes from baseline to final assessment, often aligning with expected physiological adaptations following balance and strength training. This might indicate enhanced exploration of the base of support or increased confidence in maintaining balance. Our found mixed responses are consistent with previous research showing that older adults may initially display greater sway during early stages of training, due to increased motor strategy variability, followed by stabilization as training progresses.

Eyes-open area variables showed slight decreases. This could reflect early improvements in steadiness after the first few training sessions, with a plateau effect towards the end of the program. Given that many exercises challenged static stance (narrow base of support, surface perturbations), such changes align with improved control of mediolateral sway.

A lower COP velocity is suggestive of a more economical postural control, often interpreted as more efficient balance maintenance. Although nonsignificant, this trend is compatible with the focus on core and lower-limb strengthening and dynamic stability exercises included in the program (e.g., heel-to-toe walking, sit-to-stand transitions, obstacle crossing).

On the other hand, area and velocity measures showed mixed trends. Training on unstable surfaces and with visual deprivation encouraged participants to rely more on proprioceptive and vestibular inputs, which might initially increase sway, but ultimately enhance sensory reweighting. The lack of consistent decreases may be attributable to the short duration of the program and small sample size.

Under half-squat stance, COP areas and velocities followed similar patterns, with moderate fluctuations but no clear directional change. These findings may suggest that the half-squat stance remained challenging for participants throughout the intervention, as well as training mediolateral stability in older adults. For further proof, longer interventions are needed.

Half-squat tasks demand greater muscular engagement and postural control, so it is noteworthy that several variables also showed decreases in mean sway area and path length. The intervention included functional lower-limb strengthening (e.g., mini-squats, sit-to-stand, step-ups), which may have contributed to improved stability in this position, despite the absence of statistical significance.

While the absence of statistically significant findings prevents firm conclusions, the directionality of the observed changes supports the potential utility of multicomponent exercise programs for enhancing postural control in older adults. The small sample size (N=4) likely limited statistical power, increasing the risk of Type II error. Effect size estimation (e.g., Kendall's W) and visual inspection of mean changes suggest that some variables may have clinically relevant improvements that warrant further exploration in larger cohorts.

Importantly, the training program progressively integrated static, dynamic and dual-task balance challenges, while targeting proprioceptive, vestibular and visual components of postural control. Even in the absence of significant improvements, maintaining postural stability over time is itself a positive outcome, as age-related decline would be expected without intervention.

Similar to our findings, Chittrakul et al. (2020) reported no statistically significant differences following a multicomponent balance and strength program. Yet descriptive trends suggested modest improvements in sway area and postural stability. This supports the idea that even in the absence of strong statistical outcomes, short-term exercise interventions may help maintain or slightly improve balance in older adults.

Antúnez et al. (2020), unlike other rehabilitation interventions, demonstrated that a specific proprioceptive protocol can generate clinically relevant improvements in physical performance, although its long-term efficacy remains to be established.

Our results, despite not statistically significant, are consistent with the findings of Leandri et al. (2015), who demonstrated that anterior–posterior sway with eyes closed is significantly associated with cognitive performance in older adults. This supports the idea that vestibular and sensory mechanisms play a crucial role in maintaining postural stability.

Sustaining balance capacity over time, even without marked improvements, is clinically valuable because age is typically accompanied by progressive decline. Yoon et al. (2019) also highlighted that balance impairments tend to emerge at early stages, suggesting that timely interventions are essential for preserving mobility and lowering fall risk.

The primary limitation of this study is the very small sample size, which limits statistical power. Additionally, the short intervention duration (6 weeks) may not have been sufficient to elicit robust adaptations in postural control. Future research should replicate these findings with a larger sample, a control group and longer follow-up to assess retention of training effects. Including measures of functional performance (e.g., Timed Up and Go, gait speed) may also help link force-platform metrics to clinically meaningful outcomes.

CONCLUSIONS

The present study explored the effects of a multicomponent exercise program targeting balance, strength, and coordination on postural control in older adults. Although Friedman's tests did not reveal statistically significant differences across the three measurement time points for any of the 36 variables. Descriptive trends suggested modest improvements in sway area, path length, and velocity measures—particularly under eyes-open and half-squat conditions. These results indicate that even a relatively short, low-to-moderate intensity intervention may help maintain or slightly improve postural stability in older adults, which is clinically relevant for fall prevention.

The lack of statistically significant findings is likely attributable to the small sample size and limited power, underscoring the need for larger-scale studies with longer follow-up periods. Future research should confirm these preliminary findings, explore dose–response relationships of balance and strength training, and investigate whether improvements in force-platform parameters translate into meaningful reductions in fall risk and functional disability.

