



## Impacts of pilates versus aerobic training on pulmonary function and fitness markers in healthy older adults: a randomized controlled trial

*Impactos del pilates frente al entrenamiento aeróbico en la función pulmonar y los marcadores de condición física en adultos mayores*

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### Abstract

**Introduction:** Pilates has been shown to improve pulmonary function and physical fitness in older adults. However, studies directly comparing Pilates with aerobic exercise remain limited and inconclusive.

**Objectives:** This study investigated the effects of Pilates training and aerobic exercise on pulmonary function, core muscle strength, flexibility, and cardiovascular fitness in older adults.

**Methodology:** Twenty-nine older adults were randomly assigned to three group such as control group, Pilates training group (PTG), or aerobic training group (ATG). Pilates group performed Pilates, aerobic group engaged in moderate-intensity treadmill walking, and control group maintained usual routines. Both interventions were conducted for 60 minutes, three times per week, over eight weeks. Outcomes were assessed pre- and post-intervention using two-way repeated-measures ANOVA.

**Results:** The results demonstrated that both PTG and ATG groups significantly improved pulmonary function, core muscle strength, flexibility and cardiovascular fitness performance compared with pre-test and control group ( $p < 0.05$ ). Moreover, PTG group showed a significant improvement core muscle strength by plank test compared with ATG groups ( $p < 0.05$ ).

**Discussion:** Findings align with prior research, confirming that Pilates and aerobic training improves pulmonary function and physical fitness in older adults. However, participants who underwent Pilates training program produced more substantial gains across pulmonary function, core muscle strength, and flexibility.

**Conclusion:** Pilates and aerobic training enhance physical fitness in older adults, with Pilates offering broader benefits for healthy aging.

### Keywords

Pulmonary function; fitness; pilates; older adults; flexibility.

### Resumen

**Introducción:** Se ha demostrado que el método Pilates mejora la función pulmonar y la condición física en adultos mayores. Sin embargo, los estudios que comparan directamente Pilates con el ejercicio aeróbico siguen siendo limitados e inconclusos.

**Objetivo:** Este estudio investigó los efectos del entrenamiento de Pilates y del ejercicio aeróbico sobre la función pulmonar, la fuerza de los músculos del core, la flexibilidad y la condición cardiorrespiratoria en adultos mayores.

**Metodología:** Veintinueve adultos mayores fueron asignados aleatoriamente a tres grupos: grupo control, grupo de entrenamiento de Pilates (PTG) y grupo de entrenamiento aeróbico (ATG). El grupo de Pilates realizó ejercicios de Pilates, el grupo aeróbico realizó caminata en cinta de intensidad moderada y el grupo control mantuvo sus actividades habituales. Ambas intervenciones se llevaron a cabo durante 60 minutos, tres veces por semana, durante ocho semanas. Las variables se evaluaron antes y después de la intervención mediante un ANOVA de medidas repetidas de dos factores.

**Resultados:** Los resultados mostraron que tanto el PTG como el ATG mejoraron significativamente la función pulmonar, la fuerza del core, la flexibilidad y el rendimiento de la aptitud cardiovascular en comparación con las mediciones iniciales y el grupo control ( $p < 0.05$ ). Además, el PTG mostró una mejora significativamente mayor en la fuerza del core, evaluada mediante la prueba de plancha, en comparación con el ATG ( $p < 0.05$ ).

**Discusión:** Los resultados concuerdan con investigaciones previas, confirmando que el Pilates y el ejercicio aeróbico mejoran la función pulmonar y la condición física en adultos mayores. Sin embargo, el grupo que realizó Pilates mostró mayores mejoras en la función pulmonar, la fuerza del core y la flexibilidad.

**Conclusiones:** El Pilates y el ejercicio aeróbico mejoran la condición física en adultos mayores; no obstante, el Pilates puede ofrecer beneficios más amplios para un envejecimiento saludable.

### Palabras clave

Función pulmonar; condición física; flexibilidad; adultos mayores; pilates.



## Introduction

The global population of older adults is rapidly increasing. According to the United Nations, the number of individuals aged 60 years and above is projected to rise by 34%, from 1 billion in 2019 to 1.4 billion by 2050 and is expected to reach 2.1 billion by 2100 (World Health Organization; WHO, 2020; Keating, 2022). Aging is associated with progressive physiological changes, including alterations in lung connective tissue that reduce thoracic flexibility and lung compliance, ultimately impairing respiratory function (Alvarenga, et al., 2016). In parallel, physical fitness declines with age, characterized by reductions in muscle strength, endurance, flexibility, and agility, which may compromise functional independence (Riebe et al., 2009; Donat Tuna et al., 2009).

