©Journal of Sports Science and Medicine (2025) **24**, 589-602
http://www.jssm.org DOI: https://doi.org/10.52082/jssm.2025.589

Research article

Comparing Adapted Small-Sided Team Sports and Aerobic Exercise with or without Cognitive Games: Effects on Fitness and Cognition in Older Men

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Abstract

This study investigated the effects of 12-week interventions on cognitive and physical fitness adaptations in older men with cognitive decline. We employed a randomized, parallel, and controlled design with five groups: team sports (TS), team sports with cognitive training (TS+C), aerobic exercise (A), aerobic exercise with cognitive training (A+C), and a control group (Control). Fifty older male volunteers (mean age: 69.3 ± 3.2 years) were included in the analysis. Interventions consisted of two 60-minute sessions per week for 12 weeks. Both TS and A groups participated in structured physical training, with TS involving 5v5 handball and football games, and A focusing on circuit training exercises. The TS+C and A+C groups additionally incorporated 20-minute cognitive training sessions using a software, targeting memory, attention, and executive functions. The control group maintained their usual routines. Cognitive function was evaluated using the Montreal Cognitive Assessment (MoCA). Physical fitness was assessed through six tests of the Senior Fitness Test. Results revealed significant post-intervention differences in MoCA ($p < 0.001$, $\eta p^2 = 0.622$), chair stand ($p = 0.038$, $\eta p^2 = 0.189$), up and go ($p < 0.001$, $\eta p^2 = 0.516$), and 6-minute walk test ($p = 0.001$, $\eta p^2 = 0.333$) scores among groups. Post hoc analysis showed that TS, TS+C, A, and A+C groups significantly improved in MoCA, chair stand, up and go, and 6-minute walk test compared to the control group ($p < 0.05$). No significant differences were observed for arm curl, sit and reach, or back scratch tests. Our findings suggest that 12-week interventions incorporating team sports or aerobic exercise, with or without cognitive training, can improve cognitive function and physical fitness in older men with cognitive decline, and may contribute to strategies aimed at promoting healthy aging.

Key words: Walking football, walking basketball, walking handball, running, elderly, physical exercise.

Introduction

In the context of normal aging, human senescence refers to the gradual, biological process associated with progressive declines in cognitive and physical functions, which pose significant challenges to older adults. Cognitively, senescence is associated with declines in memory, executive functions, and processing speed, largely due to structural and functional changes in the brain, particularly in regions such as the prefrontal cortex and basal ganglia (Berchtold and Cotman, 2009; Clouston et al., 2013; Shimamura, 1994). However, these cognitive changes can vary considerably between individuals, ranging from the mild, normative effects of healthy aging to more pronounced impairments seen in mild cognitive impairment (MCI) and pathological conditions such as dementia. While the degree of cognitive impairment varies across individuals, it is a common aspect of aging that may be mitigated by lifestyle choices and targeted interventions (Berchtold and Cotman, 2009). Physically, aging is often accompanied by frailty, a clinically recognized geriatric syndrome defined as a state of increased vulnerability to stressors due to cumulative declines in multiple physiological systems, which reduces the capacity to maintain homeostasis. This condition is distinct from, but may include, sarcopenia, the age-related loss of muscle mass and strength, as one of its contributing factors (Lauretani et al., 2020; Sehl and Yates, 2001). These losses occur gradually, with various organ systems declining at rates of 0.5 - 2% per year between the ages of 30 and 70. Additional physical challenges include osteopenia and the accumulation of physiological dysfunctions, often influenced by genetic predispositions, environmental stress, and sedentary behavior (Crews, 2018).

Computerized cognitive stimulation (CCS) has emerged as a promising intervention for older adults experiencing mild cognitive impairment (MCI) or mild neurocognitive disorders. Research indicates that CCS programs can contribute to slowing cognitive decline while enhancing specific domains commonly affected by aging, including episodic memory, attention, executive functions (e.g., planning, inhibition, and cognitive flexibility), working memory, processing speed, and visuospatial skills (Mapelli et al., 2013; Woods et al., 2012; 2023). These domains are particularly vulnerable in normal and pathological aging, and their decline often underlies difficulties in daily functioning and increased risk of dementia. A recent scoping review identified 27 different apps used across 34 studies aimed at training cognitive functions in older adults, with most interventions focusing on improving memory, executive functions, and attention (Silva et al., 2024). Overall, evidence from trials, systematic reviews,

Received: 06 June 2025 / Accepted: 26 June 2025 / Published (online): 01 September 2025

and meta-analyses confirms the efficacy of cognitive training in enhancing episodic memory, attention, working memory, processing speed, visuospatial skills, and executive functioning in both healthy older adults and those with MCI (Chae and Lee, 2023; Lampit et al., 2014; Tsantali et al., 2017). These cognitive improvements are largely attributed to the brain's neuroplasticity, its capacity to undergo morphological changes in response to environmental stimuli (Jasey and Ward, 2019; Toricelli et al., 2021). For instance, in a CCS intervention for 12-weeks, cognitive and emotional benefits were observed for individuals with MCI and dementia (Meireles and Vicente, 2021). Studies have also demonstrated that CCS is feasible, acceptable, and can improve various aspects of cognitive and psychosocial functioning in individuals with MCI (Djabelkhir et al., 2017). Moreover, the effectiveness of CCS may be influenced by neurobiological factors such as the severity of white matter hyperintensities (WMH), with greater cognitive improvements seen in MCI patients with less severe WMH (Djabelkhir-Jemmi et al., 2018). Although CCS interventions have proven feasible and acceptable (Djabelkhir et al., 2017), research suggests that group- or center-based approaches may be more effective than home-based online programs (Lampit et al., 2014). However, current evidence remains insufficient to confirm that cognitive training can prevent cognitive decline or the progression to dementia (Butler et al., 2018). Ongoing research is exploring the comparative effects of personalized CCS versus stimulating leisure activities in adults with mild or subjective cognitive impairment (Gómez-Soria et al., 2025). Further research is needed to determine the long-term impact and optimize implementation strategies based on dementia severity and delivery context (Woods et al., 2023).

Physical exercise has been shown to have significant preventive effects against cognitive decline and dementia in aging populations (Silva et al., 2025). Regular exercise improves cerebral blood flow, triggering neurobiological mechanisms that enhance angiogenesis, neurogenesis, synaptogenesis, and neurotransmitter synthesis (Paillard, 2015). These changes are associated with increased gray and white matter volume in cognitive-related brain areas (Paillard, 2015). Exercise interventions, particularly those that are personalized, multicomponent, and of higher intensity and longer duration, have demonstrated improvements in cognitive function, including motor control, spatial working memory, and visuospatial learning (Falck et al., 2019; Kirk-Sanchez and McGough, 2013; Pereira et al., 2019). The neuroprotective effects of exercise are dose-dependent and involve modulation of metabolic, structural, and functional dimensions of the brain (Kirk-Sanchez and McGough, 2013). However, there is substantial variability across studies regarding exercise protocols, including the type (aerobic, resistance, coordination, or mixed), intensity (low to high), frequency, and duration of training, as well as participant adherence. These inconsistencies may contribute to mixed findings in the literature and complicate efforts to establish standardized recommendations. Moreover, individual factors such as baseline fitness, cognitive status, and motivation can further influence outcomes and adherence, underscoring the importance of tailoring interventions to participant needs. Additionally, physical activity may influence aging-related epigenetic changes, including DNA methylation patterns, histone modifications, and microRNA profiles, potentially opening new avenues for preventive and therapeutic strategies (Kaliman et al., 2011).

