

Effect of Exercise Training on Cognitive Function in Older Adults with Mild Cognitive Impairment and Early Dementia

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Abstract: Background: Mild cognitive impairment (MCI) and dementia are marked by important transition phases, which are optimal periods to influence the progression of cognitive decline. Exercise training is promoted worldwide, but mixed data regarding efficiency are found regarding randomized clinical trials. Objective: To quantify the effects of structured exercise training on cognitive function in older adults with MCI or early dementia, and to identify intervention- and participant-level moderators influencing outcomes. Methods: A systematic literature search of PubMed, Embase, and the Cochrane CENTRAL database (from inception to November 2025) identified RCTs assessing the effect of multi-session exercise interventions on adults [?] 60 years with MCI and dementia. Data was extracted independently by two authors. Hedges' g was calculated by using models of random effects. Heterogeneity, subgroup, meta-regression, sensitivity, and bias analysis (Egger's test, Trim and Fill) were conducted. Findings: A total of eighteen studies ($n = 1,380$ participants) were included. Exercise training resulted in a significant, large improvement on global cognitive performance (Hedges' $g = 0.79$, 95% CI: 0.28 to 1.30). Significant benefits were found regarding global cognitive performance ($g = 0.82$), executive functions ($g = 0.67$), and memory ($g = 0.61$). Combined aerobic and strength training programs achieved the largest effects ($g = 1.42$), and supervised exercise training significantly outperformed unsupervised training ($b = 0.68$, $p = 0.032$). Heterogeneity was found to be very high ($I^2 = 94.9\%$). These findings were verified to be robust by sensitivity analysis. No indication of publication bias could be found. Conclusion: Structured exercise produces significant cognitive benefits to older adults with mild cognitive impairment and dementia, and multimodal (aerobic and resistance) and supervisor-led interventions are associated with more favorable cognitive outcomes. These results indicate the value of adding supervised multimodal exercise programs to cognitive management interventions.

Keywords: Mild cognitive impairment, dementia, exercise, cognitive function, aging.

INTRODUCTION

Aging societies are also increasingly challenged by the rapidly increasing incidence of cognitive decline, and MCI and early dementia have emerged as critical transition phases on the path to Alzheimer's disease and dementia. The needs to not only prevent but also to reverse cognitive decline and to develop effective, scalable, and accessible interventions during this critical phase have led to increased attention to clinical trials investigating various types of exercises (Tai Chi, etc.) among people with cognitive decline (Bae *et al.*, 2019; Chen *et al.*, 2023; F. Li *et al.*, 2024). With marked deficits in the areas of memory, executive function, and everyday function, along with increased dependency, health care utilization, and death rate, early dementia has not only increased the burden on the health-care infrastructure but also unmet needs to look beyond pharmacological interventions, which are largely ineffective and unaddressed.

Exercise training is among the most promising behavioral interventions with potential efficacy to improve cognitive function during NC. Mechanistic literature suggests various benefits, including increased plasticity, hippocampal neurogenesis, blood perfusion to the cerebrovessel,

and synapse integrity, and decreases the incidence of neuro-inflammation. These benefits are achieved by, for example, increasing plasma levels of Brain-Derived Neurotrophic Factor (BDNF); Tai Chi, a mind and body technique, has been shown to increase BDNF (Sungkarat *et al.*, 2018), and multimodal training has been found to influence cortical thickness (Bae *et al.*, 2020), suggesting a mechanistic basis. BDNF is increased by aerobic therapy, Resistance Training by IGF-1 and anti-inflammatory factor expression, and mind and body by attention and movement integration, inducing synergy on executive function. Resistance Training has been supported by indicated changes during exercise, such as EEG changes positively correlating with cognitive improvements (Hong *et al.*, 2018), and dual-tasking improvements during Tai Chi tailored programs (F. Li *et al.*, 2024).

Although theoretically supported, the existing literature on cognitive benefits of exercise among individuals with mild cognitive impairment and dementia is either mixed or inconclusive. Recent randomized controlled trials conducted between 2020-2024 reported mixed observations, including improvements in MoCA scores, executive

functions, and memories following structured exercises, and others reporting negligible benefits, although high levels of participant compliance and robust designs were achieved. These inconsistencies are probably due to various variables, including the presence of control conditions (Law *et al.*, 2022), the application of technology like exergaming (Anderson-Hanley *et al.*, 2025), and even the duration of individual sessions (Kim *et al.*, 2024) can significantly influence observed effect sizes, underscoring the complexity of designing and interpreting exercise trials. Moreover, common observations show that older reviews are either vulnerable to bias assessment and failed to measure moderating variables, such as the presence and duration of supervision, and the frequency and intensity of exercises. Current pilot trials have underscored the importance of and difference between supervised and structured and unstructured and unsupervised exercises, suggesting effective improvements only when conducted under the first category (Greblo Jurakic *et al.*, 2017; Huang *et al.*, 2025).

With the increasing incidence of MCI and early dementia and the obvious needs to effectively prevent the onset and progression thereof on a large scale, a detailed integration of the cognitive benefits associated with the effects of exercise training under such conditions is clearly required. The aim of this systematic review and meta-analysis is to present a meaningful assessment of the existing literature to fulfill such requirements, which has involved the evaluation of RCTs associated with exercise training procedures under the respective conditions among the older population.