Muscle mass can decrease by up to 40% in physically inactive older adults, accompanied by a 10–40% reduction in joint mobility depending on the body region (Kostić et al., 2011). Muscle strength decreases by approximately 30% with aging, typically decreasing by 12–14% per decade after the age of 50 (Hurley et al., 2000). Additionally, age-related changes in spinal structure, respiratory muscles, and diaphragmatic function contribute to reduced pulmonary capacity (Lally, 2013; Cho, 2023). These declines, although more pronounced in inactive individuals, highlight the importance of preventive exercise interventions even among healthy older adults. Maintaining physical fitness, particularly cardiorespiratory and muscular function, is therefore essential for healthy aging (Cethakritkul et al., 2021; Seo et al., 2023).

Exercise interventions such as Pilates and aerobic training have been widely recommended to counteract these age-related declines (Bullo et al., 2015; Rathi et al., 2024). Aerobic exercise is well-established intervention for improving cardiovascular and pulmonary function through sustained activation of the cardiorespiratory system (Tongtako et al., 2018, Gaviria Chavarro et al., 2025). In older adults, moderate-intensity aerobic training has been shown to increase vascular compliance, reduce arterial stiffness, and lower cardiovascular risk (Bai et al., 2022). Additionally, aerobic exercise improves functional capacity, as demonstrated by increases in 6-minute walk test performance following structured training programs (Nelson et al., 2007; Fragala et al., 2019). Evidence also indicates that aerobic training can reduce body fat and improve flexibility in older populations (Izquierdo et al., 2022). Accordingly, the American College of Sports Medicine (ACSM, 2022) recommends at least 150 minutes of moderate-intensity aerobic activity per week, which is associated with substantial reductions in all-cause mortality.

Pilates exercises have been shown to enhance strength, stability, and functional movement. Pilates is based on the principles of control, concentration, breathing, flow, and core activation. (Pilates & Miller, 2021). A central component of Pilates is its emphasis on controlled inhalation and exhalation during exercise, which promotes both respiratory efficiency and core stability. Previous studies have shown that Pilates training can enhance respiratory muscle strength, increase trunk muscle thickness, and improve core stability (Giacomoni et al., 2016; Woramontri et al., 2024; Malhotra et al., 2025). Furthermore, regular Pilates training has been associated with improvements in cardiovascular function, aerobic capacity, balance, and flexibility in older adults and clinical populations (Lim & Yoon, 2017; Hlaing et al., 2021; Rangabprai et al., 2024)

Although both Pilates and aerobic exercise have been shown to improve physical and pulmonary outcomes in older adults, existing studies have primarily examined these interventions independently. Few studies have directly compared their effects within the same experimental framework, particularly across multiple domains including pulmonary function, core muscle strength, flexibility, and cardiovascular fitness. This lack of comparative evidence limits the ability to determine the most effective exercise modality for specific functional outcomes in older populations. Therefore, the aim of this study was to compare the effects of Pilates training and aerobic exercise on pulmonary function, core muscle strength, flexibility, and cardiovascular fitness in older adults. We hypothesized that both interventions would significantly improve pulmonary function and fitness markers, with Pilates providing greater improvements in pulmonary function, core muscle strength and flexibility, and aerobic exercise yielding greater cardiorespiratory benefits.



## Method

### Participants

A total of twenty-nine older adults aged 60–77 years were recruited for this study. A priori power analysis using G\*Power 3.1.9.7, based on the study by Vécseyne et al. (2013), set the desired power at 0.80 and the significance level ( $\alpha$ ) at 0.05, indicating a minimum sample size of 18 participants across three groups. To account for potential dropouts, 29 participants were included. Participants were stratified by gender (male/female) and age (60–69 years / 70–79 years). Core muscle strength was assessed using the prone bridge (plank) test (Bohannon et al., 2018), with participants categorized into Group 1 (0–30 seconds) or Group 2 ( $\geq 31$  seconds). Participants were then randomly assigned into three groups of nine each: Pilates training (PTG), aerobic training (ATG), and control (CON).

All participants were healthy older adults. Exclusion criteria included severe cardiovascular or respiratory disease, lower back pain, tendinitis, arthritis, spondylolisthesis, scoliosis, or gout. Participants were required to perform independent movement, have controlled hypertension (120–159/80–99 mmHg) with physician clearance, and maintain stable medication regimens during the study. Additional inclusion criteria required participants to be non-smokers, not engaged in any structured exercise program, and free from dietary supplementation for at least 6 months prior to enrolment. All participants volunteered and provided written informed consent. Medical and activity histories were obtained using standardized questionnaires. The study was conducted in accordance with the Declaration of Helsinki and the ethical standards; the protocol was approved by the Human Research Ethics Committee of Walailak University (approval No. WUEC-24-333-01) and registered as a clinical trial with ClinicalTrials.gov (study # NCT07470060)

### Procedure

#### *Pilates training protocol*

The PTG group underwent Pilates protocol for 60 minutes per session, three times per week, over 8 weeks (Table 1). Participants initially completed approximately 3 weeks of basic Pilates instruction following demonstrations by a certified Pilates instructor. They then participated in the full Pilates program under the supervision of the primary investigators and research assistants, who monitored all participants throughout the study. The Pilates program involved coordinated movements including raising, lowering, stretching, and bending the body, alternating arm movements, and stepping forward, backward, sideways, and rotational movements with the legs. Each 60-minute session comprised a 10-minute warm-up, 40 minutes of core stability exercises with the Pilates program at a monitored intensity of 55%–70% Heart Rate Reserve (HRR), and a 10-minute stretching.