AUTHOR CONTRIBUTIONS

Author 1 contributed to the analysis of the results and writing of the manuscript, author 2 and author 3 contributed to the design and implementation of the research. Author 4 supervised the research project, provided guidance during all stages of the study, and critically reviewed the manuscript. All authors have read and agreed to the published version of the manuscript.

CONFLICT OF INTEREST

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ACKNOWLEDGEMENT

We would like to express our sincere gratitude to physiotherapist Ungvári Renáta for her support and involvement in this study. Her expertise and valuable feedback shaped the course of this 6-week program

REFERENCES

Antúnez- Espejo, L., Pérez-Mármol, J. M., Cardero-Durán, M. de los Á., Toledo-Marhuenda, J. V., & Albornoz-Cabello, M. (2020). The effect of proprioceptive exercises on balance and physical function in institutionalized older adults: A randomized controlled trial. *Archives of Physical Medicine and Rehabilitation, 101*(10), 1780–1788. https://doi.org/10.1016/j.apmr.2020.06.010.

Chen, X., Mao, G., & Leng, S. X. (2014). Frailty syndrome: An overview. *Clinical Interventions in Aging, 9,* 433–441. https://doi.org/10.2147/CIA.S45300.

Chittrakul, J., Siviroj, P., Sungkarat, S., & Sapbamrer, R. (2020). Multi-system physical exercise intervention for fall prevention and quality of life in pre-frail older adults: A randomized controlled trial. *International Journal of Environmental Research and Public Health, 17*(9), 3102. https://doi.org/10.3390/ijerph17093102.

Gillespie, L. D., Robertson, M. C., Gillespie, W. J., Sherrington, C., Gates, S., Clemson, L. M., & Lamb, S. E. (2012). *Interventions for preventing falls in older people living in the community. Cochrane Database of Systematic Reviews, 2012*(9), CD007146. https://doi.org/10.1002/14651858.CD007146.pub3.

Hosseini, L., Bahrampour, E., Mahmoudi, M., & Rezaei, I. (2018). Tai Chi Chuan and falls in older adults: A randomized controlled trial. *Journal of Exercise Rehabilitation, 14*(2), 282–288. https://doi.org/10.12965/jer.1836488.244.

Leandri, M., Campbell, J., Molfetta, L., Barbera, C., & Tabaton, M. (2015). Relationship between balance and cognitive performance in older people. *Journal of Alzheimer's Disease, 46*(2), 385–391. https://doi.org/10.3233/JAD-142883

Liu, C. K., & Fielding, R. A. (2011). Exercise as an intervention for frailty. Clinics in Geriatric Medicine, 27(1), 101–110. https://doi.org/10.1016/j.cger.2010.08.001.

Menz, H. B., Morris, M. E., & Lord, S. R. (2005). Foot and ankle characteristics associated with impaired balance and functional ability in older people. *Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 60*(12), 1546–1552. https://doi.org/10.1093/gerona/60.12.1546

Patar, M. G., & Scheicher, M. (2014). Effects of strength and balance training on the mobility, fear of falling, and grip strength of elderly female fallers. *Journal of Bodywork & Movement Therapies, 19*(4), 646–650. https://doi.org/10.1016/j.jbmt.2014.11.009

Pasquetti, P., Apicella, L., & Mangone, G. (2014). Pathogenesis and treatment of falls in elderly. *Clinical Cases in Mineral and Bone Metabolism, 11*(3), 222–225. https://doi.org/10.11138/ccmbm/2014.11.3.222.

Rubenstein, L. Z. (2006). *Falls in older people: epidemiology, risk factors and strategies for prevention*. Age and Ageing, 35(Suppl 2), ii37–ii41. https://doi.org/10.1093/ageing/afl084.

Sherrington, C., Michaleff, Z. A., Fairhall, N., et al. (2017). Exercise to prevent falls in older adults: An updated systematic review and meta-analysis. *British Journal of Sports Medicine, 51*(24), 1749–1757. https://doi.org/10.1136/bjsports-2016-096547.

Yoon, B., Choi, S. H., Jeong, J. H., Park, K. W., Kim, E.-J., Hwang, J., Jang, J.-W., Kim, H. J., Hong, J. Y., Lee, J.-M., Kang, J.-H., & Yoon, S. J. (2019). Balance and mobility performance along the Alzheimer's disease spectrum. *Journal of Alzheimer's Disease*. Advance online publication. https://doi.org/10.3233/JAD-190601.