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Effects of aerobic, strength, and combined exercise on cognitive functions in older adults: a systematic review

Efectos del ejercicio aeróbico, de fuerza y ejercicio combinado en las funciones cognitivas de las personas mayores: una revisión sistemática

*Enrique Cerda-Vega, *Catalina Irarrázabal-Guerra, *Leyla Sabja-Sepúlveda, *Nasley Guajardo-Sandoval, *Nicolás Roa-Chiarleoni, **Verónica Morales-Sánchez, **Rafael E. Reigal, *Nuria Pérez-Romero
*Universidad Andrés Bello (Chile), **Universidad de Málaga (España)

Abstract. Introduction: Aging is associated with a decline in cognitive functions, increasing the risk of neurocognitive impairment and limitation of activities of daily living and participation. Previous literature has pointed to physical exercise as an effective intervention; however, its characteristics still need to be specified. Objective: The aim was to synthesize the appropriate intensity, duration, frequency, and type of exercise for different types of cognitive variables. Method: A systematic review was carried out according to PRISMA, using three databases: PubMed, Scopus, and Web of Science. Experimental longitudinal studies were included, whether randomised or not, which performed physical exercise and with a control group in people over 60 years of age. Methodological quality was assessed using the PEDro scale. Results: The results yielded 11 studies finding significant improvements in all of them after performing the intervention (7 of aerobic exercise, 3 of resistance exercise and 2 of combined exercise) finding improvements in attention, memory, processing speed, executive function, inhibition, concentration, perceptual reasoning, orientation, visuospatial perception, and visuomotor organisation. Conclusions: Physical exercise appears to be a beneficial intervention for cognition in older people, with aerobic exercise being the most studied, although further research is needed. The results could benefit decision-making in rehabilitation to work on cognition in cognitively healthy older people.
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Keywords: prevention; aging; cognition; cognitive impairment; rehabilitation.

Resumen. Introducción: El envejecimiento se asocia a un declive de las funciones cognitivas, aumentando el riesgo de deterioro neurocognitivo y la limitación de las actividades de la vida diaria y la participación. La literatura previa ha señalado al ejercicio físico como una intervención eficaz; sin embargo, aún es necesario especificar sus características. Objetivo: El objetivo fue sintetizar la intensidad, duración, frecuencia y tipo de ejercicio adecuados para diferentes tipos de variables cognitivas. Método: Se realizó una revisión sistemática según PRISMA, utilizando tres bases de datos: PubMed, Scopus y Web of Science. Se incluyeron estudios experimentales longitudinales, aleatorizados o no, que realizaban ejercicio físico y con un grupo control en personas mayores de 60 años. La calidad metodológica se evaluó mediante la escala PEDro. Resultados: Los resultados arrojaron 11 estudios encontrando mejoras significativas en todos ellos tras realizar la intervención (7 de ejercicio aeróbico, 3 de ejercicio de resistencia y 2 de ejercicio combinado) encontrando mejoras en atención, memoria, velocidad de procesamiento, función ejecutiva, inhibición, concentración, razonamiento perceptivo, orientación, percepción visuoespacial y organización visomotora. Conclusiones: El ejercicio físico parece ser una intervención beneficiosa para la cognición en personas mayores, siendo el ejercicio aeróbico el más estudiado, aunque se necesita más investigación. Los resultados podrían beneficiar la toma de decisiones en rehabilitación para trabajar sobre la cognición en personas mayores cognitivamente sanas.
PROSPERO ID: CRD42024525008
Palabras clave: prevención; envejecimiento; cognición; deterioro cognitivo; rehabilitación.

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Nuria Pérez-Romero
nuria.perez@unab.cl

Introduction

The ageing is a multidimensional, continuous and natural process that occurs during human life (World Health Organization [WHO], 2022a). In this sense, from the age of 60, biological, social and personal changes occur, initiating what is considered the stage of older adulthood (Murman, 2015; WHO, 2022a). The United Nations have reported that by 2050, the 16% of the people in the world will be over 65 years old, being higher than the current 9%. In addition, 426 million people over 80 years old are projected to increase by 2050 (Department of Economic and Social Affairs, Population Division, 2022). In Chile, according to the National Institute of Statistics (INE) people over 60 years of age are expected to exceed 20% of the total population by 2026, doubling the number of people under 15 years of age. Furthermore, it represents around 32.1%, which means one third of the country indicating a large national ageing (Rojas et al., 2022). Although all people live the ageing process in different ways, with the onset of ageing, older people often experience similar circumstances, such as retirement, moving to a better house and the death of significant others (WHO, 2022b). Thus, there is a decrease in brain volume (Arazi et al., 2021), increased cerebrospinal fluid, focal neuronal loss and non-generalised changes in neuronal arborisation (Salech et al., 2012; Shankar, 2010). Consequently, there is a decrease in the brain-derived neurotrophic factor (BDNF) (Tarassova et al., 2020), which is actively involved in brain plasticity, playing an important role in neuronal proliferation, differentiation and survival (Amagase et al., 2023; Vaynman et al., 2004). In the other hand, at the functional level, there is a deterioration in cognitive functions, a decrease in processing speed, impairment of working memory and reduced motor skills (Burke & Barnes, 2006; Murman, 2015).

Cognitive functions are mental processes essential for everyday life that enable social interactions and information processing, considering the context and one's own experience (Glisky, 2007; Wilson, 2002). These include perception, attention, memory, language and executive functions (Harvey, 2019). Thus, within the functions, they can be categorised into basic and complex processes, with basic processes being responsible for directing, receiving, processing and retaining information and more complex processes such as executive functions, which are responsible for monitoring and regulation during the performance of more complex cognitive tasks (Friedman & Miyake, 2017; Miyake et al., 2000). In adulthood, cognitive functions begin to decline, becoming more pronounced in old age (Salech et al., 2012), affecting people's functional capacity. This can result in difficulties in socialising, lack of energy and autonomy, independence, impairment in activities of daily living (ADLs), social participation as well as in their quality of life (Alvarado García & Salazar Maya, 2014; Zavala et al., 2006) and an increased risk of neurocognitive disorders (Wong et al., 2023). However, it is important to bear in mind that some scientific studies assess the reported cognitive functions globally and not specifically and may show "impure" measures or inferences that cannot be assigned to a specific skill (Bauselas, 2014).

