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Research article

The Effect of Aerobic or Strength Training in Elderly with Cognitive Decline: The Fit4Alz Project

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Abstract

This study aimed to examine the effects of aerobic and strength training methodologies, either combined with or without cognitive training, on mitigating cognitive decline. A total of 154 subjects were recruited (72.8 ± 6.1 years, 69% females) and were divided into four groups: i) strength plus cognitive training (STCT, n = 56); ii) strength training (ST, n = 23); iii) aerobic training (AT, n = 41); and iv) aerobic plus cognitive training (ATCT, n = 34). Subjects were previously cognitively assessed and showed cognitive decline (less than 26 points on the Montreal Cognitive Assessment, MoCA). For 12 weeks, all groups performed 3 times a week, for 60 minutes, a training program corresponding to their attributed group. The MoCA test and the Senior Fitness test were applied at the beginning and the end of the intervention. A repeated-measures ANCOVA revealed significant time-by-group interactions for physical performance measures, including the 2-minute step-in-place ($p = 0.026$), arm curl ($p < 0.001$), chair sit-and-reach ($p < 0.001$), back-scratch ($p < 0.001$), 8-foot up-and-go ($p < 0.001$), and 6-minute walk tests ($p < 0.001$). However, no significant improvements were observed for cognitive function (MoCA, $p = 0.242$) or lower body strength (chair stand, $p = 0.411$). The AT group showed greater improvements in upper body strength compared to STCT and ST ($p < 0.001$; $d = 0.698$; $p = 0.004$; $d = 0.598$), while STCT significantly improved flexibility compared to ATCT ($p < 0.001$; $d = 1.049$). ATCT had the greatest improvements in aerobic endurance compared to STCT and ST ($p = 0.004$; $d = 0.133$; $p < 0.001$; $d = 0.350$). It was demonstrated that aerobic and strength training significantly improved overall physical performance in elderly individuals. However, no significant effects were observed on cognitive performance. Although these findings suggest that both aerobic and strength exercise, with or without cognitive training, improve overall physical fitness, further research is needed to determine its impact on cognitive performance.

Key words: Cognitive training, cognition, dementia, intervention.

Introduction

Dementia is an umbrella term for several brain diseases that are mostly progressive (World Health Organization, 2017). Alzheimer's Disease (AD) is the most common form of dementia, with a prevalence of 60 to 80% of cases (Alzheimer's Association, 2015). This progressive neurodegenerative disease is known to impair cognitive functions (Cass, 2017), decreasing the ability of processing speed, executive functions, memory, and visuospatial abilities (Hoogendam et al., 2014; Tzioras et al., 2023), which significantly interferes with the activities of daily living and leads to loss of independence (McKhann et al., 2011; World Health Organization, 2017). It should be highlighted that although aging is the greatest risk factor for AD development (with the Alzheimer's Association estimating that 81% of people who have AD are 75 yr or older) (Alzheimer's Association, 2015), dementia is not exclusive to the elderly, with young onset dementia (defined as the onset of symptoms before the age of 65 years) accounting for up to 9% of cases (Alzheimer's Disease International and World Health Organization, 2012). AD is a process that could last many years from its onset, starting with some complaints that characterize the mild cognitive impairment (MCI) state (Porsteinsson et al., 2021). At this stage, the daily activities remain largely intact, and independence is preserved (Cendoroglo, 2014; Anderson, 2019). During the last years, however, it has been repeatedly shown that the aging brain and body remain plastic and that older adults' capacity can be improved through systematic motor or cognitive training (Erickson and Kramer, 2009; Xu et al., 2022).

An estimated 54% of AD risk factors have been found preventable (Mercerón-Martínez et al., 2021), with physical inactivity at the top of the highest of those risk factors (Norton et al., 2014; Mercerón-Martínez et al., 2021). Indeed, with a huge sample (163,000 non-demented participants), Hamer and Chida (Hamer and Chida, 2009) found that physical activity reduces the risk of dementia and AD by 28% and 45%, respectively. Other studies corroborate this link between the prevention of AD and physical exercise (PE) (Flicker et al., 2005; Smith et al., 2010; Cámara-Calmaestra et al., 2022), noticing that PE could improve cognitive functions, such as attention, processing speed, executive function, and memory. Moreover, better fitness levels and better muscle strength have each been positively associated with better cognitive functions (Ruscheweyh et al., 2011; Duchowny et al., 2022), even in studies that included self-reports of PE (Qian et al., 2020) or cognitive decline (Yang et al., 2022). Nevertheless, PE

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also decreases the chance of developing AD indirectly by reducing several other risk factors for cognitive decline, including hypertension, dyslipidemia, diabetes, depression and sleep problems (Sewell et al., 2021; Cámara-Calmaestra et al., 2022).

One of the most cited reasons for the cognitive benefits of PE is its ability to enhance blood flow and vascularization, leading to improved oxygen and nutrient delivery to the brain (Fernandes et al., 2018). However, research suggests that exercise provides additional advantages beyond vascular improvements, including increased gray matter volume in the frontal brain regions (Colcombe et al., 2006) and the hippocampus (Erickson et al., 2011). PE like aerobic exercise has also been linked to higher levels of orexin-A and orexin-B (Messina et al., 2016), two neuropeptides synthesized in the hypothalamus that support neurogenesis and strengthen connections between hippocampal neurons. Orexin-A plays a crucial role in cognitive function, exhibiting neuroprotective and anti-apoptotic properties while enhancing attention and working memory (Deadwyler et al., 2007). Meanwhile, orexin-B/hypocretin-2 (OxB/Hcrt-2) increases brain-derived neurotrophic factor (BDNF) mRNA expression, leading to elevated BDNF production (Chieffi et al., 2017). As a key neurotrophic factor, BDNF is essential for cognition (Lee et al., 2015), modulating long-term potentiation and synaptic plasticity in the hippocampus to facilitate learning and memory (Nettiksimmons et al., 2014), while also improving working memory in the prefrontal cortex (Yeom et al., 2016). Moreover, PE boosts the production of other neurotrophic factors, such as insulin-like growth factor 1 (IGF-1), which plays a key role in neovessel maturation and stability (Jacobo and Kazlauskas, 2015), and vascular endothelial growth factor (VEGF), which promotes angiogenesis (Morland et al., 2017) and is directly associated with neurogenesis and enhanced synaptic function.

Most studies, including PE to improve cognitive abilities, have focused on aerobic exercises (Gordon et al., 2008; Sobol et al., 2016). A few studies have also combined aerobic with resistance training methods (Bossers et al., 2015; Pedrinolla et al., 2020). However, our understanding of the benefits of PE is limited by inconsistencies in methodologies across studies. For instance, some studies do not allow for predicting the relative merits of different exercise regimens, particularly those incorporating varying levels of resistance, cardiovascular, and flexibility training, which are often important for individuals designing fitness programs (Cámara-Calmaestra et al., 2022). Furthermore, training parameters, such as frequency, intensity, and duration, are often poorly described (Lam et al., 2018; Wollesen et al., 2020). Training programs typically range from 8 weeks to 15 months, although evidence suggests that positive effects on physical function can be achieved within 9 to 16 weeks (Lam et al., 2018). It remains unclear if the relationship is dose-dependent, but higher levels of physical activity appear to correlate with a decreased risk (Yaffe et al., 2001).

