

Review article

## Comparative Efficacy of Different Aquatic Exercise Modalities on Cognitive Function in The Elderly: A Systematic Review and Network Meta-Analysis

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### Abstract

Cognitive decline poses a major challenge in aging populations, and aquatic exercise may offer cognitive benefits while reducing injury risk. This systematic review and network meta-analysis (NMA) evaluated the comparative effectiveness of different aquatic exercise modalities on cognitive function in older adults. Major electronic databases were searched from inception to January 2026 for randomized controlled trials (RCTs) examining aquatic exercise and cognitive outcomes in adults aged  $\geq 60$  years; studies were independently assessed by two reviewers. Interventions were categorized as aquatic cognitive-motor exercise, aquatic aerobic exercise, aquatic high-intensity interval training (HIIT), and aquatic strength training. A frequentist NMA was used to synthesize direct and indirect evidence, with effect sizes expressed as standardized mean differences (SMDs). Nine RCTs (involving 324 participants) met the inclusion criteria. Aquatic cognitive-motor exercise showed the highest probability of being the most effective intervention (SUCRA [surface under the cumulative ranking curve] = 85.36%), followed by aquatic aerobic exercise (61.44%) and aquatic strength training (51.80%). Aquatic HIIT (49.12%) and land-based exercise (48.34%) demonstrated moderate effects. Among all modalities only aquatic cognitive-motor exercise showed statistically significant improvements compared with non-exercising controls. Based on the currently available limited evidence, aquatic cognitive-motor exercise may be the most effective aquatic modality for improving cognitive function in older adults. All aquatic exercise modalities provided cognitive benefits at least comparable to those of land-based exercise. The findings suggest that cognitive engagement, rather than exercise intensity alone, may be crucial for maximizing the efficacy of the intervention. However, as only nine RCTs were included, these findings should be interpreted with caution given the limited size and density of the evidence network.

**Key words:** Aquatic exercise, cognition, aquatic cognitive-motor exercise, older.

### Introduction

The United Nations' World Population Prospects 2022 predicts that the proportion of the elderly population will rise to 16% by 2050 (United Nations Department of Economic and Social Affairs, Population Division, 2022). This demographic shift poses significant challenges for aging societies worldwide. Although aging does not inevitably cause severe cognitive deterioration, it does increase the risk of

cognitive decline, which, if left unaddressed, can markedly impair older adults' quality of life. Moreover, cognitive decline may progress into serious neurodegenerative conditions such as Alzheimer's disease and dementia (Kazazi et al., 2018).

Physical exercise can mitigate cognitive decline in older adults through mechanisms such as enhanced neurogenesis, increased cerebral blood flow, reduced inflammation, and synaptic plasticity (De Miguel et al., 2021). It also supports brain networks for executive function, attention, and memory (Won et al., 2021), with aerobic exercise improving episodic memory (Johansson et al., 2022) and resistance training enhancing inhibitory control (Liu-Ambrose et al., 2010). However, older adults are prone to exercise-related injuries due to physical vulnerabilities. Aquatic exercise addresses this by leveraging water properties—buoyancy, hydrostatic pressure, and resistance—to enhance neuromuscular function in those with neurological conditions, whether through active forms such as swimming or passive immersion (Deng et al., 2024; Becker, 2009). Immersion at chest level improves blood circulation, venous return, and cerebral blood flow (Carter et al., 2014), while buoyancy reduces joint impact, prolongs balance reaction time, and alleviates fall-related anxiety (Kwok et al., 2024). Recent evidence further indicates that aquatic exercise may particularly benefit episodic memory and overall cognitive health in aging populations (Tang et al., 2022; Waller et al., 2016).

Common aquatic interventions for cognitive enhancement in older adults include: 1) aerobic exercise, involving continuous rhythmic activities (e.g., aquagym or walking) to boost cardiovascular fitness and cerebral blood flow; 2) high-intensity interval training (HIIT), alternating intense bursts with rest to enhance metabolic and vascular responses; 3) strength training, using water resistance or equipment to promote muscle strength, neurotrophic factors, and neuronal connectivity; and 4) cognitive-motor exercise, combining cognitive tasks (e.g., memory exercises) with motor activities to foster neuroplasticity and functional integration (Maneemai et al., 2024; So et al., 2024). Aerobic exercise may facilitate A $\beta$  clearance across the blood-brain barrier by increasing low-density lipoprotein receptor-related protein-1 levels (Khodadadi et al., 2018). Resistance training promotes cerebral blood supply, enhances the expression of neurotrophic factors, and strengthens neuronal connectivity (Sáez de Astasu et al.,

2017). Cognitive-motor exercise simultaneously activates cognitive functions and motor systems, promoting neuroplasticity and functional integration (Cai et al., 2014).

Although various aquatic exercise modalities show promise for cognitive improvement in older adults, no head-to-head randomized controlled trials have compared their relative effectiveness. This gap hinders the selection of optimal interventions for clinicians and researchers. Network meta-analysis (NMA) addresses this by integrating direct and indirect evidence from RCTs, allowing simultaneous multi-intervention comparisons, effect rankings, and precise insights despite sparse direct data—extending pairwise meta-analysis for evidence-based geriatric decisions. Therefore, this review aimed to conduct a NMA to evaluate the effects of different aquatic exercise interventions on cognitive function in older adults.

## Methods

### Protocol registration

This study was registered in the International Prospective Register of Systematic Reviews database (PROSPERO) under registration identification number CRD42025641350, in accordance with the Preferred Reporting Items for Systematic Reviews and Network Meta-Analyses (PRISMA-NMA) guidelines (Hutton et al., 2015).

### Information Sources and Study Selection

The literature search was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines and the PRISMA extension for searching (PRISMA-S). The search aimed to identify randomized controlled trials (RCTs) evaluating the efficacy of aquatic exercise on cognitive function in elderly populations. Electronic databases were searched from inception through January 2026, with no language restrictions. Databases searched included Web of Science, PubMed, Embase, Cochrane Library, and China National Knowledge Infrastructure.

Additionally, hand searches of the reference list from included studies, relevant systematic reviews, and meta-analyses were conducted to identify any additional eligible trials.

Key search term groups were as follows (Supplementary Table 1):

Population (Elderly): "elderly" OR "older adults" OR "aged" OR "seniors" OR "geriatric" OR "aging" OR "elder".

Intervention (Aquatic Exercise): "aquatic exercise" OR "aquatic therapy" OR "hydrotherapy" OR "water-based exercise" OR "aquatic rehabilitation" OR "water aerobics" OR "swimming therapy" OR "swim".

Outcome (Cognitive Function): "cognitive function" OR "cognition" OR "cognitive impairment" OR "cognitive performance" OR "neuropsychological tests".

The primary outcome was the pre- to post- intervention difference in global cognition measured by validated cognitive assessments, including but not limited to the Mini-Mental State Examination (MMSE), MMSE-K, Montreal Cognitive Assessment (MoCA) (T-score), DSST,

HDS-R, SDMT, Raven's Progressive Matrices test, and the Stroop color-word test. These outcomes were incorporated into the NMA. The categorization of activities included in this network meta-analysis was based on the descriptions provided in the original included studies.

Inclusion criteria were: 1) RCTs involving elderly participants (mean age  $\geq 60$  years); 2) interventions involving aquatic exercise therapy; 3) controls consisting of no intervention or other exercise therapies; 4) assessment of cognitive outcomes using validated tools (e.g., MMSE, MoCA, or domain-specific tests); and 5) sufficient data for effect size calculation.

Exclusion criteria included: 1) non-RCT designs; 2) studies on non-elderly populations; 3) interventions without an aquatic component; 4) studies lacking cognitive outcome measures; and 5) case reports, descriptive studies, or conference proceedings.

Reasons for exclusion at the full-text stage were documented. The PRISMA flow diagram details the number of records identified, screened, and included.

### Data extraction

Once the search strategy was defined and executed across the databases, all retrieved articles were imported into reference management software (EndNote) to remove duplicates. Two reviewers independently screened all titles and abstracts of the search results for relevant articles. Full texts were then evaluated with respect to the inclusion and exclusion criteria. For any non-English publications identified during this process, two bilingual investigators independently assessed eligibility and extracted data, with relevant sections translated into English to ensure accurate interpretation. Any discrepancies were adjudicated by a third author.

Two researchers extracted data from the included studies using a standardized extraction form. Key extracted fields included first author, publication year, country/region, exercise modality, sample size (experimental and control groups), participant demographics (age and sex), intervention characteristics (type, duration, frequency, and intervention period), and primary outcome measures.

For studies with missing data, corresponding authors were contacted via email. If no response was received after the first attempt, a follow-up email was sent one week later. Studies with unresolved missing data after two contact attempts were excluded from the analysis.

### Quality evaluation and risk of bias assessment

The methodological quality and risk of bias of the 9 included studies were assessed using the Cochrane Risk of Bias tool (RoB 2.0) for randomized trials (Sterne et al., 2019). The RoB 2.0 tool, as applied to network meta-analyses (NMAs), was employed to evaluate individual study bias across five core risk domains, each addressing specific methodological aspects of trial design, conduct, and reporting. These domains are: 1) Bias arising from the randomization process; 2) Bias due to deviations from intended interventions; 3) Bias due to missing outcome data; 4) Bias in measurement of the outcome; and 5) Bias in the selection of the reported result (Sterne et al., 2019). Each domain was rated as "low risk," "some concerns" or "high risk".

Disagreements during the assessment were resolved through discussion among reviewers.