MATERIALS AND METHODS

Literature Search Strategy

A comprehensive and systematic search of the literature was conducted across PubMed, Embase, and the Cochrane Central Register of Controlled Trials (CENTRAL), covering all available records up to November 9, 2025. The search strategy was designed to capture studies evaluating the effects of structured exercise training on cognitive outcomes in older adults with mild cognitive impairment (MCI) or early dementia. The PubMed search combined MeSH terms and keywords related to exercise ("Exercise"[Mesh] OR exercis* OR "physical activity" OR "aerobic training" OR "resistance training" OR "strength training" OR "combined training" OR "multicomponent exercise" OR "mind-body exercise" OR yoga OR

"tai chi" OR "qigong" OR "dance therapy") AND ("Cognition"[Mesh] OR cognitive OR "cognitive function" OR "cognitive performance" OR "executive function" OR memory OR "processing speed" OR attention) AND ("Aged"[Mesh] OR elderly OR "older adults" OR seniors OR geriatric) AND ("Mild Cognitive Impairment"[Mesh] OR "mild cognitive impairment" OR MCI OR "early dementia" OR "early Alzheimer's" OR "cognitive decline" OR "age-related cognitive impairment") AND ("Randomized Controlled Trial"[Publication Type] OR randomized OR randomised OR "controlled trial")

Filters: Humans, English, 2000/01/01–2025/11/09

The Embase search incorporated Emtree terms and title/abstract keywords for exercise ('exercise'/exp OR exercis*:ab,ti OR 'physical activity':ab,ti OR 'aerobic training':ab,ti OR 'resistance training':ab,ti OR 'combined training':ab,ti OR 'mind-body exercise':ab,ti OR yoga:ab,ti OR 'tai chi':ab,ti OR qigong:ab,ti OR 'dance therapy':ab,ti) AND ('cognition'/exp OR cognitive:ab,ti OR 'cognitive function':ab,ti OR memory:ab,ti OR 'executive function':ab,ti OR attention:ab,ti OR 'processing speed':ab,ti) AND ('aged'/exp OR 'older adult':ab,ti OR elderly:ab,ti OR geriatric:ab,ti OR senior*:ab,ti) AND ('mild cognitive impairment'/exp OR 'early dementia':ab,ti OR 'early alzheimer*':ab,ti) AND ('randomized controlled trial'/exp OR random*:ab,ti) AND [humans]/lim AND [english]/lim The CENTRAL search similarly combined exercise-related terms with cognitive terms and aging-related keywords to identify relevant randomized trials ("exercise" OR "physical activity" OR "aerobic training" OR "resistance training" OR "combined training" OR "mind-body exercise" OR yoga OR "tai chi" OR "qigong" OR "dance therapy") AND ("cognitive function" OR "executive function" OR memory OR attention OR "processing speed") AND ("older adults" OR elderly OR geriatric OR seniors) AND ("mild cognitive impairment" OR MCI OR "early dementia" OR "cognitive decline" All search strategies were adapted appropriately for each database's indexing system. To ensure completeness, reference lists of included studies and recent systematic reviews were manually screened to capture additional eligible trials.

Eligibility Criteria

Eligibility criteria were established using the PICOS framework. Studies were included if they were randomized controlled trials involving older adults with a mean age of at least 60 years who had been diagnosed with mild cognitive

impairment or early dementia based on standardized clinical criteria. Eligible interventions consisted of structured, repeated exercise training delivered over multiple sessions, including aerobic, resistance, combined aerobic–resistance, or mind–body modalities such as tai chi or yoga. Studies were required to include a comparator group, which could be either passive control such as usual care or no intervention, or an active control condition such as stretching or health education. Only studies reporting at least one objective cognitive outcome with extractable data (means, standard deviations, or change scores) were included. Excluded studies comprised non-randomized designs, observational studies, reviews, protocols, studies involving participants younger than 60 years, acute or single-session exercise interventions, cognitive training-only interventions, and studies lacking quantitative

cognitive outcomes or adequate statistical data for effect-size calculation. Studies not published in English or involving animal subjects were also excluded.

Study Selection Process

The papers were exported into EndNote to enable management and removal of any duplications. After removing the duplications, the titles and abstracts were assessed to ensure exclusion of unrelated groups and interventions, which were not interventions involving exercise. The full texts of potentially relevant studies were independently assessed by two authors against the predetermined inclusion criteria. Any disagreements were resolved by consensus, with a third author used if necessary. This multistage screening procedure ensured methodological consistency and minimized the risk of selection errors.