In recent years, cognitive training using computer-based programs has gained increased attention in research, representing a promising new approach to combating age-related cognitive decline and preventing dementia (Chae and Lee, 2023). In a recent scoping review including interventions with the purpose of training cognitive functions in older adults, it was identified 27 different apps used in 34 studies. The focus of the majority of those interventions was on improving memory, executive functions, and attention (Silva et al., 2024). In general, studies – including reviews and meta-analyses – have proven the efficacy of cognitive training in improving episodic memory, attention, working memory, processing speed, visuospatial skills, and aspects of executive functioning in healthy older adults and with MCI (Lampit et al., 2014; Tsantali et al., 2017; Chae and Lee, 2023). Its success is due to the neuroplasticity capacity of the brain (Toricelli et al., 2021), which refers to the brain's ability to undergo morphological changes in response to environmental stimuli (Jasey and Ward, 2019). Nevertheless, it was highlighted that it appears to be less effective when completed by individuals at home using online programs compared to a group- or center-based, facilitated approach (Lampit et al., 2014).

Building on the promising hypothesis that behavioral strategies, such as PE and cognitive training, may delay cognitive decline, the present study aimed to investigate the effects of aerobic and strength training methodologies, either combined with or without cognitive training, on mitigating cognitive decline. Specifically, this study sought to address gaps in the literature, including whether strength training alone can positively impact cognitive functions and whether combining physical and cognitive training offers greater benefits than either intervention alone. Indeed, most studies focus solely on aerobic training and provide limited detail regarding key training load components such as volume, intensity, and frequency. Given that individuals with moderate cognitive decline show greater improvements in physical fitness tests compared to those with severe cognitive impairment (Lam et al., 2018) and that interventions targeting cognitive function at this stage are more likely to succeed, the study focuses on individuals with MCI. We hypothesized that (i) both training modalities would help delay cognitive decline and (ii) the combination of physical and cognitive training would yield greater improvements in cognitive function.

Methods

Participants

The sample size was predetermined based on a prior investigation into the effects of a physical exercise intervention on cognition in older adults (Kraiwong et al., 2021). Using the G*Power v.3.1.9.7 software (Kiel University, Kiel, Germany) (Faul et al., 2007), considering an ANOVA repeated measures, within-between interactions across 4 groups and 2 measurement points, with an effect size (f) of 0.19 -derived from a partial eta squared of 0.035 observed in global cognition (measured with MoCA) (Kraiwong et al., 2021)- and setting significance threshold of 0.05 and desired power of 0.95. The G*Power software indicated a minimum required of 124. A total of 192 elderly subjects of both sexes were invited to be part of the present study, but 19 were excluded because they performed above 26 points in the Montreal Cognitive Assessment (MoCA). This tool is a validated and reliable method for cognitive screening, demonstrating high sensitivity compared to other assessments, such as the Mini-Mental State Examination (MMSE) (Freitas et al., 2012; Islam et al., 2023). Thus, those who scored above 26 do not exhibit cognitive decline (Freitas et al., 2012); 5 had an injury that limited movement and four did not show a willingness to continue with the training sessions. The remaining 164 were recruited to participate in the present study. However, seven subjects failed to complete 80% of the training sessions, and 3 missed one moment of assessments. In the end, it was included 154 subjects. They made part of the Fitness for Alzheimer Project (Fit4Alz), founded by the European Union (ERASMUS-SPORT-2022-SCP). The following terms were adopted as inclusion criteria: i) have 65 or more years of age; ii) not present physical limitations that limit practice; iii) score 26 or less in the MoCA, indicating a cognitive decline; iv) participate in at least 80% of the training sessions during the interventions; and v) participate in all moments of evaluations. All subjects who did not comply with all the required steps were excluded.

The recruitment process involved directly contacting the elderly people through our partners in the project, opting for a convenience sampling strategy because it provided easy access to the target population. Through municipality or sports associations, subjects were invited to participate in the study, and those who expressed interest in volunteering were included in the list of potential participants.

The study lasted 16 weeks. Twelve weeks were dedicated to the intervention, while the initial two weeks were for baseline assessments, and the final two weeks were for post-intervention evaluations.

Study design

The current research followed a randomized controlled study design involving old adults who were assigned into four groups: i) strength plus cognitive training (STCT), ii) strength training (ST), iii) aerobic training (AT), and iv) aerobic plus cognitive training (ATCT). The sample was recruited through voluntary participation, and within each group, a random selection process was used to determine who would receive cognitive training and who would only receive physical training. The study followed the CONSORT guidelines to ensure a comprehensive reporting of information (Merkow et al., 2021). The research began after approval from the Ethics Committee of the Instituto Politécnico de Viana do Castelo, reference: CECSVS2024/02/vi.

Older adults were informed about the study's design, the associated risks, and the potential benefits. After voluntarily agreeing to participate, they signed informed consent forms. The study followed the ethical guidelines outlined in the Declaration of Helsinki.

Physical exercise programs

The interventions were implemented over 12 consecutive weeks, comprising 60-minute sessions conducted three times per week, with a 48-hour interval between each session. These sessions took place at partner facilities located in Portugal, Serbia, Italy, and Poland and were facilitated by the research team, which designed and prescribed both aerobic and strength training programs. The training protocols for the interventions are detailed in Table 1 and Table 2. Both experimental groups -those receiving cognitive training and those not- participated in identical aerobic and strength training sessions to ensure consistent conditions across the groups. In each exercise in the aerobic plans, three variations were included, allowing the teacher to adapt to each individual. Also, the rate of perceived exertion (RPE) was used in every training session and every exercise to understand the effect of the load implemented. This tool, originally developed by Borg (Borg, 1998)and later adapted to a 0-to-10 scale (Foster et al., 2001), has been widely used and validated to monitor internal load, which reflects an individual's perceived exertion in response to the externally applied training or exercise load. Over the weeks of the intervention, the load was adjusted based on the RPE indicated by the subjects, increasing the weight in strength exercises and modifying the exercise variable in aerobic training.

Cognitive training sessions

The cognitive training sessions were conducted using the software developed in the Fit4Alz project (https://fit4alz.wixsite.com/fit4alz). This software was based on a prior study (Silva et al., 2024), which identified that the primary focus of software designed to stimulate cognitive functions was mainly on memory, attention, and executive functions. Consequently, the Fit4Alz software features two games for each cognitive function, with five levels of difficulty and a score at the end of each game, reflecting the time taken to complete the task. Each session of cognitive training lasted 20 minutes and was performed after the physical training. In each session, it was stimulated a different cognitive function, and subjects had the same number of sessions of each cognitive function stimulation.