### Statistical analysis

The primary objective of this NMA was to investigate the effects of different aquatic exercise modalities on cognitive function in older adults. Given the unique structure of NMAs (Li et al., 2014), all experimental groups were defined as aquatic exercise interventions, while control groups included no intervention or alternative exercise therapies. The experimental and control groups were defined based on the original study's designation for studies comparing two aquatic exercise groups.

NMAs were conducted according to the following steps. First, heterogeneity across studies was evaluated using the  $I^2$  statistic and the  $p$ -value from the Cochran's  $Q$  test. Interpretation followed established thresholds. An  $I^2$  less than 30% was considered nonimportant heterogeneity, between 30% and 50% was considered moderate, between 50% and 75% was considered substantial, and 75% or higher was considered high heterogeneity (Higgins and Thompson, 2002). Funnel plots were used to assess potential publication bias or small-study effects (Hutton et al., 2014).

Second, the assumption of transitivity was examined through comparison of clinical and methodological features across included studies, and no major violations were observed. The network structure was grounded in graph theory, where interventions are represented as nodes and direct trial comparisons as edges, forming a connected evidence network (Li et al., 2014). The core principle lies in visualizing direct and indirect evidence integration through topological mapping. The network must satisfy connectivity, ensuring that at least one path exists between any two nodes. Nodes are weighted according to the number of trials, including the respective treatments. The larger the node's size and the thicker the lines, the more studies are involved (Li et al., 2014).

As a form of meta-analysis, NMA synthesizes both direct and indirect comparisons. Direct comparisons are derived from RCTs that explicitly evaluate two interventions, with effects pooled via meta-analysis to generate posterior distributions of relative efficacy (Thorlund and Mills, 2012). Indirect comparisons are based on the premise that indirect effect estimates are obtained from effect estimates from two comparisons sharing a common comparator (Han et al., 2022), and are enabled by shared comparators and constructed within a frequentist framework by modeling the network as a connected graph where interventions (nodes) are linked via direct or indirect pathways (Hutton et al., 2014). A node-splitting analysis was applied to evaluate potential incoherence between direct and indirect evidence. Thus, the validity and reliability of pairwise comparisons in NMA have been extensively validated across multiple studies (Hutton et al., 2014). The output provides probabilistic rankings of interventions, confidence intervals for pairwise effects, and surface under the cumulative ranking curve (SUCRA) values. The confidence in the evidence for all comparisons was assessed using the CINeMA framework. This framework evaluates six domains (within-study bias, reporting bias, indirectness,

imprecision, heterogeneity, and incoherence) to ultimately rate the confidence in the evidence for each pair of interventions as High, Moderate, Low, or Very low (Nikolakopoulou et al., 2020).

Since all outcome measures in this study were continuous variables, the SMD with 95% CIs was selected as the effect size metric (Borenstein et al., 2010). All analyses were conducted using the R language (version 4.2.2) in the RStudio environment, employing the following packages: data manipulation: "tidyr", "dplyr"; network visualization: "igraph"; meta-analysis: "netmeta", "meta", "metafor". These packages were utilized to perform heterogeneity assessments, consistency evaluations, and comparative effect size analyses for the primary outcomes derived from cognitive assessment tools (MMSE, MMSE-K, MoCA T-score, DSST, HDS-R, SDMT, Raven's Progressive Matrices test, and Stroop color-word test) (Béliveau et al., 2019).

## Results

### Study Selection

A total of 903 records were included. After the removal of duplicates, the titles and abstracts of 391 records were screened, and the full texts of 21 articles were evaluated. Nine studies met the inclusion criteria and were included in this review and the network meta-analysis (Carral and Perez, 2007; Dunlap et al., 2024; Jang et al., 2021; Kang et al., 2020; Kooncumchoo et al., 2025; Kwok et al., 2024; Ploydang et al., 2023; Sato et al., 2015; So et al., 2024). The detailed selection process for including these trials is presented (Figure 1).

### Quality assessment of the included studies

The results of the risk of bias assessment are reported in Figure 2. The assessment of trial quality was performed independently by two authors, according to the Cochrane Risk of Bias 2.0 (RoB 2) tool for randomized trials. Based on the RoB 2 assessment, none of the included studies were judged to be high risk of bias. Consequently, the pre-specified sensitivity analysis excluding high-risk studies could not be performed. In most studies, researchers were involved in the intervention delivery and outcome assessments, and the participants were not blinded to group allocation. After evaluating the risk of bias in the studies, six studies were considered to have some concerns arising from deviations from intended interventions (Carral and Perez, 2007; Jang et al., 2021; Kang et al., 2020; Kwok et al., 2024; Ploydang et al., 2023; Sato et al., 2015). Overall, six studies were assessed as having some concerns (Dunlap et al., 2024; Kang et al., 2020; Kwok et al., 2024; Ploydang et al., 2023; Sato et al., 2015; So et al., 2024), and three studies were assessed as having low risk (Carral and Perez, 2007; Jang et al., 2021; Kooncumchoo et al., 2025).

### Characteristics of the included studies

This study included a total of nine randomized controlled trials (RCTs) conducted across diverse regions: two from Hong Kong, China (Kwok et al., 2024; So et al., 2024), two from South Korea (Jang et al., 2021; Kang et al., 2020), two from Thailand (Kooncumchoo et al., 2025; Ploydang et al., 2023), and one each from Spain (Sato et al., 2015), the

United States, and Japan (Carral and Perez, 2007). Among these, three studies enrolled exclusively female participants (Carral and Perez, 2007; Kang et al., 2020; Kwok et al., 2024), while the remaining six included both male and female populations (Dunlap et al., 2024; Jang et al., 2021; Kooncumchoo et al., 2025; Ploydang et al., 2023; Sato et al., 2015; So et al., 2024), with two studies focusing on mild cognitive impairment (Kooncumchoo et al., 2025; Ploydang et al., 2023), and another focusing on type II diabetes (Ploydang et al., 2023), collectively encompassing 324 participants aged 60 - 90 years.

Aquatic exercise interventions were categorized into six modalities, and some studies involved more than one modality: 1) Aquatic high-intensity interval training, 3 studies (Carral and Perez, 2007; Jang et al., 2021; Kwok et al., 2024), 2) Aquatic aerobic exercise, 4 studies (Kang et al., 2020; Kooncumchoo et al., 2025; Ploydang et al., 2023; So et al., 2024), 3) Aquatic cognitive-motor exercise, 3 studies (Dunlap et al., 2024; Kooncumchoo et al., 2025; Sato et al., 2015.), 4) Aquatic strength training, 2 studies (Carral and Perez, 2007; Sato et al., 2015.), 5) Land-based exercise, 3 studies (Jang et al., 2021; Kwok et al., 2024; So et al., 2024), and 6) Nonexercising control, 3 studies (Dunlap et al., 2024; Kang et al., 2020; Ploydang et al., 2023).

Intervention parameters varied in session duration (20 - 60 minutes/session, predominantly 45 minutes), frequency (1 - 3 sessions/week, mostly 2 - 3 sessions), and intervention length (6 - 12 weeks, with 12 weeks as the most common duration), incorporating formats such as aquatic-only, land-based, or hybrid training regimens (Table 1).

### Risk of bias and publication bias

The heterogeneity analysis results indicated an  $I^2$  statistic of 47.9% (95% CI: 0.0% - 75.8%), a Q statistic of 15.36 (df = 8), with a corresponding p-value of 0.0525. The results suggest moderate heterogeneity among studies ( $I^2 \approx 48\%$ ); however, the 95% confidence interval is wide, ranging from no heterogeneity (0%) to substantial heterogeneity (75.8%). The p-value of the Q test is slightly greater than 0.05, indicating that the heterogeneity does not reach statistical significance.

### Network characteristics

To assess the efficacy of aquatic exercise for improving cognitive function in older adults, the network characteristics incorporated six interventions with seven direct pairwise comparisons (Figure 3). All trials were two-arm clinical trials. Participant distribution across intervention groups was as follows: Nonexercising control (39 participants), Land-based exercise (57 participants), Aquatic cognitive-motor exercise (concurrent or alternating aquatic exercise with cognitive training; 43 participants), Aquatic aerobic exercise (64 participants), Aquatic high-intensity interval training (repeated cycles of high-intensity aquatic exercise interspersed with lower-intensity recovery periods, typically comprising 6 - 10 intervals; 83 participants), and Aquatic strength training (strength and endurance training; 38 participants). The most frequently evaluated intervention was Aquatic aerobic exercise, reflecting their prominence in current aquatic exercise research for cognitive enhancement.

