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Review

Comparative efficacy of cognitive training modalities in cognitive impairment: A systematic review and network meta-analysis

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ABSTRACT

Background: Cognitive training is a widely utilized non-pharmacological intervention to enhance cognitive performance in individuals with cognitive impairment. Despite its potential, significant ambiguity remains regarding its definition, optimal modalities, and design parameters. It remains unclear which types of cognitive training are relatively optimal for different levels of cognitive impairment or how intervention designs can maximize therapeutic benefits.

Objectives: This systematic review and network meta-analysis aimed to compare the effects of various cognitive training modalities on cognitive, psychological, and quality-of-life outcomes in individuals with cognitive impairment. Additionally, it sought to identify optimal intervention approaches, clarify key design parameters, and examine critical factors influencing treatment efficacy.

Methods: A comprehensive search was conducted across 12 databases from the establishment of the database until October 24, 2024, to identify eligible randomized controlled trials (RCTs) evaluating cognitive training interventions. Data were analyzed using pairwise meta-analysis and network meta-analysis in Review Manager 5.4 and Stata 18.

Results: Totally 43 RCTs were included. Pairwise meta-analysis revealed that cognitive strategy training demonstrated superior to active control (AC) or passive control (PC) in improving language function, immediate memory, depressive symptoms and quality of life. However, no significant effects were detected regarding cognitive impairment severity, delivery format, interventionist expertise level, training duration, or control type. Network meta-analysis further identified reminiscence therapy as the most pronounced effective intervention for improving global cognition across all stages of cognitive impairment.

Conclusions: Reminiscence therapy has been demonstrated as a relatively optimal cognitive training modality for enhancing cognitive function in individuals with varying levels of cognitive impairment. Future studies should prioritize longitudinal investigations to validate the durability of therapeutic benefits and incorporate neuroimaging and biomarker analyses to elucidate underlying mechanisms. High-quality RCTs remain imperative to strengthen the evidence base and evaluate the consistency of effects across diverse cognitive training interventions.

1. Introduction

Cognitive impairment, encompassing subjective cognitive decline (SCD), mild cognitive impairment (MCI), and dementia, represents a significant and growing public health challenge worldwide [1,2]. Characterized by deficits in memory, language, and other cognitive functions, dementia alone affects over 55 million individuals globally, with nearly 10 million new cases diagnosed annually [3,4]. Projections indicate a dramatic rise to 152.8 million cases by 2050, underscoring the urgent need for effective interventions [5]. While pharmacological treatments, such as cholinesterase inhibitors, remain first-line therapies, their efficacy is variable, often accompanied by adverse effects, and their long-term benefits remain uncertain [6,7]. In contrast, non-pharmacological interventions, particularly cognitive training (CT), have gained prominence due to their safety, non-invasiveness, and cost-effectiveness, offering a promising alternative for individuals resistant to or intolerant of pharmacological treatments [8,9].

CT is recognized to encompass multiple domains, including but not limited to orientation, perceptual abilities, attention, memory, executive function, logical reasoning, processing speed, and language func-

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tion [8]. Current research has primarily focused on memory, attention, executive function, and visuospatial cognition [10,11], reflecting the domains most vulnerable to age-related and pathological cognitive decline. Cognitive training includes four types: Cognitive Strategy Training (CST), Reminiscence Therapy (RT), Mindfulness Meditation Therapy (MMT), and Modified Therapies (MT). CST represents a widely implemented intervention targeting multiple cognitive domains [12], while RT primarily engages the memory domain through structured reminiscence to enhance long-term recall. MMT, on the other hand, emphasizes attention regulation and reducing cognitive fatigue [13]. Notably, although CT shares overlapping features with cognitive stimulation and rehabilitation, certain cognitive stimulation (e.g., music therapy) and cognitive rehabilitation (e.g., aerobic exercise) targeting executive function and visuospatial cognition are increasingly classified as CT based on operational definitions [14–17]. Through expert consensus, this review categorizes interventions combining complex cognitive-oriented therapeutic trials with supplementary elements of cognitive stimulation (e.g., orientation training), cognitive rehabilitation (e.g., goal-setting), or psychoeducation as MT [18].

CT, a structured, skill-oriented intervention, targets specific cognitive domains such as memory, attention, executive function, and visuospatial cognition. Evidence shows that CT can effectively improve cognitive function in individuals with neurodegenerative and vascular cognitive disorders, particularly when administered in controlled settings [19,20]. However, the field is hampered by significant heterogeneity in the definition and implementation of CT, with studies often conflating it with cognitive stimulation or cognitive rehabilitation. This lack of conceptual clarity has led to inconsistent inclusion criteria across studies, complicating the interpretation of results and limiting the generalizability of findings. For instance, some meta-analyses have included cognitive behavioral therapy and cognitive stimulation under the umbrella of CT, further obscuring the distinct mechanisms and outcomes associated with each approach [21,22].

Recent research has sought to disentangle these methodologies, proposing a framework that distinguishes CT as a targeted, skill-based intervention focused on measurable improvements in cognitive processes rather than task completion rates [18]. Within this framework, studies have revealed divergent outcomes across different populations. For example, memory-specific training has shown superior efficacy in MCI patients compared to multi-domain cognitive strategy training, while the opposite pattern is observed in SCD populations, where comprehensive cognitive interventions yield greater benefits [23,24]. These findings suggest that the neurocompensatory mechanisms underlying cognitive decline may vary across preclinical and clinical stages, necessitating tailored intervention strategies.

Despite these advances, critical gaps remain. The efficacy gradient of various CT modalities across populations with differing cognitive impairment severity remains unclear. Notably, similar CT interventions may yield opposing outcomes in SCD, MCI, and dementia patients, highlighting the need for precision in intervention design [23,24]. Additionally, the influence of delivery methods—such as face-to-face training, internet-based programs, and group versus individual sessions—on long-term outcomes remains underexplored. These factors, which modulate social engagement and cognitive load distribution, may play a pivotal role in sustaining therapeutic benefits [25,26]. Furthermore, the lack of standardized definitions and implementation protocols has created clinical dilemmas, leaving practitioners without evidence-based criteria for intervention selection and hindering the comparability of research findings [18].

To address these challenges, network meta-analysis (NMA) has emerged as a powerful tool for evaluating multiple interventions and establishing effectiveness rankings [27]. By synthesizing evidence from randomized controlled trials, NMA can provide high-level evidence to guide clinical decision-making and optimize intervention strategies. This study aims to conduct a systematic NMA of published randomized controlled trials on CT in cognitive impairment populations, comparing the effects of various CT modalities on cognitive function improvement. Additionally, it will assess the efficacy and acceptability of different delivery formats, offering insights into the design of personalized, evidence-based interventions.

2. Methods

This protocol for a systematic review and network meta-analysis has been registered with PROSPERO (CRD42024600327). The methodology adheres to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Network Meta-Analyses (PRISMA-NMA) guidelines [28], ensuring standardized reporting throughout the investigation.

2.1. Search strategy

A comprehensive literature search was conducted across the following databases from their inception through October 24, 2024: PubMed, Cochrane Library, Web of Science, Embase, CINAHL, Scopus, PsycINFO, Wanfang, VIP, SinoMed, CNKI, and the China Medical Journal Full-text Database. The search strategy comprised three principal components:("cognitive dysfunction" OR "cognitive impairment*" OR "cognitive deficit*" OR "cognitive decline*" OR "subjective cognitive decline" OR "Cognitive Disorder*" OR "Mental Deterioration*")**AND** ("Cognitive Training" OR "Rehabilitation Nursing" OR "Cognitive Remediation" OR "cognitive therapy" OR "cognitive psychotherapy")**AND** ("randomized controlled trial" OR "randomized" OR "randomly" OR "trial" OR "placebo" OR "groups"). For a more detailed description of the search strategy, please refer to Supplementary Table 1.

2.2. Inclusion and exclusion criteria

Inclusion criteria for the studies were as follows: (1) Participants: Individuals diagnosed or clearly assessed with cognitive impairment, aged 18 years or older; (2) Intervention: Interventions meeting the definition of CT encompass various independently conducted training modalities, including attention training, neurofeedback training, and associative training; (3) Control: Active controls(AC)(participants engaged in some form of activity, experiencing a similar level of interaction with researchers but without a structured intervention during this time), passive controls (PC)(no intervention, waiting list, or placebo), and pairwise comparisons among all interventions; (4) Outcomes must include overall cognitive impairment assessments post-treatment, such as MMSE and MoCA; (5) Study design: Randomized controlled trials published in both Chinese and English.

Exclusion criteria for the studies were as follows: (1) Articles not subjected to peer review; (2) Reviews, animal studies, and duplicate publications; (3) Non-randomized controlled experimental studies with a predefined protocol; (4) Studies from which data could not be extracted after contacting the authors (When studies with inaccessible original data are identified, initial contact with the first or corresponding author is initiated via email. If no response is received within seven days, a follow-up contact attempt is made. Studies remaining unresponsive after both contact attempts are excluded from the analysis); (5) Literature that has a high risk of bias as assessed by the revised Cochrane Risk of Bias Tool for Randomized Trials (RoB 2.0); (6) Studies with incomplete data, such as those lacking a predefined protocol.

2.3. Literature selection and data extraction

All literature was imported into EndNote 20, and duplicates were removed. Subsequently, two reviewers (LBL and SW) independently screened the titles and abstracts to identify studies relevant to the topic. Eligible articles were fully downloaded and assessed by the same two independent reviewers. Data from the included studies were extracted by the two independent reviewers (LBL and SW). Any discrepancies arising

from this process were resolved through consensus between the reviewers or, when necessary, with the assistance of a third reviewer (CQW).

The two reviewers (LBL and SW) used a pre-defined standardized form to independently extract key information. The primary data extracted included: (1) Author; (2) Year of publication; (3) Country; (4) Participants (age, sex, sample size, diagnostic criteria, and level of cognitive impairment); (5) Intervention characteristics (type of intervention, delivery format, duration per individual session, frequency, and total time); and (6) Outcomes (overall cognitive impairment, cognitive function across dimensions, depression, and quality of life). The analysis focused on baseline measurements and immediate post-intervention outcomes. Baseline-referenced change values (mean ± standard deviation) were extracted as the core analytical dataset. When unavailable, standard deviations were derived from alternative dispersion metrics including standard errors, 95 % confidence intervals (CIs), range values, or interquartile ranges [29].

2.4. Risk of bias

The risk of bias in included studies was independently evaluated by two reviewers (LBL and SW) using the RoB 2.0 [30]. Any discrepancies between the reviewers were resolved through discussion to reach consensus or, if necessary, by consultation with a third reviewer. The assessment covered five domains: Bias arising from the randomisation process; Bias due to deviations from intended interventions; Bias due to missing outcome data; Bias in measurement of the outcome; Bias in selection of the reported result. Finally, an overall risk of bias for each study was determined. The risk-of-bias judgments for each domain are "low risk of bias", "some concerns" or "high risk of bias". If all elements of the assessment are at low risk, this means that there is little or no risk of bias. If the assessment partially meets the low risk, this means that the risk of bias is medium. If none of the elements meet the low risk, this means that the risk of bias is very high.

2.5. Data analysis

Pairwise meta-analyses were conducted using Cochrane's Review Manager software (version 5.4) when at least three studies reported identical outcomes under the same comparison; otherwise, a narrative synthesis was performed. Mean differences and standard deviations were either directly extracted or calculated from published data. For studies utilizing multiple neuropsychological tests to assess the same outcome, the most frequently used test across included studies was selected for data synthesis. Standardized mean differences (SMDs) with CIs were calculated as pooled effect size measures. A threshold of $P < 0.05$ was considered statistically significant.