Outcomes

The data collection was the same before and at the end of the intervention. It included two different sessions, one for cognitive assessment and another for physical fitness assessment. All the assessments were conducted indoors in a controlled environment, always in a morning session. In the first session, the MoCA was conducted by four professionals. Those who scored above 26 points in the MoCA were excluded from the study. The remaining subjects were invited to be part of the study and participate in the second session. In the second session, a trained team of five evaluators applied all the assessments. The group was divided into small groups of 4/5 elements that followed a predefined sequence starting with the anthropometric measurements, then a warm-up was conducted to prepare for the six tests of the Senior Fitness Test (Rikli and Jones, 2013): i) chair stand; ii) arm curl; iii) chair sit and reach; iv) back scratch; v) foot up and go; and vi) six-minute walk or 2-minute step in place test.

Anthropometric measurements

Measurements were performed in an appropriate room, with participants wearing light clothing and being barefoot. Standing height was measured to the nearest 0.1 cm using

Table 1. Description of plan A and B of aerobic training sessions.

	Time	Phase	Exercise	Methodology	Intensity	HR
Plan A	5'	Warm-up	Single-joint and multi-joint exercises that allow for the gradual increase of body temperature. If possible, activities that individuals enjoy and promote group participation.	Continuous	5/6 RPE	60%
	42-44'	Fundamental	**Two times:** 1. Jumping jacks 3. Walk out 9. High knee 10. Lunge 4. Kipping 8. Plank knee	6 x 2' 1' rest between each repetition 4-6' walk between sets	7/8 RPE	75-85%
	3'	Cool down	Walking or some low activity	Continuous	3/4 RPE	40%
Plan B	**Time**	**Phase**	**Exercise**	**Methodology**	**Intensity**	**HR**
	5'	Warm-up	Single-joint and multi-joint exercises that allow for the gradual increase of body temperature. If possible, activities that individuals enjoy and promote group participation.	Continuous	5/6 RPE	60%
	42-44'	Fundamental	**Two times:** 2. Burpees 6. Squat 7. Lunge with kick 11. Butt kicks 5. Running 12. Step up and down	6 x 2' 1' rest between each repetition 4-6' walk between sets	7/8 RPE	75-85%
	3'	Cool down	Walking or some low activity	Continuous	3/4 RPE	40%

RPE: rate of perceive exertion; HR: heart rate.

Table 2. Description of the strength training plan.

	Time	Phase	Exercise	Methodology	Intensity	HR
Weeks 1 to 12	5'	Warm-up	Single-joint and multi-joint exercises that allow for the gradual increase of body temperature. If possible, activities that individuals enjoy and promote group participation.	Continuous	5/6 RPE	60%
	42-44'	Fundamental	**Two blocks of tri-sets** **1st block:** 1 hip-dominant exercise 1 anti-core exercise 1 upper pull exercise **2nd block:** 1 knee-dominant exercise 1 anti-core exercise 1 upper push exercise	**Hip- and knee-dominant exercises** **1st week:** 2x5 reps **2nd week:** 2x8 reps **3rd week:** 2x10 reps **4th week:** 3x8 reps **5th week:** 3x10 reps **Weeks 6-8:** 3x12 reps **Weeks 9-12:** 3x15 reps **Anti-core holds** **1st week:** 2x10s **2nd week:** 2x20s **3rd week:** 2x25s **Weeks 4-12:** 3x30s	4/5 RIR	75-85%
	3'	Cool down	Walking or some low activity	Continuous	3/4 RPE	40%

RPE: rate of perceive exertion; RIR: repetitions in reserve; reps: repetitions; HR: heart rate.

a portable stadiometer (Seca 213, Hamburg, Germany). Body mass was recorded to the nearest 0.1 kg using a standard scale. Each measurement was taken twice, and the average of the two was used.

Chair stand

The objective of this assessment was to evaluate the strength and endurance of the lower limbs using a stopwatch and a chair with a backrest, approximately 43 cm in seat height. For safety, the chair was positioned against a wall or stabilized to prevent movement during the test. The participant sits in the chair with their back supported and feet flat on the floor while the evaluator stands nearby, holding the chair for stability. During the procedure, the participant crosses their arms, placing their middle fingers on their shoulders. Upon the evaluator's signal, they stand up fully and then return to a seated position, aiming to complete as many full stand-sit actions as possible within 30 seconds. The evaluator demonstrates the test once to ensure the participant understands the procedure, and the test is then conducted once for assessment.

Arm curl

To evaluate the strength and endurance of the upper limb, a stopwatch, a chair without armrests, and hand weights (2.3 kg for women and 3.6 kg for men) were used. The participant sat upright with their dominant side near the edge of the chair, holding the weight in a handshake grip, starting with the arm extended and perpendicular to the floor. The evaluator stabilized the upper arm to ensure proper form throughout the test. Upon the evaluator's signal, the participant rotated their palm upward, flexed the arm fully, and then returned to the extended position. They aimed to complete as many repetitions as possible within 30 seconds. After a brief demonstration and practice repetitions, the official test was conducted once.

Chair sit and reach

To evaluate lower limb flexibility, it was used a chair without armrests, approximately 43 cm high, and a 45 cm ruler. For safety, the chair was positioned against a wall for stability. The participant sat with their body aligned such that the inguinal line was parallel to the chair seat, one leg flexed with the foot off the ground, and the preferred leg extended in front. The evaluator stayed close to assist. The participant then leaned forward, trying to touch their toes by sliding their hands down the extended leg while keeping their back straight. The position was held for two seconds, and if the knee flexed, the participant was instructed to sit back until it was straightened. The participant performed two test trials, and the better was registered.

Back Scratch

Subjects stood near the evaluator, who was positioned behind them. The participant placed their preferred hand on the same shoulder, reaching down the back, while the other hand was placed behind, reaching upward to touch or overlap the extended fingers. The evaluator ensured the middle fingers were aligned without the participant grasping their fingers. The participant completed two practice attempts followed by two official test attempts. The score was based on the distance of overlap or the distance between the tips of the middle fingers, recorded to the nearest centimeter. Negative results (-) indicated the shortest distance, while positive results (+) indicated overlap. The best value was used for performance assessment, with the signs noted on the scoring sheet.

Foot up and go

This test assesses physical mobility, focusing on speed, agility, and dynamic balance. The required instruments included a stopwatch, measuring tape, cone (or marker), and a chair approximately 43 cm high, positioned against a wall for stability. The cone was placed 2.44 m from the chair, with at least 1.22 m of free space around it. The participant started seated with an upright posture, one foot slightly ahead of the other. The evaluator stood midway to assist if needed. At the signal, the participant stood, walked quickly around the cone, and returned to sit down. Timing began at the signal and stopped when the participant was seated. After a demonstration, the participant practiced once before completing two attempts. The score was based on the time taken, with the best (shortest) time used for performance evaluation. Participants were reminded that the goal was to walk quickly (without running) around the cone and back to the chair.

Six-minute walk

Aerobic endurance was measured using a stopwatch, measuring tape, cones, poles, chalk, and markers. For safety reasons, chairs were placed at various points outside the circuit. The course was set up with a total distance of 45 meters, marked in segments of 5 meters using chalk or tape, in a well-leveled and well-lit area. Participants began standing at the start of the course while the evaluator positioned themselves nearby to record the time. At the signal, participants walked as quickly as possible (without running) around the course for as many laps as they could within the time limit. Participants were allowed to stop and rest as needed before continuing. The evaluator entered the course after all participants had started and informed them of the elapsed time. The six-minute walking test utilized the 45 m course marked in 5 m segments.