Several factors have allowed physical exercise to be associated not only with physical health (Oliveira et al., 2024; Seok et al., 2024) but also as a protective factor against cognitive decline associated with ageing and neurodegenerative diseases (Kirk-Sanchez & McGough, 2014; Larson et al., 2006). This has been addressed by some studies, explaining both its characteristics and possible mechanisms. A meta-analysis evaluating the effects on general cognition in older people with mild cognitive impairment found that multicomponent (SMD =0.84, 95%CI 0.31 to 1.36, p =0.002), short-duration (SMD =0.83, 95% CI 0.18 to 1.19, p = 0.001), high-intensity (SMD = 0.77, 95% CI 0.18 to 1.36, p = 0.011), high-frequency exercise (SMD = 1.28, 95% CI 0.41 to 2.14, p = 0.004) may be the most effective (Yang et al., 2023). Thus, although some studies found no significant effects on some components such as radial diffusivity (SMD = − 0.26, 95%CI [− 0.84, 0.32], p = 0.126), mean diffusivity (SMD = − 0.29, 95%CI [− 1.07, 0.49], p = 0.463) or hippocampal volume (SMD = 0.25, 95%CI [− 0.10, 0.61], p = 0.164) (Zhang et al., 2024), these physiological mechanisms have been described as an effect of physical exercise in cognition that includes increased cerebral blood flow (Barnes, 2015; Xu et al., 2023), mediation of inflammation, facilitation of synaptogenesis, elevated levels of neurotrophins involved in neurogenesis (Radak et al., 2010), enhanced fractional anisotropy related to the with matter (Zhang et al., 2024) or increased BDNF facilitating brain plasticity (Lu et al., 2023). Consequently, the influence of physical exercise in the prevention of cognitive decline has been demonstrated in previous studies as an improvement in cognitive reserve, allowing compensation of affected functions (Ahlskog et al., 2011; Cheng et al., 2016; Domingos et al., 2021; Lojo-Seoane et al., 2018; Morris et al., 2017; Northey et al., 2018; Sanders et al., 2019). In this sense, physical exercise is understood as a planned, structured and repetitive physical activity performed with a goal in mind, often with the aim of improving or maintaining a person's physical condition (Caspersen et al., 1985; Thompson et al., 2013). Therefore, the types of exercises used in chronic intervention programmes for older people are usually aerobic exercises, strength exercises or a combination of both (Contreras-Osorio et al., 2022; Sanders et al., 2019), however studies reported that aerobic exercises are the most used (Fleg, 2012).

Previous reviews in this area suggest that independent of the modality of the physical training programme, there are significant benefits in cognitive function and neuroplasticity (Bray et al., 2021; Herold et al., 2019; Hortobágyi et al., 2022; Xu et al., 2023; Sanders et al., 2019; Turner et al., 2021; Zhao et al., 2022). These studies include older people with different baseline cognitive states (Coelho-Junior et al., 2020; Zhao et al., 2022; Zhou et al., 2020), with specific pathologies, using brain imaging (Zheng et al., 2019) or assess physiological responses (Herold et al., 2019; Lu et al., 2023). However, most of them do not specify the intensity, duration and frequency of the training programme, as well as the types of cognitive domains, with a predominance of reports on general cognition, which are important aspects to consider for intervention dosing (Kassa & Grace, 2020). For example, Zhou et al. (2020) conducted a systematic review that focused on the older adult population, including aerobic, yoga, Tai Chi, multimodal and elastic band training. It showed statistically significant results associated with language, memory and executive functions; however, the intensity was not specified, there is no specific cognition dimension related to the exercise modality and some of the participants have known mild cognitive impairment. Something similar can be found with the meta-analytical study of Xu et al. (2023) which studied the effect of cognitive function in older adults, but the eligibility criteria was set from 50 years onwards, which could influence the results. In addition, the final analysis of the interventions did not specify exercise intensity, and the criteria included cognitive functions in a general way, in many cases basing their analyses on Mini Mental, as well as physical activity in addition to physical exercise. Due to the above and

considering the benefits of physical exercise for the older adult population, this review seeks to detail the most appropriate dosage in relation to the training modality. Therefore, emphasis will be placed on intensity, because it is associated with markers of neuroplasticity (Hortobágyi et al., 2022) and, in addition, this data could allow the adequacy and individualisation of training associated with various health conditions such as, for example, diagnosis of frailty and sarcopenia in the elderly, both health conditions that could be prescribed at low intensities, in order to provide user safety and avoid complications (Casas Herrero et al., 2015; Font-Jutglà et al., 2020). Therefore, the aim of the study was to determine the effects and characteristics (intensity, duration, frequency and type of exercise) of aerobic, strength and combined exercises on every kind of cognitive ability in healthy older adults.

Method

Search Strategy

A systematic search was conducted according to the international standards of the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) (Page et al., 2021) and was registered in PROSPERO with the ID CRD42024525008. Three databases were used: PubMed, Web of Science and Scopus. The systematic review was carried out with the same words and use of Booleans but different filters depending on each database (Table 1). The words and synonyms were chosen according to the eligibility criteria with two families of words: cognitive functions and physical exercise. Original articles published in databases, which were fully available, were selected. In addition, the bibliographic references in the chosen studies were reviewed to verify the existence of research that could be useful and eligible. The data search was done on 15th April 2024.

Table 1.
Search strategy

Database	Search Strategy
PubMed	(((((Cognition[Title/Abstract]) OR ("Cognitive function"[Title/Abstract])) OR ("Executive function"[Title/Abstract])) OR (Attention[Title/Abstract])) OR (Memory[Title/Abstract])) AND ((((("Exercise"[Title/Abstract]) OR ("Exercise training"[Title/Abstract])) OR ("Physical activity"[Title/Abstract])) OR ("Aerobic exercise"[Title/Abstract])) OR ("Resistance training"[Title/Abstract])) OR ("Physical exercise"[Title/Abstract]))
Scopus	(TITLE (cognition) OR TITLE ("Cognitive function") OR TITLE ("Executive function") OR TITLE (memory) OR TITLE (attention)) AND (TITLE (exercise) OR TITLE ("Physical exercise") OR TITLE ("Exercises training") OR TITLE ("Physical activities") OR TITLE ("Aerobic exercise") OR TITLE ("Resistance training")) AND (EXCLUDE (DOCTYPE , "re") OR LIMIT-TO (DOCTYPE , "ar")) AND (EXCLUDE (EXACTKEYWORD , "Animals") OR EXCLUDE (EXACTKEYWORD , "Cross-sectional Study") OR EXCLUDE (EXACTKEYWORD , "Mice") OR EXCLUDE (EXACTKEYWORD , "Disease Models, Animal") OR EXCLUDE (EXACTKEYWORD , "School Child") OR EXCLUDE (EXACTKEYWORD , "Children") OR EXCLUDE (EXACTKEYWORD , "Young Adult"))
Web of Science	1: TI=(Cognition) 2: TI=("Cognitive function") 3: TI=("Executive function") 4: TI=(Memory) 5: TI=(Attention) 6: #1 OR #2 OR #3 OR #4 OR #5 7: TI=(Exercise) 8: TI=("Physical exercise") 9: TI=("Exercises training") 10: TI=("Physical activities") 11: TI=("Aerobic exercise") 12: TI=("Resistance training") 13: #7 OR #8 OR #9 OR #10 OR #11 OR #12 14: #6 AND #13 15: #6 AND #13 AND Article (Document Types) 16: (#15) NOT TI=("systematic review") 17: (#16) NOT TI=("adolescent*") 18: (#17) NOT TI=("child*") 19: (#18) NOT TI=("meta analysis") 20: (#19) NOT TI=(mice) 21: (#20) NOT TI=(animal*) 22: (#21) NOT TI=(dementia)

Note: date of the search April, 15th, 2024.

