Multicomponent strength training, cognition and muscle quality in older adults. Systematic review and narrative synthesis

Entrenamiento de fuerza multicomponente, cognición y calidad muscular en adultos mayores. Revisión sistemática y síntesis narrativa

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Abstract

Introduction: Population aging is associated with progressive declines in both muscular and cognitive function. Multicomponent exercise programs are widely recommended; however, the specific contribution of muscle quality, beyond mere muscle mass, to cognitive outcomes remains a critical gap in current evidence.
Objective: The aim was to systematically review and synthesize the effects of multicomponent resistance-based exercise interventions on cognition and indicators of muscle quality in older adults, highlighting the role of the muscle-brain axis as a central explanatory factor.
Methodology: A systematic search was conducted in PubMed, Web of Science, Scopus, and CINAHL Complete. Clinical trials evaluating chronic multicomponent exercise interventions with resistance training as a central component were included. Outcomes involved executive functions, while muscular emphasized strength, power, and functional performance as indicators of muscle quality. Risk of bias was assessed using the RoB-2 tool.
Results: Eight randomized controlled trials were included. Most studies reported improvements in executive functions, particularly inhibitory control and cognitive flexibility, alongside concurrent gains in muscular strength and power. Associations with cognitive outcomes were more consistent for muscle quality indicators than for muscle mass.
Discussion: Findings suggest that neuromuscular demands play a relevant role in mediating cognitive benefits. This highlights that functional adaptations may be more determinant for cognitive health than quantitative changes in muscle volume.
Conclusions: Multicomponent resistance-based exercise supports executive functioning, with muscle quality emerging as a key factor for designing more precise clinical interventions.

Keywords

Cognitive functions; elderly; physical fitness; muscle strength; systematic review.

Resumen

Introducción: El envejecimiento asocia descensos progresivos en funciones musculares y cognitivas. Aunque el ejercicio multicomponente se recomienda ampliamente, la contribución de la calidad muscular, más allá de la masa, a la cognición es una brecha crítica en la evidencia.
Objetivo: El objetivo fue revisar sistemáticamente y sintetizar los efectos de las intervenciones de ejercicio multicomponente basadas en la fuerza sobre la cognición e indicadores de calidad muscular en adultos mayores, destacando el papel del eje músculo-cerebro como factor explicativo central.
Metodología: Se realizó una búsqueda sistemática en PubMed, Web of Science, Scopus y CINAHL Complete. Se incluyeron estudios clínicos que evaluaran intervenciones crónicas de ejercicio multicomponente con el entrenamiento de fuerza como componente central. Los resultados cognitivos incluyeron las funciones ejecutivas, mientras que los musculares enfatizaron la fuerza, la potencia y el rendimiento funcional como indicadores de calidad muscular. El riesgo de sesgo se evaluó mediante la herramienta RoB-2.
Resultados: Se incluyeron ocho ensayos controlados aleatorios. La mayoría de los estudios informaron mejoras en las funciones ejecutivas, particularmente en el control inhibitorio y la flexibilidad cognitiva, junto con ganancias concurrentes en la fuerza y potencia muscular. Las asociaciones con los resultados cognitivos fueron más consistentes para los indicadores de calidad muscular que para la masa muscular.
Discusión: Los hallazgos sugieren que las demandas neuromusculares desempeñan un papel relevante en la mediación de los beneficios cognitivos. Esto resalta que las adaptaciones funcionales pueden ser más determinantes para la salud cognitiva que los cambios cuantitativos en el volumen muscular.
Conclusiones: El ejercicio multicomponente basado en la fuerza favorece el funcionamiento ejecutivo, emergiendo la calidad muscular como un factor clave para el diseño de intervenciones clínicas más precisas.

Palabras clave

Ancianos; aptitud física; fuerza muscular; funciones cognitivas; revisión sistemática.

Introduction

Population aging is associated with a progressive increase in functional and cognitive decline, directly affecting autonomy and quality of life in older adults (Martins et al., 2024). In this context, physical exercise has become one of the most effective non-pharmacological interventions for promoting healthy aging (Kroemer, 2025). Multicomponent exercise programs that integrate resistance training, aerobic endurance, balance, and flexibility are widely regarded as the gold standard for older adults (Y. Li et al., 2022), due to their capacity to act synergistically on multiple physiological systems and to prevent or reverse states of frailty (Prommaban et al., 2024).

The relevance of resistance training lies in its ability to preserve muscle mass; however, its contribution extends beyond the structural component of muscle tissue (Kendall et al., 2025). The loss of muscular strength, and especially muscle power, represents one of the main determinants of age-related functional decline and reflects alterations in neuromuscular control that precede the loss of muscle mass (Baltasar-Fernandez et al., 2025). For this reason, resistance training constitutes a key stimulus for preserving the integrity of the neuromotor system, with relevant functional and cognitive implications (Siddique et al., 2022).

Cognitive aging does not occur uniformly across domains (Goh et al., 2011). Among the different cognitive domains, executive functions (e.g., inhibitory control, cognitive flexibility, and working memory) play a fundamental role in behavioral regulation and functional independence (Salas et al., 2026). Available evidence indicates that the cognitive benefits of physical exercise are selective and tend to be concentrated in tasks that require a high level of executive control (Roldán & Olmedo, 2025). In this context, chronic resistance training has been consistently associated with improvements in inhibitory control and cognitive flexibility (Wu & Huang, 2025). Similarly, benefits in working memory have been reported, particularly when training incorporates demands related to movement speed and temporal control, suggesting that the quality of the neuromotor stimulus is a key determinant of the observed cognitive effects (Feter et al., 2023).