The Cochrane Q statistic and I^2 statistic were used to assess heterogeneity. If $P > 0.1$ and $I^2 \leq 50$ %, heterogeneity is considered insignificant, and a fixed-effects model is employed for analysis. Conversely, if $P < 0.1$ and $I^2 > 50$ %, heterogeneity is deemed significant, warranting the use of a random-effects model. For outcomes exhibiting significant heterogeneity, sensitivity analyses were conducted by excluding outliers. Subgroup analyses were performed to explore the impact of various factors on outcomes reported in over ten studies [31], including the clinical severity of cognitive impairment (MCI vs. dementia), country, level of intervention (professional vs. non-professional), delivery method (group-based vs. individual-based, internet-based vs. face-to-face), duration of training (short: ≤ 12 weeks vs. medium: 13–24 weeks vs. long: > 24 weeks), total number of training sessions (short: ≤ 36 times vs. medium: 37–72 times vs. long: > 72 times), intervention site (Hospital vs. Community vs. Family), and type of control (AC vs. PC). A funnel plot was utilized to assess publication bias for outcomes reported in the studies; notable asymmetry suggested a high risk of bias.

NMA was performed using Stata 18.0 software (network and network graphs packages). The network package executed analyses within a frequentist framework using random-effects models. A network graph with nodes and edges was constructed to visualize intervention comparisons, where node size corresponded to study population size and edge thickness reflected the number of studies comparing paired interventions. SMDs with 95 % CIs were pooled using random-effects models. Transitivity was assessed through visual inspection of potential effect modifiers including participant characteristics, intervention protocols, risk of bias distributions, and clinical heterogeneity across comparisons [32]. Local inconsistency between direct and indirect evidence was evaluated using node-splitting analysis, with $P < 0.05$ indicating significant disagreement. Detected inconsistencies prompted systematic investigation of potential effect modifiers and non-transitivity concerns [33]. Results were presented through all possible pairwise comparisons, including mixed-effects estimates (integrating direct and indirect evidence) and indirect comparisons. Treatment hierarchies were established using surface under the cumulative ranking curve (SUCRA) values, where higher percentages (approaching 100 %) indicate superior cognitive improvement efficacy, while lower values reflect poorer therapeutic performance.

2.6. Certainty assessment

Evidence quality was assessed using the CINeMA framework [34,35], a GRADE adaptation for network meta-analysis developed by the Cochrane Comparing Multiple Interventions Methods Group. This web-based tool evaluates six domains: Within-study bias (risk of bias in included studies), Reporting bias (publication and selective reporting biases), Indirectness, Imprecision, Heterogeneity, and Incoherence. Each domain received one of three confidence ratings: "no concerns," "some concerns," or "major concerns." For within-study bias and indirectness assessments, two independent reviewers (LBL and SW) evaluated individual studies. Discrepancies were resolved through consensus discussion. Domain-specific judgments were aggregated to assign four confidence levels (very low, low, moderate, high) to each treatment effect estimate, consistent with standard GRADE classifications. All evaluations were conducted through the official CINeMA web application.

3. Results

3.1. Literature screening process and results

The study selection process was summarized in the PRISMA flowchart (Fig. 1). A total of 23,663 studies were identified through database searches, supplemented by 17 additional studies from reference lists of prior reviews. Following duplicate removal, 15,206 unique articles for systematic screening. Of these, 14,860 were excluded as irrelevant based on title and abstract review, and 15 articles could not be retrieved. The full texts of the remaining 348 articles were assessed for eligibility, resulting in the exclusion of 305 studies for the following reasons, including discrepancies in study design, inclusion of non-cognitively impaired patients, interventions that did not meet the criteria for CT, and the presence of reports as conference abstracts. Ultimately, 43 RCTs, involving 3356 participants, were included in the network meta-analysis.

3.2. Characteristics of included studies

The characteristics of the included RCTs are summarized in Supplementary Table 2. The studies were published between 2007 and 2024, enrolled a total of 3356 participants with cognitive impairment. These studies originated from nine countries, with China contributing the largest proportion. Among the 43 included studies, 36 were two-arm trials, and 7 were three-arm trials. The majority of participants were older adults aged 60 years or above. The duration of intervention averaged 16 weeks (range: 6–96 weeks), with an average of 48 treatment sessions (range: 8–288 sessions). Most interventions were administered by non-specialized personnel who received specific training and followed

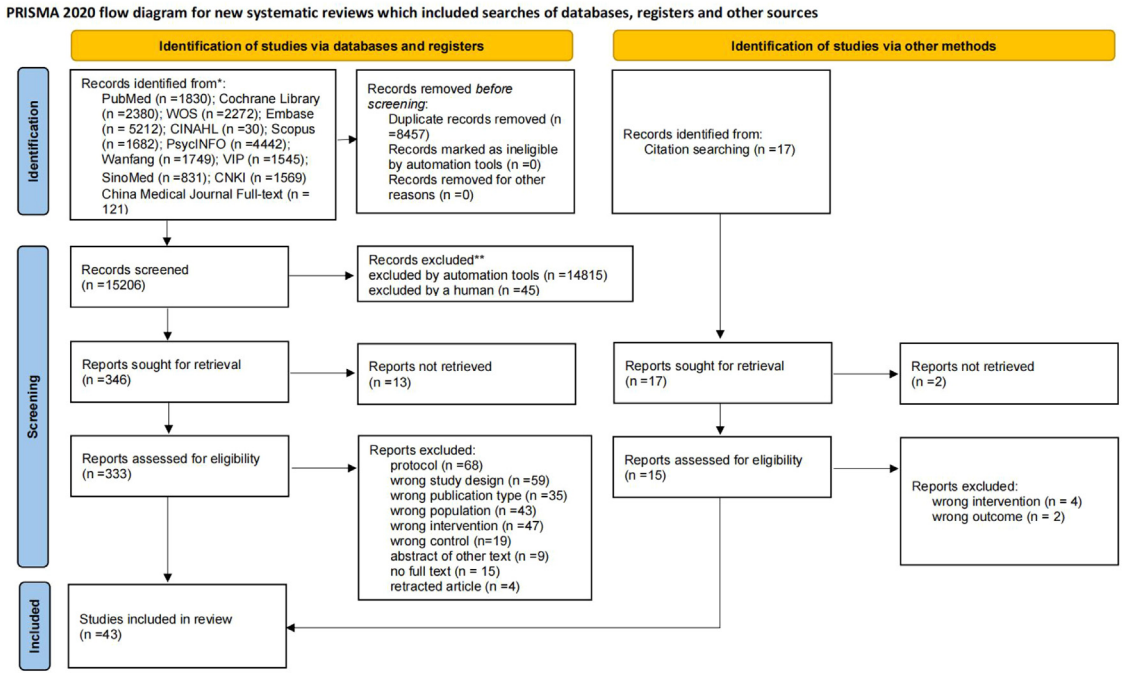

Fig. 1. PRISMA flow diagram.

a standardized manual (34 RCTs, 79.1 %), while the remaining studies involved licensed professionals implementing treatments under similar guidance (9 RCTs, 20.9 %).

3.3. Risk of bias assessment

Among the 43 included studies, 13 were rated as having a low risk of bias, while the remaining 30 studies were classified as having some concerns. Specifically, 19 studies raised "some concerns" due to inadequate reporting of the randomization process and allocation concealment. Furthermore, 15 studies were categorized as having "some concerns" due to biases arising from deviations from intended interventions, and 3 studies raised "some concerns" regarding missing outcome data. Additionally, 5 studies demonstrated "some concerns" in the outcome measurement. For further details, please refer to Supplementary Table 3.

3.4. Network meta-analysis results

Cognitive impairment progression encompasses three stages: SCD, MCI, and dementia. Among the included studies, five investigated SCD populations [36–40], with only one study [39] exclusively focusing on SCD participants. The remaining two studies combined SCD and MCI cohorts. Due to insufficient data from the single SCD-focused study for constructing network models, pooled analyses of SCD and MCI populations were performed to systematically evaluate the efficacy of CT across different cognitive impairment stages. The analysis revealed consistent outcomes across global cognitive measures, with no significant differences observed among SCD, MCI, and dementia groups (Supplementary Tables 4–6).

3.4.1. Global cognition

Fig. 2A presents the network diagram of global cognitive impairment interventions, comprising 43 studies with satisfactory connectivity for primary outcomes and no inconsistency detected in global tests. The most frequent compared interventions were CST versus PC, MT versus PC, and CST versus AC. RT demonstrated limited connectivity, being compared solely with PC and MT without forming closed loops with other interventions. Relative effect estimates revealed significant improvements in global cognition versus PC for CST (SMD=0.83), RT (SMD=1.58), MMT (SMD =0.93), and MT (SMD=0.61). Compared to AC, RT (SMD=1.67) and CST (SMD=0.91) demonstrated superior efficacy. RT and CST outperformed MT (SMD=1.15 and 1.07, respectively), with non-significant differences among remaining interventions (Fig. 3). SUCRA analysis ranked RT highest for cognitive improvement probability (95.8 %), followed by MMT (71.0 %), CST (66.9 %), MT (41.3 %), PC (13.7 %), and AC (11.3 %) (Fig. 4a).

3.4.2. Subjective cognitive decline and mild cognitive impairment cognition

Fig. 2B illustrates the network diagram for SCD and MCI comparisons, comprising 23 studies with no inconsistency detected in global testing. Two closed loops were identified: one between MT and CST, and the other involving both PC and AC with CST and MMT. Relative effect estimates indicated that RT significantly outperformed all cognitive interventions in enhancing outcomes for SCD and MCI. CST was more effective than both MT (SMD=2.53) and PC (SMD=1.31). Compared to AC, RT, CST, and MT demonstrated greater improvements in cognitive levels (SMD=4.22, 1.81, and 1.63, respectively) (Fig. 3). SUCRA rankings revealed that RT had the highest likelihood of cognitive improvement (99.6 %), followed by CST (69.6 %), as detailed in Fig. 4b

3.4.3. Dementia cognition

Fig. 2C presents the network diagram for dementia comparisons, comprising 20 studies with no inconsistency detected in global testing. The most common interventions for dementia treatment included CST versus PC, MT versus PC, CST versus AC, and RT versus PC. Relative effect estimates indicated that RT (SMD=1.36), MMT (SMD=1.21), CST (SMD=1.03), and MT (SMD=1.24) were all effective in improving cognitive function in dementia patients compared to PC. Notably, CST demonstrated superior efficacy over MT in enhancing cognitive outcomes (SMD=5.20) (Fig. 3). RT was ranked highest for likelihood of cognitive improvement (95.8 %), followed by MMT (77.3 %), as detailed in Fig. 4c.