Eligibility criteria

Eligibility criteria were selected according to the PICOS methodology detailing population (P), interventions (I), comparisons (C), outcomes (O) and study design (S), as shown in Table 2. Mainly, studies reporting pre- and post-intervention data were included to understand the effects of different types of exercise (aerobic, strength and combined) on cognitive functions. Table 2 specifies each of the eligibility criteria, both inclusion and exclusion. Articles were included if they were at least 4 weeks of intervention. The type of study selected included only experimental studies longer than four weeks and no maximum duration. Cohort studies were not considered due to their observational nature. However, all studies that included a detailed longitudinal intervention without restriction by long duration, whether randomized or not, were considered.

Table 2.
PICOS eligibility criteria.

PICOS	Inclusion criteria	Exclusion criteria
1. Population	1.1. Healthy older adults 1.2. Men or women 1.3. Over 60 years	1.1. Who have a diagnosis of a known neurocognitive disorder such as Alzheimer's disease. 1.2. Who have pathologies that do not allow them to exercise.
2. Intervention	2.1. Aerobic, strength or combined (strength and aerobic) exercise. 2.2. Duration of the intervention (>4 weeks).	2.1. Exercises focused on sports (Competitive) or other training modalities other than aerobic, strength or combined exercises.
3. Comparator	3.1. Group of older adults without recognised neurocognitive disorder, who do not perform physical exercise.	3.1. No control group.
4. Outcome	4.1. Effects on cognitive variables of attention, memory, executive function, perceptual reasoning, processing speed, visual-spatial perception, orientation, concentration and visual-motor organisation.	4.1. Measurements with non-standardised and non-validated instruments. 4.2. Indirect assessments (e.g. through the caregiver). 4.3. Studies that do not provide sufficient data to differentiate according to cognitive variable (e.g. screenings that do not show their subtests).
5. Study type	5.1 Longitudinal experimental studies (randomised or non-randomised).	5.1 Any other type of study.

Data collection process

The literature found was ordered using two bibliographic reference managers, EndNote 20 and Mendeley. First, the duplicates were removed, and the remaining duplicates were also manually checked to remove them. This was done equally by each of the authors, dividing the list of documents generated, in alphabetical order. Then, the titles and abstracts of all other studies were screened for inclusion. It was independently reviewed four authors (C. I.-G., L. S.-S., N. G.-S. and N. R.-C.).

This was followed by a further cross-check (C. I.-G., L. S.-S., N. G.-S. and N. R.-C.). Finally, the whole team carried out an analysis to verify the work and in case of discrepancy, a consensus was discussed and reached at group level. The team applied the PRISMA flowchart (Page et al., 2021), to track and credit the file selection process. Then, two authors reviewed all the process (N. P.-R. and E. C.-V.).

Data extraction

Data extraction was performed by the authors (C. I.-G., L. S.-S., N. G.-S. and N. R.-C.) and subsequently reviewed by other two authors (N. P.-R. and E. C.-V.). The data extracted were year of publication, author, sample size and participant characteristics specifically gender, age, physical condition and comorbidities. Also, the description of the physical training programme (i.e. type of exercise), weekly frequency, duration of the intervention (in weeks), session duration (in minutes) and intensity, dimensions of the domains of cognition that were assessed (attention, memory and/or executive function) and tasks or scales used. Finally, data were extracted and synthesised in a Microsoft Excel 2021 spreadsheet and subsequently reported using self-made tables.

Risk of bias assessment

The incorporated studies were individually assessed for their risk of bias by four authors (C. I.-G., L. S.-S., N. G.-S. and N. R.-C.) and subsequently reviewed by other two authors (N. P.-R. and E. C.-V.). The review was conducted using the Physiotherapy Evidence Database (PEDro) scale, which contains 11 criteria (Elkins et al., 2013). The first item is not quantified but must be considered. The remaining items awards 1 point for each criterion met (Gómez-Conesa et al., 2015) and the resulting score for each study was interpreted according to: ≤ 3 points: 'poor' quality, 4 to 5 points: 'moderate' quality and 6 to 10 points: 'high' quality (Paci et al., 2022; Ramírez-Campillo et al., 2020; Contreras-Osorio et al., 2022). However, this assessment was reported to provide more information, and no studies were eliminated for methodological quality criteria.

Results

A total of 4317 articles (1046 from Pubmed; 1381 from Web of Science and 1890 from Scopus). Subsequently, a total of 976 duplicates (966 in Mendeley reference manager and 10 in Endnote 20) were removed. A total of 3031 were excluded by title and abstract. Then, after reading the full text, studies were excluded for not reporting training intensity (n = 111), for using mainly self-report questionnaires (n = 90), and for not having a control group (n = 98). Therefore, after analysis, a total of 11 articles were included for this systematic review as they met the established inclusion criteria. In total, there was 282 participants in experimental groups and 354 participants in control groups.

2024, Retos, 60, 1341-1355

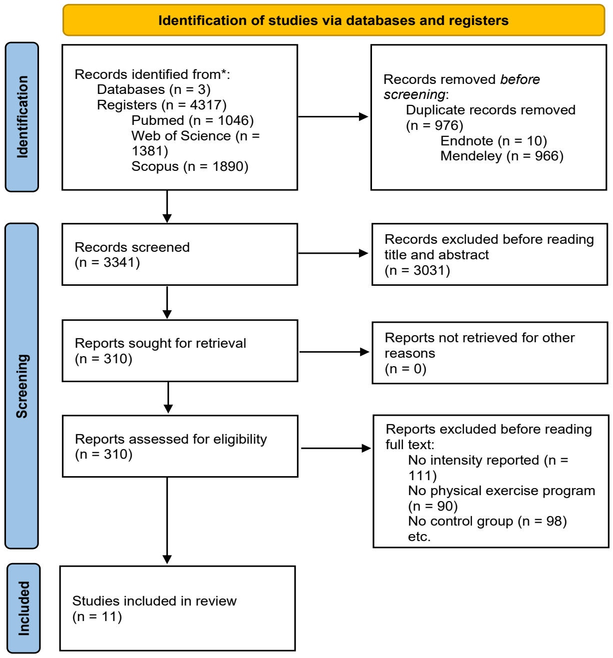

Figure 1. PRISMA flujogram.