Conceptually, muscle health in aging has evolved from an approach centered on the quantity of muscle mass toward a perspective that prioritizes muscle quality and function (Lacio et al., 2021). Variables such as maximal strength, muscle power, and the capacity to generate force rapidly and efficiently have been shown to be more robust predictors of functional and cognitive performance than muscle mass alone (Travaglini et al., 2025). Simple functional measures, such as handgrip strength or lower-limb power, are consistently associated with cognitive performance and specific executive domains, positioning muscle function as a sensitive marker of central nervous system status (Uchida et al., 2023).

From this perspective, muscle is no longer understood solely as a peripheral tissue but rather as an effector highly dependent on neural control (Lecce et al., 2025). Chronic resistance training induces early neuromuscular adaptations, including improvements in cortical activation, motor unit synchronization, and the efficiency of corticospinal pathways (Buckinx & Aubertin-Leheudre, 2019). These adaptations largely explain the functional improvements observed even in the absence of significant changes in muscle mass (Clark, 2019) and reinforce the notion that neuromotor muscle quality reflects central processes of neural plasticity (Romare et al., 2023). In this sense, muscular strength and power may be interpreted as functional expressions of central nervous system integrity during aging (James et al., 2021). These improvements are supported by specific neurobiological mechanisms, such as the release of neurotrophic and hormonal factors with direct effects on brain structure and function. Among these, brain-derived neurotrophic factor (BDNF) has been widely linked to neuroplasticity processes (Wang & Holsinger, 2018), while insulin-like growth factor 1 (IGF-1) has been proposed as a key mediator connecting muscular adaptations with cognitive benefits (Perice et al., 2016). Complementarily, neuroimaging studies have shown that resistance training is associated with structural brain changes, including increases in gray matter density in regions critical for cognition, such as the hippocampus and prefrontal cortex (Kušleikienė et al., 2025), as well as preservation of white matter integrity (Herold et al., 2019).

Despite these advances, the available evidence shows considerable heterogeneity in the cognitive effects associated with resistance training (García-García et al., 2025). Part of this variability may be explained by differences in the neuromotor demands of exercise and by the limited consideration of indicators of muscle quality and neuromuscular function in existing studies (Wollesen & Voelker-Rehage, 2025). In this context, an exclusive focus on traditional parameters such as muscle mass or training dosage may be insufficient to fully understand the relationship between resistance training and cognition in older adults (Sui et al., 2020).

Therefore, the aim of this systematic review was to integrate this conceptual framework to clarify the role of muscle quality as a central explanatory axis in the relationship between resistance exercise and cognition, providing a novel perspective on the muscle-brain axis that guides future interventions toward more precise and functionally relevant strategies in the context of healthy aging.

Method

Study design

The review protocol was developed in accordance with the guidelines established by the methodology Preferred Reporting Items for Systematic Review and Meta-Analysis Protocols (PRISMA-P) (Page et al., 2021). The study was registered in the international systematic review registry PROSPERO (Moher et al., 2015), with the registration number CRD420261286390.

Eligibility criteria

Study eligibility was determined using a predefined framework, summarized in Table 1, and applied consistently throughout the selection process. The included studies were required to align with the conceptual and methodological scope of this review. Only studies that assessed cognitive performance using validated neuropsychological instruments and reported changes following a structured intervention period were considered. Both cognitively healthy older adults and individuals presenting cognitive decline were included to allow a comprehensive evaluation across different cognitive statuses. To ensure adequate methodological rigor, the review prioritized experimental and quasi-experimental designs that enabled the examination of intervention-related effects over time. Studies that did not conform to the overall scope of the review or lacked sufficient methodological quality were excluded, as detailed in Table 1.

Table 1. Eligibility criteria for studies

	Inclusion	Exclusion
Population	Older adults (mean age of the sample ≥60 years, without restriction according to sex or fitness level	Studies include participants where the population characteristics are not clearly defined or reported.
Intervention	Chronic strength exercise as multicomponent training part. without restrictions on modality, intensity, or setting, provided that the strength stimulus is clearly defined and reproducible.	Single sessions, or the effects of strength exercise cannot be isolated or clearly described.
Comparator	Group not exposed to the intervention program. The control group may be active or passive.	Studies lacking a valid comparison group, or where the control condition does not allow distinguishing the specific effects of the strength intervention
Outcomes	Main outcome of the cognitive assessment (general or executive function) before and after the intervention. Secondary outcome on muscle quality or condition an author's criterion.	Studies that rely exclusively on subjective reports, or indirect measures that are not specific to executive functioning or muscle quality.
Study design	Longitudinal randomized controlled trials (RCTs), and non-RCTs.	Qualitative designs, case reports, cross-sectional analyses, or reviews that do not provide pre–post data outcomes.

RCT = Randomized controlled trial.