3.5. Pairwise meta-analysis

Supplementary Figure. 1 demonstrates that cognitive training showed significant efficacy in improving cognitive function compared

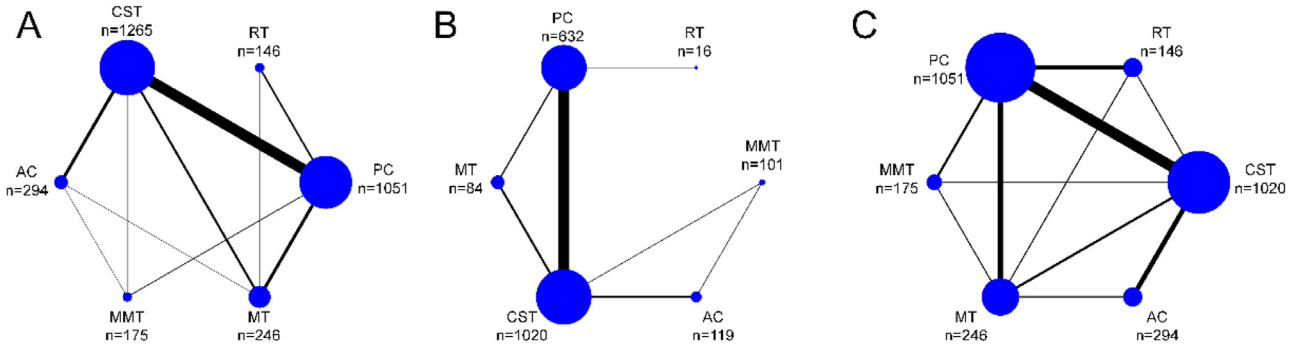

Fig. 2. Network analysis of interventions targeting: (A) global cognition, (B) subjective cognitive decline and mild cognitive impairment, and (C) dementia cognition. Note: PC: Passive control; AC: Active control; CST: Cognitive Strategy Training; RT: Reminiscence Therapy; MMT: Mindfulness Meditation Therapy; MT: Modified Therapies; n:Total number of patients.

Global cognition

RT	-	-	-	**1.07(0.79, 1.35)**	-
0.65(-0.57,1.87)	MMT	-0.05(-0.29, 0.20)	-	**1.35(0.92,1.79)**	-
0.76(-0.12,1.63)	0.11(-0.80,1.01)	CST	1.08 (-0.04, 2.20)	**0.63 (0.38, 0.88)**	**1.18 (0.33, 2.03)**
1.15(0.19,2.11)	0.50(-0.51,1.51)	0.40(-0.21,1.00)	MT	**0.61(0.31,0.92)**	-
1.58(0.75,2.41)	**0.93(0.01,1.85)**	**0.83(0.46,1.19)**	0.43(-0.16,1.02)	PC	-
1.67(0.58,2.76)	1.02(-0.03,2.06)	**0.91(0.24,1.59)**	0.52(-0.34,1.38)	0.09(-0.66,0.84)	AC

Subjective cognitive decline and mild cognitive impairment cognition

RT	-	-	-		-
2.41(0.47,4.36)	CST	**2.53 (1.31, 3.74)**	-	**1.31(0.99,1.63)**	**1.94(1.76,2.12)**
2.59(0.51,4.67)	0.17(-0.66,1.01)	MT	-	**2.75(1.49,4.01)**	-
3.00(0.67,5.32)	0.58(-0.70,1.86)	0.41(-1.12,1.94)	MMT	-	-
3.05(1.15,4.95)	**0.64(0.21,1.06)**	0.46(-0.40,1.32)	0.05(-1.30,1.40)	PC	-
4.22(2.07,6.36)	**1.81(0.90,2.71)**	**1.63(0.40,2.86)**	1.22(-0.11,2.55)	**1.17(0.17,2.17)**	AC

Dementia cognition

RT		-	-	-	**4.30(3.34,5.26)**
0.15(-1.36,1.65)	MMT	-	-	-	-
0.33(-0.70,1.37)	0.19(-1.08,1.45)	CST	0.44(-0.19,1.07)	**5.20(4.41, 5.98)**	**2.41(1.96,2.86)**
0.62(-0.75,2.00)	0.48(-1.08,2.03)	0.29(-0.66,1.24)	AC	-	-
0.91(-0.21,2.04)	0.77(-0.54,2.07)	0.58(-0.28,1.44)	0.29(-0.90,1.49)	MT	**1.24(0.45,2.04)**
1.36(0.41,2.31)	**1.21(0.00,2.43)**	**1.03(0.42,1.64)**	0.74(-0.35,1.83)	0.45(-0.32,1.21)	PC

Fig. 3. Network meta-analysis of effectiveness comparison.
Note: The left lower field presents the results of the network meta-analysis; the right upper field presents the results of pairwise meta-analyses. All statistically significant effects are shown in bold. PC: Passive control; AC: Active control; CST: Cognitive Strategy Training; RT: Reminiscence Therapy; MMT: Mindfulness Meditation Therapy; MT: Modified Therapies.

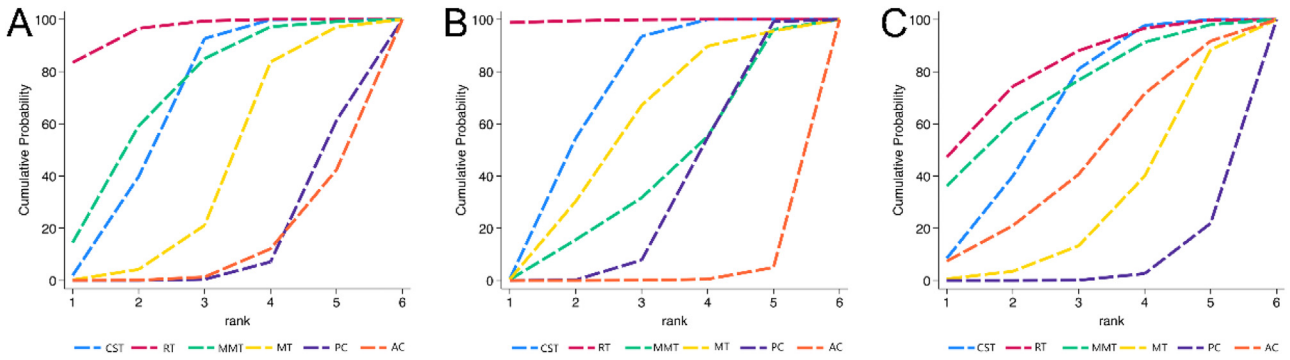

Fig. 4. Rank probabilities of cognitive training interventions for: (A) global cognition; (B) subjective cognitive decline and mild cognitive impairment; and (C) dementia cognition.
Note: PC: Passive control; AC: Active control; CST: Cognitive Strategy Training; RT: Reminiscence Therapy; MMT: Mindfulness Meditation Therapy; MT: Modified Therapies.

to AC/PC (SMD = 0.83, 95 % CI [0.62, 1.05], $P < 0.00001$) among middle-aged and older adults with cognitive impairment. Given the predominance of CST in the included studies and the limited reported data on cognitive domains, depression, and quality of life, pairwise meta-analysis was restricted to comparisons between CST and AC/PC controls in cognitive domains and secondary outcomes, as illustrated in Supplementary Figure. 2 and 3. Regarding cognitive domains, CST demonstrated superior efficacy to controls in enhancing verbal function and immediate memory. For secondary outcomes, CST showed significant improvements over controls in alleviating depressive symptoms and improving quality of life.

3.6. Sensitivity analysis

Sensitivity analyses following sequential exclusion of higher-weight studies demonstrated low between-study sensitivity. Although heterogeneity decreased post-exclusion, the primary significant findings remained unchanged. The point estimates of pooled effect sizes remained within the original 95 % CIs, indicating no substantial alterations to the conclusions. (Supplementary Figure 4.)

3.7. Subgroup analysis

3.7.1. Subgroup analysis in network meta-analysis

This study evaluated the relative optimal parameters of different CT intervention modalities through subgroup analyses of network meta-analyses. Notably, the Long (>24 weeks) training duration subgroup and Internet-based delivery mode failed to establish valid networks. Significant inconsistency ($P < 0.05$) was observed in subgroups utilizing face-to-face delivery, medium training duration (13–24 weeks), Medium total intervention frequency (37–72 times), and hospital-based implementation sites, while other subgroups demonstrated non-significant inconsistency ($P > 0.05$; Supplementary Tables 7–15). Network diagrams, SUCRA rankings, and league table results (Supplementary Figure 5, Supplementary Figure 6, Supplementary Table 16) revealed distinct efficacy hierarchies across subgroups. In group-based interventions, RT exhibited the highest probability of cognitive improvement (77.3 %), followed sequentially by CST, MMT, MT, PC, and AC. For individual interventions, RT maintained superiority (98.5 %), succeeded by MMT, CST, MT, PC, and AC. Professional-led subgroups demonstrated an efficacy hierarchy of MMT > CST > AC > MT > PC, whereas non-professional implementations showed RT dominance (95.9 %) with subsequent rankings of MT > MMT > CST > PC > AC. Internet-based interventions presented a hierarchy of RT > CST > AC > MT > PC. Short-duration interventions (≤12 weeks) revealed RT's optimal efficacy (94.4 %), followed by MMT > CST > MT > PC > AC. Low-frequency interventions (≤36 sessions) ranked RT > CST > MT > MMT > PC > AC, while high-frequency interventions (>72 times) demonstrated MMT > CST > MT > PC > AC. Community-based implementations showed MT superiority (71.6 %) with subsequent rankings of CST > RT > PC > AC, whereas home-based interventions reinstated MMT dominance (88.1 %), followed by MT > CST > PC > AC.

3.7.2. Subgroup analysis of pairwise meta-analysis

Building upon subgroup analyses from network meta-analyses, pairwise meta-subgroup analyses were conducted to further compare subgroup influences on global cognition and identify modifiable elements for intervention optimization, providing insights for clinical interventions targeting cognitively impaired populations. As illustrated in Fig. 5, multidimensional analyses revealed consistent patterns. Regarding practitioner qualifications and delivery modalities, CT demonstrated significant effectiveness across all subgroups ($P < 0.0001$) when administered by professionals or trained paraprofessionals through diverse formats including group-based, individual, internet-mediated, or face-to-face sessions, though no significant between-group differences emerged. Notably, trained paraprofessionals exhibited larger effect sizes (SMD = 0.96) compared to professionals (SMD = 0.62). Internet-based delivery (SMD = 1.00) surpassed face-to-face implementation (SMD = 0.76), while individualized training (SMD = 0.96) outperformed group-based formats (SMD = 0.69). Across cognitive impairment stages (SCD, MCI, dementia; $P < 0.0001$), CT maintained effectiveness without significant intergroup variation, though demonstrated particular efficacy in SCD and MCI phases. All four CT interventions proved effective compared to ACand PC ($P < 0.0001$), with AC showing marginally superior efficacy (SMD = 0.98) versus PC (SMD = 0.79). Analyses of training duration, session frequency, and implementation sites confirmed significant effectiveness across all subgroups ($P < 0.0001$), again revealing nonsignificant between-group differences. Optimal outcomes emerged in community settings (SMD = 1.05), interventions exceeding 24 weeks (SMD = 1.14), and protocols comprising 37–72 times (SMD = 0.89).

3.8. Certainty of evidence

Despite the considerable number of studies included in the network, the overall certainty of evidence for intervention effects is predominantly moderate to low. High-certainty evidence is confined to direct comparisons between RT and PC. Moderate certainty is observed for the direct comparisons of CST versus MT, MT versus both AC and PC, as well as the indirect comparisons involving RT versus MT and AC, and PC versus AC. The certainty of evidence for all other direct or indirect comparisons remains low. Detailed results are shown in Supplementary Figure 7.