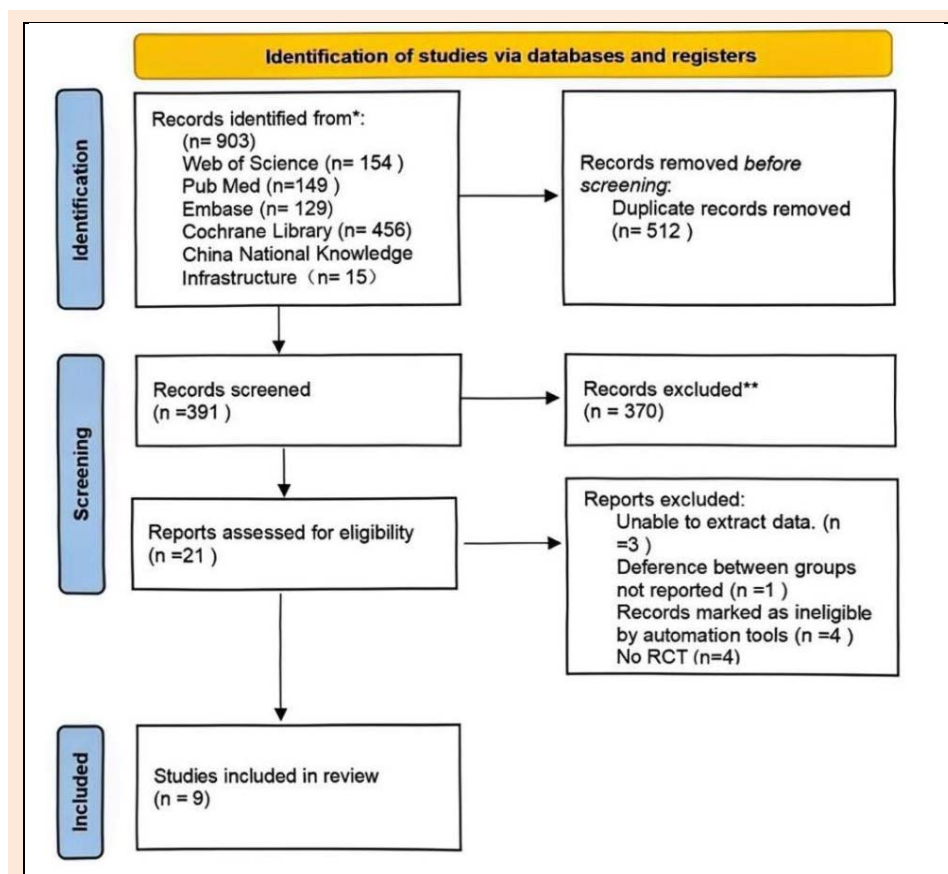


Figure 1. Flow chart.

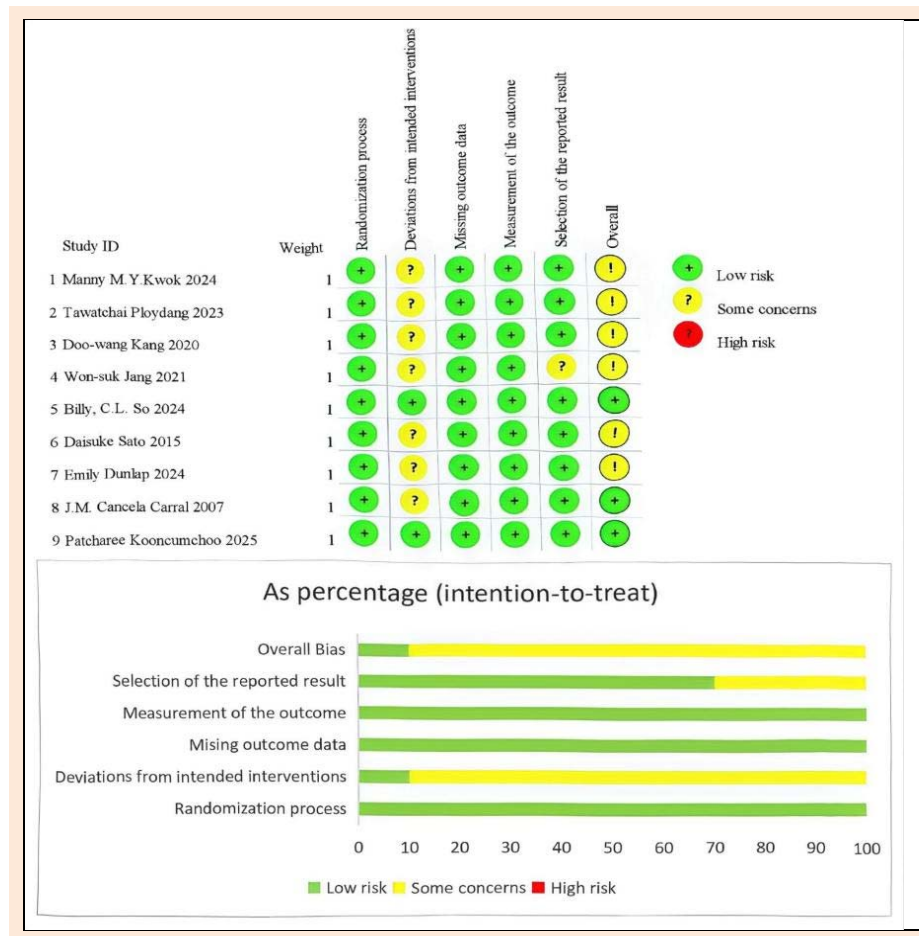


Figure 2. The results of the risk of bias assessment.

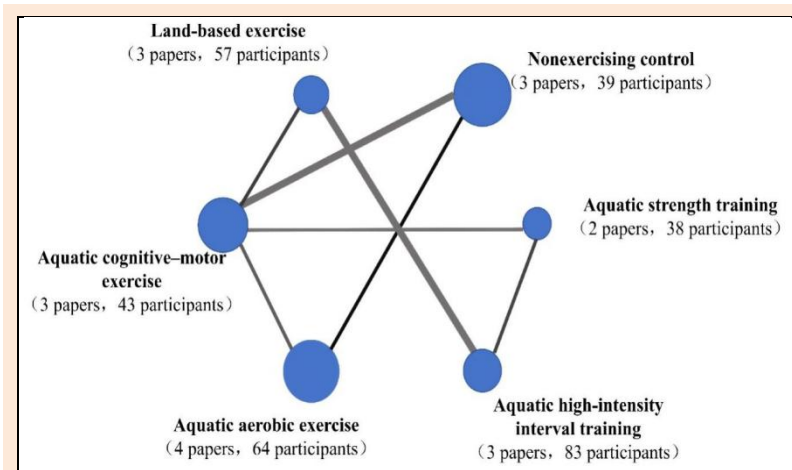


Figure 3. Network meta-analysis plot for the assessment of aquatic exercise. Nodes are weighted according to the number of trials, including the respective treatments. The larger the node's size and the thicker the lines, the more studies are involved. Effect of aquatic exercises on cognition.

The consistency assumption was tested by comparing direct and indirect evidence, looking for overall differences, using a node-splitting model. The pairwise comparisons in the global analysis revealed no significant differences between direct and indirect evidence (all p-values > 0.05) (Table 2). The consistency between direct and indirect evidence across multiple intervention comparisons was further evaluated: the direct estimate ranged from -1.77 to 1.72; the indirect estimate ranged from -1.34 to 1.89; and the network estimate ranged from -1.26 to 1.76,

further supporting the consistency between direct and indirect evidence across the examined comparisons (Figure 4).

Although SUCRA rankings indicate relative probability of being the best intervention, they do not quantify absolute clinical effect. Based on the results of the frequentist analysis, we evaluated the relative ranking of all six interventions using two complementary metrics: the P-score, which estimates the average probability of one treatment being better than the others, and the SUCRA (Surface Under the Cumulative Ranking Curve), which reflects the

probability of a treatment being among the best (Figure 5). The SUCRA data synthesis showed that Aquatic cognitive-motor exercise reached the highest probability of being the best treatment, with a SUCRA value of 85.36% and a P-score of 86.05%. Aquatic aerobic exercise ranked second, with a SUCRA of 61.44% and a P-score of 65.71%, followed by Aquatic strength training (SUCRA = 51.80%, P-score = 50.72%) and Aquatic high-intensity interval training (SUCRA = 49.12%, P-score = 46.99%). Land-based exercise showed a SUCRA of 48.34% and a P-score of 46.13%. All exercise interventions demonstrated substantially higher probabilities of improving cognitive outcomes compared to the Nonexercising control (SUCRA = 3.94%, P-score = 4.40%). Confidence in the evidence for all comparisons in this network meta-analysis was rated as High using the CINeMA framework (Supplementary Figure 1).

A fixed-effect model was employed in the meta-analysis comparing the effects of exercise interventions versus the non-exercising control on cognition in older adults (Figure 6). The standardized mean difference (SMD) results for the various interventions relative to the control group were as follows: Aquatic strength training (F) [SMD = -0.13, 95% CI (-1.00, 0.74)], Land-based exercise (B) [SMD = 0.24, 95% CI (-0.58, 1.06)], Aquatic

high-intensity interval training (E) [SMD = 0.40, 95% CI (-0.46, 1.25)], Aquatic cognitive-motor exercise (C) [SMD = 0.48, 95% CI (0.02, 0.95)], and Aquatic aerobic exercise (D) [SMD = 0.51, 95% CI (-0.08, 1.11)]. The horizontal axis ranged from -1 to 1, representing standardized mean difference values. Notably, only Aquatic cognitive-motor exercise (C) demonstrated a statistically significant difference, as its confidence interval did not include zero. The remaining comparisons showed non-significant effects.

**Table 2. Pairwise direct and indirect comparison to assess consistency in the unspecified cognitive impairment analysis by node-splitting model.**

Pairwise	Direct Evidence	Indirect Evidence	p-Value
C:A	1.72	1.89	0.88
D:A	0.8	0.63	0.88
B:C	-1.77	-0.56	0.41
B:E	-0.13	-1.34	0.41
C:D	1.09	0.92	0.88
C:F	0.5	1.71	0.41
E:F	0.07	-1.14	0.41

A: Nonexercising control; B: Land-based exercise; C: Aquatic cognitive-motor exercise; D: Aquatic aerobic exercise; E: Aquatic high-intensity interval training; F: Aquatic strength training.