Team-based sports and recreational activities have been increasingly recognized as effective strategies for promoting both physical and cognitive health in older adults. Unlike structured exercise interventions, which are typically goal-directed and standardized in intensity and format, recreational team sports often emphasize enjoyment, social interaction, and spontaneous physical engagement, which may yield distinct cognitive and psychosocial benefits. Research indicates that engaging in sports such as football, handball, and basketball can significantly enhance cardiovascular fitness and other health-related parameters, even in previously inactive individuals (Castagna et al., 2020). Furthermore, sustained participation in physical and recreational activities from mid-life into older age is associated with better cognitive performance later in life (Gavett et al., 2023). While aerobic exercise has traditionally received the most attention, emerging evidence suggests that team sports may offer distinct cognitive benefits, targeting specific domains such as executive function and attention (Sogaard and Ni, 2018). These benefits are likely due not only to the physical demands of the activities but also to the social interaction, decision-making, and motor coordination required during gameplay, which may enhance cognitive reserve and delay age-related decline. Literature suggests that engaging in cognitively and socially complex physical activities, such as team sports, can lead to improved executive function, memory, and processing speed in older adults (Netz, 2019) and may contribute to building cognitive reserve by promoting neural efficiency and adaptability (Stern et al., 2020). Notably, community-based initiatives such as football programs for men with early-onset dementia have demonstrated improvements in quality of life for both participants and their carers (Carone et al., 2016). Additionally, serious games that combine cognitive training with physical movement have shown promise for individuals with dementia, mild cognitive impairment, and Alzheimer's disease (McCallum and Boletsis, 2013), further underscoring the multifaceted value of interactive, game-based approaches to healthy aging.

Based on the growing evidence suggesting that behavioral strategies, such as physical exercise and cognitive training, can help delay cognitive decline, this study set out to examine the effects of a 12-week intervention using team-based games and aerobic training, both with and without cognitive stimulation, on slowing cognitive deterioration. Outcomes will be compared with a control group that did not engage in any physical exercise during the intervention period. Considering that individuals with moderate cognitive decline demonstrate more significant 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 be effective, the study focused on older adults with MCI. We hypothesized that (i) both physical training approaches may offer valid strategies for delaying cognitive decline and that (ii) the combined intervention of physical exercise and cognitive stimulation would lead to superior improvements in cognitive function compared to either intervention alone.

Methods

Experimental approach to the problem

To compare the effects of TS, TS+C, A, A+C, and a control group, a randomized, parallel, and controlled study design was implemented. Participants were randomly assigned to groups using a computer-generated block randomization method to ensure balanced allocation across the five study arms. The aim was to assess the impact of 12-week interventions on cognitive and physical fitness adaptations in older men. After recruitment, participants were randomly assigned to groups prior to the initial assessment. Randomization involved assigning each participant a code number, which was then allocated to a group through a random draw conducted by an independent person not involved in the study. Once randomized and allocated, participants remained in their assigned groups throughout the study. A convenience sampling strategy was used to enhance recruitment, targeting institutions already engaged with potential participants to increase the likelihood of enrollment. While this approach supported efficient recruitment, it may have introduced selection bias, potentially limiting the external validity and generalizability of the findings to broader populations. The study took place during the winter and spring months, with all interventions conducted in indoor facilities to facilitate adherence and ensure a consistent intervention process. All participants were evaluated during the week prior to the start of the 12-week intervention period and re-evaluated in the week following its completion. Participants were advised to engage only in the activity assigned within the study. Additionally, they were instructed to maintain their usual nutrition, hydration, and sleep habits throughout the intervention period, including those in the control group, who were asked not to initiate any new structured physical or cognitive activities during the 12 weeks.

Participants

From the initial pool, 59 volunteers were identified as suitable for the study after being assessed against the eligibility criteria. To be included, participants needed to: i) be 65 years of age or older; ii) possess no physical limitations that would prevent participation; iii) in line with the original validation by Nasreddine et al. (Nasreddine et al., 2005), participants with a Montreal Cognitive Assessment (MoCA) score of 26 or below were considered to exhibit cognitive decline, a threshold commonly used to indicate potential mild cognitive impairment (MCI); iv) attend a minimum of 80% of training sessions; and v) take part in all evaluation activities. Exclusion applied to those who did not fulfill these conditions. For this reason, three participants were excluded before group allocation due to scoring above 27 on the MoCA test. Additionally, six participants were excluded during the intervention period for missing more than 50% of the sessions. These excluded participants were distributed as follows: one from the TS group, one from the TS+C group, one from the A group, and three from the A+C group. Ultimately, 50 older male volunteers were included in the analysis: TS (n = 10), TS+C (n = 10), A (n = 10), A+C (n = 9), and Control (n=11). The average age of the participants was 69.3 ± 3.2 years. Figure 1 shows the flow of participants throughout the different phases of the study.

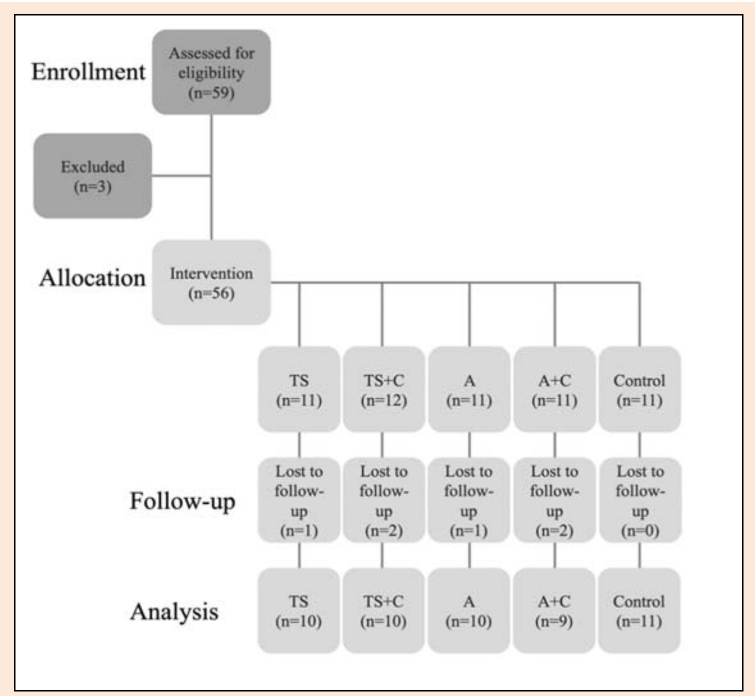

Figure 1. Participant flow diagram. TS: team sports; TS+C: team sports + cognitive training; A: aerobic; A+C: aerobic + cognitive training.

This study was approved by the Ethics Committee of the Instituto Politécnico de Viana do Castelo (protocol code: CECSVS2024/02/vi). Participants gave free informed consent, understanding their data would be protected and they could withdraw whenever they wished.

Interventions

Interventions were implemented over 12 weeks, with participants completing two 60-minute sessions per week, separated by 72 hours of rest. Conducted at partner facilities across, these sessions were guided by the research team, who also developed the prescribed aerobic and team sports training programs. Prior to the start of the intervention, instructors were selected based on their level of commitment and alignment with the researchers' values. A preparatory training session was then conducted to ensure they understood the importance of standardizing the intervention process and were equipped to implement the training plan as designed by the research team. Full training protocols are detailed in Table 1 and Table 2. The aerobic training regimen incorporated three distinct exercise variations, stratified by complexity, to facilitate individualized adaptation by instructors. Concurrently, the Rate of Perceived Exertion (RPE) served as a measure for assessing workload intensity across sessions.