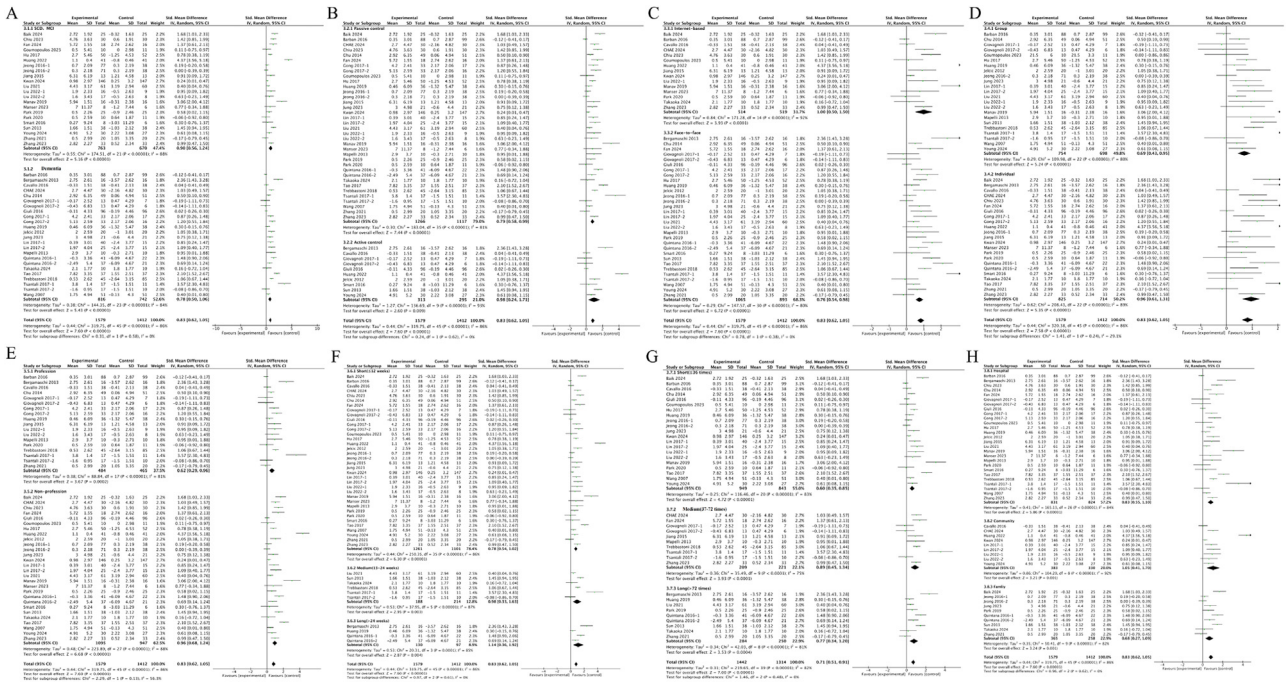

Fig. 5. The effects of heterogeneous patient characteristics on global cognitive function in middle-aged and older adults with cognitive impairment.
Note: A: Diagnosis; B: Types of control; C/D: Delivery mode; E: Intervention level; F: Training duration; G: Total number of interventions; H: Intervention site; CST: Cognitive Strategy Training; RT: Reminiscence Therapy; MMT: Mindfulness Meditation Training; MT: Modified Therapy; NA: not available; SCD: Subjective cognitive decline; MCI: Mild cognitive impairment.

3.9. Publication bias

Funnel plot analysis revealed no substantial asymmetry across the NMA subgroups for global cognition, SCD/MCI or dementia outcomes, and intervention parameters, indicative of no significant publication bias. Detailed results are presented in Supplementary Figures 8–9.

4. Discussion

4.1. Summary of findings

This network meta-analysis comprehensively examined diverse stages of cognitive impairment, synthesizing evidence from 43 randomized controlled trials encompassing 3356 individuals with cognitive disorders. The results demonstrated that CST, RT, MMT, and MT all showed more effective than PC or AC conditions in enhancing cognitive function. For populations with varying severity levels of cognitive impairment, RT emerged as the relatively optimal CT intervention modality, addressing a critical gap in hierarchically ranking therapeutic efficacy across cognitive training paradigms [18]. The investigation conducted an in-depth examination of how key design parameters within intervention protocols moderated treatment effectiveness. However, subgroup analyses revealed no statistically significant variations across clinical severity of impairment, practitioner expertise levels, delivery format, intervention duration, training frequency, implementation setting, or control group typology. In the pairwise meta-analysis, CST demonstrated more pronounced improvements in language function and immediate memory when compared to PC/AC. Moreover, CST was confirmed to be effective in alleviating depressive symptoms and enhancing patients' quality of life.

4.2. Effects of cognitive strategy training on cognitive function, depressive symptoms, and quality of life

Network meta-analyses indicate that CST is widely utilized in existing cognitive intervention studies but exhibits significantly lower efficacy compared to RT. This discrepancy may stem from differences in neural plasticity activation pathways and patient adherence. Memory impairment remains the primary symptom of cognitive decline, while alterations in other domains—such as language function, attention, and executive function—are closely linked to memory deficits [41]. Although CST employs multidimensional training (including memory, executive function, and attention modules) to significantly increase gray matter volume in the right angular gyrus and intraparietal sulcus regions [42], its complex multitask paradigms and time-intensive nature may reduce patient adherence, thereby diminishing intervention efficacy [43]. Notably, only one high-quality RCT directly comparing CST and RT has been identified [44], underscoring the preliminary nature of current evidence. Large-scale, multicenter RCTs are urgently needed to strengthen the evidence base.

Pairwise meta-analysis further revealed selective cognitive domain improvements with CST, demonstrating significant advantages in verbal function (SMD=0.58, 95 % CI [0.36–0.80], $P < 0.00001$) and immediate memory (SMD=0.49, 95 % CI [0.01–0.96], $P < 0.05$). These findings align with previous reports by Feng et al. [45]. The domain-specific advantages of CST in linguistic processing and immediate memory retention provide compelling evidence to substantiate early-stage intervention strategies for populations manifesting age-associated memory complaints. The neurobiological mechanisms may involve gray matter volume expansion in the inferior temporal/fusiform gyrus and cortical thickening in the temporo-limbic-prefrontal circuitry, potentially enhancing linguistic processing and attenuating hippocampal atrophy [46,47]. It is noteworthy that a 5-year longitudinal study demonstrated sustained benefits of CST on delayed memory recall and clinical global cognition measures in MCI patients, achieved through relatively brief, cost-effective interventions [48]. However, the current analysis revealed non-significant effects of CST on delayed memory improvement, further corroborating that its cognitively demanding multi-task paradigm and time-intensive nature may impose excessive patient burden [43]. Furthermore, age-related structural alterations in medial temporal regions - including neuropathological changes and potential incipient

Alzheimer's disease pathology in some participants - may inherently limit the durability of memory training effects in older populations [49,50]. Notably, subgroup analyses demonstrated comparable (if not superior) therapeutic outcomes achieved by non-professionals relative to trained professionals, substantiating the viability of scaling CT implementation through caregiver-mediated training initiatives. Simplified CST protocols administered by family members or community volunteers under remote guidance present a pragmatic solution for reducing reliance on clinical infrastructure. Moreover, the standardized architecture of CST facilitates digital augmentation, with AI-driven adaptive CST protocols capable of dynamically modulating task difficulty based on real-time performance metrics to optimize adherence and therapeutic outcomes [51]. Such innovations preserve core therapeutic principles while enhancing accessibility for homebound and rural populations through technology-mediated delivery platforms.

CST also exhibited transdiagnostic benefits in ameliorating depressive symptoms and improving quality of life. This therapeutic effect may stem from its modulation of the cognitive control network - comprising the dorsolateral prefrontal cortex, dorsal anterior cingulate cortex, and precentral gyrus [52]. The integrity of this network demonstrates neurocircuitry coupling with both executive functioning and emotional regulation [53]. Targeted training might enhance emotional compensation mechanisms through executive function improvement while boosting self-efficacy, thereby alleviating depressive mood and enhancing life quality [54].

While CST's multi-target approach offers advantages as a mainstream cognitive intervention, its complex multidomain training paradigm may compromise treatment adherence and efficacy consistency. Future research should prioritize developing personalized CST protocols with optimized dosing parameters, coupled with multimodal investigations to elucidate neuroplasticity mechanisms. Such advancements will facilitate the establishment of precision cognitive rehabilitation frameworks.

4.3. Effects of reminiscence therapy on global cognitive function

This study advances current understanding of CT interventions across varying cognitive impairment levels, establishing a more robust evidence base. Network meta-analysis suggests RT may be a relatively optimal intervention for cognitive improvement, consistent with Chen et al.'s findings despite their classification of RT as neuropsychological training [55]. In contrast to conventional CST paradigms emphasizing strategic learning, RT's specificity resides in its core mechanism of activating autobiographical memory networks through multimodal sensory stimulation - a process demonstrating remarkable congruence with critical neuroplastic remodeling pathways affected by aging or pathological neurological states. This autobiographically-based neural remodeling mechanism may better align with the pathological characteristics of age-related cognitive decline [56]. Notably, the specific activation of hippocampal-prefrontal cortical functional connectivity during memory retrieval [57] provides neurobiological evidence for RT's dual effects on enhancing both episodic memory and executive function. Compared to CST, RT's mobilization of emotional resources from personal life histories may induce more sustained intervention effects through neuroplasticity and cognitive reserve construction [58,59].

Current research predominantly focuses on standardized protocols like CST while overlooking cultural embeddedness and individual experiential differences. Emerging evidence suggests RT demonstrates stable effect sizes across multicultural samples, potentially through default mode network activation that systematically strengthens semantic memory via metacognitive functions [60]. This emotion-to-cognition conversion mechanism may explain its superior performance in complex cognitive task transfer. However, research on RT's neural mechanisms remains limited to behavioral observations. Future investigations should employ neuroimaging to elucidate temporal dynamics within the amygdala-hippocampal-subcortical circuit during emotional memory reconsolidation processes. Particular emphasis should be placed on characterizing the sequential activation patterns underlying RT's unique neurorestorative effects.

Furthermore, the implementation of RT has expanded beyond traditional photo or object-based cues. Contemporary approaches integrate virtual reality (VR) technology [61] to construct spatiotemporally continuous autobiographical memory scenarios, combined with robot-assisted rehabilitation [62,63] and hybrid board games [64], effectively enhancing cognitive function. These technology-driven refinements preserve the therapy's core strength in emotional arousal while enabling real-time modulation of intervention intensity through integrated neurofeedback systems. Future investigations should quantify neurophysiological responses to nostalgic stimuli across diverse cultural contexts to establish a personalized intervention parameter database. The growing global burden of cognitive disorders associated with population aging, combined with RT's cost-effectiveness and implementation feasibility, necessitates integration into public health prevention frameworks via development of standardized, community-adaptable intervention protocols.

This investigation highlights RT's intervention mechanisms extending into breakthrough applications transcending current research paradigms. First, by leveraging emotionally salient life events, RT not only enhances episodic memory encoding efficiency in Alzheimer's patients but potentially establishes novel memory reconsolidation protocols for post-traumatic stress or anxiety disorders. Second, its neuroplasticity-inducing properties enable synergistic integration with anti-amyloid pharmacotherapies, forging a dual-pathway intervention framework combining molecular clearance with neural network remodeling. Notably, RT's limbic system restructuring effects suggest non-pharmacological intervention pathways for Parkinson's disease depressive subtypes and frontotemporal dementia. Of particular scientific interest is the prospective synergy achieved through temporally coupling RT's emotional memory activation with neuromodulation technologies like transcranial magnetic stimulation, potentially amplifying transsynaptic plasticity through coordinated neural entrainment. While these extensions remain beyond current clinical trial frameworks, the multi-target mechanisms elucidated herein provide neurobiological substantiation for cross-disease applications. Future research priorities should focus on three innovative directions: developing digital biomarker-guided RT dosage optimization systems, designing chronotherapeutic sequences integrating neuromodulation-pharmacotherapy-RT triad interventions, and establishing culturally adaptive virtual reality protocols for autobiographical memory activation across diverse populations.