**Table 1. Characteristics of the studies included in the network.**

Authors	Country	Sample Size	Intervention Method Intervention: Control	Age	Weeks	Weekly Exercise Frequency	Time	Exercise Program	Cognitive Assessment Test	Other Indicators
Kwok et al. (2024)	Hong Kong, China	I: 39	Aquatic HIIT	I: 66.3±5.0 C: 65.7±6.2	8	2	20 min	Deep water run or run: weeks 1-2 (10 bouts of 2-minute exercise at 80%-85% HRmax + 1-minute active recovery 50% HRmax), weeks 3-5 (10 bouts of 2-minute exercise at 85%-90% HRmax + 1-minute active recovery at 50% HRmax, weeks 6-8 (10 bouts of 2-minute exercise at 90%-95% HRmax + 1-minute active recovery at 50% HRmax. NR	MMSE MoCA	Cardiorespiratory fitness Triglycerides Total Cholesterol HDL LDL
		C: 31	Land-based exercise							
Ploydang et al. (2023)	Thailand	I: 17	Aquatic aerobic exercise	I: 69±3.7 C: 69.2±5.3	12	3	60 min	Nordic Walking in Water: weeks 1-6(40%–50%HRR), weeks 6-12(50%–60% HRR).  Usual care	MMSE MoCA Stroop color test (s) Trail Making Test Part B (s)	Vascular function Cerebrovascular function Biochemical variables
		C: 17	Nonexercising							
Kang et al. (2020)	South Korea	I: 17	Aquatic aerobic exercise	I: 73.8±4.0 C: 73.4±4.2	16	3	60 min	Jogging, jumping jacks, cross country, pendulum, and other similar exercises: weeks 1-4 (40%–50%HRR), weeks 5-8 (50%–60% HRR), weeks 9-12 (60%–65%HRR), weeks 13-16 (65%–70%HRR).  Usual care	MMSE-K	BDNF IGF-1 VEGF BMI
		C: 10	Nonexercising							
Jang et al. (2021)	South Korea	I: 13	Aquatic HIIT	I: ≥65 C: ≥65	12	3	40 min	Aquatic walking, jumping jack, standing jump, and other similar exercises: Weeks1-12  NR	MMSE-K	Triglycerides HDL LDL IGF-1
		C: 12	Land-based exercise							

I: Intervention, C: Control, HIIT: high-intensity interval training, NR: Not Reported, HDL: High-Density Lipoprotein, LDL: Low-Density Lipoprotein,

**Table 1. Continue...**

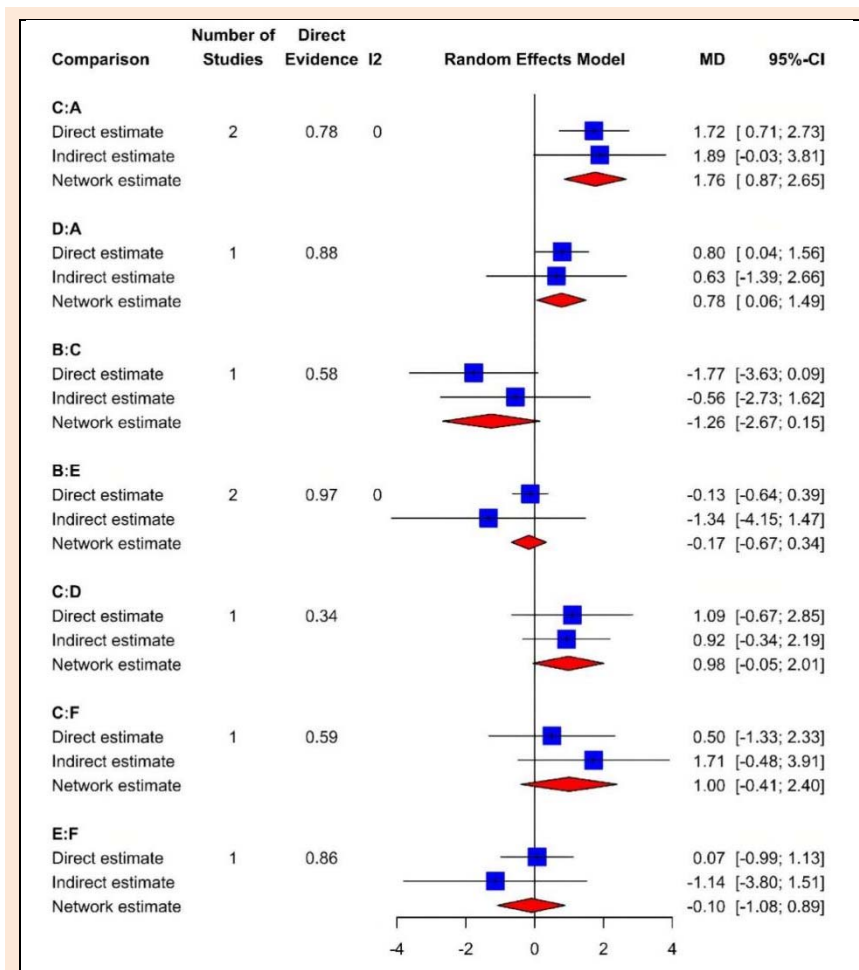
Authors	Country	Sample Size	Intervention Method Intervention: Control	Age	Weeks	Weekly Exercise Frequency	Time	Exercise Program	Cognitive Assessment Test	Other Indicators
So et al. (2024)	Hong Kong, China	I: 14	Aquatic aerobic exercise	I: 65.9±0.8 C: 65.9±1.0	NR	NR	30 min	Both groups performed a 20-minute running exercise. In the Land group, participants ran at a speed and treadmill grade predetermined from a prior incremental test. In the Aquatic group, participants were required to run in the desired cadence, which was monitored by a metronome.	DSST	Cerebral blood flow
		C: 14	Land-based exercise							
Sato et al. (2015)	Japan	I: 7	Aquatic cognitive–motor exercise	I: 69-76 C: 69-86	10	1	50 min	10 minutes of walking, 30 minutes of aquatic cognitive exercises, and 10 minutes of water-based stretching and relaxation.	HDS-R	Physical functions
		C: 7	Aquatic strength training					10 minutes of walking, 30 minutes of strength and step exercises (including striding movements), and 10 minutes of water-based stretching and relaxation.		
Dunlap et al. (2024)	USA	I: 13	Aquatic cognitive–motor exercise	I: 83±7 C: 81±8	8	3	45 min	Aquatic exercise and cognitive training: Weeks 1-8 (10-minute warm-up; 25-minute training phase; 10-minute cool-down)	Stroop color-word test	Neurotrophic factors Functional mobility Balance
		C: 12	Nonexercising					Usual care		
Kooncumchoo et al. (2025)	Thailand	I: 23	Aquatic cognitive–motor exercise	I: 69.4±3.7 C: 68.3±3.3	12	3	60 min	10-min warm-up, 40-min of aerobic exercise, simultaneously with cognitive training involving recalling a number and color, and a 10-min cool-down.	MoCA	Two MST BaPWV (cm/s)
		C: 23	Aquatic aerobic exercise					10 min of warm-up, 40-min of aerobic exercise(hip flexion and abduction, side back kick, etc), and 10-min cool-down.		
Carral et al. (2007)	Spain	I: 31	Aquatic strength training	I: 68.5±3.40 C: 68.3±3.5	9	2	45 min	Aquatic exercise: Weeks 1-9 (6 of muscular resistance in the water, 9 of moving in different positions, etc.) + Strength Training: weeks 5-9 (aerobic resistance and mobility of the joints, body-building, etc)	MMSE	Quality of life Cardiorespiratory fitness
		C: 31	Aquatic HIIT					Aquatic exercise: Weeks 1-9 (6 of muscular resistance in the water, 9 of moving in different positions, etc.) + Calisthenic Training: Weeks 5-9(walking, aerobic resistance, etc)		

I: Intervention, C: Control, HIIT: high-intensity interval training, NR: Not Reported, HDL: High-Density Lipoprotein, LDL: Low-Density Lipoprotein.

**Publication Bias Analysis**

Publication bias was assessed using a funnel plot. Visual inspection revealed that the data points were approximately symmetrically distributed around the vertical midline, indicating a low likelihood of significant publication bias. This was further supported by the statistical results, which showed that the majority of p-values were greater than

0.05. Although the p-value for Study 7 reached statistical significance (p = 0.008), and Study 3 approached it (p = 0.054), all other comparisons were non-significant (p = 0.114 - 0.919). The absolute t-values across all studies ranged from 0.10 to 2.74, with degrees of freedom varying from 10.10 to 65.55 (Supplementary Figure 2), training day.



**Figure 4.** Forest plot for global inconsistency. The mean difference is in the Cognitive Assessment test for older adults, and the closer the value is to zero, the greater the consistency. **A:** Nonexercising control; **B:** Land-based exercise; **C:** Aquatic cognitive-motor exercise; **D:** Aquatic aerobic exercise; **E:** Aquatic high-intensity interval training; **F:** Aquatic strength training. Ranking of intervention.

**Discussion**

The findings of the present study indicate that Aquatic cognitive-motor exercise, which integrates aquatic exercise with cognitive training within a single protocol, appears to be the most effective aquatic exercise modality for improving cognition in older adults. The second most effective intervention was Aquatic aerobic exercise. Although aquatic high-intensity interval training (HIIT) is currently a popular exercise modality among older adults, it appeared less effective for cognitive improvement in the present analysis. These findings have important implications for intervention planning, given that a greater proportion of existing studies have examined aquatic aerobic exercise or aquatic HIIT as strategies to improve cognition in older adults (Figure 3). Accordingly, clinicians and researchers may consider adopting Aquatic cognitive-motor exercise to enhance cognitive function in older adults.