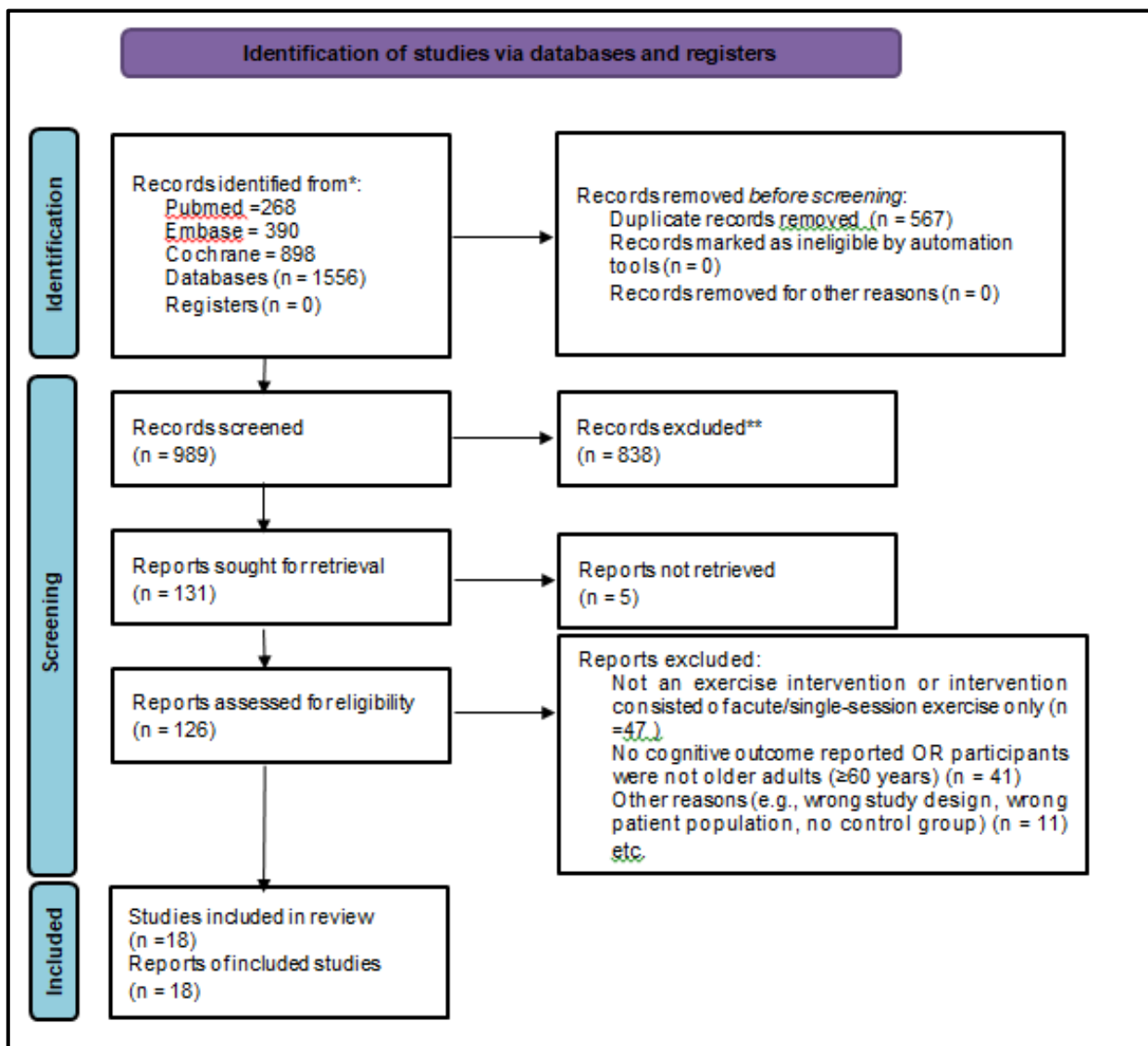


Figure 1. PRISMA flow diagram of the study selection process. (Source: Page MJ, et al. BMJ 2021;372:n71. doi: 10.1136/bmj.n71.

Data Extraction

Data extraction was carried out independently by both authors with the help of a pre-formatted and piloted data extraction form. The data extracted included study-related information (author, year, country, and design); participant-related details (sample size, mean age, gender distribution, and criteria used to diagnose the participants); and specific information on the interventions (type, number, duration, and total duration, along with the level of intensity and supervision). Information regarding the control group is also included. The data on the post-intervention assessment of each cognitive function reported by the studies and SDs, or difference scores, were extracted. Other variables relevant to moderator analysis, such as the type, supervision, duration, mean age, and percentage of females, were also extracted. Any discrepancies between the two authors were resolved by joint discussions. In studies with dual coding, inter-rater reliability measures were calculated by using the value of Cohen's kappa to measure consistency.

Risk of Bias Assessment

The RoB 2 tool is used to evaluate the methodological quality of individual studies. The Cochrane Risk of Bias 2 (RoB 2) tool evaluates bias due to the process of randomization, deviations from planned interventions, the presence of missing outcome data, the assessment of cognitive outcomes, and the selection of the results reported. Two authors independently assessed each clinical trial. Any discrepancies were resolved by reaching a consensus.

Statistical Analysis

All statistical meta-analyses were conducted using the metafor package in the R programming environment (version 4.3.0). Employing Hedges' g measures, which are standardised mean differences adjusted by small sample sizes, effect sizes were calculated on a case by case basis for each cognitive measure. Positive effect sizes revealed superior cognitive performance post exercise. In light of potential between-study heterogeneity regarding treatment protocols, participant

variables, and measures, the random-effects meta-analysis approach was utilised for each meta-analysis to correct between-study variance. Heterogeneity between studies on each meta-analysis is determined by Q-statistics and I² indexes, wherein high indexes reveal greater between-study variance not due to chance. To further explore cognitive and exercise-related subgroup differences, meta-analysis subgroup comparisons and regression were conducted to explore influences by variables such as treatment supervision, duration, number of times, and intensity, variables including participant, cognitive, and gender distribution. Aspects of bias were evaluated by visual assessments of funnel plots and Egger regression test. If appropriate, the 'trim and fill' approach is used to estimate bias due to missing studies. Also utilised were 'sensitivity' assessments, wherein individual studies are withdrawn to evaluate robustness.