4.4. The impact of mindfulness meditation therapy and modified therapies on cognitive function

Through SUCRA and league table analyses, this investigation revealed that RT demonstrated superior intervention efficacy across cognitive impairment severity strata. Specifically, within dementia cohorts, RT showed statistically superior cognitive enhancement effects compared to alternative interventions, with MMT securing secondary efficacy rankings. Conversely, among SCD and MCI populations, MT exhibited greater cognitive improvement than MMT. These stratified efficacy profiles underscore the necessity for disease-stage-specific adaptation of therapeutic modalities.

The therapeutic specificity of MMT in dementia populations appears fundamentally linked to its anxiety-modulation properties, operating through tripartite neuroregulatory mechanisms: cognitive resource reallocation via suppression of default mode network hyperactivation [65], augmented attentional regulation through prefrontal-parietal network potentiation [66], and sustained cognitive performance optimization via cognitive fatigue mitigation [67]. Neuroimaging evidence demonstrates MMT-induced gray matter density increases in prefrontal cortices and hippocampi [68,69], structural modifications hypothesized to enhance psychomotor speed and information processing through opti-

mized synaptic pruning efficiency. While MMT's particular efficacy in high-anxiety or attention-deficit subgroups may stem from functional remodeling of limbic-cortical circuitry, systematic fMRI investigations remain imperative to elucidate covariant mechanisms underlying its dual anxiolytic and cognitive enhancement effects [70]. Furthermore, within the network meta-analysis subgroups, MMT demonstrated maximal cognitive enhancement efficacy under parameters involving professional administration, intervention frequencies exceeding 72 times, and home-based implementation. This phenomenon likely originates from professionals facilitating neuroplastic reorganization in prefrontal cortices and default mode networks through precise technique demonstration, personalized regimen adjustments, and real-time neurofeedback. High-frequency interventions (>72 times) surpass critical thresholds for synaptic remodeling, enabling cumulative effects of gray matter thickening and attentional regulation. Home environment integration amplifies meditation skill generalization through contextual reinforcement, establishing a synergistic mechanism integrating structured guidance, sustained practice, and environmental assimilation. Ultimately, this tripartite optimization enhances metacognitive monitoring capacity while reducing neural expenditure on mind-wandering, collectively achieving superior cognitive performance optimization.

MT's distinctive efficacy arises from its poly-target synergistic mechanisms: structured social engagement enhances cognitive reserve capacity while targeted aerobic exercise potentiates hippocampal neurogenesis [71,72], establishing a tripartite "cognitive-kinetic-social" intervention paradigm. Though demonstrating notable community-based implementation potential, current protocols suffer from critical standardization deficits - notably absent operational manuals and unquantified "modified" parameters (e.g., cognitive task complexity gradients, exercise intensity thresholds). Future research should prioritize developing MT consensus guidelines aligned with CONSORT standards to codify core components and mitigate methodological heterogeneity.

Building upon current evidence, this study proposes a stratified intervention framework: RT serves as foundational therapy across the disease continuum, MMT warrants prioritization for dementia patients with prominent anxiety/attention deficits, while MT demonstrates optimal utility in SCD/MCI early intervention and community prevention contexts. Three critical research imperatives emerge: 1) developing biomarker-guided prediction models (e.g., plasma p-tau217-based therapeutic responsiveness indices); 2) engineering differentiated training modules targeting neuropsychiatric symptoms like apathy and anxiety; 3) implementing ≥24-month longitudinal studies to delineate dose-response relationships and decay patterns of neuroplastic changes.

4.5. Comparative efficacy of diverse cognitive training protocols on global cognition

The complementary findings from both analytical approaches reveal methodological synergies, with NMA demonstrating enhanced estimation precision and broader intervention comparability through indirect evidence synthesis. Notably, reduced heterogeneity in specific NMA subgroups suggests diminished random error via cross-trial evidence integration. NMA-derived efficacy hierarchies expose modality-specific therapeutic profiles, with RT's consistent superiority across most subgroups warranting mechanistic investigation. Its dominance likely stems from a dual-pathway mechanism: cerebrovascular enhancement through vascular endothelial growth factor (VEGF)-mediated perfusion optimization [58], coupled with BDNF-driven synaptic plasticity potentiation – a process demonstrating dose-dependent neuroplastic adaptations in preclinical models [59]. MMT's context-dependent efficacy in community settings underscores environmental modulation of intervention effectiveness, aligning with cognitive reserve theory's emphasis on brain-environment interplay dynamics [65]. While non-inferiority between professional and paraprofessional administration ($P > 0.05$) supports tiered healthcare implementation, the observed SMD divergence necessitates MCID-referenced interpretation to determine clinical significance. This performance gradient highlights the importance of cost-benefit analyses when scaling evidence-based interventions across resource-variable settings.

Pairwise meta-subgroup analyses further revealed that community-based, internet-delivered personalized CT administered by paraprofessionals demonstrated superior effect sizes, aligning with prior observations [73,74]. This efficacy may stem from CT's focus on maintaining and enhancing fundamental cognitive capacities, which typically require neither complex medical infrastructure nor specialized psychological expertise. Trained paraprofessionals generally possess sufficient competency to administer such programs effectively. Notably, conventional CT implementations often face resource-intensive demands for staffing, researcher training, and administrative oversight, with sustainability challenges arising from personnel availability and attrition during implementation [75]. Face-to-face group interventions introduce additional accessibility barriers, particularly temporal and spatial constraints requiring sustained attendance over weeks – a significant challenge for older adults with chronic health conditions or mobility limitations [75,76]. These obstacles are exacerbated for rural/remote populations with limited transportation options. Emerging evidence suggests organizational adaptations may enhance accessibility, as demonstrated by Glynda et al.'s findings that transitioning trial personnel to community organizations improved service availability for cognitively impaired older adults. Furthermore, this review highlights that CT protocols exceeding 24 weeks with moderate frequency (37–72 times) yielded superior outcomes, corroborating evidence indicating maximal cognitive improvement from interventions sustained >8 weeks [55]. Crucially, subgroup analyses detected no significant differential effects across practitioner qualifications (professionals vs. paraprofessionals), delivery formats (individual/group, internet/face-to-face), or cognitive impairment severity (SCD/MCI/dementia). This non-differentiation may stem from multiple methodological constraints: imbalanced representation across cognitive impairment stages (only 5 SCD studies versus predominant MCI/dementia populations), limited statistical power from small subgroup-specific sample sizes (e.g., only 4 RT studies in dementia subgroups, 1 RT study in MCI subgroups), and substantial heterogeneity across intervention protocols (duration, frequency) and outcome measures (diverse cognitive assessment tools) even within identical subgroups or CT modalities. Such variability likely attenuated true effect detection while inflating measurement noise.

The clinical translation of these findings requires cautious interpretation considering methodological constraints. Imbalanced subgroup sample sizes may compromise estimation precision and inconsistency detection in network analyses, particularly introducing uncertainty in long-duration intervention subgroups with fragile network structures. The observed inverted U-shaped dose-response relationships between intervention intensity and cognitive improvement necessitates development of personalized dosing frameworks guided by neuroplasticity biomarkers. Future investigations should prioritize three optimization pathways. First, a priori stratification hypotheses should be mechanism-driven, categorizing subgroups by CT modalities' neural targets (e.g., RT targeting default mode networks, CST engaging frontoparietal circuits) rather than relying solely on demographic or implementation parameters. Second, methodological rigor requires prospective power calculations incorporating power analyses for critical subgroups to ensure ≥80 % statistical power, coupled with false discovery rate (FDR) correction for multiple comparisons to mitigate Type I error inflation. Third, granular phenotypic stratification integrating comorbid neuropsychiatric symptoms (apathy, anxiety) could enhance heterogeneity exploration. Implementation science metrics should be systematically incorporated, including fidelity assessments through standardized tools like the TiDieR checklist, with protocol adherence quantified as covariates in meta-regression models. This multidimensional refinement will advance precision medicine paradigms in cognitive rehabilitation research.

4.6. The impact of heterogeneity of included literature on research outcomes

This investigation systematically elucidates the methodological heterogeneity inherent in cognitive training interventions and proposes corresponding analytical approaches. At the intervention design level, substantial variability manifests across studies in implementation duration (6 to 96 weeks), session frequency (8 to 288 sessions), and core module composition. Particularly for MT as a multimodal intervention, while defined as combining cognitive stimulation with goal-setting, inconsistent constituent ratios across studies create ill-defined dosing parameters that contribute to disparate efficacy outcomes. Participant heterogeneity spans the cognitive continuum from SCD to dementia, with baseline cognitive profiles, comorbidities, and neuropathological burden (e.g., differential beta-amyloid deposition levels) constituting critical biological moderators potentially influencing intervention effects through distinct mechanistic pathways. Outcome assessment heterogeneity persists despite universal focus on global cognition, with scale-specific sensitivity profiles warranting attention - for instance, the Montreal Cognitive Assessment's emphasis on executive functions may introduce complementary or conflicting priorities compared to other instruments.

To quantify and address heterogeneity, this study implemented a multidimensional analytical framework. Methodological variance was assessed through Cochrane Q-tests and I^2 statistics, with all meta-analyses employing random-effects models to account for between-study variability. Standardized mean differences unified measurement scales, while subgroup analyses systematically examined moderators including cognitive impairment stages and practitioner qualifications. Sensitivity analyses through iterative exclusion of outlier studies (>1 year duration) confirmed robustness, with core findings maintaining directionality and statistical significance, thereby affirming methodological reliability.

Persistent residual heterogeneity reflects inherent diversity in real-world clinical research. While conclusions provide population-level effect estimates, their applicability to specific pathological subtypes (e.g., mild cognitive impairment patients with severe white matter hyperintensities) requires validation. Although scale standardization addressed metric discrepancies, psychometric limitations in domain-specific assessment priorities persist, necessitating development of comprehensive assessment frameworks.

Future research should prioritize: 1) establishing standardized reporting guidelines for core intervention components, particularly constituent-specific dosing parameters in multimodal protocols; 2) developing cross-disease core outcome measurement systems integrating neuroimaging biomarkers with cognitive assessments; 3) employing individual participant data meta-analysis to decode baseline characteristic effects on therapeutic responsiveness; 4) designing targeted intervention protocols for neuropathological subtypes, such as precision cognitive training strategies for beta-amyloid positive cohorts. Advancing these directions will enhance methodological harmonization and strengthen evidence-based clinical translation.