2-minute step-in-place test

This test was conducted as an alternative to the six-minute walk test for individuals who used orthopedic devices while walking or those who experienced difficulties with balance. The purpose of the test was to measure aerobic endurance. The equipment required included tape for marking the wall, a stopwatch, and a wall. During the procedure, the subject stood upright next to the wall, with the tape placed at the midpoint between the patella and the iliac crest. The subject then marched in place for two minutes, aiming to lift their knees to the height of the tape. Resting was permitted, and participants were allowed to hold onto the wall or a stable chair for support. The test was stopped after two minutes.

Statistical procedures

A preliminary assessment of normality and homogeneity was conducted using the Kolmogorov-Smirnov test and Levene’s test, respectively, confirming the assumptions of normality ($p > 0.05$) and homogeneity ($p > 0.05$) for the samples. To isolate the effect of baseline values on the magnitude of post-intervention differences between groups, a repeated-measures ANCOVA was performed, testing the interaction between time and groups, with baseline levels as the covariate. Partial eta-squared (η_p^2) was calculated to determine the effect size of the tests. Pairwise comparisons were conducted using the Bonferroni test, and effect sizes were measured using Cohen’s (d) (Hopkins et al., 2009), with the following interpretation thresholds: 0.0 - 0.2, trivial effect size; 0.2 - 0.6, small effect size; 0.6 - 1.2, moderate effect size; and 1.2 - 2.0, large effect size. Statistical analyses were performed using SPSS (IBM SPSS Statistics for Windows, Version 29.0.2.0, Armonk, NY: IBM Corp) with a significance level of $p > 0.05$.

Results

Out of the initially recruited 192 volunteers for this randomized experimental study, 154 were ultimately included in the final analysis (Figure 1). Of those, 107 were women, and 47 were men. On average, participants were 72.8 ± 6.1 years old, with a height of 1.63 ± 0.09 m, a body mass of 69.8 ± 11.7 kg, and a body mass index of 29.8 ± 26.4 kg/m^2. Table 3 present the descriptive statistics of the anthropometric data for the participants, categorized by group.

A repeated-measures ANCOVA, using baseline levels as a covariate, revealed significant interactions between time and group for the following tests: the 2-minute step-in-place test (95% CI, 92.29 to 98.50, $F = 3.852$; $p = 0.026$; $\eta_p^2 = 0.098$, trivial ES), arm curl test (95% CI, 10.94 to 21.69, $F = 12.699$; $p < 0.001$; $\eta_p^2 = 0.206$, small ES), chair sit and reach (95% CI, 6.84 to 7.94, $F = 8.742$; $p < 0.001$; $\eta_p^2 = 0.151$, trivial ES), back and scratch test (95% CI, -3.98 to -2.83, $F = 7.095$; $p < 0.001$; $\eta_p^2 = 0.126$, trivial ES), 8-foot up and go test (95% CI, 5.47 to 5.59, $F = 7.828$; $p < 0.001$; $\eta_p^2 = 0.138$, trivial ES), and 6-minute walk test (95% CI, 523.93 to 535.64, $F = 9.364$; $p < 0.001$; $\eta_p^2 = 0.158$, trivial ES). However, no significant interactions between time and group were found for the MoCA (95% CI, 23.33 to 23.78, $F = 1.412$; $p = 0.242$; $\eta_p^2 = 0.029$) and chair stand test (95% CI, 18.42 to 19.01, $F = 0.965$; $p = 0.411$; $\eta_p^2 = 0.019$). Table 4 exhibits the descriptive statistics and inferential comparisons between groups.

Figure 2 exhibits the within-group and between-group comparisons for the MoCA, chair stand test, and arm curl test. Moreover, AT group had significantly greater arm curl performances than STCT (mean difference: +4.4 n; p < 0.001; d = 0.698), ST (mean difference: +4.1 n; p = 0.004; d = 0.598), and ATCT (mean difference: +6.2 n; p < 0.001; d = 0.553).

Figure 2 displays the within-group and between-group comparisons for the chair sit and reach test, back and scratch test, and the 8-foot up-and-go test. Considering the performances in the sit and reach test, the STCT was significantly better than ATCT (mean difference: +7.4 cm; p < 0.001; d = 1.049), while AT was significantly better than ATCT (mean difference: +5.2 cm; p = 0.006; d = 1.022). In the post-intervention, the ATCT performed significantly better in the back-and-scratch test compared to the STCT (mean difference: +5.8 cm; p < 0.001; d = 0.687), ST (mean difference: +7.1 cm; p = 0.001; d = 1.359), and AT (mean difference: +5.8 cm; p = 0.002; d = 0.543). Following the intervention, AT performance in the 8-foot up-and-go test was significantly worse compared to the STCT (mean difference: +0.7 s; p < 0.001; d = 0.143), ST (mean difference: +0.6 s; p = 0.014; d = 0.737), and ATCT (mean difference: +0.6 s; p = 0.004; d = 0.455).