Search strategy and selection process

Two reviewers (F.J.S. and V.L.C.) will independently identify eligible studies through a comprehensive and systematic search of literature. Electronic searches will be conducted in the following databases: PubMed, Web of Science, Scopus, and CINAHL Complete. Full details of the search strings, keywords, and Boolean combinations tailored to each database are reported in Supplementary Material S1. To ensure broad coverage of the existing evidence, no limitations related to publication year, participant sex, or language will be imposed. All references retrieved from the searches will be compiled into a reference management system, where duplicate records will be identified and removed prior to screening. The study selection process will follow a two-step approach. First, titles and abstracts will be screened to exclude clearly irrelevant records. Subsequently, the full texts of potentially relevant articles will be assessed for eligibility. Any disagreements between the two reviewers during either phase will be addressed through discussion, and when necessary, a third reviewer (C.P.A.) will be consulted to reach consensus.

Data extraction and management

Relevant studies will be identified through an independent and systematic literature search conducted by two reviewers (F.J.S. and V.L.C.). All records retrieved will be imported into reference management software (EndNote 2025 for Windows), and duplicate entries will be removed before the screening process begins. Study selection will be carried out in sequential stages. In the initial phase, titles and abstracts will be reviewed to identify potentially relevant studies. Articles deemed eligible at this stage will then undergo full-text evaluation. When essential information is missing, corresponding authors will be contacted following established protocols (Butler et al., 2016).

Any discrepancies arising between reviewers during the selection process will be resolved through consensus; when agreement cannot be reached, a third reviewer (C.P.A.) will be consulted to make a final determination.

Risk-of-Bias assessment

Methodological quality and potential sources of bias in the included studies were independently assessed by two reviewers (F.J.S. and O.V.G.). All randomized controlled trials were evaluated using the Cochrane Risk of Bias 2 (RoB 2) tool, which is widely applied in health and rehabilitation research to examine the internal validity of intervention studies (Sterne et al., 2016).

Any disagreements arising during the assessment process were resolved through discussion between the reviewers, and when consensus could not be reached, a third reviewer (C.P.A.) was consulted to provide a final judgment. A formal evaluation of the overall certainty of the evidence, such as the GRADE framework, was not conducted, as the primary aim of this review was to provide a structured synthesis of the existing literature rather than to inform clinical decision-making or guideline development (Kolaski et al., 2023).

Narrative synthesis

Data synthesis was conducted using a structured narrative approach, in line with current recommendations for systematic reviews in which quantitative pooling is not appropriate (Page et al., 2021). Given the heterogeneity among included studies with respect to intervention composition, outcome measures, participant characteristics, and study designs, a meta-analysis was not undertaken (Rai et al., 2020).

The narrative synthesis was organized around five predefined thematic axes, established a priori to ensure conceptual coherence and analytical transparency. These axes addressed: (1) the role of multicomponent exercise interventions combining resistance training with other physical capacities as an integrated approach to healthy aging (Forsyth et al., 2024); (2) the selective effects on executive function domains, particularly inhibitory control, cognitive flexibility, and working memory (Logan & Lim, 2025); (3) the contribution of muscular health, emphasizing functional and neuromotor indicators of muscular quality rather than muscle mass alone (Virto et al., 2024); (4) proposed muscle–brain pathways, including neurobiological and structural mechanisms linking resistance training to cognitive outcomes (McNeish et al., 2025); and (5) potential moderators of intervention response, such as training characteristics, sex-related differences, and baseline cognitive status (Ge et al., 2025).

Within each thematic axis, findings were synthesized descriptively, considering the direction and consistency of reported effects. When available, relative magnitudes of change were summarized without formal statistical aggregation. Greater interpretative weight was assigned to studies with lower risk of bias and clearer methodological reporting. Patterns of convergence and divergence across studies were examined to contextualize the strength and limitations of the available evidence (Campbell et al., 2020).

Results

Study selection

The systematic search across the selected databases identified a total of 23,487 records. After the removal of duplicate entries, the remaining studies underwent title and abstract screening based on the predefined eligibility framework. Articles considered potentially relevant were subsequently retrieved for full-text assessment. Following full-text evaluation, eight studies fulfilled the methodological and conceptual scope of the review and were included in the qualitative narrative synthesis (Table 2). The entire screening and selection process was conducted in accordance with the PRISMA 2020 guidelines and is illustrated in Supplementary Figure S2.

Study characteristics

The included studies predominantly implemented multicomponent exercise interventions in which resistance training represented a core component, commonly combined with balance, aerobic, and functional exercises. Intervention duration varied from short-term programs to longer protocols lasting several weeks or months, with training sessions most frequently prescribed two to three times per week. Resistance training components were generally delivered at moderate to high intensity and, in several studies, emphasized functional strength or power-oriented movements targeting major muscle groups. Cognitive outcomes were assessed using standardized neuropsychological instruments, primarily focusing on executive function domains, including inhibitory control, cognitive flexibility, and working memory. Measures of muscular health extended beyond muscle mass and frequently included indicators of muscular strength, power, or functional performance as proxies of muscular quality. Detailed intervention characteristics and outcome measures are presented in Table 3.