4.7. Impact of clinical severity of cognitive impairment on global cognition

The current study revealed through subgroup effect heterogeneity analysis that CT was found to significantly promote overall cognition in individuals with SCD and MCI, outperforming its effects in dementia patients, although the intergroup heterogeneity test did not achieve statistical significance. These findings were consistent with those of Nicole et al. [77], who only observed the effects of computerized CT on overall cognition in these two cohorts, neglecting traditional CT methods. Notably, current evidence suggested an insufficient response in dementia patients that needed to be deconstructed from the perspective of neurodegenerative pathology staging. Explanations based on neurobiological mechanisms indicated that the treatment response to CT was positively correlated with neural plasticity reserves. In advanced stages of dementia (e.g., Braak stages IV-VI of Alzheimer's disease), irreversible structural remodeling was reported in the hippocampal-cortical circuit. Aβ42 oligomers were found to induce synaptophysin expression downregulation (reduced by 40–60 %) through mitochondrial toxic pathways [78]. Furthermore, over-phosphorylation of tau protein (p-tau217) was observed to lead to axonal transport deficits, which resulted in a significant reduction in synaptic density (a 57.3 % decrease in late-stage AD compared to the MCI stage) [79]. Additionally, neuroinflammatory cascade responses, characterized by increases in IL-6 and TNF-α levels by 2–3 times, accelerated the apoptosis of cholinergic neurons. This triad of pathological insults severely diminished the synaptic remodeling capacity relied upon by CT, resulting in diminished clinical effects compared to the SCD/MCI stages. It was important to note that the conclusion regarding the lower beneficial effects of CT on overall cognition for dementia patients was preliminary, as most of the included studies exhibited low to moderate evidence quality, insufficient sample sizes, and involved mixed populations at different stages of dementia. Therefore, conclusions regarding the efficacy of CT for dementia patients should be interpreted cautiously. Early dementia patients were found to exhibit only mild cognitive impairment and may have possessed greater structural brain resources for enhancement. Based on the neuroplasticity window theory, it was suggested that future research could establish an individualized Neuroplasticity Potential Index (NPI) using multimodal biomarkers (e.g., Aβ-PET SUVR, FDG-PET metabolic rates, DTI white matter integrity) to guide intervention timing. For example, it was indicated that combining anti-Aβ monoclonal antibodies (such as lecanemab) with computer-adaptive training in the AD-related MCI stage could reduce the annual hippocampal volume loss by 29 %, thereby delaying neurodegeneration [80]. Additionally, enhancing residual plasticity through non-invasive brain stimulation was suggested as an alternative approach.

4.8. Impact of cognitive training on global cognition: A CINeMA-Based evaluation

This systematic review evaluated the quality of evidence from CT studies using the CINeMA framework, revealing moderate-to-low confidence in treatment effects. This limitation primarily stems from concerns regarding indirectness (as indicated in risk of bias summary charts) and substantial heterogeneity across studies. Most included trials focused on older populations (mean age >60 years), while non-standardized intervention protocols (e.g., variable training frequency, intensity, and duration) raised concerns about indirect comparisons. The observed heterogeneity significantly impacts clinical interpretation, partially attributable to inadequate control of confounding factors like baseline cognitive function and inclusion of dementia patients at varying disease stages. For instance, the pooled analysis contained: one study [81] enrolling MCI/mild dementia patients, two studies [82,83] including mild-to-moderate dementia cases, and one trial [84] incorporating participants spanning mild-to-severe dementia. Furthermore, inconsistent assessment of cognitive domains (e.g., visuospatial abilities vs. executive function) and diverse measurement tools exacerbated heterogeneity. Notably, no significant incoherence was detected across studies, with direct and indirect evidence generally demonstrating consistency. The narrow confidence intervals observed limited decision-making uncertainty, resulting in minimal concerns regarding imprecision.

Building on these findings, future research should prioritize bridging the gap between evidence generation and clinical needs while enhancing methodological rigor to improve result reliability and generalizability. High-quality RCTs should employ rigorous RCT designs with blinded outcome assessments, accompanied by detailed reporting of participant adherence and attrition reasons. Additionally, utilizing individualized data analysis (such as growth mixture models) to identify potential efficacy differences among subgroups was considered an important strategy. It was also suggested that standardized CT intervention protocols (including content, dosage, and implementation methods) be developed, alongside the use of unified core assessment tools to promote

the advancement of multicenter collaborative research. To shift the research paradigm from "demonstrating efficacy" to "defining applicability conditions and effect boundaries," extended longitudinal follow-ups are essential for verifying sustained benefits. Integrating neuroimaging biomarkers and mechanistic studies will further elucidate intervention pathways. These advancements will provide robust scientific evidence and practical guidance for developing targeted cognitive interventions.

4.9. Strengths and limitations

This review was the first to systematically examine the effects of different types of CT on cognitive decline in individuals with SCD, MCI, and clinical stages of dementia through meta-analysis and network meta-analysis. First, a comprehensive search strategy was employed to screen suitable randomized controlled trials across 12 databases, ensuring that the evidence level upon which this review was based met the highest standards. Second, compared to previous reviews, this review incorporated updated studies that aligned more closely with the definition of CT, encompassing interventions applied to patients with varying degrees of cognitive decline. Relevant studies were included strictly based on the latest guidelines for the definition of CT, and interventions containing components other than cognitive behavioral therapy were excluded to avoid interference with the training effects. Furthermore, this review explored the impact of various intervention factors on treatment benefits, providing guidance for the development of effective training programs.

Despite this, several limitations were identified in the current study. First, only 12 databases were searched, which may have led to the omission of publications from other registered databases or alternative resources, as well as unpublished studies, thereby introducing publication bias. Second, the evidence quality of the included studies exhibited poor indirectness and high heterogeneity, which could affect the internal validity and accuracy of the study results. Third, the review primarily focused on statistical differences without adequately assessing the clinical significance differences between groups. Additionally, economic evaluations of the interventions were not conducted, which may limit the clinical applicability of the review findings, particularly in supporting policy-making. Fourth, insufficient description of intervention delivery modalities (e.g., face-to-face, internet-based, group-based, or individual-based) was identified in a subset of incorporated studies during data extraction. This insufficient reporting prevented comprehensive analysis of various combinations and interactive factors of delivery modalities, potentially compromising the evidence quality of this systematic review. Fifth, the "optimal" conclusion of RT is mainly based on indirect comparisons from network meta-analysis, and the number of RT studies included is limited, which may affect the stability of the ranking. The existing evidence is concentrated on short-term outcomes ($\leq$ 12 weeks), and it is impossible to confirm whether the long-term advantages of RT will continue. Finally, only post-intervention effects were assessed, and further research is needed to explore the long-term impacts of these CT interventions.

4.10. From evidence to implementation: a roadmap for cognitive training integration

This research framework achieves multidimensional methodological and theoretical advancements aligned with contemporary scientific developments. Future cognitive intervention literature will exhibit temporal sensitivity and exponential proliferation, particularly requiring standardization in delineating intervention windows and dose-response relationships. We advocate establishing transregional clinical trial registries to systematically archive longitudinal intervention data across cognitive decline stages, prioritizing epidemiological repository expansion in low/middle-income nations while quantifying cultural adaptation indices on therapeutic efficacy. Methodological innovations should incorporate triple-blind designs with machine-learning-powered blinding assessment algorithms alongside standardized digital biomarker frameworks integrating wearable device monitoring, multimodal cognitive assessment applications, and biofluid assay standardization protocols.

Translational implementation necessitates prioritized development of objective metric systems. While current evidence demonstrates robust episodic memory enhancement, the neural mechanisms underlying prefrontal functional improvement require elucidation through high-resolution tractography tracking white matter reorganization, metabolic imaging of hippocampal activation patterns, and computational modeling of neuroplasticity dynamics. Clinical translation should adopt stepped precision intervention pathways: biomarker-based screening in primary care, imaging-guided personalized training in secondary hospitals, and cost-effectiveness analysis of combinatory therapies at tertiary centers. For resource-limited regions, implementation strategies emphasize portable neuromonitoring technologies, culturally-adapted autobiographical memory databases, and value-based reimbursement models.

Theoretical innovation manifests through a multidimensional framework integrating molecular biomarkers with brain network metrics via neuroplasticity window prediction algorithms. This paradigm concurrently evaluates cognitive trajectories, healthcare resource optimization, and societal benefit translation through complex systems theory, while establishing an ethical assessment matrix for digital interventions addressing data sovereignty, technological inclusivity, and cultural congruence. Practical implementations include offline-enabled training modules and collectivism-adapted protocols that balance technological accessibility with participatory equity, exemplified by culturally-sensitive virtual reality platforms maintaining therapeutic fidelity across diverse populations. Furthermore, the cooperative efforts between health authorities and professional associations should reach a consensus on the definition of core CT, implementation plans and quality benchmarks. Despite these insights, the methodological quality of the included studies was medium to low, highlighting the necessity of conducting more rigorous investigations. Future research must clarify randomization and allocation of hidden procedures, transparently report loss data, and adopt compliance optimization strategies.

5. Conclusion

The findings demonstrate that the impact of cognitive training on global cognition remains consistent regardless of dementia severity, interventionist qualifications, delivery format, training duration, or control group type. Notably, RT emerges as a potentially optimal intervention for cognitive enhancement across populations with varying degrees of cognitive impairment. However, the current meta-analysis of cognitive domains and RT interventions incorporated a limited number of studies, which may compromise evidence reliability due to restricted sample sizes. This limitation underscores the necessity to establish standardized cognitive training protocols and implement uniform core assessment tools to facilitate multicenter collaborative studies. Future research should prioritize longitudinal investigations to verify intervention sustainability and incorporate neuroimaging biomarkers to elucidate underlying mechanisms. Such advancements will enable a paradigm shift from merely establishing cognitive training efficacy to precisely defining its applicable conditions and functional boundaries within dementia care frameworks.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

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Data and materials availability

The raw data necessary to perform the analysis are available from the corresponding author on reasonable request.

Supplementary figure and table legends

Supplementary Figure 1. Forest plot of Pairwise Meta-Analysis for cognitive training outcomes.

Supplementary Figure 2. Forest plot of Pairwise Meta-Analysis for cognitive domains.

Supplementary Figure 3. Forest plot of Pairwise Meta-Analysis for depression and quality-of-life outcomes.

Supplementary Figure 4. Sensitivity analyses.

Supplementary Figure 5. Network Analysis of Subgroup Intervention Parameters.

Note: PC: Passive control; AC: Active control; CST: Cognitive Strategy Training; RT: Reminiscence Therapy; MMT: Mindfulness Meditation Therapy; MT: Modified Therapies.

Supplementary Figure 6. Probabilistic Ranking of Subgroup Intervention Parameters:(A)Intervention Level-Non-profession; (B)Delivery Mode-Group;(C) Delivery Mode-Individual;(D) Intervention Level-Profession;(E) Intervention Level-Non-profession;(F) Training Duration-Short (≤12 weeks); (G) Total number of interventions- Short (≤36 times); (H) Total number of interventions-Long (>72 times); (I) Intervention Site-Community;(J) Intervention Site-Family;

Note: PC: Passive control; AC: Active control; CST: Cognitive Strategy Training; RT: Reminiscence Therapy; MMT: Mindfulness Meditation Therapy; MT: Modified Therapies.

Supplementary Figure 7. Summary Table for credibility assessment using confidence in Network Meta-Analysis (CINeMA).

Note: PC: Passive control; AC: Active control; CST: Cognitive Strategy Training; RT: Reminiscence Therapy; MMT: Mindfulness Meditation Therapy; MT: Modified Therapies.

Supplementary Figure 8. Funnel plots evaluating publication bias in cognitive assessments: (A) global cognition, (B) subjective cognitive decline and mild cognitive impairment, and (C) dementia cognition.

Note: PC: Passive control; AC: Active control; CST: Cognitive Strategy Training; RT: Reminiscence Therapy; MMT: Mindfulness Meditation Therapy; MT: Modified Therapies.