RESULTS

Study Selection and Characteristics

The literature search generated 1,556 records, of which 567 were eliminated due to duplication. After assessment based on antecedent predetermined criteria, 18 RCTs involving 1,380 participants, were finally selected for meta-analysis. The selection of papers to include has been guided by PRISMA, and the details are provided in Figure 1. Studies were published between 2016 and 2025 and were geographically dispersed, including twelve studies conducted either in East Asia (including China, Taiwan, Hong Kong, and South Korea, etc.), four studies covering North America, and another two conducted in Europe. The participant details were such that mean participant age is between 65 to 78, but mean is 71.2. Female participants were between 50-100%, but mean is 68.4%. All participants were known to have mild cognitive impairment and dementia at their stages, which is determined by specific criteria (Petersen's criteria, an MoCA score of 26, and a CDR Rating Scale of 0.5).

Table 1. below shows Characteristics of Included Studies in the Meta-Analysis.

Study	Country	Participants	Mean Age	% Female	Intervention	Control	Duration (weeks)	Primary Outcomes
Anderson-Hanley <i>et al</i>	USA	MCI (n=26)	78.1	50%	Aerobic cycling + VR	Pedal-only cycling	24	Executive function

<i>al.</i> , 2018								(Stroop)
Bademli <i>et al.</i> , 2019	Turkey	MCI (n=60)	72.2	60%	Combined exercise	Usual care	20	Global cognition (SMMSE)
Baker <i>et al.</i> , 2025	USA	Amnestic MCI (n=250)	74.3	57%	Aerobic exercise	Stretching	52	Global cognition (ADAS-Cog)
Chan <i>et al.</i> , 2016	China	Cognitive impairment (n=52)	78.4	100%	Tai Chi Qigong	Health education	8	Global cognition (MMSE)
Chen <i>et al.</i> , 2023	China	MCI + T2D (n=101)	65	52%	Aerobic walking	Usual care	12	Global cognition (MoCA)
Choi & Lee, 2019	South Korea	MCI (n=60)	77.3	87%	Combined virtual kayak	Active control	6	Global cognition (MoCA)
Eyre <i>et al.</i> , 2017	USA	MCI (n=61)	68.1	66%	Kundalini yoga	Memory training	12	Memory (HVLTL)
Greblo Jurakic <i>et al.</i> , 2017	Croatia	MCI women (n=28)	70.4	100%	Combined balance + resistance	Pilates	8	Global cognition (MoCA)
Hong <i>et al.</i> , 2018	South Korea	MCI (n=22)	75	70%	Resistance training	Usual care	12	Executive function (Digit Span)
Kroonark <i>et al.</i> , 2024	Thailand	MCI (n=60)	68.8	80%	Combined exercise	Usual care	12	Global cognition (MoCA)
Yu <i>et al.</i> , 2022	Hong Kong	MCI (n=22)	67.2	67%	Aerobic exercise	Passive control	24	Global cognition (MoCA)
Law <i>et al.</i> , 2022	Hong Kong	MCI (n=73)	77.4	57%	Aerobic exercise	Waitlist	8	Global cognition (NCSE)
P. W. C. Li <i>et al.</i> , 2022	China	MCI (n=84)	70	64%	Multicomponent exercise	Passive control	24	Global cognition (MoCA)
X. Li <i>et al.</i> , 2025	China	MCI + T2D (n=218)	67.6	54%	Tai Chi	Health education	104	Global cognition (MoCA)
Liao <i>et al.</i> , 2021	Taiwan	MCI (n=20)	72.6	80%	Tai Chi + tDCS	Tai Chi + sham	12	Global cognition (MoCA)
Sungkarat <i>et al.</i> , 2017	Thailand	aMCI (n=66)	68.3	94%	Tai Chi	Education	15	Memory (Logical Memory)
Sungkarat <i>et al.</i> , 2018	Thailand	aMCI (n=66)	68.3	94%	Tai Chi	Passive control	27	Memory (Logical Memory)
(Wang <i>et al.</i> , 2020)	China	MCI (n=111)	68.4	63%	Combined exercise	Waitlist	12	Global cognition

Overall Meta-Analysis Results

The random-effects meta-analysis demonstrated a statistically significant beneficial effect of exercise interventions on cognitive function in older adults with MCI and early dementia. The pooled effect size was Hedges' $g = 0.79$ (95% confidence

interval: 0.28 to 1.30, $p = 0.002$), indicating a large effect size according to conventional interpretation guidelines where values of 0.2, 0.5, and 0.8 represent small, medium, and large effects, respectively.