Multiple studies have also confirmed the effectiveness and reliability of combining cognitive and motor exercises in healthy and cognitively impaired populations. Yang et al. (2020) reported that combined interventions can improve cognitive and physical functions in older adults with mild cognitive impairment (MCI). Venegas et al. (2024) comparing 13 different interventions, identified

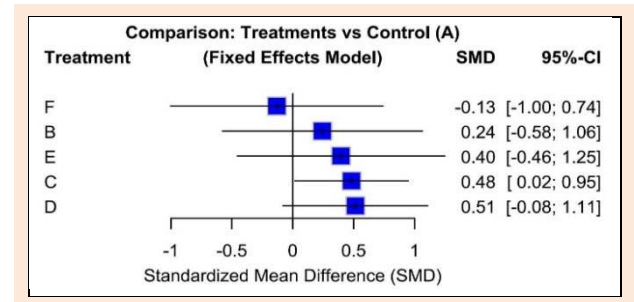
physical-cognitive exercise as one of the most effective nonpharmacological treatments for cognitive impairment. Yu et al. (2025) found that longer-term multi-domain cognitive-motor training may improve cognitive function in patients with amnesic MCI. Moreover, aquatic cognitive-motor exercise demonstrated a statistically significant advantage over the non-exercising control in the present NMA (Figure 6), providing further support for these findings.

The underlying mechanisms driving these observations are theoretically and biologically plausible. Cognitive-motor exercise enhances physical capacities, such as aerobic fitness, through its motor component, thereby improving brain structure and function. Simultaneously, the cognitive training component selectively stimulates higher-order brain functions, primarily improving memory, visuospatial abilities, attention, and other cognitive domains in individuals with mild cognitive impairment (MCI). These two components work synergistically, complementing and reinforcing distinct neural functions to produce a combined effect on cognition, maximizing intervention efficacy, and improving cognitive performance (Anderson-Hanley et al., 2018; Park et al., 2019; F. Yu et al., 2018). Cognitive-motor exercise has been shown to benefit cognitively frail populations by increasing gray matter

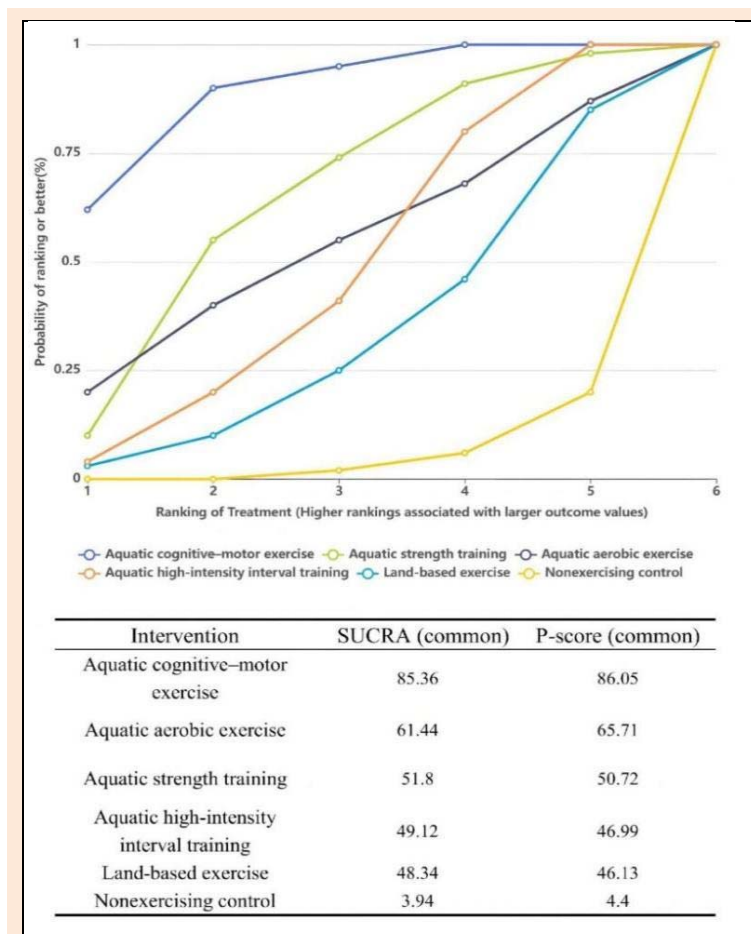
density, improving functional efficiency in specific brain regions, enhancing functional connectivity within neural networks, modulating dopamine receptor density, and preserving white matter integrity (Toril et al., 2014). Furthermore, the combination of physical and cognitive training can synergistically induce neuroplasticity, promoting neurogenesis and synaptogenesis (Di Benedetto et al., 2017; Venegas-Sanabria et al., 2024). Notably, aquatic immersion, due to hydrostatic pressure, redistributes blood toward the upper body and increases cerebral blood flow. This has been confirmed by elevated blood flow velocity in the middle cerebral artery and posterior cerebral artery, providing a plausible explanation for the cognitive-enhancing mechanisms of aquatic exercise (Carter et al., 2014). Beyond hydrostatic effects, the thermal properties of water (e.g., warmth) may further promote relaxation, reduce psychological stress, and facilitate neural recovery, potentially amplifying cognitive benefits (Shukla, 2025). In addition, the physical properties of water, such as buoyancy and resistance, specifically augment cognitive-motor exercise by reducing joint stress and enabling safer dual-tasking compared to land-based equivalents, allowing greater focus on cognitive elements while minimizing fall risk and fatigue (Dunlap et al., 2024).

Cognitive-motor exercise is particularly relevant to activities of daily living, as many routine activities like crossing streets inherently require simultaneous cognitive and motor processing. Rezola-Pardo et al.'s study with 188

cognitively frail older adults further substantiated these findings, demonstrating that dual-task exercise targeting essential cognitive functions for daily living (such as attention, executive functions, and semantic memory) outperformed exercise alone in improving gait speed, physical function, cognition, and mood (Rezola-Pardo et al., 2019). Compared with conventional physical exercise, cognitive-motor exercise demonstrates superior efficacy in enhancing cognition-related activities, including optimizing postural control and motor performance, thereby elevating quality of life through this dual-benefit approach (Khan et al., 2022; Tao et al., 2022).



**Figure 6.** Interval plot comparing the effect on global cognition between aquatic interventions and control in older adults. **A:** Nonexercising control; **B:** Land-based exercise; **C:** Aquatic cognitive-motor exercise; **D:** Aquatic aerobic exercise; **E:** Aquatic high-intensity interval training; **F:** Aquatic strength training.



**Figure 5.** Surface under the cumulative ranking plot and ranking table comparing the effects of aquatic exercise on Cognitive Assessment test. Comparing each of the exercise therapies with control.

Other aquatic exercise methods besides Aquatic cognitive–motor exercise are also worth discussing and analyzing. Previous studies have demonstrated that aerobic exercise enhances cardiorespiratory function in older adults (De Miguel et al., 2021), and that the level of cardiorespiratory fitness is positively correlated with brain plasticity following exercise training (Berchicci et al., 2013; Perissiou et al., 2018). Nevertheless, Aerobic exercise may not represent the optimal intervention for improving cognition in older adults. One possible explanation is that the transition from exercise to cognitive–motor exercise induces significantly greater activation of the prefrontal cortex, thereby requiring greater cognitive engagement than aerobic exercise alone (Ding et al., 2024). This study also found aerobic exercise to be superior to strength training, which is consistent with the 2019 World Health Organization (WHO) guidelines titled "Risk reduction of cognitive decline and dementia" (Bull et al., 2020). In contrast, Wang et al.'s prior network meta-analysis reported that resistance exercise outperformed aerobic exercise—a discrepancy that may be attributable to differences in sample size, population characteristics, and the specific focus of the present analysis on aquatic strength training as a distinct subtype of resistance exercise (Wang et al., 2019).

The SUCRA value for aquatic HIIT in this review was 49.12%. While HIIT has consistently demonstrated favorable outcomes in other literature (Oliveira et al., 2024). The unique physiological and safety considerations of older adults may make it difficult to achieve the requisite training intensities in an aquatic environment. Differences between land and water environments could also contribute to its slightly inferior performance. More research on aquatic high-intensity interval training is needed to verify and further explore its effects. The close proximity between the SUCRA value of aquatic high-intensity interval training (49.12%) and that of the land-based group (48.34%) indicates that aquatic exercise can achieve at least comparable, if not superior, effectiveness to land-based training.

Several limitations of the present review warrant future consideration. First, the evidence base is limited, with only nine studies included and relatively small sample sizes, which may reduce the precision and reliability of SUCRA rankings. Second, the absence of long-term follow-up data precluded assessment of the sustainability of cognitive benefits, as well as subgroup analyses for specific populations such as those with MCI. Third, disparities in post-intervention sample sizes across studies may limit the generalizability and comparability of findings, and variations in exercise parameters (e.g., frequency, intensity, session duration) across trials may compromise the stability and comparability of the results. Clinical heterogeneity among included populations—ranging from healthy older adults to those with MCI or type 2 diabetes—was not formally examined through subgroup analyses, due to the insufficient number of studies within each subgroup. Furthermore, the aggregation of diverse cognitive outcomes into a single composite effect size using (SMD) introduces conceptual heterogeneity, as the included instruments — global screening tools (e.g., MMSE, MMSE-K, MoCA T-score, HDS-R) and domain-specific measures (e.g., DSST and

SDMT for processing speed, Raven's Progressive Matrices for fluid reasoning, and the Stroop color-word test for executive function and selective attention)—assess overlapping, but distinct cognitive constructs. This heterogeneity, not fully captured by statistical indices, may compromise the construct validity, interpretability, and reliability of the pooled effect estimates. Additionally, most individual effect estimates were imprecise, as reflected by wide confidence intervals, suggesting insufficient statistical power rather than true null effects. Finally, the funnel plot's ability to detect publication bias is inherently constrained in a small, sparse network. These limitations highlight important priorities for future research without undermine the overall clinical relevance of the present findings.