Table 1. Pilates training protocol

	Warm up & Stretches	Repetition	Time
1	Breathing, Imprint & Release		
2	Hip Release		
3	Hip Rolls		
4	Scapula Protraction/Retraction		
5	Arm Circles	5 times/exercise	10 minutes
6	Scapula Elevation/Depression		
7	Head Nods		
8	Spine Rotation		
9	Clam Shells		
	Exercise	Repetition	Time
1	Toe Taps		
2	Ab Prep		
3	Prone Heel Squeeze		
4	Single Leg Extension		
5	One Leg Circle	5 times/exercise	
6	Shoulder Bridge Prep 1 & 2		
7	Hundred Prep		
8	Roll Up Prep		
9	Side Leg Lifts		
10	Breaststroke Preps		
11	Breaststroke		
12	Swimming		

(Repetitions were increased every two weeks as participants' Rate of Perceived Exertion (RPE) declined.)



13	Half Roll Back		
14	Birddog		
15	Spine twist		
Cool-down & Stretches		Repetition	Time
1	Spine Stretch Forward		
2	Shell Stretch		
3	Side Bending	5 times/exercise	10 minutes
4	Cat Stretch		
5	Roll Down		

### *Aerobic training protocol*

The ATG group participated in 60-minute sessions for 8 weeks, a session consisted of a moderate-intensity aerobic exercise program (55%–70% HRR) using treadmill walking for each session consisted of a 10-minute warm up, moderate-intensity aerobic exercise program for 40 min, and a 10-minute cool down.

HRR represents the heart rate reserve, was calculated using the as calculated using Tanaka's formula (Tanaka et al., 2001) and was monitored by the researcher using a Polar Verity Sense heart rate monitor arm strap to maintain the heart rate within the specified intensity level range. Exercise intensity in both groups was monitored using heart rate monitors to ensure that participants maintained the prescribed HRR range during each session.

### *Instrument*

#### General physiological characteristics

Regarding general physiological characteristics, resting heart rate and blood pressure were measured using a digital blood pressure monitor (Microlife BP B1 Standard, Taiwan). Body composition was measured using a bioelectrical impedance analyzer (Body Composition Analyzer; ACCUNIQ BC 380; Korea).

#### Pulmonary function testing

Pulmonary function was measured in all the participants using a calibrated computerized spirometer (Gas analyzer; VO2max Tracker Ergospirometer (MES), Poland) according to the American Thoracic Society recommendations (Graham et al., 2019). The participants then inserted the mouthpiece into their mouth and placed a nose clip on their nose while sitting on a chair. They performed three acceptable spirometers, of which the largest and second largest forced vital capacity (FVC) and forced expiratory volume in 1 s (FEV1) values did not vary by >0.15 L, and the best FEV1 and FVC maneuvers were retained for analysis. Finally, the maximum voluntary ventilation was measured.

#### Flexibility testing

Flexibility was assessed using two standard tests. Lower limb flexibility was measured with the sit-and-reach test according to ACSM guidelines (ACSM, 2022). Participants performed a warm-up, then sat with their legs fully extended against a sit-and-reach box and reached forward, holding the maximal stretch for 3 seconds while maintaining knee extension. The distance reached was recorded as a measure of forward flexibility. Upper limb flexibility was evaluated using the back-scratch test. Participants extended their dominant arm overhead while reaching behind their back and attempted to touch or overlap the middle finger of the other hand, which reached upward from behind. The distance between the fingertips was measured, with positive values (+X cm) indicating overlap, zero (0 cm) indicating fingertips just touching, and negative values (–X cm) indicating a gap, reflecting upper body flexibility. Both tests were scored following standardized procedures to ensure consistency. (Lavín-Pérez et al., 2023)

#### Core muscle strength testing

Participants were instructed to assume a prone position on a yoga mat, supporting their body with only the forearms and toes in contact with the surface. following standardized procedures described by Bohannon et al. (2018). Upon the command "go," they were to maintain a neutral alignment of the head, neck, back, and hips for as long as possible. Timing with a digital stopwatch began once the position was assumed and ended when the participant either voluntarily stopped or failed to maintain the required posture.