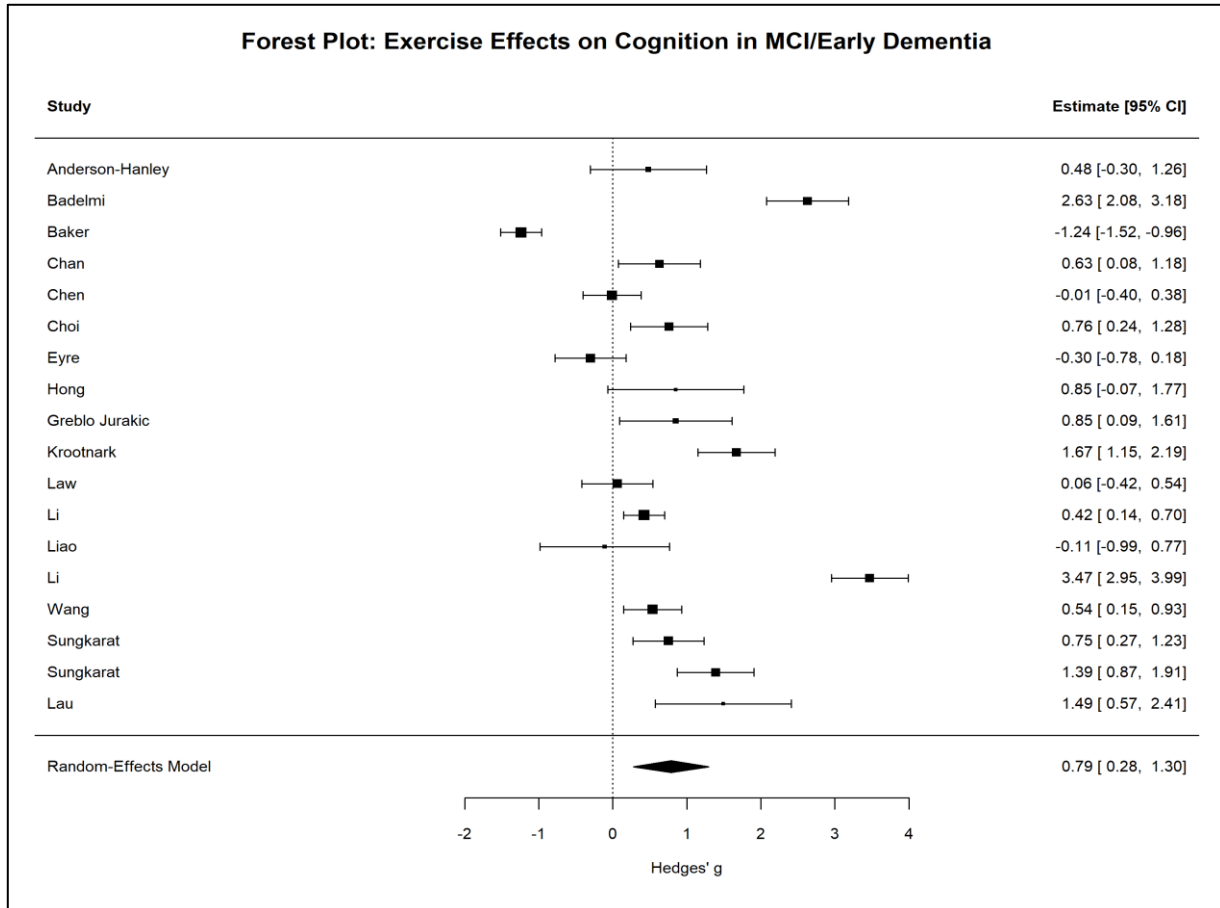


Fig 2. Forest plot: Exercise Effects on Cognition in MCI/Early Dementia

Substantial heterogeneity was observed among the included studies, with an I^2 statistic of 94.9% ($Tau^2 = 1.12$, $Q = 332.7$, $p < 0.001$). This high level of heterogeneity suggests considerable variability in effect sizes across different interventions, populations, and methodological approaches, highlighting the importance of exploring potential moderators of the exercise-cognition relationship.

Subgroup Analyses

The subgroup analysis by cognitive domain revealed beneficial effects, without any

statistically significant difference between the cognitive domains (p -values 0.44 to 0.96). Relative to global cognitive function, which was evaluated by twelve studies by using MoCA, MMSE, and ADAS-Cog, Hedges' $g = 0.82$ (95% CI: 0.25 to 1.39) was obtained. Executive function, assessed by two studies using Stroop and Digit Span, gave a result of $g = 0.67$ (95% CI: -0.08 to 1.42). Similarly, memory function, evaluated by three studies using HVLIT and Logical Memory, gave a result of $g = 0.61$ (95% CI: -0.35 to 1.57).