The interventions were performed in an older adult population aged 60 to 90 years, male and female, with no known cognitive impairment. The total duration of the workouts ranged from 3 months to 1 year, from 20 to 90 minutes per session. None of the articles specified any type of comorbidity.

Risk of bias

After analysis of risk of bias using the PEDro scale a total of 11 studies were analysed. The results of the scores for each item are displayed in table 3.

Table 3.
PEDro Scale results.

Studies	1	2	3	4	5	6	7	8	9	10	11	TOTAL
Alghadir et al. (2016)	1	0	0	1	0	0	0	1	1	1	1	5
Antunes et al. (2015)	1	0	0	1	0	0	0	1	1	1	1	5
Brown et al. (2021)	1	0	0	1	0	0	0	1	1	1	1	5
Albinet et al. (2010)	1	1	1	1	0	0	0	1	1	1	1	7
Albinet et al. (2016)	1	1	1	1	0	0	0	1	1	1	1	7
Coelho-Junior et al. (2020)	1	1	1	1	1	0	0	1	1	1	1	8
Furlano et al. (2023)	1	1	0	1	0	0	0	1	1	1	1	6
Jonasson et al. (2017)	1	1	1	1	1	0	0	1	1	1	1	8
Nagamatsu et al. (2013)	1	1	1	1	0	0	0	1	1	1	1	7
Napoli et al. (2014)	1	1	1	1	0	0	0	1	1	1	1	7
Vedovelli et al. (2017)	1	0	0	1	0	0	0	1	1	1	1	5

Note: PEDro: Physiotherapy Evidence Database scale.

Aerobic exercise

Seven studies were found according to inclusion and exclusion criteria with a total sample of 420 participants of which 176 were men and 244 were women. In addition, 229 individuals comprised experimental groups (EG) and 191 control groups (CG) (Table 4).

The total duration of the training programs was from 3 to 6 months with a frequency of 2 to 3 days per week for 30-60 minutes. The intensity of four studies was determined by reserve heart rate (HRR) ranging from 40%-80%, one study with maximum heart rate between 40%-85%, one study with perceived exertion/Borg index between 13-18 and finally one study used an intensity according to anaerobic or lactic threshold. The results of the present systematic review regarding the impact of aerobic exercise on attention involved four studies (Alghadir et al., 2016; Albinet et al., 2016; Antunes et al., 2015; Jonasson et al., 2017) in which statistically significant improvements were obtained in the experimental groups of the studies involved, giving to highlight the study of Alghadir et al. (2016) where a significant improvement was reflected in the CG ($p \leq .05$) but very significant in the GE ($p \leq .01$).

Immediate memory involved two studies evaluated with the tests (Jonasson et al., 2017; Antunes et al., 2015). Unfortunately, in the study by Jonasson et al. (2017), the result of each test is not specified in detail, however, it delivers the values at the general level of immediate memory where the EG obtained a significant improvement in contrast to the GC (Jonasson et al., 2017). On the other hand, one study indicates that there was a significant difference comparing both groups, where again the EG had a statistically improvement compared to the CG (Antunes et al., 2015).

Five studies were involved in the executive functions (Brown et al., 2021; Albinet et al., 2010; 2016; Antunes et al., 2015; Jonasson et al., 2017) in which significant improvements in the GE were obtained. It is noteworthy in the study of Brown et al. (2021) in which only within the high intensity group there was a significant improvement ($p \leq .05$) of this cognitive variable associated with changes in cardiorespiratory fitness. On working memory two studies were involved (Albinet et al., 2016; Jonasson et al., 2017) where some improvements were obtained in the CG being in the EG where the significant improvements were obtained ($p \leq .05$).

In processing speed, it was found that two studies evaluated this variable (Antunes et al., 2015; Jonasson et al., 2017) where both studies obtained a significant improvement in EG ($p \leq .05$) compared to the CG being lower its change. For inhibition, two studies were found evaluating this variable (Jonasson et al., 2017) where very significant improvements in EG were found ($p \leq .01$) and other (Nagamatsu et al., 2013) in which significant differences were found GE of aerobic exercise ($p \leq .05$).

Table 4.
Characteristics of aerobic exercise studies.