## Cardiovascular fitness testing

Cardiovascular fitness was measured using the 6-minute walk test (6MWT) following the guidelines of the 2002 American Thoracic Society (ATS Committee on Proficiency Standards for Clinical Pulmonary Function Laboratories, 2002), requiring minimal equipment as follows: a stopwatch, measuring tape, cones, and adhesive tape to mark a 40 × 5 m (or 45 × 5 yards) rectangular walking area. After a 10-minute rest and ensuring appropriate attire, each participant walked for 6 min, attempting to cover the maximum distance possible without running, with rest periods permitted. The total distance walked was estimated and recorded accurately, thus providing a quantifiable measure of an individual's functional exercise capacity

## Data analysis

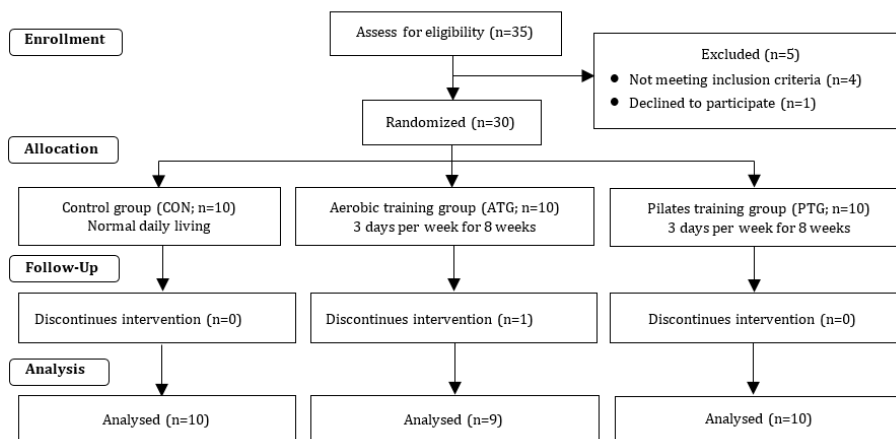
Data was analysed using IBM SPSS Statistics version 25 for Windows (IBM Corp., Armonk, NY, USA). The normality of the distribution of the variables was tested using the Shapiro–Wilk test. Core muscle strength, pulmonary function, flexibility, and cardiorespiratory fitness were analysed before and after the tests. The Two-way repeated analysis of variance was performed to compare variables between pre- and post-test and between groups. Statistical significance was defined as  $p < 0.05$ .

## Results

### General physiological characteristics

The CONSORT flow diagram of participant recruitment, allocation, and follow-up is presented in Figure 1, in accordance with the CONSORT guidelines (Schulz et al., 2010). A total of 35 older adults were assessed for eligibility, of whom 5 were excluded (4 did not meet the inclusion criteria and 1 declined to participate). Consequently, 30 participants were randomized into three groups ( $n = 10$  per group): Pilates Training Group (PTG), Aerobic Training Group (ATG), and Control Group (CON). All participants in the PTG and CON completed the study, whereas one participant in the ATG withdrew. In total, 29 participants were included in the final analysis.

Figure 1. CONSORT Flow Diagram for the Present Study



The general characteristics of participants at baseline and after the intervention are presented in Table 2. No significant baseline differences were observed among groups in terms of height, weight, BMI, body fat percentage, resting heart rate (RHR), systolic blood pressure (SBP), or diastolic blood pressure (DBP).

Table 2. General characteristics data.

Variables	CON (n=10, M1/W9)		ATG (n=9, M1/W8)		PTG (n=10, M1/W9)	
	Pre	Post	Pre	Post	Pre	Post
Height (cm)	157.40 ± 3.44	157.50 ± 3.57	157.00 ± 5.36	157.11 ± 5.30	155.40 ± 5.82	156.00 ± 5.93
Weight (kg)	57.87 ± 5.99	58.82 ± 5.64	58.71 ± 7.21	58.43 ± 7.12	57.80 ± 7.39	56.44 ± 7.71
BMI (kg/m <sup>2</sup> )	25.17 ± 3.99	25.40 ± 4.02	24.96 ± 3.92	24.73 ± 4.14	24.26 ± 4.81	23.61 ± 4.23
Fat (%)	34.26 ± 9.08	35.27 ± 8.89	34.95 ± 4.39	34.98 ± 4.69	33.68 ± 5.44	33.36 ± 5.51
RHR (bpm)	76.80 ± 9.83	77.00 ± 10.07	76.67 ± 6.46	73.44 ± 5.43	76.20 ± 4.98	77.50 ± 3.89
SBP (mmHg)	131.60 ± 6.90	131.90 ± 4.20	133.00 ± 7.43	131.89 ± 6.94	132.80 ± 3.91	132.00 ± 6.65
DBP (mmHg)	73.80 ± 11.25	72.30 ± 7.23	77.44 ± 12.32	74.89 ± 10.37	78.00 ± 12.28	76.80 ± 9.38

Data are presented as means ± standard deviations.