Table 2. Subjects' characteristics from the included studies

Reference	Study Design	N	Gender (Woman %)	Age yrs (SD)	BMI	Cognitive status	Muscle quality index
Suzuki et al. (2012)	RCT	50; Exp: 25; Cr: 25.	46%	76.0 ± 7.1	Not reported	CDR 0.5	SPPB: 10.3. HGS: 29.3 ± 5.5 kg.
Sánchez-Sánchez et al. (2022)	RCT	188; Exp:94; Cr: 94	70.2%	84.06 ± 4.77	27.0 ± 3.9	GDS 4	SPPB: 7.31 ± 2.59 puntos. HGS: 19.37 ± 7.23 kg.
De Bruin et al. (2015)	RCT	60; Exp: 30; Cr: 30	Mixed	78.8 ± 5.3	Not reported	>22 (MMSE)	Overload principle: ability to support weighted vests up to 10 kg
Smolarek et al. (2016)	RCT	37; Exp: 29; Cr: 8	100%	65.87 ± 5.69	27.5 ± 4.5	<26 (MoCA)	LLS (Chair test): 16.0 ± 2.7 rpt. ULS: 12.5 ± 3.0 rpt.
Jurakic et al. (2017)	RCT	24; Exp: 14; Cr: 14	100%	70.4 ± 3.93	Not reported	19-25 (MoCA)	HUBER: % Isometric force (50-75% MVC).
Montero-Odasso et al. (2023)	RCT	175; Exp: 35; Cr (1-4): 35	49.1%	73.1 ± 6.6	28.0 ± 7.9	MCI (Petersen criteria)	SPPB: 10.0 ± 1.6. Gait speed: 117 ± 21.6 cm/s.
De Oliveira Silva et al. (2019)	RCT	46; Exp: 20; Cr: 26	41-85%	76.8 ± 6.8	26.8 ± 4.2	CDR 0.5-2	8-foot Up & Go: 6.5 ± 1.1 s. VO2max: 26.9 ml/kg/min.
Tarazona-Santabalbina et al. (2016)	RCT	100; Exp: 51; Cr: 49	51-57%	Ex: 79.7 ± 3.6; Cr: 80.3 ± 3.7	30.0 ± 4.2	>24 (MMSE)	SPPB: 8.6 ± 2.0. HGS: 24.5 kg (mean).

BMI = Body Mass Index; CDR = Clinical Dementia Rating; Cr = Control group; cm = centimeter; Exp = Experimental group; F = Female; GDS = Global Deterioration Scale; HGS = Handgrip Strength pressure; Kg = kilograms; LLS/ULS = Lower/Upper Limb Strength; M = Male; MCI= Mild Cognitive Impairment; min = minute; MMSE = Mini-Mental State Examination; MoCA = Montreal Cognitive Assessment; MVC = Maximum Voluntary Contraction; N = Total sample size; Non-RCT = Non-Randomized Controlled Trial; NR = Not Reported; RCT = Randomized Controlled Trial; RPE = Rating of Perceived Exertion; Rpt = Repetitions; s = seconds; SD = Standard Deviation; yrs = Years of age; SPPB = Short Physical Performance Battery; Vcop = Velocity of the center of pressure; VO2max = Maximum Oxygen consumption.

Table 3. Intervention characteristics of the included studies

Autor	Exercise program	Frequency	Session Length	Duration	Intensity	Cognitive Domains / Instrument	Cognitive Effects or Outcomes	Muscle Quality or Health Metrics / Instruments	Muscle Quality or Health Outcomes
Suzuki et al. (2012)	Multicomponent: Strength (20 min), aerobic, and balance.	2days/week	90 min	12 months	60% Max HR	Global & Memory: MMSE, WMS-R, Fluency, Stroop.	Improvement in MMSE (p=0.04), immediate memory (p=0.03), and fluency (p=0.02).	General Physical Performance & Adherence.	Maintained physical performance levels; 79.2% program adherence.