Reference	Sample; country	Age (M±SD)	Gender M/W	EG	CG	Cognitive baseline	Cognitive variables, instruments and results
Alghadir et al., 2016	100; CG: 50 EG: 50; Arabia	CG: 67.3 ± 2.8 EG: 66.8 ± 3.7	CG: 30/20 EG: 35/15	F: 3 t/w I: 60-70%, 45-60 min. T: 5.5 months T: Treadmill	No exercise	LOTCA CG:97.8 ± 7.91 EG:86.6 ± 8.24	LOTCA: Attention: CG (Pre: 3.7 ± 0.51- Post: 3.9 ± 0.18 *), EG (Pre: 2.1 ± 0.31- Post: 5.3 ± 0.45**) Concentration: CG (Pre: 3.7 ± 0.51 – Post: 3.9 ± 0.18*). EG (Pre: 2.1 ± 0.31 – Post: 5.3 ± 0.45**) Perceptual reasoning: CG (Pre: 23.7 ± 3.7 – Post: 26.8 ± 2.95*), EG (Pre: 9.6 ± 2.65 – Post: 315 ± 2.6**) Orientation: CG (Pre:12.8 ± 1.8 - Post:16.7 ± 2.5*), EG (Pre:9.0 ± 2.3- Post: 21.8 ± 0.5**) Visual perception: CG (Pre:18.2 ± 2.9- Post:21 ± 0.98*) EG (Pre:11.3 ± 2.5- Post:18.1 ± 1.9**) Spatial perception: CG (Pre:10.5 ± 0.4- Post:13.5 ± 0.4*), EG (Pre:9.5 ± 2.1- Post:21.13 ± 0.91**) Visomotor organization: CG (Pre: 23.7 ± 3.7- Post:26.8 ± 2.95*) EG (Pre:9.6 ± 2.65- Post:315 ± 2.6**)
Antunes et al., 2015	45; CG: 23 EG: 22 Brazil	CG: 66.00 ± 3.84 EG: 68.09 ± 5.49	CG: 23/0 EG: 22/0	F: 3 t/w I: According to anaerobic threshold, initial duration 20 min gradually increased to a maximum of 60 min. T: 6 months T: Cycle ergometer	No exercise	Not reported	WAIS-IV Digit Span Numbers forward: attention, short term memory, CG (Pre:5.73 ± 2.31 - Post:5.64 ± 2.04), EG (Pre:5.57 ± 1.93 - Post:7.26 ± 1.66). Digit Symbol: Processing speed CG (pre: 36.41 ± 18.59 – post: 29.64 ± 8.00), EG (pre: 32.48 ± 11.21 - post:38.87 ± 8.03*). Block Design: perceptual reasoning EG (pre: 17.91 ± 12.66 – post: 23.83 ± 9.61*), CG (pre:18.32 ± 7.43 – post: 18.82 ± 5.59). Rey-Osterrieth Complex Figure short term memory, CG (Immediate withdrawal Pre: 11.68 ± 6.9- Post: 13.0 ± 7.4) GE (Significant immediate withdrawal Pre: 14.50 ± 7.61- Post: 16.33 ± 7.01*) Wisconsin Card Sorting Test: Executive Function, GE (Attempts Pre: 64.39 ± 2.44 - Post: 88.74 ± 13.69*, Errors Pre: 59.83 ± 22.72 - Post: 39.26 ± 13.69*, Complete categories Pre: 4.09 ± 2.48- Post: 6.35 ± 2.27*) GC (Attempts Pre: 67.09 ± 17.10 - Post: 69.59 ± 16.19, Errors Pre: 61.05 ± 18.38 - Post: 58.41 ± 16.19, Complete categories Pre: 3.59 ± 2.13- Post: 3.77 ± 1.97) Toulouse-Piéron Test: Attention and concentration CG (cancellations pre: 91.95 ± 33.10 – post: 83.68 ± 27.23), GE (cancellations pre: 77.70 ± 25.70 – post: 99.43 ± 31.91*)
Brown et al., 2021	99; CG:32 EG 1: 34 EG 2: 33 Australia and New Zeland	GC: 68.7 ± 5.9 EG1: 68.4 ± 4.2 EG2: 70.2 ± 5.3	CG: 13/19 EG1: 16/18 EG2: 16/17	EG 1: F: 2 t/w, I: Continuous pedalling effort 13 (50-60%) for 50 min, T: 6 months EG 2: Warm up and warm out 10 min. pedalled effort 11 (30-40% aerobic capacity), F: 2 t/w, I: 11 cycle ergometer intervals 1-minute-high effort (>80%; Borg scale 18.0) interspersed with 2 minutes active recovery (30-40%; scale of Borg 12.0) for 50 min. T: 6 months T: Cycle ergometer	An information session on the benefits of exercise for physical and brain health. No exercise instruction.	MoCA CG: 26.7 ± 2.0 EG1: 26.4 ± 2.8 EG2: 26.0 ± 2.1	Trails B, Flanker y Set-shifting task: Executive function. Does not specify results according to test. GE (Pre 0.17 - 0.30), GC (Pre 0.13 – Post 0.18). (shift:13.89**)

Note: CG: control group; EG: experimental group; F: frequency; I: intensity; T: time; t/w: times a week; LOTCA: Loewenstein Occupational Therapy Cognitive Assessment Battery; M ± SD: Mean ± Standard Deviation; M/W: Men/Women; min: minutes; MoCA: Montreal Cognitive Assessment; MMSE: Mini-Mental State Examination; WAIS-IV: Wechsler Intelligence Scale for Adults-IV.

Table 4.
Characteristics of aerobic exercise studies (continued).

Reference	Sample and country	Age (M±SD)	Gender M/W	EG	CG	Cognitive baseline	Cognitive variables, instruments and results
Albinet et al., 2016	36; CG: 17 EG: 19 France	CG: 66 ± 5 EG: 67 ± 5	CG: 4/13 EG: 6/13	EG: F: 2 t/w, I: Individualized to gradually increase from 40 to 65% of the RHR (moderate to vigorous intensity), using the Karvonen formula for 40 min, T: approximately 5 months, T: Swimming	Stretching program: Consisted of balance control exercises, inter-segmental coordination exercises and whole body stretches	MMSE CG: 28.74 ± 1.50 EG: 29.11 ± 1.05	Stroop task: attention and executive function, CG (pre 50.6 ± 9.6 – post 49.9 ± 9.8), EG (pre 49.6 ± 6.8 – post 45.4 ± 8.3) Verbal Running Span: working memory, CG (pre-32 ± 7.4 – post 34.3 ± 9.5), EG (pre 32.4 ± 7.5 – post 37.8 ± 7.8) Spatial Running Span: working memory, CG (pre 23.8 ± 12.1 – post 23.4 ± 12), EG (pre 24.5 ± 10.2 – post 26.6 ± 7.7) 2-back task: working memory, CG (pre 24.2 ± 2.3 – post 25.4 ± 2.2), EG (pre 23.8 ± 2- post 23.9 ± 2.5) Plus–Minus task: executive function, CG (pre 37.2 ± 18.8 – post 25.5 ± 16.3), EG (pre 37.4 ± 26.4 – post 24.9 ± 19.5) Dimension-switching task: executive function. CG (pre 45 ± 106 – post 101 ± 100), EG (pre 97 ± 119 – post 120 ± 59)
Jonasson et al., 2017	58; CG: 29 EG: 29 Sweden	CG: 68.97 ± 2.91 EG: 68.40 ± 2.54	CG: 0/29 EG: 0/29	F: 3 t/w, I: 40-80% HR max, 30-60 min. per session, T: 6 months, T: Stationary bike, elliptical bike or jogging on an athletic track	Stretching and toning to improve strength, flexibility and balance. NOT DOSED	MMSE CG: 29.46 ± 0.64 EG: 28.96 ± 1.16	Word recognition test, Free recall task, Paired associates task: memory, CG (pre 0.22 ± 0.87 – post 0.17 ± 1.02), EG (pre −0.17 ± 0.50 – post 0.08 ± 0.86) Trail making task 2 and 3, Digit-symbol task, Letter comparison: processing speed, CG (pre 0.12 ± 0.99 – post 0.05 ± 1.04), EG (pre 0.08 ± 0.61 – post 0.37 ± 0.47) Automated operation span: executive function Backward digit span: working memory Flanker task: inhibition CG (pre −0.06 ± 0.89 – post 0.16 ± 0.91), EG (pre 0.07 ± 0.71 – post 0.50 ± 0.76)
Albinet et al., 2010	24; CG: 12 EG: 12 France	CG: 70.4±3.4 EG:70.9±4.9	CG: 5/7 EG: 6/6	F: 3 t/w, I: Individualized gradually increasing from 40 to 60% FCR (HRR) + (resting HR) between sessions for 40 min. active (1 hour per session), T: 3 months, T: Gradual walk and run	Stretches	MMSE CG: 29±0.9 EG: 28.5±1.1	Wisconsin Card Sorting Test (WCST): executive function, EG (Errors: Pre:34.5 ± 17.8, Post:26,9±17.6) *, CG (Pre: 25.4 ± 15.1, Post:28.9 ± 15.7)
Nagamatsu et al., 2013	86; CG: 28 EG1: 30 EG2: 28 Canada	CG: 75.1 ± 3.6 EG1: 75.6 ± 3.6 EG2: 73.9 ± 3.4	CG: 0/28 EG1: 0/30 EG2: 0/28	F: 2 t/w, I: 40% - 80%RHR, 60 min. T: 6 months, T: Progressive walking	Balance and tone (stretches and full range of motion, sand relaxation)	MOCA CG: 22.5 ± 2.8 EG1: 22.2 ± 2.8 EG2: 21.4 ± 3.4	Rey Auditory Verbal Learning Test (RAVLT): inhibition, CG (pre 41.00 (8.63) – post 43.00 (9.61)), EG 1(pre 40.88 (8.36) – post 44.36 (11.29)), EG 2 (pre 39.58 (9.04) – post 43.38 (10.95)))