BMI, body mass index; RHR, resting heart rate; SBP, systolic blood pressure; DBP, diastolic blood pressure.-

The results of the two-way repeated measures ANOVA are summarized in Table 3. There were no significant main effects of time or group for height, BMI, fat percentage, SBP, or DBP ( $p > 0.05$ ). However, a significant time × group interaction was observed for weight ( $F = 12.37$ ,  $p < 0.001$ ,  $\eta^2 = 0.487$ ), indicating that changes over time differed among the three groups. Similarly, a significant interaction effect was found for resting heart rate (RHR) ( $F = 3.70$ ,  $p = 0.039$ ,  $\eta^2 = 0.222$ ).

Table 3. The comparison of general physiological characteristics variables was conducted using two-way repeated measures ANOVA among CON, ATG, and PTG groups, and between pre- and post-tests within each group.

Variables	Main effects and interaction	Two-ways repeated ANOVA				
		F	df	p	Power	Partial Eta Squared
Height (cm)	Time	2.72	1	0.111	0.36	0.095
	Group	0.34	2	0.716	0.10	0.025
	TxG	1.03	2	0.370	0.21	0.074
Weight (kg)	Time	1.41	1	0.246	0.208	0.051
	Group	0.13	2	0.882	0.07	0.010
	TxG	12.37	2	0.000*	0.991	0.487
BMI (kg/m <sup>2</sup> )	Time	2.01	1	0.168	0.28	0.072
	Group	0.271	2	0.765	0.09	0.020
	TxG	2.78	2	0.081	0.50	0.176
Fat (%)	Time	0.75	1	0.394	0.13	0.028
	Group	0.14	2	0.874	0.07	0.010
	TxG	2.21	2	0.130	0.41	0.145
RHR (bpm)	Time	0.68	1	0.418	0.13	0.025
	Group	0.21	2	0.811	0.80	0.016
	TxG	3.70	2	0.039**	0.62	0.222
SBP (mmHg)	Time	.195	1	0.662	0.07	0.007
	Group	0.06	2	0.946	0.06	0.004
	TxG	0.13	2	0.883	0.07	0.009
DBP (mmHg)	Time	1.76	1	0.196	0.25	0.063
	Group	0.48	2	0.624	0.12	0.036
	TxG	0.09	2	0.911	0.07	0.007

\* $p < 0.05$ , significant difference within a group.

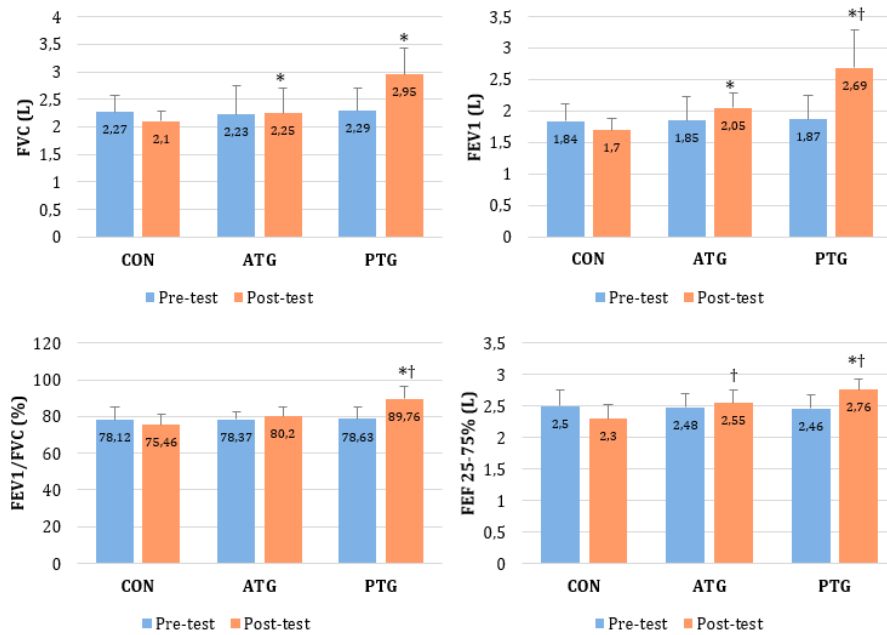
\*\* $p < 0.05$ , significant difference between groups at the same period.