Participants engaged in cognitive training (i.e., TS+C and A+C) have used the Fit4Alz software (https://fit4alz.wixsite.com/fit4alz), designed to target memory, attention, and executive functions. The software provided two games per function, each with five progressive difficulty levels. This design drew from a prior scoping review (Silva et al., 2024) that identified prevalent cognitive training software areas: memory (e.g., 'Make pairs,' 'Play the sequence'), attention (e.g., 'Find the differences,' 'Face to face'), and executive functions (e.g., 'Stroop,' 'Tap or avoid'). Progression to more challenging levels depended entirely on in-game performance; participants who failed to complete a task within the two-minute time limit did not advance, while those who succeeded moved forward. A score, based on task completion time, was awarded after each game. Each 20-minute cognitive session followed the physical training, with a different cognitive function addressed in each session to guarantee an even distribution of training across all cognitive domains.

The control group did not receive any specific intervention during the 12-week study period. They continued their usual routines and were only required to attend the assessment sessions.

Measurements and outcomes

Data was collected in two distinct sessions both before and after the intervention. The first session focused on cognitive assessment, while the second was dedicated to physical fitness evaluation. All assessments were held indoors in a controlled environment during morning hours. A team of researchers administered the MoCA test in the initial session. Participants were organized into small groups of 4-5 and followed a pre-established sequence of activities. This session began with anthropometric measurements, followed by a warm-up, before proceeding to the six Senior Fitness Test components (39): i) chair stand; ii) arm curl; iii) chair sit-and-reach; iv) back scratch; v) 8-foot up-and-go; and vi) six-minute walk or 2-minute step-in-place test. It is important to note that no follow-up assessments were conducted after the post-intervention phase. This absence of longitudinal follow-up is a limitation of the study design, as it prevents evaluation of the long-term sustainability of the observed effects.

Table 1. **Description of weekly training sessions of team sports training sessions.**

	Duration	Phase	Exercises	Regimen	Intensity
Session 1	5 min	Warm-up	Exercises involving one or multiple joints that promote a gradual rise in body temperature	10 reps per exercise	5-6 RPE
Session 1	40 min	Main	5v5 handball game 5v5 football game	2 sets of 7 min /3 min rest 2 sets of 7 min /3 min rest	7-8 RPE
Session 1	5 min	Cold down	Walking	Continuous	3-4 RPE
Session 2	5 min	Warm-up	Exercises involving one or multiple joints that promote a gradual rise in body temperature	10 reps per exercise	5-6 RPE
Session 2	40 min	Main	5v5 basketball game 5v5 football game	2 sets of 7 min /3 min rest 2 sets of 7 min /3 min rest	7-8 RPE
Session 2	5 min	Cold down	Walking	Continuous	3-4 RPE

RPE: rate of perceived exertion.

Table 2. **Description of weekly training sessions of aerobic training sessions.**

	Duration	Phase	Exercises	Regimen	Intensity
Session 1	5 min	Warm-up	Exercises involving one or multiple joints that promote a gradual rise in body temperature	10 reps per exercise	5-6 RPE
Session 1	40 min	Main	Two sets of each: Jumping jacks; Walk out; High knee; Lunge; Kipping; Plank knee	6 x 2' 1' rest between each repetition 4-6' walk between sets	7-8 RPE
Session 1	5 min	Cold down	Walking	Continuous	3-4 RPE
Session 2	5 min	Warm-up	Exercises involving one or multiple joints that promote a gradual rise in body temperature	10 reps per exercise	5-6 RPE
Session 2	40 min	Main	Two sets of each: Burpees; Squat; Lunge with kick; Butt kicks; Running; Step up and down	6 x 2' 1' rest between each repetition 4-6' walk between sets	7-8 RPE
Session 2	5 min	Cold down	Walking	Continuous	3-4 RPE

RPE: rate of perceived exertion.

MoCA
As a cognitive assessment tool, the MoCA is both reliable and validated. It has showed sensitivity, particularly in comparison to alternative measures such as the Mini-Mental State Examination (MMSE) (Freitas et al., 2012; Islam et al., 2023). MOCA evaluates several domains, including attention, memory, language, visuospatial skills, executive function, and orientation. The test is scored out of 30 points, with a score of 26 or above typically considered normal. A score below 26 may indicate cognitive impairment, with lower scores suggesting greater cognitive difficulties. The MoCA test was administered in person by a trained researched, who verbally presented a series of tasks and recorded the participant's responses.

Chair stand test
To measure lower limb strength and endurance, a test was conducted using a stopwatch and a stabilized chair. The chair, roughly 43 cm in seat height and with a backrest, was secured against a wall or otherwise made immobile for participant safety. The participant positioned themselves with their back against the chair and feet flat on the floor, with an evaluator nearby providing additional chair stability. With arms crossed and middle fingers on shoulders, participants were instructed to stand completely and then sit down as many times as possible within a 30-second period after receiving the evaluator's signal. A single demonstration by the evaluator preceded the formal test to ensure clarity.

Arm curl test
Upper limb strength and endurance were evaluated using a stopwatch, an armrest-free chair, and hand weights (2.3 kg for women; 3.6 kg for men). Participants sat upright, dominant arm extended perpendicularly while gripping the weight. To ensure proper execution, an evaluator stabilized the upper arm. Upon signal, participants rotated their palm up, fully flexed the arm, and returned to extension, aiming for the highest number of repetitions within 30 seconds. Following a brief demonstration and practice, the test was performed once.

Back Scratch test
To evaluate flexibility, participants stood near an evaluator, who positioned themselves behind them. Participants then reached with their dominant hand from over their shoulder, down their back, while simultaneously bringing their other arm up from behind, aiming to touch or overlap their extended fingers. The evaluator ensured proper alignment of the middle fingers, preventing them from touching initially. Following two practice trials, participants completed two official test attempts. Scoring involved measuring the distance between the middle fingertips or the extent of their overlap, recorded to the nearest centimeter. A negative score (-) represented the shortest distance between fingers, whereas a positive score (+) indicated overlap. The top performance was used for assessment, with all observations of overlap or distance noted on the scoring sheet.

Sit and reach test
Lower limb flexibility was assessed using an armrest-free chair (around 43 cm high) and a 45 cm ruler. For stability, the chair was secured against a wall. Participants sat with their inguinal line parallel to the seat, one leg bent off the ground, and the other extended forward. An evaluator was present for support. Participants then leaned forward, sliding hands down the extended leg to touch their toes, while keeping a straight back. This position was held for two seconds, with instructions to straighten a bent knee if observed. Two trials were completed, and the best outcome was logged.

Up and go test
Measuring physical mobility, including speed, agility, and dynamic balance, was the goal of this test. It utilized a stopwatch, measuring tape, a cone (or marker), and a stabilized chair (about 43 cm high). The cone was set 2.44 meters from the chair, with 1.22 meters of clear surrounding space. Participants began seated upright, one foot slightly ahead of the other, with an evaluator close by for support. At the signal, they stood up, walked quickly around the cone, and returned to their seat. The timer started at the signal and paused upon reseating. After a demonstration, a single practice trial was allowed before two official attempts. The quickest (shortest) time achieved was used for the score. Participants received a reminder to walk quickly, not run, when navigating the cone and returning to the chair.

6-min walk test
Aerobic endurance was assessed using a stopwatch, measuring tape, cones, poles, chalk, and markers. For safety, chairs were positioned along the circuit. The 45-meter course, marked every 5 meters with chalk or tape, was in a well-lit, level area. Participants started with an evaluator ready to time them. Upon signal, they walked as fast as possible (no running), completing as many laps as they could in 6 minutes. Participants were allowed to rest as needed. The evaluator joined the course after the start to provide time updates. The 5-meter markings were key for this 6-minute walk test.