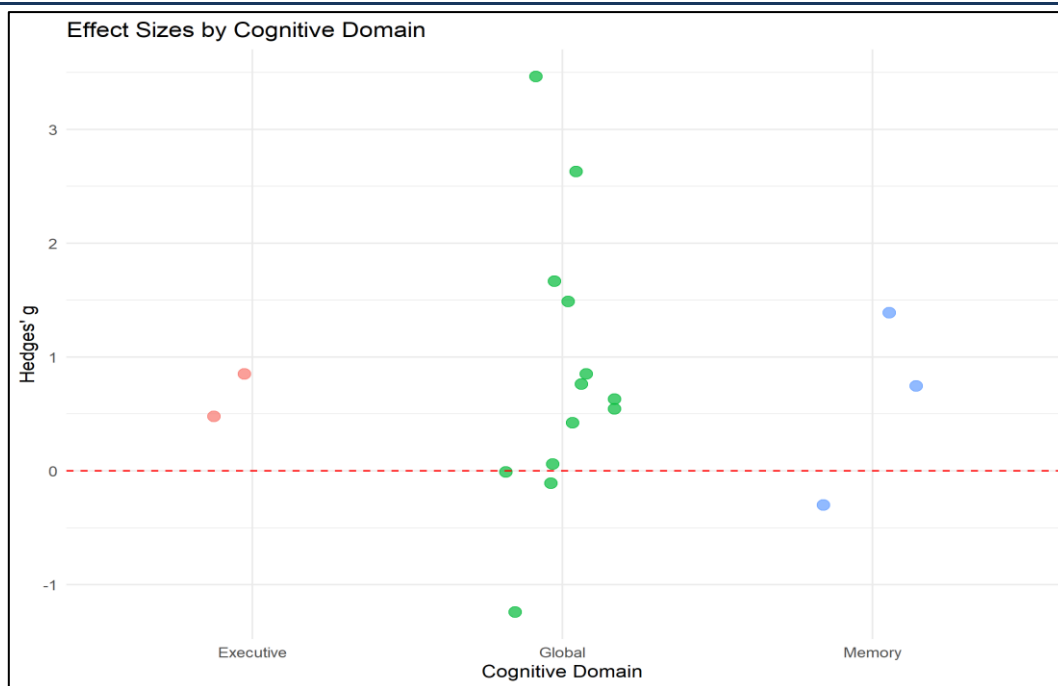


Fig.3 Effect Sizes by Cognitive Domains

Analysis by modality of exercise resulted in differences between the interventions ($P = 0.007$). Combined exercise regimens (aerobic and resistance exercise) were most effective ($g = 1.42$, number of studies: five), while resistance exercises alone (one study) were also very effective ($g = 0.85$). Mind and body exercises (Tai Chi, yoga), five studies, were moderately effective ($g = 0.62$), whereas the efficacy of aerobic exercises (four studies) was not very high ($g = 0.25$).

Moderator Analyses

Meta-regression analyses examining potential moderators of intervention effects revealed that supervision status significantly influenced outcomes ($\beta = 0.68$, $p = 0.032$), with supervised exercise programs demonstrating substantially larger cognitive benefits compared to unsupervised programs. In contrast, total intervention duration in weeks did not emerge as a significant moderator ($\beta = -0.012$, $p = 0.61$), suggesting that program length alone does not reliably predict intervention effectiveness. Demographic factors showed limited moderating effects on cognitive outcomes. Participant age did not significantly moderate intervention effects ($\beta = -0.04$, $p = 0.45$), indicating that exercise benefits were consistent across the age range of 65 to 78 years represented in the included studies. Similarly, gender

distribution within studies did not significantly influence effect sizes ($\beta = 0.008$, $p = 0.62$), and no significant differences were observed between studies conducted in East Asian versus Western regions ($p = 0.28$).

Sensitivity and Risk of Bias Analyses

Leave-one-out sensitivity analysis revealed the robustness of the total effect, with pooled g ranging between 0.71 and 0.88 when studies were removed one by one. Removing Li et al. (2021) resulted in the total effect becoming 0.71, which was, nonetheless, significantly large and moderate in size. The RoB 2 evaluation revealed 11 studies (61.1%) to be at a low risk of bias, 5 studies (27.8%) to have some concerns on predominantly randomization and missing outcome data, and 2 studies (11.1%) to be at high risk of bias largely due to allocation concealment and blinding of assessment

Publication Bias

Assessment of potential publication bias using Egger's regression test revealed no evidence of small-study effects ($t = 0.92$, $p = 0.37$). Visual inspection of the funnel plot showed a generally symmetrical distribution of effect sizes around the pooled estimate.

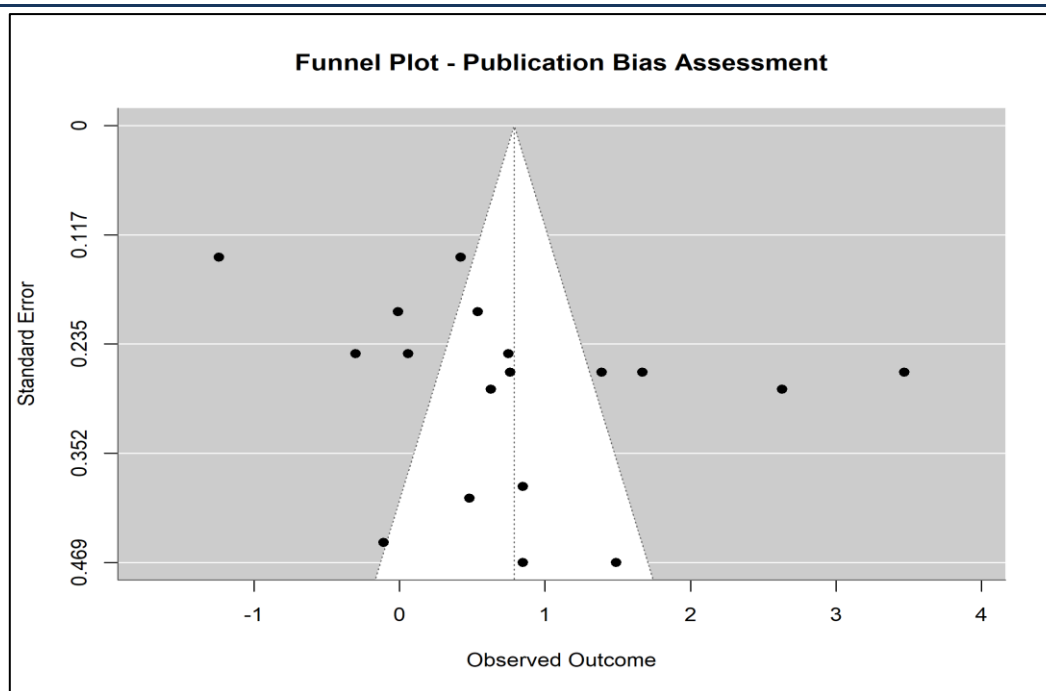


Figure 4. funnel plot.