Note: CG: control group; EG: experimental group; F: frequency; I: intensity; T: time; t/w: times a week; LOTCA: Loewenstein Occupational Therapy Cognitive Assessment Battery; M ± SD: Mean ± Standard Deviation; M/W: Men/Women; min: minutes; MoCA: Montreal Cognitive Assessment; MMSE: Mini-Mental State Examination; WAIS-IV: Wechsler Intelligence Scale for Adults-IV.

In the concentration variable, there were 2 studies which used tests to measure this variable, Antunes et al. (2015) where significant improvements were found in the GE ($p \leq .05$) versus the CG and other study Alghadir et al. (2016), find a significant improvement in the CG ($p \leq .05$) but a very significant improvement in the GE ($p \leq .01$). For perceptual reasoning, 2 studies were found. One of them Antunes et al. (2015) which obtained a significant improvement in the GE ($p \leq .05$) compared to the CG, and other Alghadir et al. (2016) finding a very significant improvement in the EG ($p \leq .01$) than in the CG. Finally, the remaining variables of orientation, visual-spatial perception and visuomotor organization obtained a highly significant improvement ($p \leq .01$) as did the others mentioned above.

Strength exercise

There were 3 studies included, with a total sample of 166 participants, of which EG was 109 and GC was 57. Of the total sample, 144 persons belonged to the female sex and 22 to the male sex. Regarding the frequency, intensity, time and type (FITT) principle, the total duration of the training programs ranged from 4 to 6 months, with a frequency of 3 days per week, with the exception of Coelho-Junior et al. (2020) who only refer that the training was performed in the mornings from 8:00 to 12:00. The intensity used for strength exercise ranged from 70-80% 1RM (Table 5).

In Coelho-Junior et al. (2020) study, an exercise program was carried out with two experimental groups, which performed strength exercises at the same intensity with the difference that EG1 or low speed resistance training group performed a lower number of sets with a higher number of repetitions, on the contrary GE2 or high-speed resistance training group performed a higher number of sets with fewer repetitions. As for the main findings we have that both experimental groups (EG1 and EG2) presented an evident improvement compared to the control group (CG) that performed flexibility. However, the EG2 group improved significantly in the test in comparison to EG1 and CG (Coelho-Junior et al., 2020), as an observation it should be noted that other values than GE2 were not specified. Another study presented a significant improvement in the CG in contrast to the EG (Furlano et al., 2023). However, in the third study found there was no significant difference (Nagamatsu et al., 2013).

In working memory, an improvement was found in the CG that worked on tone and balance (Furlano et al., 2023). In processing speed the EG had a significant improvement over the control group (GC) (Furlano et al., 2023). Finally, in selective attention both groups had comparable improvements in selective attention and midpoint response inhibition relative to baseline, however, it was the EG who had significant results at the end of the study (Furlano et al., 2023).

Table 5.
Characteristics of strength exercise studies.

Reference	Sample and country	Age (M±SD)	Gender M/W	EG	CG	Cognitive baseline	Cognitive variables, instruments and results
Furlano et al., 2023	20; CG: 10 EG: 10 Canada	68.7 ± 5.7	10/10	F: 3 t/w. I: 2 sets of 6 to 8 repetitions incrementally, so that all participants reached 80% of 1 RM T: 6 months T: Weightlifting	Exercises including stretching, range of motion exercises, core strength exercises, balance exercises and relaxation techniques; only body weight will be applied	Not reported	Rey Auditory Verbal Learning Test (RAVLT): Long-term auditory-verbal memory EG pre: 7.0 – post: 9,0), CG (pre: 7.0 – post: 12.5 Digit Span Test: working memory EG pre: 1.9 – post: 1.0, CG pre: 2.5 – post: 3.5 Trail Making Test A (TMT): processing speed EG 33.7 – post: 23.1, CG pre: 40.9 – post: 41.5 STROOP test: selective attention EG pre: 44.1 – post: 36.9, CG pre: 52.4 – post: 41.6
Coelho-Junior et al., 2020	60; CG: 19 (pre fragile 10 and fragile 09) EG1: 19 (pre fragile 11 and fragile 08) EG2: 22 (pre-fragile 11 and fragile 11) Brazil	Pre fragile CG: 65 ± 3.5 EG1: 65 ± 3.5 EG2: 65 ± 2.8 Fragile CG: 75.0 ± 9.2 EG1: 75 ± 4.6 EG2: 73 ± 7.5	Pre fragile CG: 0/10 EG1: 2/9 EG2: 0/11 Fragile CG: 3/6 EG1: 2/6 EG2: 5/6	F: in the mornings 8am to 12pm I: EG1: 4 sets of 8 to 10 repetitions at 70-75% of 1 (1RM). The concentric and eccentric phases were carried out for approximately 2.5 seconds EG2: 8 sets, 3 to 5 repetitions at 70-75% 1RM. The eccentric phase was carried out for approximately 2.5 seconds T: 4 months T: Exercises for lower limbs with weight	Flexibility sessions	MMSE Pre fragile CG: 23.4 ± 1.5 EG1: 24.3 ± 1.9 EG2: 23.2 ± 1.8 fragile CG: 16.0 ± 2.0 EG1: 13.8 ± 3.7 EG2: 15.6 ± 4.5 Pre fragile CG: 2.0 ± 0.7 EG1: 1.6 ± 0.8 EG2: 1.6 ± 0.7 Fragile CG: 4.4 ± 1.4 EG1: 5.5 ± 1.4 EG2: 5.5 ± 1.3	Rey Auditory Verbal Learning Test (RAVLT): Long-term auditory-verbal memory EG1 presents a significant improvement (p = 0.01) STROOP TEST: attention did not show changes It is important to mention that the study did not contain the results quantitatively, but rather, it was done graphically.
Nagamatsu et al., 2013	86; CG: 28 EG1: 30 EG2: 28 Canada	CG: 75.1 ± 3.6 EG1: 75.6 ± 3.6 EG2: 73.9 ± 3.4	CG: 0/28 EG1: 0/30 EG2: 0/28	F:2 t/w. I: 7RM method, 2 sets of 6-8 repetitions T: 6 and a half months	Balance and tone (stretch and movements throughout the range of motion, sand relaxation)	MOCA CG: 22.5 ± 2.8 EG1: 22.2 ± 2.8 EG2: 21.4 ± 3.4	Rey Auditory Verbal Learning Test (RAVLT): inhibition, CG pre 41.00 ± 8.63 – post 43.00 ± 9.61, EG1pre 40.88 ± 8.36 – post 44.36 ± 11.29, EG2 pre 39.58 ± 9.04 – post 43.38 ± 10.95