Statistical procedures
An a priori power analysis was conducted using G*Power (Version 3.1.9.7, Kiel University, Kiel, Germany(Faul et al., 2007)) to determine the necessary sample size for mixed ANOVA design. For this calculation, it was adopted a conventional alpha level of $\alpha = 0.05$ and desired a statistical power of $1-\beta = 0.95$. Based on prior literature conducted in recreational football and impact on 6-min walk test (Duncan et al., 2022), we anticipated a $f = 0.454$ effect size. The G*Power analysis indicated that a total sample size of $N = 30$ participants would be required to detect the specified effect with the given power and alpha levels.

To analyze the effects of five groups on cognitive and physical fitness outcomes, a repeated measures ANOVA with a mixed design (time and group) was conducted using IBM SPSS Statistics (version 28.0; USA). Sphericity was evaluated using Mauchly's Test of Sphericity, and where violated, the Greenhouse-Geisser correction was applied. The assumption of normality for the residuals was assessed using the Shapiro-Wilk test ($p > 0.05$). In cases of significant main or interaction effects ($p < 0.05$), Bonferroni-corrected post hoc tests were performed to identify specific group differences or changes over time. Partial eta-squared (ηp2) values are reported as measures of effect size, with values of 0.01, 0.06, and 0.14 indicating small, medium, and large effects, respectively.

Results

A significant interaction between time and group was observed for the MoCA test ($F_{(4,45)} = 18.538$; $p < 0.001$; $\eta p^2 = 0.622$), chair stand test ($F_{(4,45)} = 2.614$; $p = 0.048$; $\eta p^2 = 0.189$), arm curl test ($F_{(4,45)} = 4.816$; $p = 0.003$; $\eta p^2 = 0.300$), up and go test ($F_{(4,45)} = 11.997$; $p < 0.001$; $\eta p^2 = 0.516$) and 6-minute walk test ($F_{(4,45)} = 5.627$; $p < 0.001$; $\eta p^2 = 0.333$). The interaction effect on the MoCA test and the up and go test represent large effects, indicating substantial differences in performance changes between groups over time. Additionally, post hoc analyses revealed that the groups receiving combined interventions (TS+C and A+C) demonstrated significantly greater improvements than the control group in most outcomes, with large effect sizes (Cohen's d > 0.8), reinforcing the practical relevance of these findings. Table 3 shows the descriptive statistics (mean and standard deviation) and mixed ANOVA results for the outcomes across the five groups.

MoCA

At baseline, there was no significant difference in MoCA scores among the five groups, ($F_{(4,45)} = 2.295$, $p = 0.074$, $\eta p^2 = 0.169$). Although not statistically significant, the effect size is above the threshold for a large effect, suggesting a potentially meaningful difference that may not have reached significance due to limited sample size.

Table 3. Descriptive statistics (mean and standard deviation) and mixed ANOVA results for the outcomes across the five groups.

Measure	Group	Mean (Pre)	Std. Deviation (Pre)	Mean (Post)	Std. Deviation (Post)	Mixed ANOVA
MoCA (score)	TS	21.0	1.7	25.6	2.1	Time: $F = 245.743$; $p < 0.001$; $\eta p^2 = 0.845$
	TS+C	21.4	1.8	26.9	1.7	
	A	22.2	2.0	24.4	3.1	
	TS+C	23.4	1.8	26.6	1.8	Time*group: $F = 18.538$; $p < 0.001$; ηp2 = 0.622
	Control	22.1	2.1	22.7	1.7	
Chair Stand (n)	TS	17.4	3.2	19.7	2.7	Time: $F = 12.786$; $p < 0.001$; $\eta p^2 = 0.221$
	TS+C	17.3	5.0	20.0	5.0	
	A	16.5	4.2	16.9	2.9	
	TS+C	16.7	1.9	18.4	3.0	Time*group: $F = 2.614$; $p = 0.048$; ηp2 = 0.189
	Control	16.1	4.4	15.6	3.8	
Arm Curl (n)	TS	18.2	2.8	22.6	2.1	Time: $F = 15.480$; $p < 0.001$; $\eta p^2 = 0.256$
	TS+C	18.6	3.9	22.8	5.3	
	A	18.5	4.0	19.1	4.6	
	TS+C	17.9	1.7	18.8	4.4	Time*group: $F = 4.816$; $p = 0.003$; ηp2 = 0.300
	Control	19.7	3.6	19.0	3.6	
Back scratch L (cm)	TS	-8.30	4.57	-6.90	4.18	Time: $F = 11.925$; $p = 0.001$; $\eta p^2 = 0.209$
	TS+C	-7.10	7.33	-5.85	7.82	
	A	-7.50	6.10	-7.20	6.07	
	TS+C	-7.56	8.34	-5.33	9.27	Time*group: $F = 1.326$; $p = 0.275$; ηp2 = 0.105
	Control	-5.91	6.28	-5.64	5.77	
Back scratch R (cm)	TS	-4.30	5.81	-3.70	5.52	Time: $F = 1.010$; $p = 0.320$; $\eta p^2 = 0.022$
	TS+C	-3.50	7.46	-2.80	6.43	
	A	-5.60	5.02	-5.20	4.78	
	TS+C	-4.56	5.13	-4.78	5.14	Time*group: $F = 0.155$; $p = 0.960$; ηp2 = 0.014
	Control	-4.73	7.21	-4.18	6.23	
Sit and reach L (cm)	TS	-1.60	8.06	0.30	8.26	Time: $F = 6.188$; $p = 0.017$; ηp2 = 0.121
	TS+C	0.40	4.88	2.50	3.44	
	A	0.80	4.89	1.80	6.37	
	TS+C	0.11	2.98	2.44	3.54	Time*group: $F = 0.409$; $p = 0.801$; ηp2 = 0.035
	Control	-0.55	5.80	-0.27	5.39	
Sit and reach R (cm)	TS	1.80	5.65	3.30	5.31	Time: $F = 6.932$; $p = 0.012$; ηp2 = 0.133
	TS+C	-1.80	3.49	-0.70	4.03	
	A	0.70	4.37	1.90	4.75	
	TS+C	-1.56	6.25	2.00	3.04	Time*group: $F = 1.693$; $p = 0.168$; ηp2 = 0.131
	Control	2.64	5.75	2.00	4.71	
Up and go (s)	TS	5.16	0.78	4.47	0.60	Time: $F = 22.809$; $p < 0.001$; $\eta p^2 = 0.336$
	TS+C	5.23	0.97	4.56	1.02	
	A	5.10	0.73	4.85	0.72	
	TS+C	5.50	0.85	4.92	0.65	Time*group: $F = 11.997$; $p < 0.001$; ηp2 = 0.516
	Control	5.17	0.77	5.72	1.05	
Walk (m)	TS	493.1	65.8	571.4	46.8	Time: $F = 67.411$; $p < 0.001$; $\eta p^2 = 0.600$
	TS+C	487.1	80.0	573.8	99.4	
	A	498.2	51.6	567.2	45.4	
	TS+C	495.4	62.4	581.1	65.2	Time*group: $F = 5.627$; $p < 0.001$; $\eta p^2 = 0.333$
	Control	482.2	78.2	476.0	78.1	

TS: team sports; TS+C: team sports + cognitive training; A: aerobic; A+C: aerobic + cognitive training; L: left; R: right.