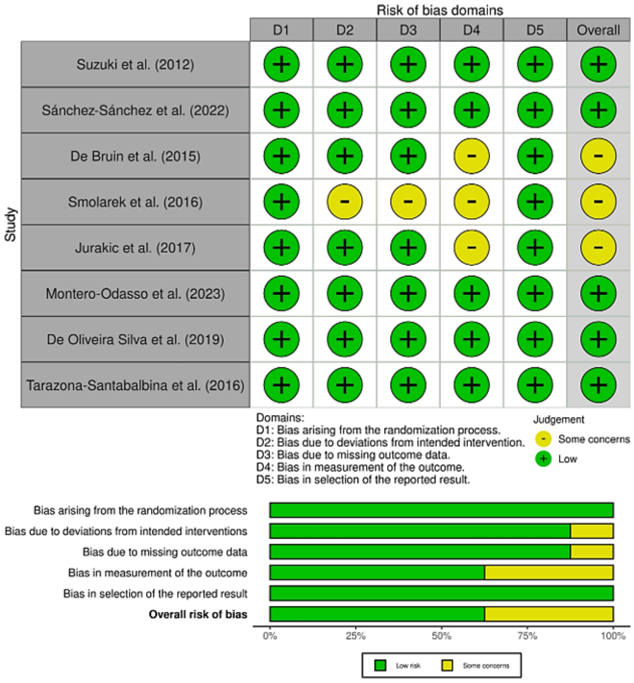
Sánchez-Sánchez et al. (2022)	Vivifrail: Strength (resistance), balance, and gait.	3days/week	30-60 min	3 months	Progressive: Levels A-D based on initial SPPB.	Global: MoCA.	Significant improvement in the MoCA cognitive domain ($p < 0.05$).	Locomotion (SPPB) and Vitality (Handgrip Strength).	Significant increase in SPPB score ($p=0.02$) and Handgrip Strength ($p < 0.001$).
De Bruin et al. (2015)	Multicomponent: 20min of strength, 20min of aerobic and 20min of balance.	2 days/week	60 min	6 months	Mod-Vigorous: Borg (RPE) 5–7.	Executive: TMT-B (attention), Working Memory, WMS-R.	Improvement in Shifting Attention (TMT-B) and Working Memory.	Strength (max reps with 10kg vest) and Balance (unstable surfaces).	Interventions were adapted to maintain moderate-to-vigorous intensity (Borg 5-7); gains maintained at 1-year follow-up.
Smolarek et al. (2016)	Resistance: 12 exercises (upper and lower limbs).	3days/week	Not reported	3 months	Moderate: 60–75% of estimated 1-RM.	Global: MoCA.	19% increase in global cognitive capacity ($p=0.01$).	Upper Limb Strength (ULS) (Arm Curl) and Lower Limb Strength (LLS) (Chair Test).	58% increase in ULS and 68% increase in LLS ($p=0.01$) after 12 weeks.
Jurakic et al. (2017)	HUBER: Core strength and balance vs. Pilates.	3days/week	30 min	2 months	HUBER: 50-75% MVC.	Multiple: MoCA (7 subscales).	Improved MoCA; HUBER superior in visuospatial/executive domain.	Core Strength/Stability (HUBER device MVC) and Isometric Endurance.	Progressive increase in load from 50% to 75% MVC; enhanced core muscle function.
Montero-Odasso et al. (2023)	Aerobic-Resistance: Progressive (walking and machines).	3days/week	90 min	5 months	Progressive: Systematic Borg (RPE).	Global: ADAS-Cog-13 and ADAS-Cog-Plus.	Significant improvement in ADAS-Cog-13 ($p=0.005$).	Physical Performance (SPPB) and Gait Speed (cm/s).	Sustained physical activity levels; slight decline in control vs. exercise group.
De Oliveira Silva et al. (2019)	Multimodal: Aerobic, strength, balance, and flexibility.	2days/week	60 min	3 months	Moderate: 70% VO2max; 8–12 rpt.	Executive: MMSE, CDT, Fluency, Stroop.	Improved Verbal Fluency ($p=0.05$) and mobility in MCI.	Mobility/Agility (8-foot up and go), Aerobic capacity (VO2max), and Total Training Strength.	Significant improvement in 8UG ($p=0.03$); 115% increase in total strength and 53% in VO2max (MCI group).
Tarazona-Santabalbina et al. (2016)	Multicomponent: Strength, aerobic, and proprioception.	5days/week	65 min	6 months	Strength: Progression 25% to 75% 1-RM.	Global: MMSE.	9% improvement in MMSE ($p=0.025$) and frailty reversal.	Functional Capacity (SPPB, PPT, Tinetti) and Body Composition (Fat Mass %).	Significant improvement in SPPB ($p=0.007$), Tinetti ($p=0.007$); significant reduction in Fat Mass ($p=0.019$).

1-RM = One Repetition Maximum; ADAS-Cog = Alzheimer's Disease Assessment Scale-Cognitive; CDT = Clock-Drawing Test; cm = centimeter HR = Heart Rate; HRmax = Maximum Heart Rate; Kg = Kilograms; LLS/ULS = Lower/Upper Limb Strength; MHR = Maximum Heart Rate Reserve; MCI= Mild Cognitive Impairment; min = Minutes; MMSE = Mini-Mental State Examination; MoCA = Montreal Cognitive Assessment; MVC = Maximum Voluntary Contraction; PPT = Physical Performance Test; RPE = Rating of Perceived Exertion; Rpt = Repetitions; s = Seconds; SPPB = Short Physical Performance Battery; TMT = Trail Making Test; VO2max = Maximum Oxygen consumption; WMS-R = Wechsler Memory Scale-Revised.

Risk-of-Bias assessment

The risk of bias of the randomized controlled trials (RCTs; n = 8) was assessed using the Cochrane Risk of Bias 2 (RoB 2) tool. As illustrated in Figure 1, all included studies employed randomized allocation procedures. Overall, the risk of bias was judged to be low, although the study by Smolarek et al. (2016) presented a notable imbalance in final group sizes, leading to some concerns in the randomization process (Domain 1). Due to the nature of exercise-based interventions, participant blinding was not feasible across studies. Nevertheless, several trials, including those by Montero-Odasso et al. (2023) and Sánchez-Sánchez et al. (2022) mitigated potential bias using an intention-to-treat (ITT) analyses and by ensuring a clear separation between intervention delivery and outcome assessment personnel (Domain 2). Most studies adequately addressed missing outcome data, particularly those applying linear mixed-effects models, which are robust to missing data under the assumption of missing at random (Domain 3). The highest risk of bias was identified in studies in which it was unclear whether outcome assessors were blinded to group allocation, as observed in De Bruin et al. (2015) and Jurakic et al. (2017) potentially influencing performance-based cognitive assessments (Domain 4). Reporting bias was generally low, with most trials demonstrating a high level of transparency in outcome reporting and adherence to CONSORT guidelines (Domain 5). Overall, three out of eight RCTs were classified as presenting some concerns, while the remaining studies were rated as having a low risk of bias.

Figure 1. Risk of bias for randomized controlled trial studies.