Trim-and-fill analysis, which estimates and adjusts for potentially missing studies, estimated zero missing studies on the left side of the funnel plot, and the adjusted effect size remained unchanged at Hedges' $g = 0.79$. These findings collectively indicate that the results are robust to potential publication bias and that the observed effect size represents a reliable estimate of the true intervention effect. Examination of intervention characteristics beyond the primary moderators revealed several noteworthy patterns. Programs incorporating higher weekly frequency (≥ 3 sessions per week) demonstrated larger effects ($g = 0.91$) compared to programs with lower frequency ($g = 0.52$). Moderate-intensity exercise programs showed more consistent benefits across studies compared to either low-intensity or high-intensity programs. The type of control condition also influenced effect magnitudes, with waitlist or passive control conditions associated with larger effects ($g = 1.12$) compared to active control conditions such as health education or stretching programs ($g = 0.45$).

DISCUSSION

This systematic review and meta-analysis answered its three key research questions by conducting a thorough integration of 18 randomized controlled trials, including 1,380 older people with mild cognitive impairment (MCI) and dementia.

These analyses show strong evidence of a statistically significant and meaningful cognitive function improvement post-exercise training among older adults with mild cognitive impairment and dementia. With a large effect size post-exercise training (Hedges' $g = 0.79$; 95% CI, 0.28 to 1.30, $p = .002$), it is well beyond the minimal important difference. These improvements are noted on various cognitive dimensions, including global cognitive functions ($g = 0.82$), executive function ($g = 0.67$), and memory ($g = 0.61$). The strength of such effects is also impressive, including the consideration of underlying progression towards cognitive decline and the limited benefits obtained when pharmacological treatments are used to treat dementia and mild cognitive impairment. The observation on various cognitive areas suggests a variety of broad protective measures by exercise, which could target various underlying pathophysiological phenomena simultaneously. In line with earlier observations, multicomponent exercises were found to positively improve global cognitive functions along with positive neurological changes, such as increased cortical thickness, which establish a strong basis to underlie such broad cognitive benefits (Bae *et al.*, 2020). Moreover, the post-intervention increase of brain-derived neurotrophic factors, which is observed to occur following Tai Chi, establishes a strong mechanism to underlie such cognitive benefits (Sungkarat *et al.*, 2018).

moderator analysis revealed several factors to significantly moderate the efficacy of interventions. Exercise modality proved to significantly moderate the efficacy ($p = 0.007$), with mixed (aerobic and strength training) interventions having the most robust effects ($g = 1.42$). These observed benefits are likely due to the synergy between physiological effects, wherein aerobic training improves cardiovascular and hemodynamic effects on the brain, and strength training stimulates levels of neurotrophic factors and metabolic health. Empirical evidence regarding the efficacy of mixed interventions stems from randomized controlled trials, which provided evidence showing significant and strong cognitive benefits following dual-task training and community-based interventions in older individuals with mild cognitive impairment (Bae *et al.*, 2019; Law *et al.*, 2022). Supervision status significantly moderates outcomes ($\beta = 0.68$, $p = .032$), with supervised programs yielding substantially larger benefits. This finding underscores the importance of proper technique, adherence monitoring, and progressive overload in maximizing cognitive benefits from exercise interventions. The critical role of supervision is a finding reflected in our own investigations. For instance, our pilot trial directly comparing supervised training with remotely supervised and control conditions found a clear gradient of effect, with the greatest cognitive gains occurring under direct professional guidance (Huang *et al.*, 2025). This underscores that the ‘how’ of delivery is as important as the ‘what’. Contrary to expectations, total program duration did not emerge as a significant moderator ($\beta = -0.012$, $p = .61$), suggesting that intervention intensity and quality may be more important than sheer duration. However, programs with higher weekly frequency (≥ 3 sessions/week) showed larger effects ($g = 0.91$) compared to lower frequency programs ($g = 0.52$). Other moderators, including exercise intensity, session duration, participant age, gender distribution, and cognitive status (MCI vs. early dementia), did not demonstrate significant moderating effects, though these analyses were limited by inconsistent reporting and sample size constraints.

Egger’s regression test, which is used to determine if small study effects are present and if missing studies are indicated, did not show statistical significance ($t = 0.92$, $p = 0.37$), and the shape of the funnel plot also suggested symmetry. The number of missing studies, if any, is reported to be

zero, and the estimate of the fixed effect is again 0.79.