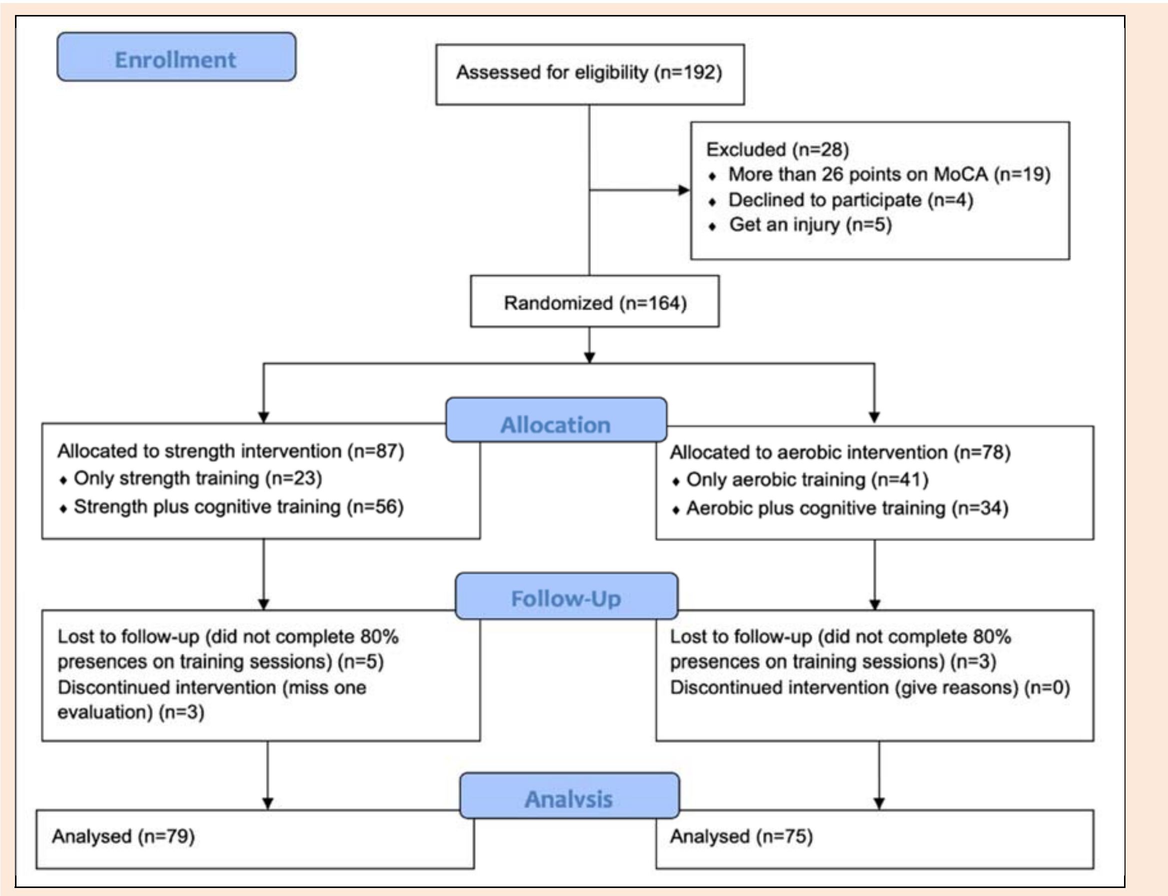

Figure 1. CONSORT 2010 flow diagram.

Table 3. Descriptive statistics (mean ± standard deviation) of the anthropometric information of the included participants.

	STCT (n = 56)	ST (n = 23)	AT (n = 41)	ATCT (n = 34)
Men (n)	29	6	3	9
Women (n)	27	17	38	25
Age (years)	73.8 ± 7.1	73.1 ± 4.4	71.9 ± 6.3	71.9 ± 4.9
Height (m)	1.65 ± 0.09	1.60 ± 0.10	1.61 ± 0.08	1.66 ± 0.08
Body mass (kg)	68.9 ± 10.4	68.1 ± 13.8	69.8 ± 11.7	72.2 ± 12.4
Body mass index (kg/m^2)	35.7 ± 43.1	26.4 ± 4.4	26.9 ± 4.1	26.1 ± 4.4

STCT: strength and cognitive training; ST: strength training; AT: aerobic training; ATCT: aerobic and cognitive training.

Table 4. Descriptive statistics (mean ± standard deviation) and inferential comparisons between groups.

		STCT (n = 53)	ST (n = 22)	AT (n = 41)	ATCT (n = 34)
MOCA (A.U.)	Pre	20.2 ± 5.4	22.1 ± 2.7	23.2 ± 2.2	24.1 ± 2.6
	Post	24.1 ± 4.5	23.9 ± 3.9	25.7 ± 2.1	26.1 ± 2.7
	Post-pre difference (%)	19.3	8.1	10.8	8.3
	p-value | d (within-group)	p < 0.001 | d = 0.788	p = 0.003 | d = 0.545	p < 0.001 | d = 1.134	p < 0.001 | d = 0.755
Chair stand test (n)	Pre	18.1 ± 5.4	18.1 ± 5.0	15.1 ± 2.8	16.1 ± 3.7
	Post	21.7 ± 5.0	21.9 ± 5.6	19.5 ± 4.4	19.1 ± 4.6
	Post-pre difference (%)	19.9	21.0	29.1	18.6
	p-value | d (within-group)	p < 0.001 | d = 0.692	p < 0.001 | d = 0.717	p < 0.001 | d = 1.222	p < 0.001 | d = 0.723
Arm curl test (n)	Pre	18.5 ± 6.1	19.4 ± 4.8	18.7 ± 4.5	22.3 ± 4.0
	Post	21.6 ± 6.1 [c]	22.6 ± 4.9 [c]	26.1 ± 6.8 [a,b,d]	22.7 ± 5.5 [c]
	Post-pre difference (%)	16.8	16.5	39.6	1.8
	p-value | d (within-group)	p < 0.001 | d = 0.508	p < 0.001 | d = 0.660	p < 0.001 | d = 1.310	p = 0.204 | d = 0.084
2-min Step Test (n)	Pre	76.1 ± 14.7	-	97.7 ± 34.5	92.1 ± 19.5
	Post	81.4 ± 13.6 [c]	-	117.9 ± 44.7 [a]	106.6 ± 19.1
	Post-pre difference (%)	7.0	-	20.7	15.7
	p-value | d (within-group)	p = 0.265 | d = 0.375	-	p < 0.001 | d = 0.510	p = 0.060 | d = 0.751
Chair sit-and-reach (cm)	Pre	9.3 ± 11.7	0.7 ± 4.2	10.5 ± 8.7	3.9 ± 11.7
	Post	12.2 ± 10.1 [c]	3.6 ± 5.4	10.8 ± 7.9 [a,d]	1.5 ± 10.3 [c]
	Post-pre difference (%)	31.2	414.3	2.9	−61.5
	p-value | d (within-group)	p < 0.001 | d = 0.266	p = 0.710 | d = 0.604	p = 0.127| d = 0.036	p = 0.002 | d = 0.218
Back and scratch test (cm)	Pre	−6.2 ± 10.1	−9.5 ± 6.0	−3.0 ± 8.7	−4.6 ± 9.7
	Post	−2.9 ± 10.6 [d]	−6.5 ± 6.1 [d]	−0.8 ± 8.1 [d]	3.9 ± 9.2 [a,b,c]
	Post-pre difference (%)	−53.2	−31.6	−73.3	−184.8
	p-value | d (within-group)	p = 0.001 | d = 0.319	p = 0.256 | d = 0.496	p = 0.006 | d = 0.262	p < 0.001 | d = 0.899
8-foot up and go test (s)	Pre	6.4 ± 2.2	5.4 ± 0.9	5.5 ± 1.1	5.7 ± 0.9
	Post	5.3 ± 1.6 [c]	4.8 ± 0.7 [c]	5.5 ± 1.2 [a,b,d]	5.0 ± 1.0 [c]
	Post-pre difference (%)	−17.2	−11.1	0.0	−12.3
	p-value | d (within-group)	p < 0.001 | d = 0.579	p < 0.001 | d = 0.750	p = 0.168 | d < 0.001	p < 0.001 | d = 0.737
6-minute walk test (m)	Pre	522.5 ± 69.2	535.2 ± 84.6	-	469.5 ± 73.2
	Post	547.5 ± 72.3 [d]	531.0 ± 70.0 [d]	-	557.9 ± 83.8 [a,b]
	Post-pre difference (%)	4.8	−0.8	-	18.8
	p-value | d (within-group)	p < 0.001 | d = 0.353	p = 0.769 | d = 0.051	-	p < 0.001 | d = 1.126

STCT: strength and cognitive training; ST: strength training; AT: aerobic training; ATCT: aerobic and cognitive training; a: significantly different from STCT (p<0.05); b: significantly different from ST (p<0.05); c: significantly different from AT (p<0.05); d: significantly different from ATCT (p<0.05).