Study	D1	D2	D3	D4	D5	Overall
Suzuki et al. (2012)	+	+	+	+	+	+
Sánchez-Sánchez et al. (2022)	+	+	+	+	+	+
De Bruin et al. (2015)	+	+	+	-	+	-
Smolarek et al. (2016)	+	-	-	-	+	-
Jurakic et al. (2017)	+	+	+	-	+	-
Montero-Odasso et al. (2023)	+	+	+	+	+	+
De Oliveira Silva et al. (2019)	+	+	+	+	+	+
Tarazona-Santabalbina et al. (2016)	+	+	+	+	+	+

Domains:
D1: Bias arising from the randomization process.
D2: Bias due to deviations from intended intervention.
D3: Bias due to missing outcome data.
D4: Bias in measurement of the outcome.
D5: Bias in selection of the reported result.

Judgement
- Some concerns
+ Low

Narrative synthesis

Multicomponent interventions as an integrated approach

Supervised multicomponent training programs reported adherence rates ranging from 79.2% in 12-month protocols to 87% in 20-week interventions. After 12 weeks of implementation of the Vivifrail program, a significant improvement was observed in the composite intrinsic capacity score ($\beta = 0.48$; $P < 0.001$), as well as in its specific domains of locomotion, cognition, and vitality. The MEP program, following 24 weeks of training at a frequency of five days per week, achieved a reversal of frailty status in 31.4% of participants, whereas no reversals were observed in the control group. Similarly, the combination of aerobic–resistance exercise with sequential cognitive training resulted in a 2.64-point improvement on the ADAS-Cog-13 scale ($p = 0.005$; $d = 0.71$) compared with the control condition.

Selective effects on executive function domains

Interventions incorporating simultaneous cognitive challenges demonstrated improvements in alternating attention (shifting) and working memory, with a favorable time × intervention interaction for virtual dance and memory-walking groups (DANCE/MEMORY) compared with physical exercise alone. In women with mild cognitive impairment (MCI), training using the HUBER visual feedback device yielded significantly higher scores in the visuospatial/executive domain ($p < 0.05$; $d = 0.78$) compared with Pilates training. Multicomponent programs lasting between 3 and 12 months also reported significant increases in verbal fluency, both letter ($p = 0.02$) and category ($p = 0.05$), specifically among participants with MCI. Importantly, improvements in executive functions and processing speed were maintained without significant decline for up to one year following the end of the intervention.

Muscle health: functional and neuromotor indicators

After 12 weeks of resistance training at intensities ranging from 60% to 75% of one-repetition maximum (1-RM), upper- and lower-limb strength increased by 58% and 68%, respectively ($p = 0.01$), accompanied by a 19% improvement in global cognitive performance assessed by the MoCA. The Vivifrail protocol resulted in significant gains in handgrip strength ($p < 0.001$) and Short Physical Performance Battery (SPPB) scores ($p = 0.02$) following three months of home-based intervention. In participants with MCI, multimodal exercise significantly improved mobility and agility as assessed by the 8-foot up-and-go test ($p = 0.03$) and produced a 115% increase in total training strength. Additional findings included a significant reduction in fat mass ($p = 0.019$) and improvements in balance and gait evaluated using the Tinetti scale ($p = 0.007$).

Muscle–brain: neurobiological and structural mechanisms

Chronic multicomponent training induced changes in systemic biomarkers, including a significant reduction in D-dimer levels (a coagulation marker; $p = 0.02$) and prevention of plasma protein carbonylation (a marker of oxidative stress; $p = 0.05$) after 24 weeks of exercise. Regarding aerobic capacity, participants in intervention groups exhibited mean increases ranging from 45% to 53% in maximal oxygen uptake (VO_2max). Although serum brain-derived neurotrophic factor (BDNF) showed a nominal increase in the exercise group (from 89.9 to 97.1 ng/mL), this difference did not reach statistical significance compared with the control group. Other reported mechanisms included changes in hemodynamic activity within brain regions associated with response inhibition following resistance training.

Potential moderators of intervention response

Intervention effects varied according to participants' baseline status, with greater cognitive benefits observed in individuals classified as frail ($\beta = 0.85$; $P = 0.01$) compared with their pre-frail counterparts. Regarding clinical diagnosis, multimodal exercise improved mobility and verbal fluency in participants with MCI, whereas no statistically significant cognitive changes were observed in individuals with Alzheimer's disease. Intervention type also acted as a moderator, with combined exercise and cognitive training demonstrating superiority over exercise alone (mean difference of −1.45 points on the ADAS-Cog-13; $p = 0.02$). In contrast, supplementation with vitamin D (10,000 IU three times per week) did not yield additional cognitive benefits compared with placebo ($p = 0.60$).

Discussion

The findings of the present systematic review support the proposed conceptual framework, identifying muscle quality as a central explanatory axis in the relationship between resistance exercise and cognitive function. By integrating neuromuscular and functional indicators, this study provides a novel perspective on the muscle-brain axis, suggesting that the benefits of multicomponent interventions in older adults are more closely linked to functional muscle adaptations than to quantitative changes in muscle mass. These results offer a foundation for developing more precise and functionally relevant strategies aimed at preserving autonomy and cognitive health in the context of aging.

Multicomponent interventions as an integrated approach

Current research suggests that simultaneous cognitive-motor dual-task training is particularly effective as it mirrors real-life multitasking demands and more efficiently engages shared neural resources compared to physical or cognitive training alone (Wollesen & Voelker-Rehage, 2025). Furthermore, strength-bases multicomponent intervention programs conducted over 12 weeks have demonstrated the ability to improve global functional physical condition by approximately 48.7%, significantly enhancing autonomy in older populations (García-García et al., 2025).