The finding that all aquatic exercise modalities demonstrated cognitive benefits at least comparable to those of land-based exercise, offering a safe and effective alternative for older adults with mobility limitations, osteoarticular diseases, or fear of falling. In clinical practice, a hybrid "water-land combined" model may also be considered to leverage complementary stimuli, including exercise variety, engagement, and neuroplasticity. This study reveals gaps in the existing evidence regarding long-term effects, standardized protocols, and population-specific outcomes. Accordingly, clinicians are encouraged to systematically document training parameters and individual responses when implementing aquatic exercise interventions, thereby contributing to real-world evidence accumulation and supporting the development of more precise actionable clinical guidelines in the future.

## Conclusion

In conclusion, this network meta-analysis is the first to comparatively evaluate multiple aquatic exercise modalities and suggests that aquatic cognitive–motor exercise may represent the most promising aquatic intervention for improving cognitive function in older adults (SUCRA = 85.36%), with aquatic aerobic exercise emerging as a viable alternative (SUCRA = 61.44%). Importantly, all aquatic exercise modalities yielded cognitive benefits at least as great as those of land-based exercise, supporting the integration of aquatic programs into exercise guidelines for aging populations. The finding that popular aquatic HIIT showed modest cognitive effects (SUCRA = 49.12%) suggests that intensity alone may be insufficient and that cognitive engagement appears critical for maximizing cognitive benefits. Future research priorities may include: 1) standardizing aquatic cognitive–motor training protocols with defined cognitive tasks and progression parameters; 2) conducting adequately powered RCTs with long-term follow-up; 3) exploring mechanisms through neuroimaging and biomarker studies; and 4) investigating effectiveness in specific populations including those with mild cognitive impairment and dementia, and 5) Explore the efficacy of aquatic exercise in older adults across the cognitive spectrum (from healthy to impaired).

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The datasets generated during the current study are not publicly available but are available from the corresponding author upon reasonable request. The authors declare that they have no conflict of interest. All experimental

procedures were conducted in compliance with the relevant legal and ethical standards of the country where the study was carried out. The authors declare that no Generative AI or AI-assisted technologies were used in the writing of this manuscript.

## References

- Anderson-Hanley, C., Barcelos, N. M., Zimmerman, E. A., Gillen, R. W., Dunnam, M., Cohen, B. D., Yerokhin, V., Miller, K. E., Hayes, D. J., Arciero, P. J., Maloney, M. and Kramer, A. F. (2018) The aerobic and cognitive exercise study (ACES) for community-dwelling older adults with or at-risk for mild cognitive impairment (MCI): Neuropsychological, neurobiological and neuroimaging outcomes of a randomized clinical trial. *Frontiers in Aging Neuroscience* **10**, 76. <https://doi.org/10.3389/fnagi.2018.00076>
- Becker, B. E. (2009) Aquatic therapy: Scientific foundations and clinical rehabilitation applications. *PM and R: The Journal of Injury, Function, and Rehabilitation* **1(9)**, 859-872. <https://doi.org/10.1016/j.pmrj.2009.05.017>
- Béliveau, A., Boyne, D. J., Slater, J., Brenner, D. and Arora, P. (2019) BUGSnet: An R package to facilitate the conduct and reporting of bayesian network meta-analyses. *BMC Medical Research Methodology* **19(1)**, 196. <https://doi.org/10.1186/s12874-019-0829-2>
- Berchicci, M., Lucci, G. and Di Russo, F. (2013) Benefits of physical exercise on the aging brain: The role of the prefrontal cortex. *Journals of Gerontology Series A: Biological Sciences and Medical Sciences* **68(11)**, 1337-1341. <https://doi.org/10.1093/gerona/glt094>
- Borenstein, M., Hedges, L. V., Higgins, J. P. T. and Rothstein, H. R. (2010) A basic introduction to fixed-effect and random-effects models for meta-analysis. *Research Synthesis Methods* **1(2)**, 97-111. <https://doi.org/10.1002/jrsm.12>
- Bull, F. C., Al-Ansari, S. S., Biddle, S., Borodulin, K., Buman, M. P., Cardon, G., Carty, C., Chaput, J. P., Chastin, S., Chou, R., Dempsey, P. C., DiPietro, L., Ekelund, U., Firth, J., Friedenreich, C. M., Garcia, L., Gichu, M., Jago, R., Katzmarzyk, P. T. and Willumsen, J. F. (2020) World health organization 2020 guidelines on physical activity and sedentary behaviour. *British Journal of Sports Medicine* **54(24)**, 1451-1462. <https://doi.org/10.1136/bjsports-2020-102955>
- Cai, L., Chan, J. S. Y., Yan, J. H. and Peng, K. (2014) Brain plasticity and motor practice in cognitive aging. *Frontiers in Aging Neuroscience* **6**, 31. <https://doi.org/10.3389/fnagi.2014.00031>
- Carral, J. M. C. and Perez, C. A. (2007) Effects of high-intensity combined training on women over 65. *Gerontology* **53(6)**, 340-346. <https://doi.org/10.1159/000104098>
- Carter, H. H., Spence, A. L., Pugh, C. J. A., Ainslie, P., Naylor, L. H. and Green, D. J. (2014) Cardiovascular responses to water immersion in humans: Impact on cerebral perfusion. *American Journal of Physiology: Regulatory, Integrative and Comparative Physiology* **306(9)**, 636-640. <https://doi.org/10.1152/ajpregu.00516.2013>
- De Miguel, Z., Khoury, N., Betley, M. J., Lehallier, B., Willoughby, D., Olsson, N., Yang, A. C., Hahn, O., Lu, N., Vest, R. T., Bonanno, L. N., Yerra, L., Zhang, L., Saw, N. L., Fairchild, J. K., Lee, D., Zhang, H., McAlpine, P. L., Contrepolis, K. and Wyss-Coray, T. (2021) Exercise plasma boosts memory and dampens brain inflammation via clusterin. *Nature* **600(7889)**, 494-499. <https://doi.org/10.1038/s41586-021-04183-x>
- Deng, Y., Tang, Z., Yang, Z., Chai, Q., Lu, W., Cai, Y., Luo, Y. and Zhou, Y. (2024) Comparing the effects of aquatic-based exercise and land-based exercise on balance in older adults: A systematic review and meta-analysis. *European Review of Aging and Physical Activity* **21(1)**, 13. <https://doi.org/10.1186/s11556-024-00349-4>
- Di Benedetto, S., Müller, L., Wenger, E., Düzel, S. and Pawelec, G. (2017) Contribution of neuroinflammation and immunity to brain aging and the mitigating effects of physical and cognitive interventions. *Neuroscience and Biobehavioral Reviews* **75**, 114-128. <https://doi.org/10.1016/j.neubiorev.2017.01.044>
- Ding, Q., Ou, Z., Yao, S., Wu, C., Chen, J., Shen, J., Lan, Y. and Xu, G. (2024) Cortical activation and brain network efficiency during dual tasks: An fNIRS study. *NeuroImage* **289**, 120545. <https://doi.org/10.1016/j.neuroimage.2024.120545>
- Dunlap, E., Alhalimi, T., McLaurin, N., Foroughi, F., Hsiao, H. Y. and Tanaka, H. (2024) Aquatic cognitive-motor exercise for cognition, balance, and functional mobility in older adults. *Translational Journal of the American College of Sports Medicine* **9(3)**. <https://doi.org/10.1249/TJX.0000000000000257>
- Han, J., Luan, L., Adams, R., Witchalls, J., Newman, P., Tirosh, O. and Waddington, G. (2022) Can therapeutic exercises improve proprioception in chronic ankle instability? A systematic review and network meta-analysis. *Archives of Physical Medicine and Rehabilitation* **103(11)**, 2232-2244. <https://doi.org/10.1016/j.apmr.2022.04.007>
- Higgins, J. P. T. and Thompson, S. G. (2002) Quantifying heterogeneity in a meta-analysis. *Statistics in Medicine* **21(11)**, 1539-1558. <https://doi.org/10.1002/sim.1186>
- Hutton, B., Salanti, G., Caldwell, D. M., Chaimani, A., Schmid, C. H., Cameron, C., Ioannidis, J. P. A., Straus, S., Thorlund, K., Jansen, J. P., Mulrow, C., Catalá-López, F., Gotzsche, P. C., Dickersin, K., Boutron, I., Altman, D. G. and Moher, D. (2015) The PRISMA extension statement for reporting of systematic reviews incorporating network meta-analyses of health care interventions: Checklist and explanations. *Annals of Internal Medicine* **162(11)**, 777-784. <https://doi.org/10.7326/M14-2385>
- Hutton, B., Salanti, G., Chaimani, A., Caldwell, D. M., Schmid, C., Thorlund, K., Mills, E., Catalá-López, F., Turner, L., Altman, D. G. and Moher, D. (2014) The quality of reporting methods and results in network meta-analyses: An overview of reviews and suggestions for improvement. *Plos One* **9(3)**, e92508. <https://doi.org/10.1371/journal.pone.0092508>
- Jang, W. S., Yoo, C., Ha, G., Yoon, J. and Yoon, J. (2021) Effect of aquatic interval training on muscle strength, cranial nerve growth factor (IGF-1) and cognitive function. *Sports Science* **39(2)**, 63-70. <https://doi.org/10.46394/ISS.39.2.6>
- Johansson, M. E., Cameron, I. G. M., Van der Kolk, N. M., de Vries, N. M., Klimars, E., Toni, I., Bloem, B. R. and Helmich, R. C. (2022) Aerobic exercise alters brain function and structure in Parkinson's disease: A randomized controlled trial. *Annals of Neurology* **91(2)**, 203-216. <https://doi.org/10.1002/ana.26291>
- Kang, D. W., Bressel, E. and Kim, D. Y. (2020) Effects of aquatic exercise on insulin-like growth factor-1, brain-derived neurotrophic factor, vascular endothelial growth factor and cognitive function in elderly women. *Experimental Gerontology* **132**, 110842. <https://doi.org/10.1016/j.exger.2020.110842>
- Kazazi, L., Foroughan, M., Nejati, V. and Shati, M. (2018) Association between age associated cognitive decline and health related quality of life among Iranian older individuals. *Electronic Physician* **10(4)**, 6663-6671. <https://doi.org/10.19082/6663>
- Khan, M. J., Kannan, P., Wong, T. W. L., Fong, K. N. K. and Winsler, S. J. (2022) A systematic review exploring the theories underlying the improvement of balance and reduction in falls following dual-task training among older adults. *International Journal of Environmental Research and Public Health* **19(24)**, 16890. <https://doi.org/10.3390/ijerph192416890>
- Khodadadi, D., Gharakhanlou, R., Naghdi, N., Salimi, M., Azimi, M., Shahed, A. and Heysieattalab, S. (2018) Treadmill exercise ameliorates spatial learning and memory deficits through improving the clearance of peripheral and central amyloid-beta levels. *Neurochemical Research* **43(8)**, 1561-1574. <https://doi.org/10.1007/s11064-018-2571-2>
- Kooncumchoo, P., Meekum, S., Harnmanop, S., Luangpon, N. and Yuenyongchaiwat, K. (2025) Beneficial effects of water-based exercise alone and in combination with cognitive training on cardiovascular fitness and arterial stiffness in older adults with mild cognitive impairment: A randomized controlled trial. *Life* **15(8)**, 1195. <https://doi.org/10.3390/life15081195>
- Kwok, M. M. Y., Ng, S. S. M., Myers, J. and So, B. C. L. (2024) Aquatic high-intensity interval deep water running influence on cardiometabolic health and cognitive psychological responses in women. *Medicine and Science in Sports and Exercise* **56(11)**, 2203-2210. <https://doi.org/10.1249/MSS.0000000000003500>
- Li, L., Tian, J., Tian, H., Moher, D., Liang, F., Jiang, T., Yao, L. and Yang, K. (2014) Network meta-analyses could be improved by searching more sources and by involving a librarian. *Journal of Clinical Epidemiology* **67(9)**, 1001-1007. <https://doi.org/10.1016/j.jclinepi.2014.04.003>