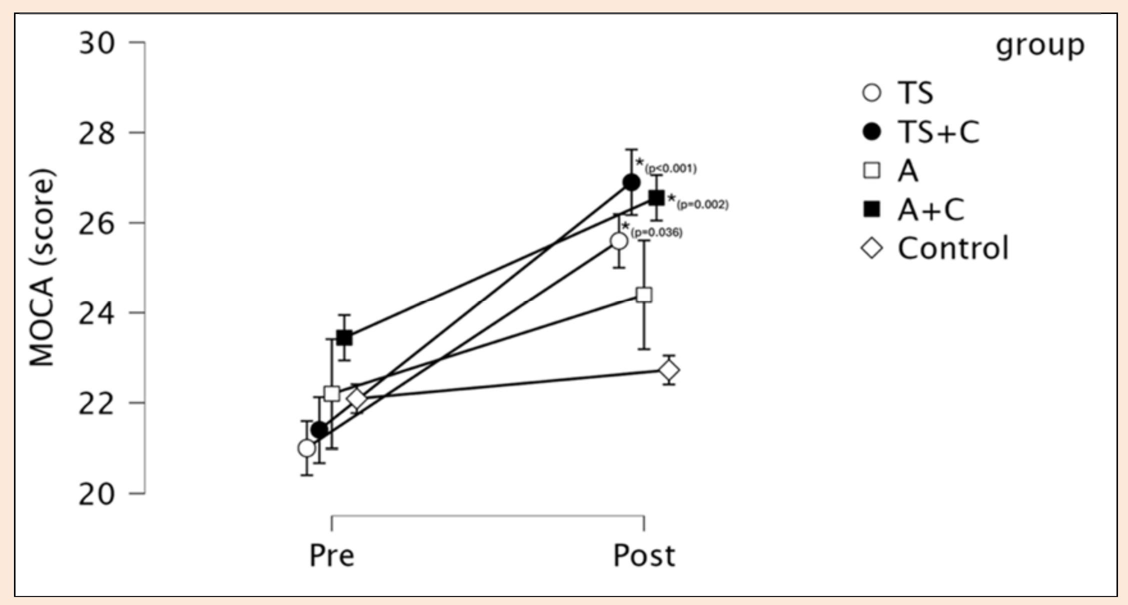

Figure 2. Changes in MoCA scores pre and post-intervention for different groups. TS: team sports; TS+C: team sports + cognitive training; A: aerobic; A+C: aerobic + cognitive training; *: significantly different from the control group ($p < 0.05$).

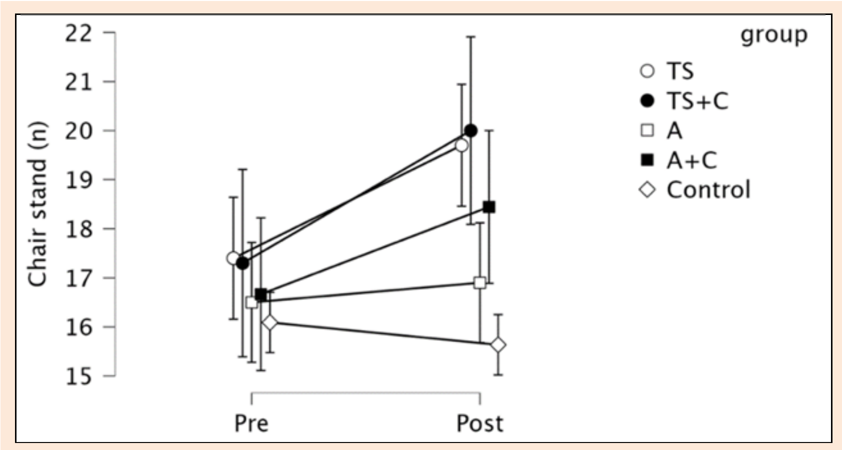

Figure 3. Changes in chair stand test scores pre and post-intervention for different groups. TS: team sports; TS+C: team sports + cognitive training; A: aerobic; A+C: aerobic + cognitive training.

At post-intervention, there was a significant difference in MoCA scores among the groups ($F_{(4,45)} = 6.584$, $p < 0.001$, $\eta p^2 = 0.369$), which represents a large effect size, indicating substantial between-group differences following the intervention. The specific post hoc group comparisons are illustrated in Figure 2.

Within group comparisons revealed there was a significant increase in MoCA scores from pre- to post-intervention for the TS group ($p < 0.001$, $\eta p^2 = 0.693$). The TS+C group also showed a significant increase in MoCA scores from pre- to post-intervention, ($p < 0.001$, $\eta p^2 = 0.763$). There was a significant increase in MoCA scores from pre- to post-intervention for the A group ($p < 0.001$, $\eta p^2 = 0.340$), reflecting a large effect, while the A+C group demonstrated a similarly large effect ($p < 0.001$, $\eta p^2 = 0.481$). In contrast, the control group showed no significant change ($p = 0.151$), and the effect size was small ($\eta p^2 = 0.045$), suggesting minimal change in cognitive performance over time without intervention.

Chair stand test

At baseline, there was no significant difference in Chair Stand test scores among the five groups ($F_{(4,45)} = 0.203$, $p = 0.936$, $\eta p^2 = 0.018$). This effect size falls within the small range, indicating minimal baseline differences across groups, which aligns with the non-significant result. At post-intervention, there was a significant difference in Chair Stand test scores among the groups ($F_{(4,45)} = 2.773$, $p = 0.038$, $\eta p^2 = 0.198$), representing a large effect size and indicating meaningful differences between groups following the intervention. Figure 3 shows the specific post hoc comparisons between groups.

There was a significant increase in Chair Stand test scores from pre- to post-intervention for the TS group ($p = 0.009$, $\eta p^2 = 0.143$), which corresponds to a large effect, indicating meaningful improvements in lower-body strength. The TS+C group also showed a significant increase in Chair Stand test scores from pre- to post-intervention ($p = 0.002$, $\eta p^2 = 0.187$), also reflecting a large effect. The A group did not show a significant change ($p = 0.636$, $\eta p^2 = 0.005$), and the effect size was negligible, suggesting no meaningful improvement. The A+C group demonstrated a marginally significant increase ($p = 0.050$, $\eta p^2 = 0.082$), with a medium effect, indicating a modest but potentially meaningful gain. The control group showed no significant change ($p = 0.573$, $\eta p^2 = 0.007$), and the effect size was very small, consistent with the lack of intervention.

Arm curl

At baseline, there was no significant difference in arm curl scores among the five groups, ($F_{(4,45)} = 0.457$, $p = 0.767$, $\eta p^2 = 0.039$). The effect size falls within the small range, suggesting only minimal variation between groups at baseline, consistent with the non-significant result. At post-intervention, there was no significant difference in arm curl scores among the groups ($F_{(4,45)} = 2.491$, $p = 0.056$, $\eta p^2 = 0.181$), the effect size was large, indicating a potentially meaningful difference that may not have reached significance possibly due to limited statistical power. Detailed comparisons between the groups are presented in Figure 4.

There was a significant increase in arm curl scores from pre- to post-intervention for the TS group ($p < 0.001$, $\eta p^2 = 0.276$) and the TS+C group ($p < 0.001$, $\eta p^2 = 0.258$), both representing large effect sizes. These results indicate strong improvements in upper-body strength for the team sports interventions. In contrast, the A group ($p = 0.575$, $\eta p^2 = 0.007$), A+C group ($p = 0.431$, $\eta p^2 = 0.014$), and Control group ($p = 0.476$, $\eta p^2 = 0.011$) did not show significant changes. The effect sizes for these three groups were negligible to small, suggesting no meaningful improvement in arm strength from pre- to post-intervention.