2024, Retos, 60, 1341-1355

T: Both a Keizer pressurized air system and free weights were used

Combined exercise

Two studies were included (table 6), with a total sample of 136 participants, of which GE was 74 and CG was 62. Of the total sample, 96 persons belonged to the female sex and 40 to the male sex. Regarding the FITT method, the total duration of the training programs ranged from 3 months to 1 year, with a frequency of 3 days per week, for 60-90 min. The intensity used for aerobic exercise ranged between 65-85% HR max, with respect to the intensity of strength exercise, it ranged between 50-80% 1RM. Regarding cognitive variables, one study reports significant improvements in EG in domains of attention, immediate memory, delayed memory, working memory, processing speed and executive function with a 3-month training (Vedovelli et al, 2017). In contrast, one article reports no significant improvements in EG of executive function, in turn, reports significant EG improvements in global cognition, this is a training period of 1 year (Napoli et al., 2014).

Table 6.
Characteristics of combined exercise studies.

Reference	Sample and country	Age (M±SD)	Gender M/W	EG	CG	Cognitive baseline	Cognitive variables, instruments and results
Vedovelli et al., 2017	29; CG: 9 EG: 20 Brazil	CG: 77.33 ± 9.89 EG: 83.00 ± 6.53	CG: 0/9 EG: 0/20	Strength: F: 3 t/w I: 50-75%1RM, 60 min. T: 3 months T: resistance bands Aerobic: F: 3 t/w I: 75-85% max HR 60min. T: 3 months T: Not specified	Maintain their usual activities and refrain from any physical exercise program	MMSE CG: 24.77 ± 3.95 EG: 24.10 ± 3.30	Backward Digit Span Test: Working Memory [F (2.38) = 3.994, η 2 ρ = 0.174, p = 0.027] Trail Making Test A and B: Processing speed, executive function and visuospatial ability Trail Making A [F (2.38) = 6.627, η 2 ρ = 0.241, p = 0.003] and Trail Making B [F (2.38) = 6.627, η 2 ρ = 0.241, p = 0.037] Logical memory test I: immediate memory [F (2,38) = 10.797, η 2 ρ = 0.238, p < 0.001] Logical memory II: delay memory [F (2.38) = 7.507, η 2 ρ = 0.320, p = 0.003] Stroop: attention [F (2.38) = 8.332, η 2 ρ = 0.149, p = 0.002]
Napoli et al., 2014	107; CG: 27 EG1: 26 EG2: 26 EG3: 28 United States	CG: 69 ± 4 EG1: 70 ± 4 EG2: 70 ± 4 EG3: 70 ± 4	CG: 9/18 EG1: 9/17 EG2: 10/16 EG3: 12/16	Strength: F: 3t/w. I: 65-80% 1RM, 30min. T: 1 year T: weightlifting machines Aerobic: F: 3 t/w I: 65 - 85% HR max, 30 min T: 1 year T: Not specified	General nutrition recommendations, prohibition of physical exercise	3MS (Minimental modified) CG: 96.3 ± 0.8 EG3: 94.9 ± 0.9	A non-significant improvement was reported in EG: Trail Making Test A: processing speed and visuospatial ability, trail making test A [-6.6 (-14.1, 0.8) p = 0.08] Trail Making Test B: executive function [-12.6 (- 31.2, 5.9) p = 0.18]. A significant improvement is reported in EG: MMSE: Global cognition: [3.0 (1.5, 4.4) p = 0.0001]

Discussion

The objective of the present review was to determine the effects and characteristics (intensity, duration, frequency and type of exercise) of aerobic, strength and combined exercises on every kind of cognitive ability in healthy older adults, finding that each exercise improvements in cognitive domain could be found depending on the tests applied by the authors.

First, all studies analyzed for aerobic exercise showed improvements in the experimental group and found no improvements in the control group, except one of them (Alghadir et al., 2016). However, in this study, when analyzing the characteristics of the sample, it was observed that the control group was physically more active than the experimental group. This could indicate that it is not only important to analyze the type of exercise, but also the level of physical activity of the person. This could be related to Brown et al. (2021) who found that changes in cardiorespiratory fitness were associated with cognitive changes before and after the intervention. Moreover, it is congruent with Antunes et al. (2015) who found cognitive improvements in relation to the applied tests as well as cardiorespiratory improvements during the intervention, mostly in the experimental group compared to the control group. In strength exercise, the experimental groups had significant improvements compared to the control groups, except for one study (Furlano et al., 2023), where the control group had significant improvements in the cognitive variable of memory, while the changes in the experimental group were not relevant. This detail is quite interesting, because the control group worked more thoroughly than the other control groups on strength, with relaxation techniques in addition to the flexibility, tone and balance exercises, which may have influenced the results. However, it is necessary to consider that the participants were randomly selected for each group and had health conditions with different severity (overweight, obesity and prediabetes), which may impact the effects of the training plan. In accordance with Domínguez et al. (2016) the adaptations produced by strength exercise will impact differently in each person and according to their health condition. Although, it is evident that memory had no significant changes, the relevance of the results in processing speed, attention and executive function should be not discarded. Also, Furlano et al. (2023) mentioned that a possible explanation is the potential use of higher order cognitive functions to perform strength training (e.g., learning new equipment, using attention, concentration during movements) can strengthen the capacity of executive function itself, rather than memory. On the other hand, another previous study (Liu-Ambrose et al., 2010) mentioned that cognitive outcomes of performed interventions suggest that strength training may benefit certain cognitive domains over others in older people, which turns out to make sense with the findings. In the 3 studies it is important to highlight that both, the control, and experimental groups, did not perform exercise outside the indicated training and, to be included, they should not have performed an aerobic or strength training plan in the last 6 months. On the other hand, in the study by Coelho-Junior et al. (2020) it is necessary to mention that there were 2 experimental groups where the participants were elderly people who were pre-fragile and fragile.