Figure 3 shows the within-group and between-group comparisons for the chair sit and reach test, back and scratch test, and the 8-foot up-and-go test. Figure 4 shows the within-group and between-group comparisons for the 2-minute step-in-place test and the 6-minute walk test. The pairwise comparisons conducted post-intervention indicated that the AT group performed significantly better on the 2-minute step-in-place test compared to the STCT group (mean difference: +15.9 n; p = 0.021; d = 1.252). Finally, in the post-intervention, the ATCT performed significantly better in the 6-minute walk test compared to the STCT (mean difference: +45.8 m; p = 0.004; d = 0.133) and ST (mean difference: +70.8 m; p < 0.001; d = 0.350).

Discussion

The present study aimed to analyze the effects of aerobic and strength training methodologies, either combined with or without cognitive training, on mitigating cognitive decline. The results showed that although aerobic and strength training interventions improved overall physical fitness performance in elderly individuals, there were no significant cognitive improvements with or without the addition of cognitive training.

The significant physical improvements observed in the 6-minute walk, chair sit-and-reach, and back scratch tests for the AT group are consistent with the well-established benefits of aerobic training interventions in improving functional capacity and mobility in elderly individuals (Bai et al., 2021). These findings are consistent with previous research showing that aerobic training in improving cardiovascular measures, such as the 6-MWT (An et al., 2024). For instance, the greater improvement in aerobic capacity in the aerobic training group is in concordance with previous evidence that showed that aerobic exercise improves vascular endothelial function, reduces arterial stiffness, and increases nitric oxide bioavailability, which are determinant factors in improving cardiovascular health and reducing the risk of disease (Vigorito and Giallauria, 2014; Murray et al., 2023). Interestingly, the group receiving aerobic and cognitive training (ATCT) demonstrated the greatest improvements in flexibility and balance, particularly in the back scratch and 8-foot up-and-go tests. Given that, it seems that combining physical and cognitive tasks may improve, to a greater extent, the neuromuscular coordination and proprioception essential for balance and flexibility. These findings are supported by the dual-task training framework, which stimulates both the body and the brain and could improve motor control and postural stability (Ghai et al., 2017; Tan et al., 2024).

While it was expected that the AT groups would have a greater level of performance in tests such as the 6-minute walk test and 2-minute step-in-place test, the AT groups had a greater performance in the arm curl test compared to the strength-focused groups. Although these findings seem to suggest that aerobic training contributed to muscular endurance in the elderly, this should be taken with caution. For example, a study conducted on sedentary older men to examine the effects of aerobic training on leg strength found that an AT intervention increased both aerobic fitness and leg strength (Lovell et al., 2010). However, the above-mentioned study (Lovell et al., 2010) used a cycle ergometer for conducting the AT intervention, which is known to increase lower body strength to a greater extent compared to other AT interventions, such as the one used in our study (see Table 1) (Ozaki et al., 2015). Indeed, a previous study conducted on twenty-five young adults compared two different exercise modality training protocols (cycle ergometer vs leg press machine) on lower body strength and found that using a cycle ergometer or leg press may produce similar strength adaptations (Silva et al., 2022). However, combined training that promotes the development of strength and aerobic fitness in the same session seems to be a more effective strategy for improving functional capacity in elderly people (Sbardelotto et al., 2019).

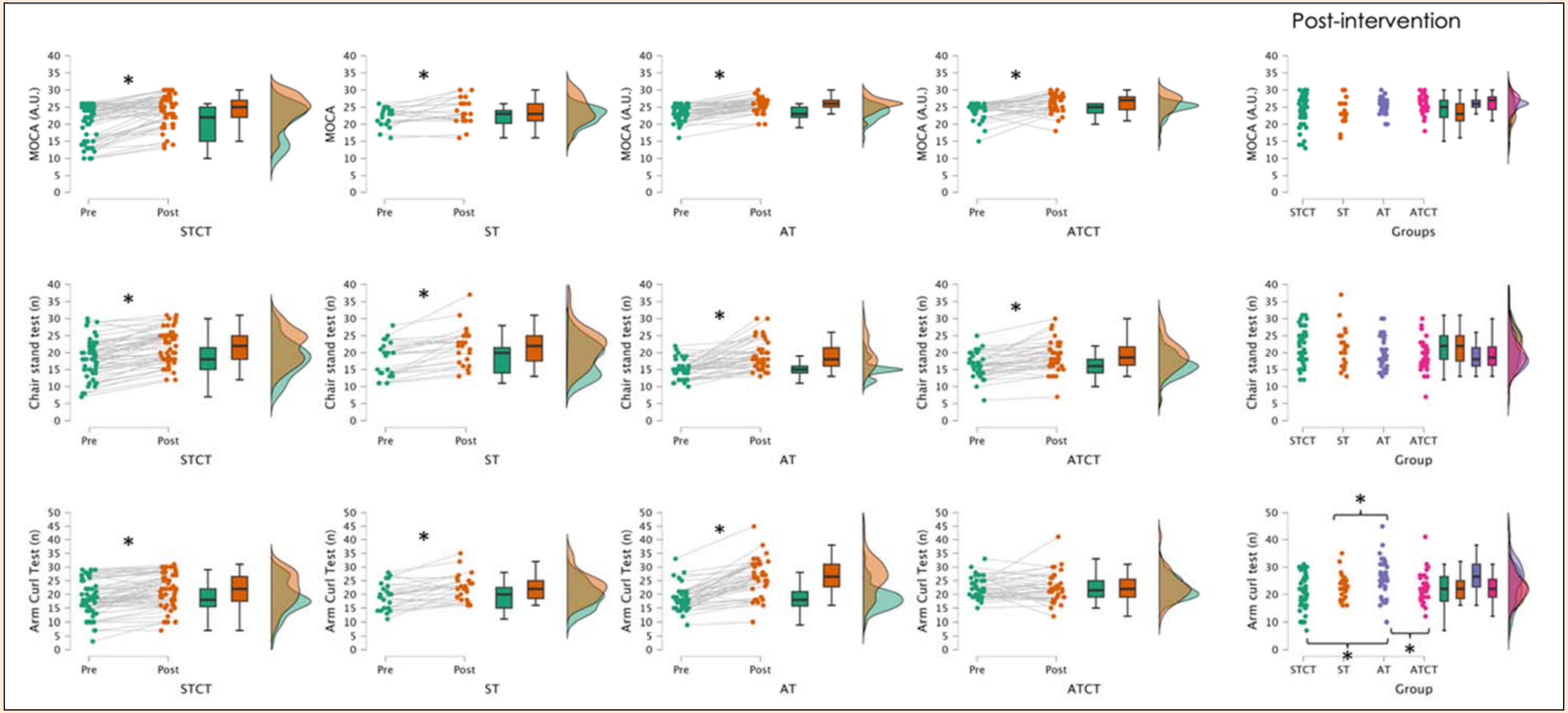

Figure 2. Illustration of within-group and between-group comparisons for the MOCA, chair stand test, and arm curl test. *: significantly different at $p<0.05$; STCT: strength and cognitive training; ST: strength training; AT: aerobic training; ATCT: aerobic and cognitive training.