Sit and reach test

At baseline, there was no significant difference in sit and reach left scores among the five groups ($F_{(4,45)} = 0.280$, $p = 0.890$, $\eta p^2 = 0.024$). This effect size falls within the small range, suggesting minimal variation in flexibility between groups at baseline. At post-intervention, there was no significant difference in sit and reach left scores among the groups ($F_{(4,45)} = 0.502$, $p = 0.734$, $\eta p2 = 0.043$). Detailed comparisons between the groups are presented in Figure 5a.

At baseline, there was no significant difference in sit and reach (right) scores among the five groups ($F_{(4,45)} = 1.469$, $p = 0.227$, $\eta p^2 = 0.115$). While not statistically significant, this corresponds to a medium-to-large effect size, suggesting moderate baseline variability that did not reach significance, potentially due to sample size. At post-intervention, no significant difference was found either ($F_{(4,45)} = 1.069$, $p = 0.383$, $\eta p^2 = 0.087$), but the effect size falls within the medium range, indicating a modest but not statistically conclusive variation in flexibility between groups. Detailed comparisons between the groups are presented in Figure 5b.

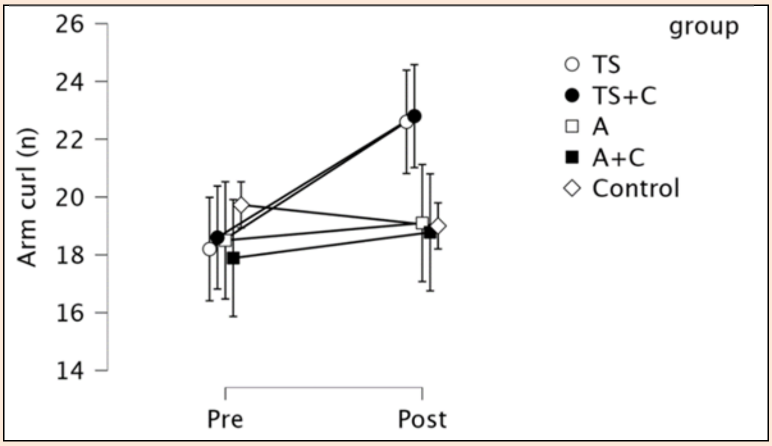

Figure 4. Changes in chair stand test scores pre and post-intervention for different groups. TS: team sports; TS+C: team sports + cognitive training; A: aerobic; A+C: aerobic + cognitive training.

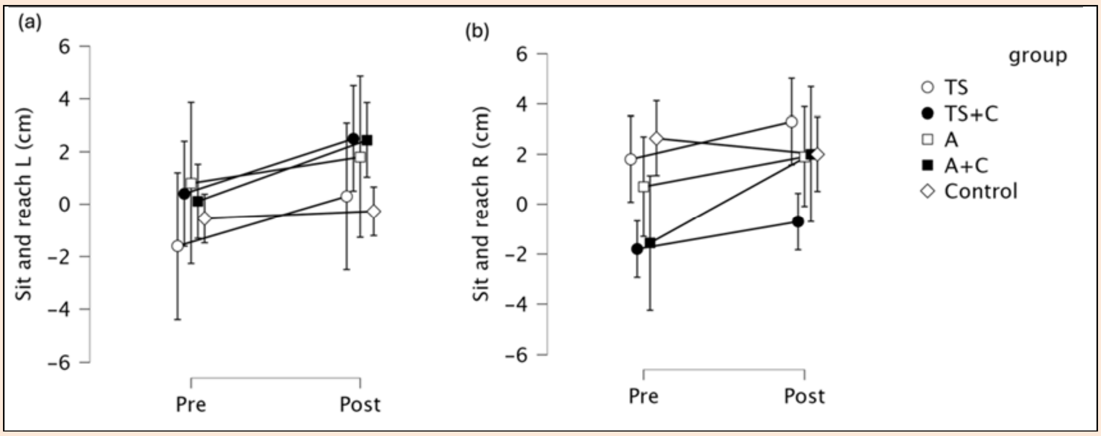

Figure 5. Changes in sit and reach left (L) and right (R) scores pre and post-intervention for different groups. TS: team sports; TS+C: team sports + cognitive training; A: aerobic; A+C: aerobic + cognitive training.

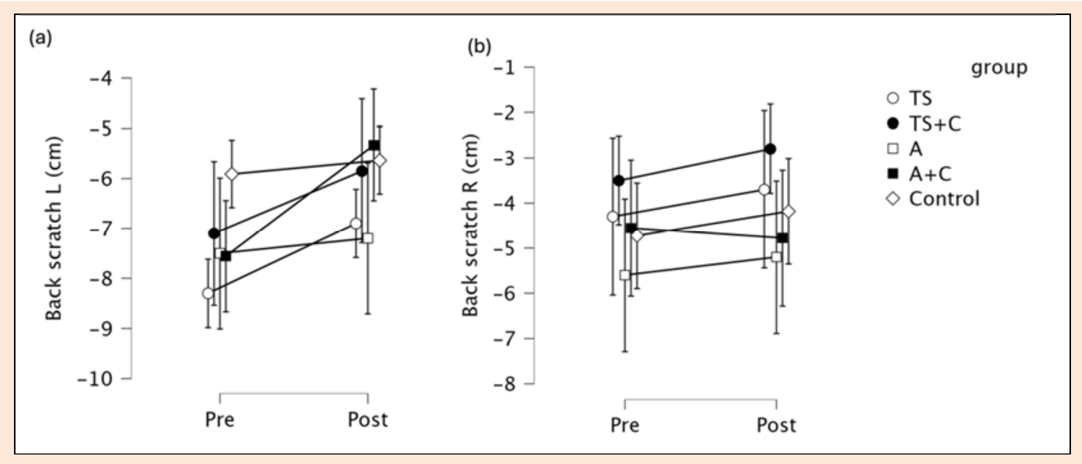

Figure 6. Changes in back scratch left (L) and right (R) scores pre and post-intervention for different groups. TS: team sports; TS+C: team sports + cognitive training; A: aerobic; A+C: aerobic + cognitive training.

Back Scratch test

At baseline, there was no significant difference in back scratch left scores among the five groups ($F_{(4,45)} = 0.187$, $p = 0.944$, $\eta p^2 = 0.016$). This effect size falls in the small range, indicating negligible variation in upper-body flexibility between groups prior to the intervention. At post-intervention, there was no significant difference in back scratch left scores among the groups ($F_{(4,45)} = 0.144$, $p = 0.965$, $\eta p^2 = 0.013$), with the effect size again being small, suggesting minimal change or differentiation between groups after the intervention. Detailed comparisons between the groups are presented in Figure 6a.

Moreover, at baseline, there was no significant difference in back scratch right scores among the five groups ($F_{(4,45)} = 0.147$, $p = 0.963$, $\eta p^2 = 0.013$). This reflects a small effect size, indicating very little variability in upper-body flexibility across groups prior to the intervention. At post-intervention, there was no significant difference in back scratch right scores among the groups ($F_{(4,45)} = 0.270$, $p = 0.896$, $\eta p^2 = 0.023$). Again, the effect size was small, suggesting limited differentiation between groups in flexibility outcomes after the intervention. Detailed comparisons between the groups are presented in Figure 6b.

Up and go test

At baseline, there was no significant difference in Up and Go Test scores among the five groups ($F_{(4,45)} = 0.280$, $p = 0.890$, $\eta p^2 = 0.024$). This corresponds to a small effect size, indicating very little variation in mobility and agility between groups before the intervention. At post-intervention, there was a significant difference in Up and Go Test scores among the groups ($F_{(4,45)} = 11.997$, $p < 0.001$, $\eta p^2 = 0.516$). This represents a very large effect size, suggesting that the interventions had a substantial and meaningful impact on performance in the up and go test. Figure 7 shows the specific post hoc comparisons between groups.