## Pulmonary Function

The effects of PTG, ATG, and CON on pulmonary function are presented in Figure 2 and Table 4. Significant improvements were observed in all pulmonary function indices: FVC, FEV1, FEV1/FVC ratio, and FEF 25–75%. Strong interaction effects were found for FVC ( $F = 45.81$ ,  $p < 0.001$ ,  $\eta^2 = 0.779$ ), FEV1 ( $F = 42.32$ ,  $p < 0.001$ ,  $\eta^2 = 0.765$ ), FEV1/FVC ( $F = 22.13$ ,  $p < 0.001$ ,  $\eta^2 = 0.630$ ), and FEF 25–75% ( $F = 36.92$ ,  $p = 0.001$ ,  $\eta^2 = 0.740$ ). Post hoc analysis indicated that the PTG group demonstrated significant increases in FVC ( $2.29 \pm 0.41$  L to  $2.95 \pm 0.47$  L,  $p < 0.05$ ) compare with pre-test. Moreover, the PTG group showed a significant improvement in FEV1 ( $1.87 \pm 0.38$  L to  $2.69 \pm 0.60$  L,  $p < 0.05$ ), FEV1/FVC ratio ( $78.63 \pm 6.25\%$  to  $89.76 \pm 6.92\%$ ,  $p < 0.05$ ), and FEF25–75% ( $2.46 \pm 0.22\%$  to  $2.76 \pm 0.16\%$ ,  $p < 0.05$ ), all of which were higher than pre-test and the CON group ( $p < 0.05$ ). The ATG group also showed significant improvement in FVC ( $2.23 \pm 0.51$  L to  $2.25 \pm 0.45$  L,  $p < 0.05$ ), and FEV1 ( $1.85 \pm 0.39$  L to  $2.05 \pm 0.23$  L,  $p < 0.05$ ) when compare with pre-test. In addition, both the ATG and PTG groups had significant increases in FEF25–75% compared with the CON group ( $p < 0.05$ ).



Figure 2. The comparison of the pulmonary function variable among the CON, ATG and PTG group.



Data are presented as means  $\pm$  standard deviations.

\* $p < 0.05$ , vs. pre-test, † $p < 0.05$ , vs. CON, ‡ $p < 0.05$ , vs. ATG

Table 4. The comparison of pulmonary function variables was conducted using two-way repeated measures ANOVA among CON, ATG, and PTG groups, and between pre- and post-tests within each group.

Variables	Main effects and interaction	Two-ways repeated ANOVA				
		F	df	p	Power	Partial Eta Squared
FVC (L)	Time	21.07	1	0.000*	0.99	0.448
	Group	3.46	2	0.040**	0.62	0.219
	TxG	45.81	2	0.000**	1.00	0.779
FEV1 (L)	Time	43.94	1	0.000*	1.00	0.628
	Group	5.37	2	0.011**	0.80	0.292
	TxG	42.32	2	0.000**	1.00	0.765
FEV1/FVC (%)	Time	15.29	1	0.001*	0.96	0.370
	Group	4.56	2	0.020**	0.72	0.260
	TxG	22.13	2	0.000**	1.00	0.630
FEF 25-75% (L)	Time	5.80	1	0.023*	0.64	0.182
	Group	2.65	2	0.090	0.48	0.169
	TxG	36.92	2	0.001**	1.00	0.740

\* $p < 0.05$ , significant difference within a group. \*\* $p < 0.05$ , significant difference between groups at the same period.

The results of core muscle strength, flexibility, and cardiovascular fitness are presented in Tables 5 and 6.

Table 5. Mean and standard deviation of the core muscle strength, flexibility, and cardiovascular fitness variables.

Variables	CON (n=10, M1/W9)		ATG (n=9, M1/W8)		PTG (n=10, M1/W9)	
	Pre	Post	Pre	Post	Pre	Post
Plank test (s)	60.10 $\pm$ 49.81	55.60 $\pm$ 41.85	66.67 $\pm$ 29.58	68.11 $\pm$ 27.42	66.40 $\pm$ 12.07	124.00 $\pm$ 9.37*†‡
BS (cm)	-2.20 $\pm$ 5.12	-6.50 $\pm$ 6.08	-2.44 $\pm$ 5.10	1.44 $\pm$ 3.84*	-2.10 $\pm$ 5.32	4.50 $\pm$ 3.41*†
SR (cm)	-0.60 $\pm$ 7.66	-4.20 $\pm$ 6.32	0.67 $\pm$ 6.30	3.56 $\pm$ 6.27*	1.10 $\pm$ 9.17	11.80 $\pm$ 4.71*†
6MWT (m)	442.60 $\pm$ 90.49	440.16 $\pm$ 55.24	459.38 $\pm$ 75.84	530.13 $\pm$ 85.35*†	508.80 $\pm$ 64.33	603.90 $\pm$ 57.37*†‡

Data are presented as means  $\pm$  standard deviations. \* $p < 0.05$ , vs. pre-test, † $p < 0.05$ , vs. CON, ‡ $p < 0.05$ , vs. ATG

FVC = forced vital capacity; FEV1 = forced expiratory volume in 1 s; FEF 25%-75% = forced expiratory flow between 25% and 75% of vital capacity; BS = Back scratch test; SR = Sit and reach test; 6MWT = 6-minute walk test.

Table 6. The comparison of the core muscle strength, flexibility, and cardiovascular fitness variables was conducted using two-way repeated measures ANOVA among CON, ATG, and PTG groups, and between pre- and post-tests within each group.