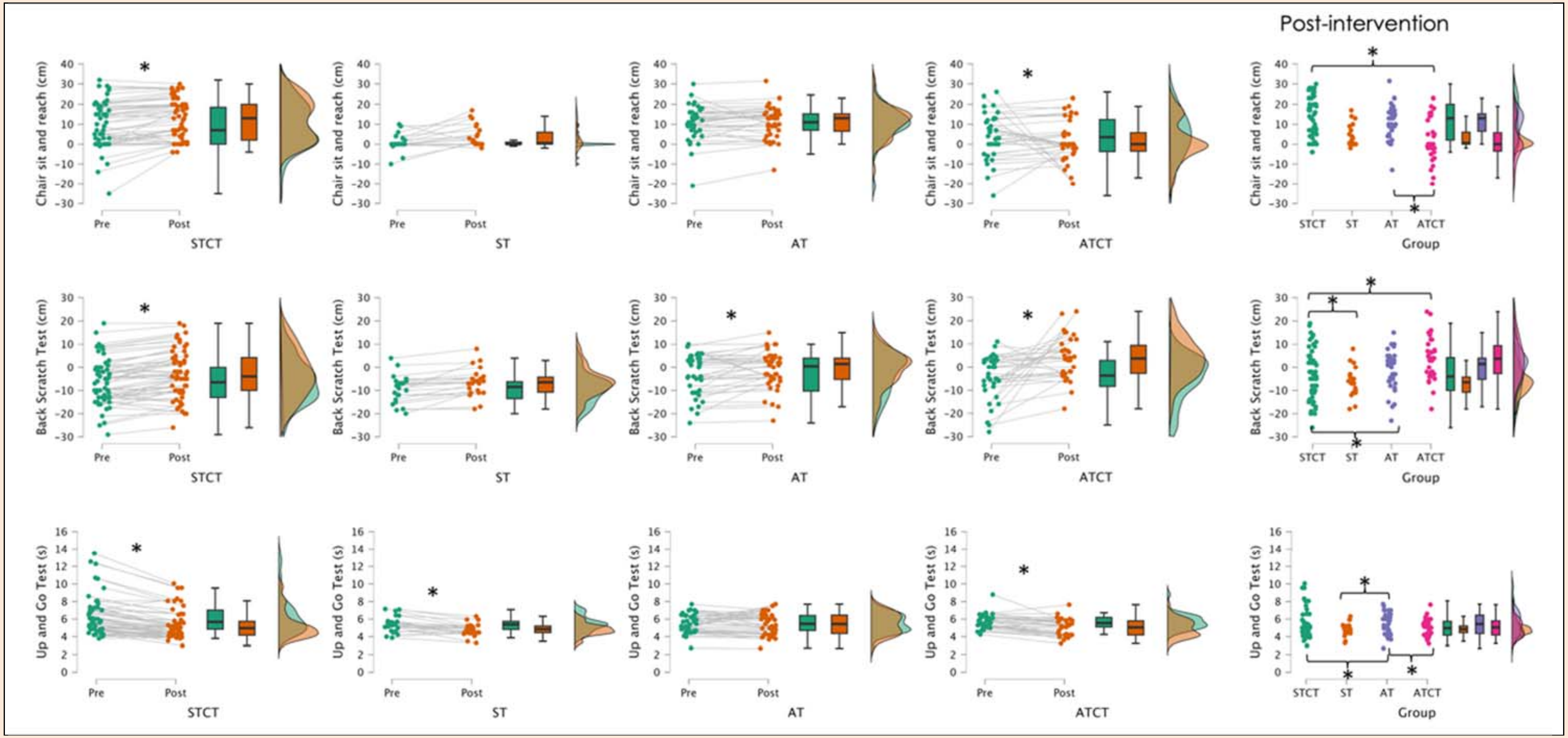

Figure 3. Illustration of within-group and between-group comparisons for the chair sit and reach test, back and scratch test, and the 8-foot up-and-go test. *: significantly different at $p<0.05$; STCT: strength and cognitive training; ST: strength training; AT: aerobic training; ATCT: aerobic and cognitive training.

On the other hand, both the strength training groups (ST and STCT) showed significant improvements in lower limb strength and endurance, as observed by the greatest level of performance in the chair stand and arm curl tests. This finding reinforces the fact that ST interventions are particularly more effective than AT interventions for maintaining or improving muscle strength in elderly populations (Di Lorito et al., 2021), which is extremely relevant for reducing the risk of falls and maintaining independence in daily activities (Ishigaki et al., 2014; Vasconcelos Rocha et al., 2016). Moreover, considering the performance in the sit and reach test and the back scratch test, the STCT was significantly better than the ATCT. The improvements in flexibility observed in the chair sit-and-reach and back scratch tests show the role of strength training in mitigating the effects of age-related muscle and joint stiffness. This is in concordance with previous research that indicates that ST interventions are more effective in improving flexibility than AT interventions (Ceballos-Laita et al., 2023). Furthermore, ST interventions have similar effects on flexibility and range of motion improvements as stretch training alone (Afonso et al., 2021). Given that, implementing ST interventions, with or without cognitive training, is effective in improving.

Despite the overall physical improvements observed in both aerobic and strength interventions, the absence of cognitive improvements in the ATCT and STCT groups may raise questions about the effectiveness of the cognitive training used in the study. The lack of significant cognitive improvement in the MoCA test contrasts with earlier studies that demonstrated the positive effects of combined cognitive and physical training on cognitive functions. Previous studies showed that dual-task training (cognitive plus physical) led to improvements in executive function, attention, and memory (Pereira Oliva et al., 2020; Park, 2021). In contrast to our findings, it was previously observed improvements in balance, gait, upper and lower body strength, flexibility, cognitive function, cognitive impairment, verbal fluency, and executive functions in the physical plus cognitive training group compared to the control group that only did cognitive training (Castellote-Caballero et al., 2024). One possible explanation for this discrepancy may be the fact that the MoCA test may not accurately measure cognitive changes over time, especially between the first and second administrations (Cooley et al., 2015). Also, the cognitive adaptations may require more prolonged interventions (e.g., 12-48 months), particularly in the elderly (Cooley et al., 2015; Campbell et al., 2023).