Regarding combined type exercise, the studies reveal an intervention with a duration of 3 months to 1 year, but the optimal training duration cannot be determined, since the results reported from both studies are opposite and therefore, not congruent regarding their effectiveness. Finally, in the intervention characteristics, it seems that longer interventions could report greater changes since, they report better results in both control and experimental groups. For example, in the study by Albinet et al. (2016) cognitive improvements for the Stroop and Verbal Running Span task were significant after 21 weeks of aerobic training, but not after a 10-week period. Furthermore, most of the interventions have a frequency of 3 times per week with a duration time of 6 months. However, this periodization does not necessarily suggest that it is the optimal one to find cognitive improvements, since improvements are evidenced in all the studies described above ranging from 3 to 6 months and from 2 to 3 times per week. In relation to intensity, improvements were found in all studies, but those that progressively increased the intensity from the beginning to the end of the intervention obtained more significant improvements in the experimental group (Albinet et al., 2016; Alghadir et al., 2016; Coelho-Junior et al., 2020; Furlano et al., 2023; Garber et al., 2011). However, one study (Nagamatsu et al., 2013) did not refer to a specific intensity percentage within its randomized clinical trial (RCT), which highlight the importance of exercise dosage according to the FITT principle to effectively establish the parameters in which strength training would generate beneficial results on the different cognitive variables. Regarding the intensity reported by the aerobic and strength studies, it was moderate to vigorous incrementally (Garber et al., 2011). Likewise, in previous literature a study, in people above 55 years, reported improvements in cognitive level at a moderate intensity and shows that physical exercise has effects on executive function (Chen et al., 2020). Regarding the FITT principle, studies performed a weekly frequency of 3 times a week with a duration of 60 to 90 minutes. Similarly, in a previous study, improvements in cognition are reported globally in people with and without cognitive impairment, in a combined training, over 65 years, with a weekly frequency is mostly 3 times a week, for 25 to 90 minutes (Heyn et al., 2008). Also, consider these parameters could be important because a study in healthy older adults showed that, regardless of training modality (combined, aerobic, resistance), there were effects on memory and executive function that were related more to training frequency than to training intensity (Sanders et al., 2019).

Limitations, practical relevance, and future lines of research

However, the results should be taken with caution due to the limited evidence. It was identified a difficulty in finding previous randomized clinical trials (RCTs) in strength or combined training that meet the inclusion criteria. Likewise, it was difficult to find previous studies that analyse and evaluate cognitive variables with standardised instruments, as well as a clear consensus between the variable measured with each standardised instrument. Deficiencies were also found in the dosage where frequency, intensity, type and/or time were not reported. It may also be important to consider the physical capacity of individuals when assessing the results and before prescribing a dose (Suryadi et al., 2024). Finally, it would be interesting to further analyse this issue according to gender, as women are more likely to participate in activities offered in social centres (Flores Tena, 2024). In this way, analysing gender differences could help to promote the practice of physical exercise in a more personalised way. Therefore, the opportunity is identified for future research lines both in Chile and abroad to investigate more about strength and combined training in the elderly population and its effects on the different cognitive variables, considering evaluations with standardized instruments and including the dosage of the exercise in detail. More research can be done in the cognitive area applied to diseases that affect or impair the cognitive part of the human being, and after the publication of this systematic review it is recommended to do experimental research with the findings that were found in this review. In relation to its practical relevance, although it is not entirely clear that it can slow down the rate of progression of reducing the risk of neurocognitive disorders (Alty et al., 2020), this study could be useful in cognitively healthy older adults to generate a greater supply of cognitive stimulation programmes by improving physical exercise. In this way, the importance of dosage and a common consensus on cognitive terms and assessments could be visualised. Additionally, it could favor active aging, slowing physiological muscle loss (Ministry of Sport, 2020), the functionality, autonomy and well-being of older people (Cortez et al., 2023). It is important to note that exercise prescription is constantly being updated, so finding something relevant in exercise prescription could provide a picture of exercise prescription in the field that we do not have consensus on.

Conclusion

The present systematic review included studies that were rated as of moderate to high methodological quality according to the PEDro scale. These studies show that aerobic, strength and combined exercise obtained significant improvements in cognitive function in older healthy people. Thus, it can be inferred based on the information obtained that aerobic exercise brings greater benefits in attention, memory and executive functions, however, this may be because aerobic training is the most studied. Therefore, it is not possible to state with certainty that this is the most beneficial over strength and/or combined exercise, as there is less evidence. The results suggest benefits in those studies with longer duration in the intervention and that progressively increased intensity from the beginning to the end of the intervention. In addition, it is important to consider the health and physical condition of each individual in a personalised way to really understand the effects. It is recommended that future lines of research investigate more about strength and combined training considering the dosage with FITT method and standardised cognitive instruments to determine its effects on the different cognitive variables in the older adult population and to consider the differences in participation by gender.

Availability of data

The data that support the findings of this study are available from the corresponding author, [N. P.-R.], upon reasonable request.

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[1]Exercise and Rehabilitation Sciences Institute, Faculty of Rehabilitation Sciences, Universidad Andres Bello, Santiago de Chile 7591538, Chile

[2]Exercise and Rehabilitation Sciences Laboratory, School of Physical Therapy, Faculty of Rehabilitation Sciences, Universidad Andres Bello, Santiago de Chile 7591538, Chile

[3]Department of Social Psychology, Social Anthropology, Social Work and Social Services, University of Málaga, 29071 Málaga, Spain

[4]Exercise and Rehabilitation Sciences Institute, Postgraduate, Faculty of Rehabilitation Sciences, Universidad Andres Bello, Santiago de Chile 7591538, Chile; nuria.perez@unab.cl

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Datos de los/as autores/as y traductor/a:

Enrique Cerda-Vega	enrique.cerda@unab.cl	Autor
Catalina Irarrázabal-Guerra	c.irarrzabalguerra@uandresbello.edu	Autora
Leyla Sabja-Sepúlveda	l.sabjaseplveda@uandresbello.edu	Autora
Nasley Guajardo-Sandoval	n.guajardosandoval@uandresbello.edu	Autora
Nicolás Roa-Chiarleoni	n.roachiarleoni@uandresbello.edu	Autor
Verónica Morales-Sánchez	vomorales@uma.es	Autora
Rafael E. Reigal	rafareigal@uma.es	Autor
Nuria Pérez-Romero	nuria.perez@unab.cl	Autora – Traductor/a