Supplementary Figure 9. Funnel Plot for Evaluating Publication Bias in Cognitive Assessments: (A)Intervention level-Non-profession;(B)Delivery mode-Group;(C) Delivery mode-Individual;(D)Intervention level-Profession;(E) Intervention level-Non-profession;(F) Training duration-Short(≤12 weeks);(G) Total number of interventions- Short(≤36 times);(H) Total number of interventions-Long (>72 times) ;(I) Intervention Site-Community;(J) Intervention Site-Family;

Note: PC: Passive control; AC: Active control; CST: Cognitive Strategy Training; RT: Reminiscence Therapy; MMT: Mindfulness Meditation Therapy; MT: Modified Therapies.

Supplementary Table 1. Search strategy.

Supplementary Table 2. Characteristics of included studies.

Note: MoCA: Montreal Cognitive Assessment; MMSE: Mini-Mental State Examination; NINCDS-ADRDA: National Institute of Neurological and Communicative Disorders and Stroke - Alzheimer's Disease and Related Disorders Association; CDR: Clinical Dementia Rating; DSM-IV: Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition; DSM-V: Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition; CST: Cognitive Strategy Training; RT: Reminiscence Therapy; MMT: Mindfulness Meditation Training; MT: Modified Therapy; NA: not available; M:man; F:female;

Supplementary Table 3. Results of risk bias.

Supplementary Table 4. The result of local inconsistency test.

Supplementary Table 5. The result of local inconsistency test.

Supplementary Table 6. The result of local inconsistency test.

Supplementary Table 7–15. The result of local inconsistency test.

Supplementary Table 16. Probabilistic Ranking of Cognitive Training Subgroup Intervention Parameters.

Note: The left lower field presents the results of the network meta-analysis; the right upper field presents the results of pairwise meta-analyses. All statistically significant effects are shown in bold. PC: Passive control; AC: Active control; CST: Cognitive Strategy Training; RT: Reminiscence Therapy; MMT: Mindfulness Meditation Therapy; MT: Modified Therapies.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Li-bing Liang: Writing – original draft, Methodology, Formal analysis. **Shan Wang:** Methodology, Formal analysis. **Kun-peng Li:** Writing – review & editing, Conceptualization. **Cai-qin Wu:** Writing – review & editing.

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Supplementary materials

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References

[1] Hyunmi C, Mitchell SVE, Longstreth WT, et al. Epilepsy, vascular risk factors, and cognitive decline in older adults. Neurology 2022. doi:10.1212/wnl.0000000000201187.

[2] Jérémy R, Yves R, Clara F, et al. Cross-sectional associations between cortical thickness and physical activity in older adults with spontaneous memory complaints: the MAPT Study. J Sport Health Sci 2023. doi:10.1016/j.jshs.2021.01.011.

[3] Iulita MF, Bejanin A, Vilaplana E, et al. Association of biological sex with clinical outcomes and biomarkers of Alzheimer's disease in adults with down syndrome. Brain Commun 2023;5(2):fcad074. doi:10.1093/braincomms/fcad074.

[4] Chutian Z, Hongjun Y, Chen-Chen F, et al. Comparing multi-dimensional fNIRS features using bayesian optimization-based neural networks for mild cognitive impairment (MCI) detection. IEEE Trans Neural Syst Rehabilitation Eng 2023. doi:10.1109/tnsre.2023.3236007.

[5] Nichols E, Steinmetz JD, Vollset SE, et al. Estimation of the global prevalence of dementia in 2019 and forecasted prevalence in 2050: an analysis for the global burden of disease study 2019. Lancet Public Health 2022;7(2):e105–25. doi:10.1016/S2468-2667(21)00249-8.

[6] Biederman J, DiSalvo M, Green A, et al. How frequent is switching from an initial stimulant family to the alternative one in the clinical setting?: a pilot study of 49 consecutively referred medication-naive adults with attention-deficit/hyperactivity disorder. J Clin Psychopharmacol 2021;41(3):310–14. doi:10.1097/jcp.0000000000001374.

[7] Lon SS. Cholinesterase inhibitors for Alzheimer's disease. Lancet 2002. doi:10.1016/s0140-6736(02)11329-8.

[8] Petersen RC, Lopez O, Armstrong MJ, et al. Practice guideline update summary: mild cognitive impairment: report of the guideline development, dissemination, and implementation subcommittee of the American academy of neurology. Neurology 2018;90(3):126–35. doi:10.1212/wnl.0000000000004826.

[9] Manuel MO, Guangyong Z, Mark S, et al. Effects of exercise alone or combined with cognitive training and vitamin D supplementation to improve cognition in adults with mild cognitive impairment. JAMA Netw Open 2023. doi:10.1001/jamanetworkopen.2023.24465.

[10] Belleville S, Clément F, Mellah S, et al. Training-related brain plasticity in subjects at risk of developing Alzheimer's disease. Brain 2011;134(Pt 6):1623–34. doi:10.1093/brain/awr037.

[11] Huntley JD, Hampshire A, Bor D, Owen A, Howard RJ. Adaptive working memory strategy training in early Alzheimer's disease: randomised controlled trial. Br J Psychiatry 2017;210(1):61–6. doi:10.1192/bjp.bp.116.182048.

[12] Sherman DS, Durbin KA, Ross DM. Meta-analysis of memory-focused training and multidomain interventions in mild cognitive impairment. J Alzheimers Dis 2020;76(1):399–421. doi:10.3233/jad-200261.