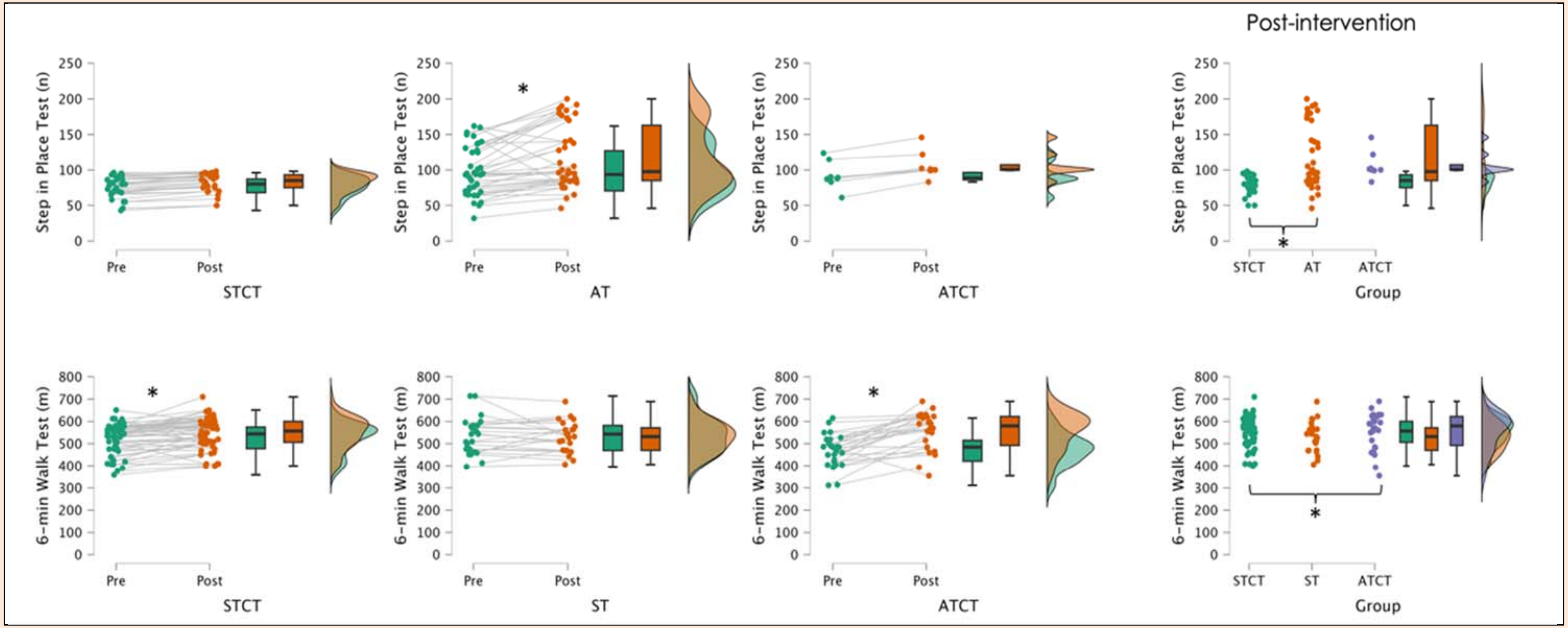

Figure 4. Illustration of within-group and between-group comparisons for the 2-minute step in place test, and the 6-minute walk test. *: significantly different at p<0.05; STCT: strength and cognitive training; ST: strength training; AT: aerobic training; ATCT: aerobic and cognitive training.

Dementia, particularly AD, is more prevalent in females than in males (Mielke et al., 2014), raising questions about the role of biological sex differences in cognitive characteristics, the rate of cognitive decline, and the impact of PE. Research suggests that brain development differs between sexes from conception to death, largely due to hormonal regulation. For instance, males tend to have more lateralized brain functions, affecting language and visuospatial processing, and may struggle with interpreting subtle facial expressions (Proverbio, 2023). Structural differences in the hippocampus and variations in functional brain connectivity further suggest sex-specific vulnerabilities to neurodegenerative diseases (Yagi and Galea, 2019). Hormones such as estrogen and progesterone play key roles in neuroprotection, synaptic function, and cognitive performance, with menopause-related hormonal declines contributing to the increased susceptibility of women to AD. Additionally, BDNF, a protein crucial for neural development, neurogenesis, dendritic growth, and long-term potentiation, has been shown to exert sex-specific effects on AD risk (Szuhany et al., 2015; Walsh and Tschakovsky, 2018). PE also appears to impact men and women differently. Studies on AT and brain health indicate that women generally experience greater cognitive benefits than men (Barha et al., 2017). Meta-analyses have shown that exercise interventions, including AT, more effectively enhance executive function in women, even in clinical populations such as those with MCI (Colcombe and Kramer, 2003). One study on older adults prone to dementia found that six months of AT improved cognitive flexibility and increased BDNF levels in women, whereas men showed a decline in BDNF but an improvement in functional capacity (Barha et al., 2017). These sex differences may be linked to dopaminergic function, estradiol's role in dopamine regulation, and BDNF's influence on cognition. Similarly, another study found that walking activity was associated with a larger subiculum surface area in the hippocampus in women, but not in men (Varma et al., 2016). Given that 69% of our sample consisted of females, this demographic characteristic may have influenced the observed improvements. However, according to Eurostat data from 2019, there were, on average, 1.33 women aged 65 or older for every man of the same age in Europe (European Union, 2025). Thus, our sample reflects the natural demographic distribution of the general European population.

This study has several limitations that should be considered when interpreting our findings. Although the included sample meets the estimated minimum number (see Methods section), the study could have more participants, which could potentially limited the statistical power to detect significant differences, particularly in cognitive outcomes. For future studies, assessments using tests that evaluate specific cognitive domains (e.g., working memory, attention), such as the Trail Making Test or verbal memory tests, could be included. Additionally, the intervention duration of 12 weeks, while sufficient for detecting physical performance changes, may not have been long enough to observe significant cognitive improvements. Moreover, the study predominantly included females, which may affect the generalizability of the findings to male populations, nevertheless, is the normal distribution of this target population. Finally, while the MoCA is a widely used tool for cognitive assessment, it might not be sensitive enough to detect small changes in cognitive function over a short period and might not cover all cognitive domains that could potentially be affected by physical and cognitive training. Further research with larger, more diverse samples and longer intervention periods is needed to better understand the relationship between physical exercise, cognitive training, and cognitive performance in older adults. Additionally, personalized cognitive training could be incorporated, or specific tasks could be combined to target and stimulate particular cognitive domains. Nevertheless, despite its limitations, the results of the present study highlight the importance of combined interventions for maintaining physical functionality in the elderly, while also pointing toward directions to enhance cognitive effects in future research.

Conclusion

This study showed that both AT and ST, whether combined with cognitive training or not, significantly improved overall physical performance in elderly individuals. AT was effective in improving aerobic capacity and upper body strength. On the other hand, the STCT had greater improvements in flexibility compared to AT. However, none of the training modalities showed significant improvements in cognitive performance. While this study observed no significant cognitive improvements within the duration and context of the interventions, it was highlighted the effectiveness of structured physical exercise programs in enhancing physical fitness among older adults. Nevertheless, future research with longer durations, with an increased number of males and diverse cognitive assessment tools is warranted to better evaluate potential cognitive effects.

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Key points

- Both aerobic training (AT) and strength training (ST), with or without cognitive training, significantly enhanced physical fitness in elderly individuals, with notable improvements in flexibility, aerobic endurance, and upper body strength. The ATCT group demonstrated the greatest gains in aerobic endurance, while STCT achieved better flexibility outcomes.
- None of the training modalities -whether combined with cognitive training or not- produced significant improvements in cognitive performance (assessed by the Montreal Cognitive Assessment) in elderly individuals with pre-existing cognitive decline.
- This study highlights the need for further research to explore strategies that effectively address cognitive improvements in populations with cognitive decline.

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