In the current review, multicomponent training programs that combine different exercise modalities demonstrated the capacity to address the multifactorial functional needs of older adults (Forsyth et al., 2024). The effectiveness of this intervention strategy, compared with isolated exercise modalities, appears to lie in its ability to simultaneously stimulate multiple physiological systems that converge on brain health (Sánchez-Sánchez et al., 2022; Suzuki et al., 2012). Whereas traditional aerobic exercise has primarily targeted vascular health, the integration of resistance, balance, and flexibility training, as implemented in programs such as Vivifrail or in the SYNERGIC trial, has demonstrated a more robust impact on intrinsic capacity and global cognitive performance (Montero-Odasso et al., 2023; Sánchez-Sánchez et al., 2022).

This enhanced effectiveness may be explained by the “enrichment hypothesis,” whereby the combination of physical load and complex motor challenges provides a scaffold for cognitive reserve (Sánchez-Sánchez et al., 2022; Suzuki et al., 2012). Although the necessity of adding formal cognitive training remains debated, findings from Montero-Odasso et al. (2023) indicate that the synergy between sequential exercise and computerized cognitive tasks yields clinically meaningful improvements in cognition, exceeding those observed with exercise alone (2.64-point improvement in ADAS-Cog-13). Accordingly, multicomponent exercise may not only preserve function but also exert a restorative effect, with the capacity to reverse physical frailty in approximately one-third of participants, supporting its role as a form of non-pharmacological “polypharmacy” (Tarazona-Santabalbina et al., 2016).

Selective effects on executive function domains

While physical exercise provides general benefits, previous reviews suggest that its effects are often selective and show the most promise for improving inhibition, working memory, and cognitive flexibility (Wollesen & Voelker-Rehage, 2025). Notably, muscle density and strength are specifically associated with domains of information processing (psychomotor function) and visual attention, suggesting that neuromotor health selectively supports higher-order cognitive control (Sui et al., 2020).

Evidence suggests that the effects of exercise on executive function domains are selective and modulated by key intervention parameters, including intensity, duration, and exercise modality (Logan & Lim, 2025). The available findings indicate that not all cognitive domains respond to the same extent, with executive functions emerging as particularly plastic in response to physical exercise (De Bruin et al., 2015; Montero-Odasso et al., 2023). Improvements in shifting attention and working memory appear to be closely related to intervention design. Specifically, studies incorporating dual-task paradigms or augmented visual feedback, such as those using the HUBER device, have demonstrated selective advantages over purely physical exercise interventions (De Bruin et al., 2015; Jurakic et al., 2017).

These task designs impose continuous inhibitory control and real-time error monitoring, thereby engaging more extensive and functionally integrated neural networks (Jurakic et al., 2017). In contrast, although verbal fluency tends to improve consistently in individuals with mild cognitive impairment following multicomponent programs lasting 3 to 12 months, this effect appears attenuated in tasks with a predominantly linguistic load when high executive demands are not embedded within the intervention (Montero-Odasso et al., 2023; Suzuki et al., 2012). A plausible explanation for this pattern lies in the transfer principle, whereby the brain optimizes motor control processes that are functionally analogous to cognitive control mechanisms, allowing gains in one domain to generalize to the other (De Bruin et al., 2015)

Muscle health: functional and neuromotor indicators

Evidence highlights that muscle strength is a far more robust indicator of cognitive health and performance than muscle mass alone (Sui et al., 2020). Resistance training specifically targeting muscle power and agility has shown significant large-scale effects on functional variables (e.g., standing up, balance), which are critical for the prevention of falls and the maintenance of independence (García-García et al., 2025).

The effects of exercise-based interventions encompass both functional and structural (neuromotor) domains and are therefore not limited to changes in muscle mass alone. Instead, they integrate aspects of muscle composition, architecture, and their relationship with functional parameters such as relative strength and power (Virto et al., 2024). Accordingly, the available evidence shifts the focus from muscle quantity toward muscle quality and functional capacity as more relevant predictors of cognitive status in older adults.

Findings from Sánchez-Sánchez et al. (2022) and Smolarek et al. (2016) support a direct association between lower-limb strength and global cognitive performance assessed by the MoCA, suggesting that muscular power may act as an indirect marker of neural integrity. One plausible explanation for this phenomenon is the concept of “muscle functional reserve”, whereby a more efficient motor system reduces the cognitive load required to perform basic activities such as walking, thereby freeing attentional resources for higher-order cognitive processes (De Oliveira Silva et al., 2019).

While high-intensity training is not the sole effective stimulus, the relationship between training dose and cognitive response remains a subject of debate. Evidence indicates that substantial gains in strength (sometimes exceeding 100%) are those most consistently associated with stable cognitive benefits (De Oliveira Silva et al., 2019; Smolarek et al., 2016). Ultimately, clinical measures such as handgrip strength and the Short Physical Performance Battery (SPPB) do not merely assess muscular function but also serve as integrative indicators of overall health and cognitive status in older adults (Sánchez-Sánchez et al., 2022).

Muscle–brain: neurobiological and structural mechanisms

Previous reviews suggest that skeletal muscle is recognized as an important source of neurotrophic factors, such as brain-derived neurotrophic factor (BDNF), which is released during contraction to regulate brain synaptic function (Sui et al., 2020). These metabolic and neurochemical changes promote brain plasticity and resources (Wollesen & Voelker-Rehage, 2025). Additionally, common pathophysiological pathways involving chronic low-grade inflammation (IL-6, CRP) and oxidative stress link the deterioration of muscle health to cognitive decline (Sui et al., 2020).