- Liu-Ambrose, T., Nagamatsu, L. S., Graf, P., Beattie, B. L., Ashe, M. C. and Handy, T. C. (2010) Resistance training and executive functions: A 12-month randomized controlled trial. *Archives of Internal Medicine* **170**(2), 170-178. <https://doi.org/10.1001/archinternmed.2009.494>
- Maneemai, O., Cujilan Alvarado, M. C., Calderon Intriago, L. G., Donoso Triviño, A. J., Franco Coffré, J. A., Pratico, D., Schwartz, K., Tesfaye, T. and Yamasaki, T. (2024) Sensory integration: A novel approach for healthy ageing and dementia management. *Brain Sciences* **14**(3), 285-300. <https://doi.org/10.3390/brainsci14030285>
- Nikolakopoulou, A., Higgins, J. P. T., Papakonstantinou, T., Chaimani, A., Del Giovane, C., Egger, M. and Salanti, G. (2020) CINeMA: An approach for assessing confidence in the results of a network meta-analysis. *Plos Medicine* **17**(4), e1003082. <https://doi.org/10.1371/journal.pmed.1003082>
- Oliveira, A., Fidalgo, A., Farinatti, P. and Monteiro, W. (2024) Effects of high-intensity interval and continuous moderate aerobic training on fitness and health markers of older adults: A systematic review and meta-analysis. *Archives of Gerontology and Geriatrics* **124**. <https://doi.org/10.1016/j.archger.2024.105451>
- Park, H., Park, J. H., Na, H. R., Hiroyuki, S., Kim, G. M., Jung, M. K., Kim, W. K. and Park, K. W. (2019) Combined intervention of physical activity, aerobic exercise and cognitive exercise intervention to prevent cognitive decline for patients with mild cognitive impairment: A randomized controlled clinical study. *Journal of Clinical Medicine* **8**(7), 940. <https://doi.org/10.3390/jcm8070940>
- Perissiou, M., Bailey, T. G., Windsor, M., Nam, M. C. Y., Greaves, K., Leicht, A. S., Golledge, J. and Askew, C. D. (2018) Effects of exercise intensity and cardiorespiratory fitness on the acute response of arterial stiffness to exercise in older adults. *European Journal of Applied Physiology* **118**(8), 1673-1688. <https://doi.org/10.1007/s00421-018-3900-5>
- Ploydang, T., Khovidhunkit, W., Tanaka, H. and Suksom, D. (2023) Nordic walking in water on cerebrovascular reactivity and cognitive function in elderly patients with type 2 diabetes. *Medicine and Science in Sports and Exercise* **55**(10), 1803-1811. <https://doi.org/10.1249/MSS.0000000000003216>
- Rezola-Pardo, C., Arrieta, H., Gil, S. M., Zarrazquin, I., Yanguas, J. J., López, M. A., Irazusta, J. and Rodriguez-Larrad, A. (2019) Comparison between multicomponent and simultaneous dual-task exercise interventions in long-term nursing home residents: The ageing-ONDUAL-TASK randomized controlled study. *Age and Ageing* **48**(6), 817-823. <https://doi.org/10.1093/ageing/afz105>
- Sáez de Asteasu, M. L., Martínez-Velilla, N., Zambom-Ferraresi, F., Casas-Herrero, Á. and Izquierdo, M. (2017) Role of physical exercise on cognitive function in healthy older adults: A systematic review of randomized clinical trials. *Ageing Research Reviews* **37**, 117-134. <https://doi.org/10.1016/j.arr.2017.05.007>
- Sato, D., Seko, C., Hashitomi, T., Sengoku, Y. and Nomura, T. (2015) Differential effects of water-based exercise on the cognitive function in independent elderly adults.
- Shukla, A. (2025) Healing waters: Aquatherapy for mental resilience and injury prevention. In Menhas, R. (Ed.), *Movement as medicine—Harnessing physical activity for holistic health across the lifespan*. IntechOpen. <https://doi.org/10.5772/intechopen.1009141>
- So, B. C. L., Cheung, H. C. Y., Zheng, Y. P., Kwok, M. M. Y., Man, E. Y. K., Mok, F. T., Ng, G. C. N., Sze, N. N. L., Tang, S. W. S. and Ng, S. M. (2024) Effect of moderate-intensity aquatic treadmill exercise on cognitive function and cerebral blood flow for healthy older adults. *Experimental Gerontology* **197**, 112605. <https://doi.org/10.1016/j.exger.2024.112605>
- Sterne, J. A. C., Savović, J., Page, M. J., Elbers, R. G., Blencowe, N. S., Boutron, I., Cates, C. J., Cheng, H. Y., Corbett, M. S., Eldridge, S. M., Emberson, J. R., Hernán, M. A., Hopewell, S., Hróbjartsson, A., Junqueira, D. R., Jüni, P., Kirkham, J. J., Lasserson, T., Li, T. and Higgins, J. P. T. (2019) RoB 2: A revised tool for assessing risk of bias in randomised trials. *BMJ* **366**, 14898. <https://doi.org/10.1136/bmj.14898>
- Tang, Z., Wang, Y., Liu, J. and Liu, Y. (2022) Effects of aquatic exercise on mood and anxiety symptoms: A systematic review and meta-analysis. *Frontiers in Psychiatry* **13**, 1051551. <https://doi.org/10.3389/fpsy.2022.1051551>
- Tao, X., Sun, R., Han, C. and Gong, W. (2022) Cognitive-motor dual task: An effective rehabilitation method in aging-related cognitive impairment. *Frontiers in Aging Neuroscience* **14**, 1051056. <https://doi.org/10.3389/fnagi.2022.1051056>
- Thorlund, K. and Mills, E. J. (2012) Sample size and power considerations in network meta-analysis. *Systematic Reviews* **1**, 41. <https://doi.org/10.1186/2046-4053-1-41>
- Toril, P., Reales, J. M. and Ballesteros, S. (2014) Video game training enhances cognition of older adults: A meta-analytic study. *Psychology and Aging* **29**(3), 706-716. <https://doi.org/10.1037/a0037507>
- United Nations Department of Economic and Social Affairs, Population Division (2022) *World population prospects 2022: Summary of results*. Available at: <https://www.un.org> (Accessed: 7 May 2025).
- Venegas-Sanabria, L. C., Cavero-Redondo, I., Lorenzo-García, P., Sánchez-Vanegas, G. and Álvarez-Bueno, C. (2024) Efficacy of nonpharmacological interventions in cognitive impairment: Systematic review and network meta-analysis. *American Journal of Geriatric Psychiatry* **32**(12), 1443-1465. <https://doi.org/10.1016/j.jagp.2024.06.012>
- Waller, B., Ogonowska-Stodownik, A., Vitor, M., Rodionova, K., Lambeck, J., Heinonen, A., and Daly, D. (2016). The effect of aquatic exercise on physical functioning in the older adult: A systematic review with meta-analysis. *Age and Ageing* **45**(5), 594-602. <https://doi.org/10.1093/ageing/afw102>
- Wang, S., Yin, H., Wang, X., Jia, Y., Wang, C., Wang, L. and Chen, L. (2019) Efficacy of different types of exercises on global cognition in adults with mild cognitive impairment: A network meta-analysis. *Ageing Clinical and Experimental Research* **31**(10), 1391-1400. <https://doi.org/10.1007/s40520-019-01142-5>
- Won, J., Callow, D. D., Pena, G. S., Gogniat, M. A., Kommula, Y., Arnold-Nedimala, N. A., Jordan, L. S. and Smith, J. C. (2021) Evidence for exercise-related plasticity in functional and structural neural network connectivity. *Neuroscience and Biobehavioral Reviews* **131**, 923-940. <https://doi.org/10.1016/j.neubiorev.2021.10.013>
- Yang, C., Moore, A., Mpofu, E., Dorstyn, D., Li, Q. and Yin, C. (2020) Effectiveness of combined cognitive and physical interventions to enhance functioning in older adults with mild cognitive impairment: A systematic review of randomized controlled trials. *The Gerontologist* **60**(8), 633-642. <https://doi.org/10.1093/geront/gnz149>
- Yu, F., Lin, F. V., Salisbury, D. L., Shah, K. N., Chow, L., Vock, D., Nelson, N. W., Porsteinsson, A. P. and Jack, C. (2018) Efficacy and mechanisms of combined aerobic exercise and cognitive training in mild cognitive impairment: Study protocol of the ACT trial. *Trials* **19**(1), 700. <https://doi.org/10.1186/s13063-018-3054-0>
- Yu, H., Ma, B. X., Feng, Y. C., He, Z. W., Li, C., Wang, Z. H., Gao, T. and Xu, X. Y. (2025) Effects of multi-domain cognitive-motor training in older adults with amnesic mild cognitive impairment: A randomized controlled trial. *Geriatric Nursing* **61**, 64-72. <https://doi.org/10.1016/j.gerinurse.2024.10.072>