[13] Lengacher CA, Reich RR, Rodriguez CS, et al. Efficacy of mindfulness-based stress reduction for breast cancer (MBSR(BC)) a treatment for cancer-related cognitive impairment (CRCI): a randomized controlled trial. J Integr Complement Med 2025;31(1):75–91. doi:10.1089/jicm.2024.0184.
[14] Zhou C. Effect of Tai Chi combined with music therapy on the cognitive function in older adult individuals with mild cognitive impairment. Front Public Health 2025;13:1475863. doi:10.3389/fpubh.2025.1475863.
[15] Calabrò RS, Bonanno M, Torregrossa W, et al. Benefits of telerehabilitation for patients with severe acquired brain injury: promising results from a multicenter randomized controlled trial using nonimmersive virtual reality. J Med Internet Res 2023;25:e45458. doi:10.2196/45458.
[16] Jelcic N, Agostini M, Meneghello F, et al. Feasibility and efficacy of cognitive telerehabilitation in early Alzheimer's disease: a pilot study. Clin Interv Aging 2014;9:1605–11. doi:10.2147/cia.S68145.
[17] Jeon H, Kim DY, Park SW, et al. A systematic review of cognitive telerehabilitation in patients with cognitive dysfunction. Front Neurol 2024;15:1450977. doi:10.3389/fneur.2024.1450977.
[18] Alex BF, Anthony M, Anita G, Julieta S, Linda C. Cognitive training for people with mild to moderate dementia. Cochrane Libr 2019. doi:10.1002/14651858.cd013069.pub2.
[19] Lam SL, Criaud M, Lukito S, et al. Double-blind, sham-controlled randomized trial testing the efficacy of fMRI neurofeedback on clinical and cognitive measures in children with ADHD. Am J Psychiatry 2022;179(12):947–58. doi:10.1176/appi.ajp.21100999.
[20] Nwosu A, Qian M, Phillips J, et al. Computerized cognitive training in mild cognitive impairment: findings in African Americans and Caucasians. J Prev Alzheimers Dis 2024;11(1):149–54. doi:10.14283/jpad.2023.80.
[21] Chen JW, Du WQ, Zhu K. Network meta-analysis of the effects of different cognitive trainings on the cognitive function of patients with mild cognitive impairment. J Psychiatr Res 2024;174:26–45. doi:10.1016/j.jpsychires.2024.03.051.
[22] Nicola G, Perminder SS. Is cognitive training an effective treatment for preclinical and early Alzheimer's disease? J Alzheimer's Disease 2014. doi:10.3233/jad-141302.
[23] Sherman DS, Mauser J, Nuno M, Sherzai D. The efficacy of cognitive intervention in mild cognitive impairment (MCI): a meta-analysis of outcomes on neuropsychological measures. Neuropsychol Rev 2017;27(4):440–84. doi:10.1007/s11065-017-9363-3.
[24] Han X, Shi DQ, Zhou XW, Yang YH. Effects of cognitive training on cognitive ability of healthy elderly people. Adv Psychol Sci 2016;24(6):909–22. doi:10.3724/SP.J.1042.2016.00909.
[25] Lee YJ, Gonzales E, Wu Y, et al. The association between activities and cognitive health: stratified analysis by APOE ε4 status. J Alzheimers Dis Rep 2024;8(1):1502–15. doi:10.1177/25424823241290528.
[26] Li H, Li C, Wang A, et al. Associations between social and intellectual activities with cognitive trajectories in Chinese middle-aged and older adults: a nationally representative cohort study. Alzheimers Res Ther 2020;12(1):115. doi:10.1186/s13195-020-00691-6.
[27] Bei P, Yi-Ting W, Qingxia Y, et al. The impact of major dietary patterns on glycemic control, cardiovascular risk factors, and weight loss in patients with type 2 diabetes: a network meta-analysis. J Evid Based Med 2018. doi:10.1111/jebm.12312.
[28] Brian H, Georgia S, Deborah MC, et al. The PRISMA extension statement for reporting of systematic reviews incorporating network meta-analyses of health care interventions: checklist and explanations. Ann Intern Med 2015. doi:10.7326/m14-2385.
[29] Xiang W, Wenqian W, Jiming L, Tiejun T. Estimating the sample mean and standard deviation from the sample size, median, range and/or interquartile range. BMC Med Res Methodol 2014. doi:10.1186/1471-2288-14-135.
[30] Jonathan ACS, Jelena S, Matthew JP, et al. RoB 2: a revised tool for assessing risk of bias in randomised trials. BMJ 2019. doi:10.1136/bmj.l4898.
[31] Higgins JPT, Green S, Ben Van D Assem. Cochrane handbook for systematic reviews of interventions. Int Coaching Psychol Rev 2020. doi:10.53841/bpsicpr.2020.15.2.123.
[32] Georgia S. Indirect and mixed-treatment comparison, network, or multiple-treatments meta-analysis: many names, many benefits, many concerns for the next generation evidence synthesis tool. Res Synth Methods 2012. doi:10.1002/jrsm.1037.
[33] Loukia MS. An empirical comparison of bayesian modelling strategies for missing binary outcome data in network meta-analysis. BMC Med Res Methodol 2019. doi:10.1186/s12874-019-0731-y.
[34] Adriani N, Julian PTH, Theodoros P, et al. CINeMA: an approach for assessing confidence in the results of a network meta-analysis. PLoS Med. 2020. doi:10.1371/journal.pmed.1003082.
[35] Theodoros P, Adriani N, Julian PTH, Matthias E, Georgia S. CINeMA: software for semiautomated assessment of the confidence in the results of network meta-analysis. Campbell Syst Rev 2020. doi:10.1002/cl2.1080.
[36] Hu LJ, Xie T, Wang H. Effect observation on multidimensional cognitive training for improving cognitive function in patients with mild cognitive impairment. Chinese Nurs Res 2017;31(21):2646–8.
[37] Yeh TT, Chang KC, Wu CY, Chen CJ, Chuang IC. Clinical efficacy of aerobic exercise combined with computer-based cognitive training in stroke: a multicenter randomized controlled trial. Top Stroke Rehabil 2022;29(4):255–64. doi:10.1080/10749357.2021.1922045.
[38] Jeong JH, Na HR, Choi SH, et al. Group- and home-based cognitive intervention for patients with mild cognitive impairment: a randomized controlled trial. Psychother Psychosom 2016;85(4):198–207. doi:10.1159/000442261.
[39] Smart CM, Segalowitz SJ, Mulligan BP, Koudys J, Gawryluk JR. Mindfulness training for older adults with subjective cognitive decline: results from a pilot randomized controlled trial. J Alzheimers Dis 2016;52(2):757–74. doi:10.3233/jad-150992.
[40] Sun j-x. The effects of cognitive training and acupoint massage on cognitive functions of the elderly with mild cognitive impairment. Chinese Nursing Res. 2013;6(3):64–7.
[41] Lopez OL, Becker JT, Jagust WJ, et al. Neuropsychological characteristics of mild cognitive impairment subgroups. J Neurol Neurosurg Psychiatry 2006;77(2):159–65. doi:10.1136/jnnp.2004.045567.
[42] Zhang H, Wang Z, Wang J, et al. Computerized multi-domain cognitive training reduces brain atrophy in patients with amnestic mild cognitive impairment. Transl Psychiatry 2019;9(1):48. doi:10.1038/s41398-019-0385-x.
[43] Yang HL, Chan PT, Chang PC, et al. Memory-focused interventions for people with cognitive disorders: a systematic review and meta-analysis of randomized controlled studies. Int J Nurs Stud 2018;78:44–51. doi:10.1016/j.ijnurstu.2017.08.005.
[44] DH N, XH Z. Effects of nostalgia therapy on cognitive function and depression in senile dementia patients. J Clinic Nursing's Practicality 2017;2(46):135–8.
[45] Feng W, Wang D, Tang L, et al. Effects of different cognitive trainings on amnestic mild cognitive impairment in the elderly: a one-year longitudinal functional Magnetic resonance imaging (MRI) study. Med Sci Monit 2018;24:5517–27. doi:10.12659/msm.908315.
[46] Engvig A, Fjell AM, Westlye LT, et al. Effects of memory training on cortical thickness in the elderly. Neuroimage 2010;52(4):1667–76. doi:10.1016/j.neuroimage.2010.05.041.
[47] Engvig A, Fjell AM, Westlye LT, et al. Effects of cognitive training on gray matter volumes in memory clinic patients with subjective memory impairment. J Alzheimers Dis 2014;41(3):779–91. doi:10.3233/jad-131889.
[48] Belleville S, Cuesta M, Bier N, et al. Five-year effects of cognitive training in individuals with mild cognitive impairment. Alzheimers Dement (AMST) 2024;16(3):e12626. doi:10.1002/dad2.12626.
[49] Jack CR Jr, Knopman DS, Jagust WJ, et al. Hypothetical model of dynamic biomarkers of the Alzheimer's pathological cascade. Lancet Neurol 2010;9(1):119–28. doi:10.1016/s1474-4422(09)70299-6.
[50] Singer T, Lindenberger U, Baltes PB. Plasticity of memory for new learning in very old age: a story of major loss? Psychol Aging 2003;18(2):306–17. doi:10.1037/0882-7974.18.2.306.
[51] Ye Y, Lei M, Chen L, et al. Efficacy of technology-based cognitive and exercise interventions for mild cognitive impairment: a systematic review, network meta-analysis, and meta-regression of randomized controlled trials. Ageing Res Rev 2024;100:102438. doi:10.1016/j.arr.2024.102438.
[52] Rayner G, Jackson G, Wilson S. Cognition-related brain networks underpin the symptoms of unipolar depression: evidence from a systematic review. Neurosci Biobehav Rev 2016;61:53–65. doi:10.1016/j.neubiorev.2015.09.022.
[53] Breukelaar IA, Antees C, Grieve SM, et al. Cognitive control network anatomy correlates with neurocognitive behavior: a longitudinal study. Hum Brain Mapp 2017;38(2):631–43. doi:10.1002/hbm.23401.
[54] Motter JN, Devanand DP, Doraiswamy PM, Sneed JR. Computerized cognitive training for major depressive disorder: what's next? Front Psychiatry 2015;6:137. doi:10.3389/fpsyt.2015.00137.
[55] Chen JW, Du WQ, Zhu K. Network meta-analysis of the effects of different cognitive trainings on the cognitive function of patients with mild cognitive impairment. J Psychiatr Res 2024;174:26–45. doi:10.1016/j.jpsychires.2024.03.051.
[56] Rhoda R. Reminiscence therapy for dementia. Issues Ment Health Nurs 2019. doi:10.1080/01612840.2019.1654572.
[57] Hakamata Y, Komi S, Sato E, et al. Cortisol-related hippocampal-extrastriate functional connectivity explains the adverse effect of cortisol on visuospatial retrieval. Psychoneuroendocrinology 2019;109:104310. doi:10.1016/j.psyneuen.2019.04.013.
[58] Villar F, Serrat R. [Talk to them: narrative care within a person-centered care framework]. Rev Esp Geriatr Gerontol 2017;52(4):216–22. doi:10.1016/j.regg.2016.06.004.
[59] Yang Z, Wildschut T, Izuma K, et al. Patterns of brain activity associated with nostalgia: a social-cognitive neuroscience perspective. Soc Cogn Affect Neurosci 2022;17(12):1131–44. doi:10.1093/scan/nsac036.
[60] Villasán-Rueda A, Sánchez-Cabaco A, Mejía-Ramírez M, Afonso RM, Castillo-Riedel E. Transcultural pilot study of the efficacy of reminiscence therapy for Mexican and Spanish older adults with different levels of cognitive decline. J Cross Cult Gerontol 2023;38(4):371–88. doi:10.1007/s10823-023-09486-2.
[61] Mao Q, Zhao Z, Yu L, Zhao Y, Wang H. The effects of virtual reality-based reminiscence therapies for older adults with cognitive impairment: systematic review. J Med Internet Res 2024;26:e53348. doi:10.2196/53348.
[62] Liu Q, Liu Z, Cheng H, et al. The impact of reminiscent music therapy and robot-assisted rehabilitation on older stroke patients: a protocol for a randomized controlled trial. Front Neurol 2024;15:1345629. doi:10.3389/fneur.2024.1345629.
[63] Yuan F, Boltz M, Bilal D, et al. Cognitive exercise for persons with Alzheimer's Disease and related dementia using a social robot. IEEE Trans Robot 2023;39(4):3332–46. doi:10.1109/tro.2023.3272846.
[64] Liu Y, Zhang C, Zhao J, Han T. The effect of a reminiscence therapy-based hybrid board game on anxiety and loneliness levels in older adults: an experimental study. Games Health J 2024;13(2):120–7. doi:10.1089/g4h.2023.0062.
[65] Kulshreshtha A, Alonso A, McClure LA, et al. Association of stress with cognitive function among older black and white US adults. JAMA Netw Open 2023;6(3):e231860. doi:10.1001/jamanetworkopen.2023.1860.
[66] Surabhi L, Mindfulness Rashmi G. Attentional networks, and executive functioning: a review of interventions and long-term meditation practice. J Cognitive Enhancement 2022. doi:10.1007/s41465-022-00254-7.
[67] Nigg JT. Annual research review: on the relations among self-regulation, self-control, executive functioning, effortful control, cognitive control, impulsivity, risk-taking, and inhibition for developmental psychopathology. J Child Psychol Psychiatry 2017;58(4):361–83. doi:10.1111/jcpp.12675.

[68] Siew S, Yu J. Mindfulness-based randomized controlled trials led to brain structural changes: an anatomical likelihood meta-analysis. Sci Rep 2023;13(1):18469. doi:10.1038/s41598-023-45765-1.
[69] Friedman NP, Robbins TW. The role of prefrontal cortex in cognitive control and executive function. Neuropsychopharmacology 2022;47(1):72–89. doi:10.1038/s41386-021-01132-0.
[70] Wojcik KD, Cox DW, Kealy D, Zumbo B. The effect of cognitive fusion on change in PTSD and depression symptom severity in veterans engaged in group psychotherapy. J Cogn Psychother 2024;38(2):169–84. doi:10.1891/jcp-2022-0035.
[71] Cordina RL, O'Meagher S, Karmali A, et al. Resistance training improves cardiac output, exercise capacity and tolerance to positive airway pressure in Fontan physiology. Int J Cardiol 2013;168(2):780–8. doi:10.1016/j.ijcard.2012.10.012.
[72] Lehmann N, Villringer A, Taubert M. Colocalized white matter plasticity and increased cerebral blood flow mediate the beneficial effect of cardiovascular exercise on long-term motor learning. J Neurosci 2020;40(12):2416–29. doi:10.1523/jneurosci.2310-19.2020.
[73] Danielle DA, Iris Y, Lynn Z, et al. Feasibility, acceptability, and impact of a self-guided e-learning memory and brain health promotion program for healthy older adults. Clin Gerontol 2022. doi:10.1080/07317115.2022.2088325.
[74] Pike K, Moller CI, Bryant C, et al. Examination of the feasibility, acceptability, and efficacy of the online personalised training in memory strategies for everyday program for older adults: single-arm pre-post trial. J Med Internet Res 2023;25:e41712. doi:10.2196/41712.
[75] Glynda K, Elizabeth M, Elizabeth R, et al. Bridging the gap between clinical trials and community care: translating a memory group for older people with mild cognitive impairment into a community-based organisation. Australas J Ageing 2019. doi:10.1111/ajag.12724.
[76] Kerryn EP, Mei San C, Camilla HH, et al. Providing online memory interventions for older adults: a critical review and recommendations for development. Aust Psychol 2018. doi:10.1111/ap.12339.
[77] Hill NTM, Mowszowski L, Naismith SL, et al. Computerized cognitive training in older adults with mild cognitive impairment or dementia: a systematic review and meta-analysis. Am. J Psychiatry 2017;174(4):329–40. doi:10.1176/appi.ajp.2016.16030360.
[78] Couvy-Duchesne B, Frouin V, Bouteloup V, et al. Grey-matter structure markers of Alzheimer's Disease, Alzheimer's conversion, functioning and cognition: a meta-analysis across 11 cohorts. Hum Brain Mapp 2025;46(2):e70089. doi:10.1002/hbm.70089.
[79] Shao K, Hu X, Kleineidam L, et al. Amyloid and SCD jointly predict cognitive decline across Chinese and German cohorts. Alzheimers Dement 2024;20(9):5926–39. doi:10.1002/alz.14119.
[80] McAlpine CS, Park J, Griciuc A, et al. Astrocytic interleukin-3 programs microglia and limits Alzheimer's disease. Nature 2021;595(7869):701–6. doi:10.1038/s41586-021-03734-6.
[81] Tetsuya T, Keiji H, Seishiro A, Eisuke I, Nobuyuki K. Effects of the abacus-based mental calculation training application "SoroTouch" on cognitive functions: a randomized controlled trial. PLoS One 2024. doi:10.1371/journal.pone.0299201.
[82] Mapelli D, Di Rosa E, Nocita R, Sava D. Cognitive stimulation in patients with dementia: randomized controlled trial. Dement Geriatr Cogn Dis Extra 2013;3(1):263–71. doi:10.1159/000353457.
[83] Domingo JQH, María Teresa MB, Ignacio JIF, et al. Mindfulness in the maintenance of cognitive capacities in Alzheimer's disease: a randomized clinical trial. J. Alzheimer's Disease 2016. doi:10.3233/jad-143009.
[84] Jing-Jy W. Group reminiscence therapy for cognitive and affective function of demented elderly in Taiwan. Int J Geriatr Psychiatry 2007. doi:10.1002/gps.1821.