Communication between the brain and skeletal muscle appears to be mediated by contraction-derived biochemical factors that influence anatomical-functional processes related to cognition (McNeish et al., 2025). This interaction is explained through biological cascades that may mitigate age-related neurodegenerative damage (De Oliveira Silva et al., 2019; Smolarek et al., 2016). The findings of the present review suggest that multicomponent exercise may strengthen connectivity within the frontoparietal network, a critical system in which motor control and executive processes converge (De Oliveira Silva et al., 2019).

At a systemic level, chronic exercise has been shown to reduce inflammation and oxidative stress, as evidenced by decreases in circulating biomarkers such as D-dimer and protein carbonylation, as reported by Tarazona-Santabalbina et al. (2016). These adaptations may contribute to the preservation of neural integrity and cognitive function during aging. The role of circulating BDNF remains debated. Although some theoretical frameworks position BDNF as a central mediator of hippocampal neurogenesis, the studies included in this review showed only modest or non-significant increases in serum BDNF levels following multicomponent exercise interventions (Tarazona-Santabalbina et al., 2016).

This pattern suggests that the cognitive benefits associated with resistance-based multicomponent training may depend less on isolated neurotrophic factors and more on integrated mechanisms, including changes in cerebral hemodynamic activity, improved cerebral blood flow, and enhanced efficiency of neural networks supporting executive control (De Bruin et al., 2015; Smolarek et al., 2016). From this perspective, skeletal muscle can be conceptualized as an endocrine organ that, when adequately stimulated, secretes bioactive factors, specially myokines, capable of modulating the neuronal microenvironment and supporting brain health in older adults (Smolarek et al., 2016).

Potential moderators of intervention response

Current research suggests that the efficacy of interventions is moderated by F.I.T.T. principles, where moderate-to-high frequency (3–7 sessions/week) and shorter session lengths (≤45 minutes) are associated with higher adherence (Wollesen & Voelker-Rehage, 2025). Other crucial moderators include Vitamin D levels, baseline physical frailty, and lifestyle risk factors such as diet, smoking, and physical inactivity, all of which influence the shared trajectory of muscle and brain health (Sui et al., 2020).

The benefits of multicomponent exercise interventions do not appear to be uniformly distributed across all populations, indicating the presence of relevant moderators influencing the cognitive response to physical exercise. The observed heterogeneity in outcomes may be partially explained by key moderating factors, particularly the principle of initial values, whereby individuals with lower initial cognitive performance or greater physical frailty exhibit a larger window of opportunity for improvement. In this regard, Sánchez-Sánchez et al. (2022) reported that frail participants achieved greater gains in global cognition, as measured by the MoCA, compared with their pre-frail counterparts.

However, the underlying clinical diagnosis represents a critical boundary condition. While exercise interventions appear to be highly effective in individuals with mild cognitive impairment, evidence suggests that in patients with more advanced Alzheimer's disease, the disruption of neural networks may be too extensive for exercise-induced adaptations to produce meaningful cognitive benefits. Consistent with this notion, De Oliveira Silva et al. (2019) reported minimal or null cognitive effects of exercise in individuals with advanced dementia.

Regarding nutritional status, the findings of this review align with previous evidence concerning vitamin D. In participants with sufficient baseline vitamin D levels, additional supplementation did not confer extra cognitive benefits beyond those induced by exercise alone. Overall, the response to multicomponent exercise interventions appears to depend largely on both the training dose and baseline cognitive status. These findings underscore the importance of individualized exercise prescription that takes into account baseline physical frailty and cognitive impairment to maximize therapeutic efficacy.

Strength and limitation for futures research

This review presents several notable strengths. First, its focus on multicomponent interventions with resistance training as a central element allowed for an integrative analysis of muscular quality as a relevant determinant of cognitive function in older adults. In addition, the exclusive inclusion of randomized controlled trials strengthens the internal validity of the findings. The narrative synthesis was structured around integrative conceptual axes, which facilitated a coherent interpretation of cognitive outcomes, neuromuscular adaptations, and potential biological mechanisms.

However, some limitations should be acknowledged. The relatively small number of included studies and the substantial heterogeneity in intervention protocols, outcome measures, and participants' cognitive status precluded the performance of a meta-analysis. Moreover, although muscular quality was commonly assessed using functional and strength-based indicators, few studies incorporated direct measures of neuromuscular mechanisms underlying these adaptations, such as electromyography or specific muscle quality indices. Future research should prioritize study designs that systematically manipulate variables related to muscular quality, such as power-oriented resistance training, and include biomarkers (e.g., BDNF or myokines) to better elucidate the mechanisms linking resistance exercise and cognitive health in aging populations.

Conclusions

The available evidence suggests that multicomponent exercise interventions incorporating resistance training are associated with benefits in executive functions in older adults, particularly in tasks requiring higher levels of cognitive control. Beyond muscle mass, indicators of muscular quality, such as strength, power, and functional performance, appear to be more closely related to cognitive outcomes. Although the current evidence remains limited, these findings support the potential of resistance training oriented toward improving muscular quality as a relevant strategy to promote cognitive health during aging.

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