There was a significant improvement in Up and Go Test scores from pre- to post-intervention for the TS group ($p < 0.001$, $\eta p^2 = 0.310$), representing a large effect size and indicating a strong enhancement in agility and dynamic balance through team sports. The TS+C group also showed a significant improvement in Up and Go Test scores from pre- to post-intervention ($p < 0.001$, $\eta p^2 = 0.294$), also reflecting a large effect size, suggesting that combining team sports with cognitive training produced substantial functional gains. The A group did not show a statistically significant change ($p = 0.102$, $\eta p^2 = 0.058$), with a small-to-medium effect size, indicating limited improvements from aerobic training alone. In contrast, the A+C group demonstrated a significant improvement ($p < 0.001$, $\eta p^2 = 0.217$), with a large effect size, supporting the efficacy of the combined aerobic and cognitive training approach.

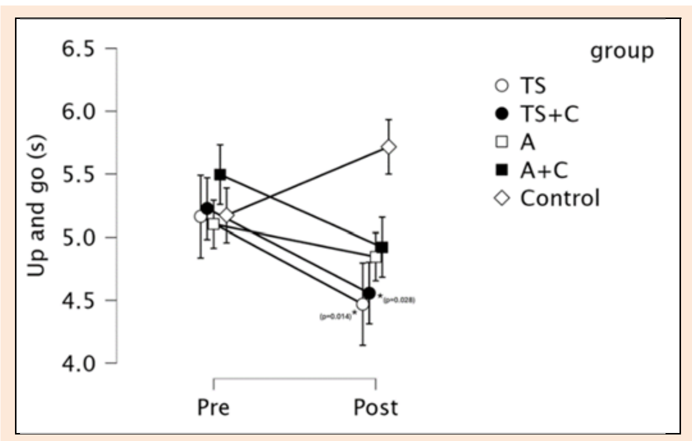

Figure 7. Changes in up and go test scores pre and post-intervention for different groups. TS: team sports; TS+C: team sports + cognitive training; A: aerobic; A+C: aerobic + cognitive training. *: significantly different from the control group ($p < 0.05$).

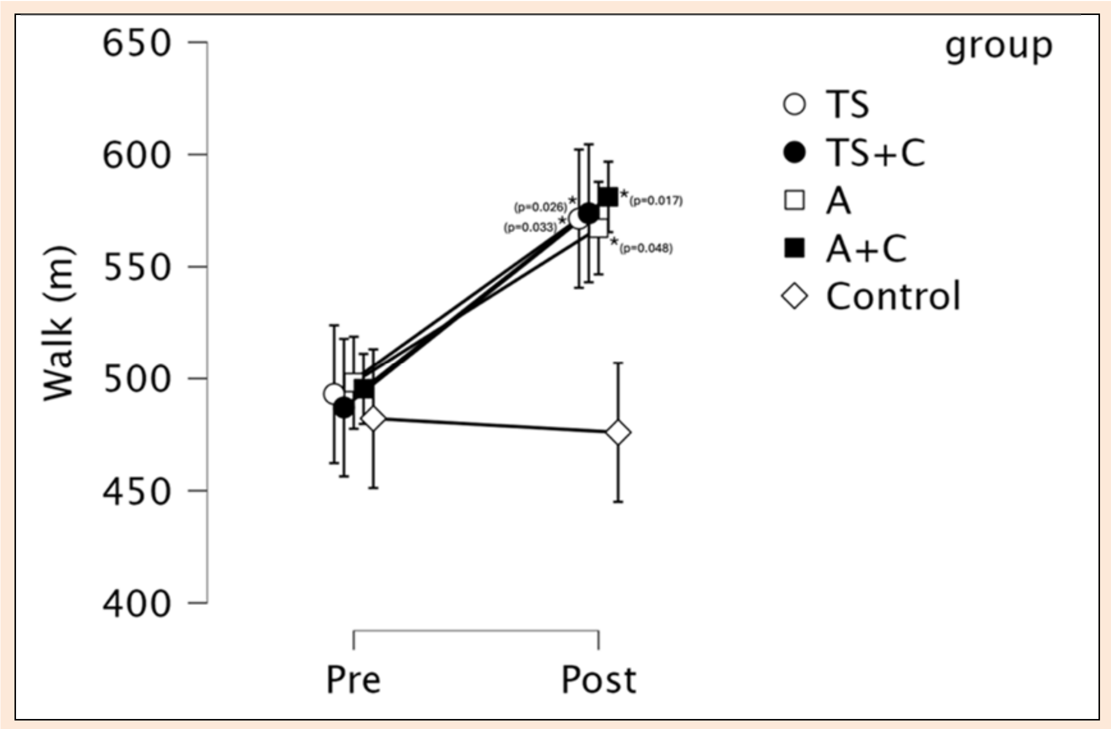

Figure 8. Changes in 6-minute walk test scores pre and post-intervention for different groups. TS: team sports; TS+C: team sports + cognitive training; A: aerobic; A+C: aerobic + cognitive training. *: significantly different from the control group ($p < 0.05$).

Interestingly, the control group also showed a statistically significant change ($p < 0.001$, $\eta p^2 = 0.233$), with a large effect size, however, this finding should be interpreted with caution, as the group did not undergo any structured intervention, and the observed change may reflect uncontrolled external factors or measurement variability.

6-Minute Walk test

At baseline, there was no significant difference in 6-minute walk test scores among the five groups ($F_{(4,45)} = 0.380$, $p = 0.822$, $\eta p^2 = 0.033$), indicating a negligible effect size and similar initial physical endurance across groups. At post-intervention, a significant difference emerged among groups ($F_{(4,45)} = 5.627$, $p = 0.001$, $\eta p^2 = 0.333$), reflecting a large effect size and suggesting meaningful differences in walking endurance attributable to the interventions. The specific post hoc group comparisons are illustrated in Figure 8.

There was a significant improvement in 6-minute walk test scores from pre- to post-intervention for the TS group ($p < 0.001$, $\eta p^2 = 0.693$), both with very large effect sizes, indicating substantial gains in aerobic endurance following team sports-based interventions with or without cognitive components. The A group also showed a significant improvement ($p < 0.001$, $\eta p^2 = 0.340$), corresponding to a large effect size, highlighting the benefits of aerobic training alone. The A+C group demonstrated significant improvement as well ($p < 0.001$, $\eta p^2 = 0.481$), a large effect size, underscoring the effectiveness of combined aerobic and cognitive training. Conversely, the control group did not exhibit significant changes ($p = 0.151$, $\eta p^2 = 0.045$), reflecting a small effect size and suggesting no meaningful improvement without intervention.

Discussion

This study aimed to investigate the impact of a 12-week intervention involving team-based games and aerobic exercise, with and without cognitive stimulation, on slowing down cognitive decline. Results showed significant intervention-related effects on cognitive and physical performance outcomes. A strong interaction between time and group was observed for the MoCA test, chair stand, arm curl, up-and-go, and 6-minute walk tests, indicating that improvements varied meaningfully across the different interventions. Although all intervention groups showed progress over time, the TS and TS+C groups consistently exhibited the largest improvements compared to the control group, particularly in outcomes such as the MoCA, up-and-go, and 6-minute walk tests. Although the TS and TS+C groups generally showed greater improvements across several outcomes, these differences were not consistently statistically significant compared to the A and A+C groups, warranting cautious interpretation of any claims of superiority. While TS-based interventions appeared to offer added benefits relative to the control group, the lack of consistent between-group significance may be partly due to limited statistical power. Notably, large effect sizes were observed in outcomes such as MoCA scores and functional mobility (up and go, walk test), suggesting potential clinical relevance even in the absence of statistically significant differences. Significant time × group interactions were observed for cognitive function, strength, mobility, and walking distance, indicating that the type of intervention influenced these domains. In contrast, flexibility-related outcomes (sit-and-reach and back scratch tests) showed no significant interactions, likely reflecting the absence of targeted stretching or range-of-motion activities in the intervention protocols.