Variables	Main effects and interaction	Two-ways repeated ANOVA				
		F	df	p	Power	Partial Eta Squared
Plank test (s)	Time	29.97	1	0.000*	1.00	0.535
	Group	4.23	2	0.026**	0.69	0.246
	TxG	63.28	2	0.000**	1.00	0.830
Back-scratch test (cm)	Time	13.72	1	0.039*	0.95	0.345
	Group	3.69	2	0.048**	0.63	0.221
	TxG	35.68	2	0.000**	1.00	0.733
Sit-and-reach test (cm)	Time	8.01	1	0.009*	0.78	0.236
	Group	3.65	2	0.013**	0.78	0.286
	TxG	12.87	2	0.000**	0.99	0.498
6MWT (m)	Time	15.28	1	0.001*	0.96	0.370
	Group	8.64	2	0.001**	0.95	0.399
	TxG	4.56	2	0.020**	0.73	0.260

\* $p < 0.05$ , significant difference within a group. \*\* $p < 0.05$ , significant difference between groups at the same period.

### Core Muscle Strength

For the plank test, there was a significant main effect of time ( $F = 29.97$ ,  $p < 0.001$ ,  $\eta^2 = 0.535$ ), group ( $F = 4.23$ ,  $p = 0.026$ ,  $\eta^2 = 0.246$ ), and a strong time  $\times$  group interaction ( $F = 63.28$ ,  $p < 0.001$ ,  $\eta^2 = 0.830$ ). Post hoc comparisons showed that the PTG group showed a significant improvement from pre- to post-test ( $66.40 \pm 12.07$  s to  $124.00 \pm 9.37$  s,  $p < 0.05$ ), which was significantly greater compared with both the CON and ATG groups ( $p < 0.05$ ). No significant changes were observed in the CON or ATG groups.

### Flexibility

Both flexibility tests demonstrated significant time  $\times$  group interactions. For the back-scratch test ( $F = 35.68$ ,  $p < 0.001$ ,  $\eta^2 = 0.733$ ), the PTG group improved from  $-2.10 \pm 5.32$  cm to  $4.50 \pm 3.41$  cm, which was significantly greater than both ATG and CON. For the sit-and-reach test ( $F = 12.87$ ,  $p < 0.001$ ,  $\eta^2 = 0.498$ ), the PTG and ATG groups improved markedly ( $1.10 \pm 9.17$  cm to  $11.80 \pm 4.71$  cm,  $p < .05$ , and  $0.67 \pm 6.30$  cm to  $3.56 \pm 6.27$  cm,  $p < .05$ , respectively), when compare with pre-test. Additionally, The PTG group had significant increases in sit-and-reach test compared with the CON group ( $p < 0.05$ ).

### Cardiovascular Fitness

For cardiovascular fitness, as assessed by the 6MWT, significant effects of time ( $F = 15.28$ ,  $p = 0.001$ ,  $\eta^2 = 0.370$ ), group ( $F = 8.64$ ,  $p = 0.001$ ,  $\eta^2 = 0.399$ ), and time  $\times$  group interaction ( $F = 4.56$ ,  $p = 0.020$ ,  $\eta^2 = 0.260$ ) were found. Post hoc analysis revealed that both the ATG ( $459.38 \pm 75.84$  m to  $530.13 \pm 85.35$  m,  $p < 0.05$ ) and PTG ( $508.80 \pm 64.33$  m to  $603.90 \pm 57.37$  m,  $p < 0.05$ ) groups exhibited significant improvements compared with pre-test and the CON group ( $p < 0.05$ ).

## Discussion

To our knowledge, few studies have directly compared the effects of Pilates and aerobic training across multiple domains of physical fitness, including pulmonary function, core muscle strength, flexibility, and cardiovascular fitness, within a single randomized controlled trial in healthy older adults. The findings of the present study indicate that both interventions improved multiple outcomes; however, Pilates training resulted in greater improvements in pulmonary function, core muscle strength, and flexibility compared with the control (CON) group.

After 8 weeks, the PTG demonstrated significant improvements in FVC, FEV<sub>1</sub>, FEV<sub>1</sub>/FVC, and FEF25–75% compared with both baseline and the CON group. These findings are consistent with previous studies reporting that Pilates training enhances pulmonary function and respiratory muscle strength in older adults (Ponde et al., 2021; Adigüzel et al., 2023; Park et al., 2023). Improvements were also observed in the ATG, particularly in FVC and FEV<sub>1</sub>, supporting evidence that moderate-intensity aerobic exercise enhances ventilatory efficiency and respiratory endurance (Bai et al., 2022). However, the greater improvements observed in the PTG suggest that Pilates may provide additional benefits for pulmonary function compared with aerobic training alone.