### Key points

- Aquatic cognitive-motor exercise ranked highest for improving cognition (SUCRA = 85.36%), followed by aquatic aerobic exercise (61.44%); all aquatic modalities were at least as effective as land-based exercise.
- Aquatic cognitive-motor exercise is the most promising for cognitive enhancement in older adults; cognitive engagement is key over intensity alone, supporting integration into guidelines for aging populations with suggestions for future research on long-term effects.

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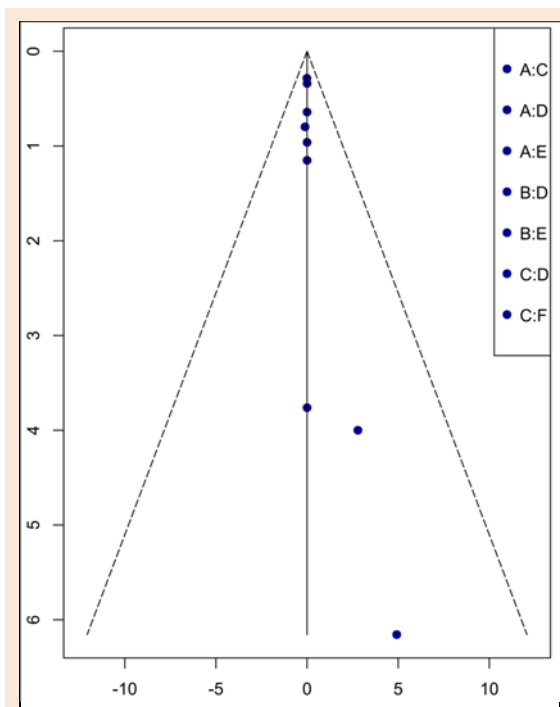
**Supplementary Table S1. Search strategies for the systematic review.**

Database	Search Strategy
PubMed	((("elderly"[Title/Abstract] OR "older adults"[Title/Abstract] OR "aged"[MeSH Terms] OR "seniors"[Title/Abstract] OR "geriatric"[Title/Abstract] OR "aging"[MeSH Terms] OR "elder"[Title/Abstract]))) AND (("aquatic exercise"[Title/Abstract] OR "aquatic therapy"[Title/Abstract] OR "hydrotherapy"[MeSH Terms] OR "water-based exercise"[Title/Abstract] OR "aquatic rehabilitation"[Title/Abstract] OR "water aerobics"[Title/Abstract] OR "swimming therapy"[Title/Abstract] OR "swim"[Title/Abstract])) AND (("cognitive function"[Title/Abstract] OR "cognition"[MeSH Terms] OR "cognitive impairment"[Title/Abstract] OR "cognitive performance"[Title/Abstract] OR "neuropsychological tests"[MeSH Terms]))
Web of Science	TS=("elderly" OR "older adults" OR "aged" OR "seniors" OR "geriatric" OR "aging" OR "elder") AND TS=("aquatic exercise" OR "aquatic therapy" OR "hydrotherapy" OR "water-based exercise" OR "aquatic rehabilitation" OR "water aerobics" OR "swimming therapy" OR "swim") AND TS=("cognitive function" OR "cognition" OR "cognitive impairment" OR "cognitive performance" OR "neuropsychological tests")
Embase	('elderly':ab,ti OR 'older adults':ab,ti OR 'aged'/exp OR 'seniors':ab,ti OR 'geriatric':ab,ti OR 'aging'/exp OR 'elder':ab,ti) AND ('aquatic exercise':ab,ti OR 'aquatic therapy':ab,ti OR 'hydrotherapy'/exp OR 'water-based exercise':ab,ti OR 'aquatic rehabilitation':ab,ti OR 'water aerobics':ab,ti OR 'swimming therapy':ab,ti OR 'swim':ab,ti) AND ('cognitive function':ab,ti OR 'cognition'/exp OR 'cognitive impairment':ab,ti OR 'cognitive performance':ab,ti OR 'neuropsychological tests'/exp)
Cochrane Library	("elderly" OR "older adults" OR "aged" OR "seniors" OR "geriatric" OR "aging" OR "elder") IN Title Abstract Keyword AND ("aquatic exercise" OR "aquatic therapy" OR "hydrotherapy" OR "water-based exercise" OR "aquatic rehabilitation" OR "water aerobics" OR "swimming therapy" OR "swim") IN Title Abstract Keyword AND ("cognitive function" OR "cognition" OR "cognitive impairment" OR "cognitive performance" OR "neuropsychological tests") IN Title Abstract Keyword
CNKI (China National Knowledge Infrastructure)	(SU='老年人' OR SU='老人' OR SU='老年' OR SU='老龄') AND (SU='水中运动' OR SU='水疗' OR SU='水中康复' OR SU='游泳' OR SU='水上运动' OR SU='水中健身') AND (SU='认知' OR SU='认知功能' OR SU='认知障碍' OR SU='记忆力')

Comparison	Number of studies	Within-study bias	Reporting bias	Indirectness	Imprecision	Heterogeneity	Incoherence	Confidence rating
Mixed evidence								
A:C	2	No concerns	Low risk	No concerns	No concerns	Major concerns	No concerns	High
A:D	1	No concerns	Low risk	No concerns	Some concerns	Some concerns	No concerns	High
B:C	1	No concerns	Low risk	No concerns	Major concerns	No concerns	Some concerns	High
B:E	2	No concerns	Low risk	No concerns	Some concerns	Some concerns	No concerns	High
C:D	1	No concerns	Low risk	No concerns	Major concerns	No concerns	No concerns	High
C:F	1	No concerns	Low risk	No concerns	Some concerns	Some concerns	Some concerns	High
E:F	1	No concerns	Low risk	No concerns	No concerns	Major concerns	Some concerns	High
A:B	0	No concerns	Low risk	No concerns	Major concerns	No concerns	No concerns	High
Indirect evidence								
A:E	0	No concerns	Low risk	No concerns	Major concerns	No concerns	No concerns	High
A:F	0	No concerns	Low risk	No concerns	Major concerns	No concerns	No concerns	High
B:D	0	No concerns	Low risk	No concerns	Major concerns	No concerns	No concerns	High
B:F	0	No concerns	Low risk	No concerns	Some concerns	Some concerns	No concerns	High
C:E	0	No concerns	Low risk	No concerns	Major concerns	No concerns	No concerns	High
D:E	0	No concerns	Low risk	No concerns	Major concerns	No concerns	No concerns	High
D:F	0	No concerns	Low risk	No concerns	Some concerns	Some concerns	No concerns	High

A:Nonexercising control;B:Land-based exercise;C:Aquatic cognitive – motor exercise ;D:Aquatic aerobic exercise;E:Aquatic high-intensity interval training;F:Aquatic strength training

**Supplementary Figure S1. Summary of certainty of evidence assessment (GRADE) for different comparisons.**



**Supplementary Figure 2. Funnel plot.**