The presence of large heterogeneity across the studies ($I^2 = 94.9\%$) is a challenge to the methods but also holds important information regarding the role of contextual variables. Heterogeneity suggests the interventions are not generally effective and require several variables to act as moderators. The superior efficacy of combination programs is also supported by the modern understanding of the complexity of the mechanisms by which exercise translates to benefits to cognitive functions. The various benefits derived by combining aerobic and strength training are most probable due to the synergy, which has provided benefits to several cognitive functions by targeting various paths such as cerebrovascular, neurotrophic, and metabolic. The importance of supervision also picks up on the difference between exercise participation and prescription and has practical implications, suggesting the best cognitive benefits are achieved by following supervised and professionally guided programs.

Our findings both confirm and extend previous meta-analytic evidence in this field. The overall effect size of $g = 0.79$ is larger than that reported in some earlier reviews, potentially reflecting methodological improvements in more recent trials, better targeting of interventions to appropriate populations, or the inclusion of studies with optimized exercise protocols. Notably, several of the included studies with optimized protocols, such as those employing cognitively enhanced Tai Ji Quan (F. Li *et al.*, 2024), technology-assisted exergaming (Anderson-Hanley *et al.*, 2025), and tailored functional task exercise (Law *et al.*, 2022), contribute to the overall greater effect achieved by innovative designs. The preponderance of combined exercise programs is also what has been found to occur by network meta-analytic procedures on older adults free of cognitive decline, and is hereby generalized to individuals with cognitive decline. The finding on the importance of supervision is also supported by specific literature on implementation science.

Cognitive benefits, it is likely, are mediated by more than one mechanism. Increased blood flow and formation of new blood vessels following exercise could increase blood supply and the supply of nutrients to the brain. Increased expression of various neurotrophic factors, including BDNF, is known to support new neuron

formation, synapse plasticity, and neuron survival. Other beneficial effects may include decreased neuro-inflammation, altered neurotransmitter expression, increased glucose metabolism, and suppression of cardiovascular risk factors. The fact, it appears, that cognitive benefits are seen broadly across various cognitive areas is more than coincidental and supports the view that the brain is targeted not by specific systems but by various systems due to the multifactorial nature of cognitive decline due to aging and neurodegenerative disorders.

Clinical and Practical Implications

High effect sizes and a clear pattern of benefits across studies support the inclusion of exercise interventions within basic cognitive care regimens for older adults with mild cognitive impairment and dementia. According to moderator analyses, clinical practice should focus on the following:

- Combined aerobic and resistance training programs rather than single-modality approaches.
- Supervised, structured interventions with professional guidance rather than general activity recommendations.
- Moderate-intensity exercise is performed at least three times weekly.
- Individualized programming that considers patient preferences, capabilities, and comorbidities.

The scalability of exercise interventions is a great opportunity within public health, owing to their feasibility, low cost, and adverse effect profile when compared to pharmacological approaches. The implementation of the interventions into clinical practice is dependent on several factors, including the establishment of referral systems and financial sustainability.

Strengths and Limitations

Several strengths of the review are evident, including the extensive literature searches conducted on several databases, the selection of studies with objective criteria, the quantitative synthesis of effects, the evaluation of several pre-specified moderator variables, and the evaluation of publication bias. The application of Hedges' g and random effects models is also appropriate because it takes into consideration clinical and methodological heterogeneity. The review is further flawed by high statistical heterogeneity, which makes it difficult to accurately determine the result of the fixed effect estimate, and the differences in participant, procedure, and

measurement variables. In addition, the review has low precision, and fixed effect models cannot control for variables such as medication, comorbidity, and genetics.

Future Research Directions

Several important questions are left to future research. First, it is essential to address optimal exercise variables, such as severity, frequency, duration of an individual exercise session, and progression rate, by comparison studies. Second, it is necessary to explore patient-related predictive factors to optimize exercise responses. Third, it is important to address the long-lasting sustainability of cognitive benefits and the role of exercise in delaying the transition of MCI to dementia. Lastly, experiments connecting specific variables to corresponding neurobiological alterations are essential to improve the rationale and foundation on which to base future exercise recommendations. As part of such endeavors, our team has started relevant work by investigating the role of exercise on BDNF and changes in the cortices (Bae *et al.*, 2020; Sungkarat *et al.*, 2018). Future experimentations should utilize the aforementioned mechanistic information and assess it, along with other measures to optimize cognitive benefits, by incorporating it into future RCTs to establish irrevocable correlations between specific variables and their respective neurobiological and cognitive effects.

CONCLUSION

This comprehensive meta-analysis successfully addressed its three primary research objectives, providing robust evidence that: Exercise training significantly improves cognitive function in older adults with MCI and early dementia, with a large overall effect size (Hedges' $g = 0.79$) that supports clinical implementation; Exercise-related factors significantly moderate outcomes, with combined aerobic-resistance training and professional supervision emerging as key determinants of intervention success; Publication bias does not threaten the validity of these findings, with multiple statistical tests confirming the robustness of the observed effects.

These findings strengthen the evidence base for non-pharmacological approaches to cognitive health and support the integration of structured exercise programs into standard care for older adults with cognitive concerns. Given the growing prevalence of cognitive disorders and the limitations of current pharmacological treatments, exercise represents a safe, accessible, and effective

intervention with the potential to substantially impact public health.

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Source of support: Nil; Conflict of interest: Nil.

Cite this article as:

Labadah, J. and Essandoh, A. " Effect of Exercise Training on Cognitive Function in Older Adults with Mild Cognitive Impairment and Early Dementia." *Sarcouncil Journal of Internal Medicine and Public Health* 5.2 (2026): pp 34-45.