The cognitive benefits observed in the team sports combined with cognitive training (TS+C) group align with growing evidence that physical activity enhances cognitive function in older adults, particularly when combined with cognitive stimulation. This combination appears to amplify gains by targeting executive functions, attention, and memory, supporting neuroplasticity and cognitive reserve. These effects are thought to be mediated by neurobiological mechanisms, including increased levels of brain-derived neurotrophic factor (BDNF), which supports synaptic plasticity and neuronal survival, improved cerebral vascularization enhancing brain perfusion, and reduced chronic inflammation (Kennedy et al., 2016; Nicastri et al., 2022). It also improves cerebral vascularization, enhancing brain perfusion and potentially reducing cognitive decline (Cabral et al., 2019; Chen and Nakagawa, 2023). Additionally, physical activity reduces chronic inflammation, further contributing to better cognitive health in aging (Chen and Nakagawa, 2023; Kennedy et al., 2016). The cognitive benefits are mediated through multiple pathways, including improved cardiovascular function, enhanced insulin sensitivity, and stress reduction (Kennedy et al., 2016). Systematic reviews have shown that aerobic exercise improves cognitive domains such as motor function, cognitive speed, and visual attention (Angevaren et al., 2008), and most studies report a positive relationship between physical activity and cognitive maintenance, including dose-response effects (Carvalho et al., 2014). Similar findings were observed among older Chinese adults (Lü et al., 2016). Moreover, cognitive and physical activities contribute to cognitive reserve through distinct but complementary mechanisms, maintaining brain structure and enhancing neural plasticity, potentially delaying cognitive decline and reducing dementia risk (Cheng, 2016; Hall et al., 2009).

All physical interventions led to improvements in strength, mobility, and aerobic capacity, particularly in the TS and TS+C groups. These results highlight the multifaceted nature of team sports, which engage participants in dynamic and functionally relevant movements. The superior outcomes observed in these groups compared to the aerobic-only group may be attributed to the higher intensity, variety, and social engagement inherent to team-based activities. Research suggests that team sports and resistance training offer significant benefits for older adults, including improvements in physical function, psychological well-being, and quality of life (Pedersen et al., 2017). Team-based activities tend to enhance intrinsic motivation and enjoyment through social interaction, whereas resistance training is often driven by extrinsic health goals (Pedersen et al., 2017). Additionally, participation in such activities has been associated with injury prevention, such as reduced risk of knee injuries and improved Functional Movement Screen (FMS) scores when preventive strategies are employed (Pan, 2023). However, despite overall physical gains, the lack of significant improvement in flexibility suggests this component was insufficiently emphasized in all intervention protocols. Flexibility often requires targeted stretching exercises, such as static or dynamic stretches, which were not a structured part of the interventions. Team sports and aerobic training tend to emphasize gross motor skills and cardiovascular demands, but they rarely include dedicated range-of-motion work. This omission likely limited participants' flexibility gains. Previous research has shown that flexibility improvements typically result from consistent, prolonged stretching routines, which may require specific programming separate from general strength or aerobic training (Nuzzo, 2020).

The superior performance of the TS and TS+C groups underscores the benefits of multicomponent interventions that combine physical, cognitive, and social stimulation. Team sports appear to offer a richer environment for promoting global health in older adults by integrating physical challenges, tactical decision-making, and interpersonal interactions. This multifaceted nature supports not only physical function and cognitive engagement but also social and psychological well-being. Although these aspects were not directly assessed in the present study, previous research indicates that participation in team sports is associated with enhanced social support, a stronger sense of belonging, and improved self-esteem in older adults (Andersen et al., 2019). Moreover, such activities are linked to higher levels of enjoyment and intrinsic motivation compared to resistance training, which tends to be driven more by extrinsic health goals (Pedersen et al., 2017). These factors, while not empirically measured here, may contribute to the greater effectiveness of team-based programs, particularly in terms of long-term adherence and engagement, as suggested by prior findings. While aerobic training is beneficial, its repetitive and less cognitively engaging nature may limit its impact relative to more complex, socially engaging activities. Overall, team sports offer a comprehensive approach to healthy aging, although policy initiatives may be necessary to facilitate and prioritize their implementation among older populations.

These findings have important implications for the design of active aging programs. Incorporating team sports into community-based interventions may enhance adherence while promoting both physical and cognitive benefits, and the addition of structured cognitive exercises can further optimize these outcomes. Health professionals and policymakers should recognize the value of socially interactive, cognitively challenging physical activities as effective strategies to support healthy aging and delay physical or cognitive decline. Future research is needed to explore the long-term effects of combined physical and cognitive interventions using larger and more diverse samples. Such studies should investigate how different components, such as intensity, frequency, duration, and type of cognitive engagement, contribute to specific cognitive and physical outcomes. Additionally, examining individual differences in responsiveness, alongside the roles of social interaction and enjoyment, may help clarify how to best tailor interventions for older adults.

Despite the promising results, several limitations should be considered when interpreting these findings. The relatively small sample size may have limited the statistical power to detect significant differences between intervention groups, particularly in outcomes where trends or large effect sizes were observed but failed to reach significance. As such, some potentially meaningful effects may have been underestimated or missed. The 12-week intervention period, while adequate to initiate improvements, may not have been sufficient to observe the full benefits of multicomponent programs, especially for domains like flexibility or cognitive reserve, which often require longer-term engagement. The absence of follow-up assessments further restricts our ability to determine the sustainability of the observed improvements over time, which is particularly relevant for cognitive and mobility-related outcomes. Thus, while the immediate effects are encouraging, caution is warranted in extrapolating these results to long-term functional or cognitive maintenance. In addition, possible self-selection bias and participant motivation (common in voluntary interventions) may have influenced adherence or responsiveness, especially in socially engaging formats like team sports. These factors may have contributed to the observed benefits in TS-based groups, independent of the intervention itself. Future studies should consider including follow-up evaluations at appropriate time points (such as 6 months post-intervention) to better assess the durability of cognitive and physical benefits. Motivation and self-selection bias may also have influenced the results.

Conclusion

The present study demonstrated that interventions involving team sports, either alone or combined with cognitive training, led to significant improvements in both cognitive performance (MoCA) and physical function (Chair Stand, Arm Curl, Up and Go, 6-Minute Walk Test), when compared to a control group. Although the group engaged in aerobic training also showed improvements, these were of a smaller magnitude. No significant changes were observed in flexibility measures (Back Scratch and Chair Sit and Reach), regardless of the intervention.

Acknowledgements

The authors have no conflict of interest to declare. This study received no specific grants, fellowships, or materials gifts from any funding agency in the public, commercial, or not-for-profit sectors. The datasets generated during and/or analyzed during the current study are not publicly available but are available from the corresponding author who organized the study.

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Key points

- Maximal sprint cycling performance was comparable between the Arm 70% condition and the Leg 70% condition.
- A mild elevation in BLC by arm priming exercise may improve the performance of high-intensity exercise.
- Low (i.e., Arm 20%) and high (i.e., Arm 140%) workloads did not provide any performance benefits.

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