The superior pulmonary adaptations observed in the PTG may be explained by the specific physiological demands of Pilates training. Unlike aerobic exercise, Pilates emphasizes diaphragmatic breathing coordinated with controlled trunk movements, which promotes integrated activation of the respiratory and core muscles. This coordination likely enhances ventilatory capacity and airway function, as reflected in the observed improvements in spirometric parameters (Talaminos Barroso et al., 2018). Furthermore, the association between core muscle strength and pulmonary function has been well documented, with previous studies demonstrating significant correlations between abdominal muscle strength, FVC, and FEV<sub>1</sub> (Kang et al., 2019). These mechanisms may explain the greater effectiveness of Pilates in improving pulmonary outcomes in the present study.

The significant improvement in plank performance observed in the PTG highlights the effectiveness of Pilates-based core stability training in enhancing trunk strength and endurance. Pilates emphasizes controlled movements and activation of deep stabilizing muscles, including the transversus abdominis, multifidus, diaphragm, and pelvic floor, in coordination with breathing (Barbosa et al., 2015; Kim & Lee, 2017). These adaptations likely improve neuromuscular control, spinal alignment, and postural stability, contributing to superior gains in core strength compared with ATG and CON. Consistent with previous findings, both Pilates and aerobic exercise have been shown to improve oxygen uptake and abdominal muscle endurance (Rayaes et al., 2019). Furthermore, Pilates training, which incorporates both isometric and dynamic movements, has been associated with improvements in muscle strength, flexibility, and respiratory function (Carrasco-Poyatos et al., 2019; Dos Reis et al., 2024).

Both PTG and ATG groups demonstrated significant improvements in upper- and lower-body flexibility, with greater gains observed in the PTG. These findings are consistent with previous studies showing that Pilates-based training improves flexibility, balance, and functional movement in older adults (Kim et al., 2020; Hlaing et al., 2021). The improvements in flexibility observed in this study may be attributed to the stretching, controlled movements, and increased range of motion incorporated into Pilates exercises. Enhanced thoracic mobility may also contribute to improved chest wall expansion and pulmonary function. Similarly, aerobic exercise has been shown to improve flexibility and overall physical fitness in older adults (Mei & Chang, 2023; Bai et al., 2022).

In the present study, both exercise interventions improved cardiovascular fitness, as evidenced by increased performance in 6MWT after 8 weeks in the PTG and ATG. These findings align with previous studies showing that both Pilates and aerobic exercise enhance functional capacity, oxygen uptake, and cardiovascular performance (Lim & Yoon, 2017; Rayaes et al., 2019; Rangabprai et al., 2024). Pilates training has also been associated with improvements in pulmonary and cardiorespiratory fitness (Giacomoni et al., 2016; Rangabprai et al., 2024), while aerobic exercise directly enhances cardiovascular and circulatory function (Nystoriak & Bhatnagar, 2018; Pinckard et al., 2019). Furthermore, combined aerobic and resistance training has been shown to improve cardiovascular and respiratory outcomes in older adults, as measured by the 6MWT (Bai et al., 2022). The observed improvements in the PTG may be related to enhanced breathing efficiency and movement control, whereas the ATG likely reflects direct cardiovascular adaptations. Together, these findings support the effectiveness of both exercise modalities for improving cardiovascular health in older adults.

Although the present findings are generally consistent with previous literature, this study contributes to existing knowledge in several important ways. First, it provides a direct comparison of Pilates and aerobic training within the same experimental framework, allowing for a clearer understanding of their relative effectiveness. Second, it evaluates multiple components of physical fitness simultaneously, rather than focusing on a single outcome. This comprehensive approach helps to identify modality-specific benefits, suggesting that Pilates may be more effective for improving pulmonary function, core stability, and flexibility, while aerobic exercise remains important for cardiovascular fitness. These findings may assist clinicians and exercise professionals in selecting targeted interventions based on specific functional goals in older adults.

This study has several limitations that should be considered when interpreting the findings. First, the sample size was relatively small, which may limit the generalizability of the results. Second, the intervention duration was limited to 8 weeks, and therefore the long-term effects of these exercise modalities were not assessed. Third, the study did not include blinding of participants or assessors, which may introduce potential bias. Fourth, physical activity performed outside the intervention was not monitored, which may have influenced the outcomes. Additionally, environmental conditions, such as room



humidity, were not recorded for each participant. Finally, the sample included a low proportion of male participants, which may limit the applicability of the findings across sexes.

## Conclusions

In conclusion, both Pilates and aerobic training appear to be effective interventions for improving physical and pulmonary fitness in older adults. Pilates may offer additional benefits in enhancing core muscle strength, flexibility, and pulmonary function, potentially due to its emphasis on controlled breathing and core stabilization. These findings suggest that Pilates could be considered as a complementary or alternative exercise modality in programs aimed at promoting healthy aging. However, given the relatively small sample size, these results should be interpreted with caution. Future research involving larger and more diverse populations, as well as longer intervention periods, is warranted to confirm these findings and further optimize exercise prescription strategies.

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