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The effectiveness of aerobic exercise and dance interventions on cognitive function in adults with mild cognitive impairment: an overview of meta-analyses

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ABSTRACT
This review summarizes meta-analyses (MAs) of randomized controlled trials (RCTs) that assessed the effectiveness of aerobic exercise and dance interventions on cognitive functions in adults with mild cognitive impairment (MCI). Five databases, MEDLINE, EMBASE, PsycINFO, PubMed, and CENTRAL, were searched. MAs that exclusively pooled the effect sizes of aerobic exercise or dance on cognitive functions in adults aged 50 and above with MCI were included. We summarized 20 MAs, including 59 unique RCTs on aerobic exercise and 12 unique RCTs on dance. The meta-meta-analysis results demonstrated that both aerobic exercise (SMD = 0.28 [.13, .43]) and dance (SMD = 0.39 [.28, .49]) significantly improve overall cognition in adults with MCI. When considering specific cognitive domains, aerobic exercise significantly improves global cognition (SMD = 0.42 [.21, .64]) but does not significantly impact executive function and memory. Dance significantly enhances global cognition (SMD = 0.4 [.01, .09]), executive function (SMD = 0.18 [.03, .32]), and memory (SMD = 0.46 [.32, .61]). The moderator analysis also supported dance's superior effect on memory. This finding suggests that the cognitively demanding nature of dance, which involves memorizing complex choreography and coordinating movements with accompanying music, provides additional benefits for memory. Overall, the current review supports that aerobic exercise and dance are effective non-pharmacological interventions to stabilize and even improve cognitive functions in adults with MCI.

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aerobic exercise; cognitive function; dance; mild cognitive impairment; overview of reviews; meta-meta-analysis

Introduction

Mild cognitive impairment (MCI) is defined as a prodromal or transitional state from normal aging to dementia (Gauthier et al., 2006; Kreutzer et al., 2011; Petersen et al., 2014). It is characterized as (1) a subjective report of cognitive complaint; (2) objective

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evidence of cognitive impairment; (3) preservation of independence in functional abilities (i.e. the ability to carry out daily activities such as cooking and cleaning); and (4) the absence of dementia (Petersen et al., 2014). A national six-year longitudinal survey targeting Americans 65+ years of age showed that the incidence of MCI was 41 per 1,000 person-years (Zhang, 2021). The conversion rate from MCI to probable dementia was 241 per 1,000 person-years. The mortality rate of MCI (135.7 per 1,000 person-years) and probable dementia (176.8 per 1,000 person-years) was 24.23 and 31.57 times, respectively, that of cognitively normal older adults (5.6 per 1,000 person-years).

Physical exercise is a promising non-pharmacological approach to maintain and improve cognitive function among adults with MCI (Erickson et al., 2019; Petersen et al., 2014; Turner et al., 2021). Various standardized tests were used to assess cognitive functions, each designed to evaluate specific aspects of cognition. Several recent meta-analyses (MAs) have examined the effects of physical exercise on cognitive functions in adults with MCI, but they have reported inconsistent findings (Biazus-Sehn et al., 2020; Law et al., 2022; Sanders et al., 2019; Wang et al., 2014). For example, Biazus-Sehn et al. (2020) found that physical exercise enhances executive function, whereas Wang et al. (2014) did not find any significant effects on executive function tasks, such as the Stroop task and the Trial Making Test. This inconsistency can be partially explained by the inclusion of various types of exercise, such as aerobic exercise, resistance training, multicomponent exercise, tai chi, yoga, and dance. Indeed, different types of exercise can have varying cognitive effects and act through distinct molecular mechanisms (Huang et al., 2022; Song et al., 2018).

Aerobic exercise is considered the most common and important type of exercise that can improve cognitive ability, slow memory loss, increase hippocampal neurogenesis, enhance neurotransmitter availability, produce brain-derived neurotrophic factors (BDNF), and increase brain volume (Budson & Solomon, 2017; Song et al., 2018; Zheng et al., 2016). Aerobic exercise refers to rhythmic and dynamic exercises that involve large muscle groups and improve cardiorespiratory endurance, such as walking, cycling, swimming, jogging, and skiing (Li et al., 2022; McDonnell et al., 2011). Although many forms of exercise are accompanied by music, including dance classes, step classes, running to music, or cycling to music, there is surprisingly little understanding of how the presence of music might contribute to the benefits of exercise for cognitive function. Research and theory have scrutinized a range of mechanisms triggered by music engagement that are relevant to cognitive function (Brancatisano et al., 2020; Brancatisano & Thompson, 2019), raising the possibility that music may play an important role in the benefits of exercise accompanied by music.

Dance represents an ideal activity to examine the role of music as it is always accompanied and coordinated by music. It is increasingly recognized as an effective way to maintain and improve cognitive function (Chen & Pei, 2018; Prinz et al., 2021; Satoh et al., 2014). Various dance programs designed for individuals MCI incorporate different choreography featuring movements such as knee bending and square-stepping (Qi et al., 2019; Zhu et al., 2020, 2018), diverse dance styles such as African dance and tango (Kropacova et al., 2019; Lazarou et al., 2017; Rektorova et al., 2020), and even Chinese square dancing which also combines a wide range of movements (Chang et al., 2021). These dance programs have demonstrated improvements in attention, executive function, memory, processing speed, and global cognition in MCI.

Although the dance programs for patients with MCI vary in style, they all share a common element – movements intrinsically synchronized with music. We postulate that the cognitive benefits of dance may result from the additive and independent benefits of music and exercise, and through their interactive effects. In dance, music's rhythmic and pitch structures are rapidly mapped onto bodily gestures and actions. The brain mechanisms underlying these complex synchronized actions may confer additional cognitive benefits beyond those experienced by exercise alone. Indeed, in comparison with a fitness program that included endurance, strength-endurance, and flexibility training, a six-month dance program increased the BDNF levels and brain volumes in areas related to higher cognitive processes (Rehfeld et al., 2018). Other research also suggests that in healthy older adults, the benefits of dance exceed those of walking for visuospatial memory and delayed recall (Merom et al., 2016).

Many MAs have summarized the pooled effect sizes of aerobic exercise and/or dance on cognitive outcomes for MCI (Chan et al., 2020; Scherder et al., 2014; Wu et al., 2021; Zheng et al., 2016). However, there is a need to comprehensively synthesize and critically appraise the existing MAs with an 'overview of reviews' approach. An overview of reviews, often known as an umbrella review or review of systematic reviews, is a robust method used to assess more than one type of intervention at a macro level by synthesizing published systematic reviews and/or meta-analyses (Andrade et al., 2022; Fusar-Poli & Radua, 2018; Gates et al., 2022). Although a recent overview of systematic reviews found that physical exercise improved the overall cognitive functions of individuals with MCI (Turner et al., 2021), it did not differentiate the effectiveness of aerobic exercise and dance. It is important to investigate the impact of different forms of exercise, given that they might benefit cognitive function in different ways (Biazus-Sehn et al., 2020; Huang et al., 2022; Song et al., 2018). Therefore, the overview of MAs reported here aims to summarize the effectiveness of aerobic exercise and dance interventions on cognitive functions in adults with MCI.

Methods

The review was performed and reported following the Preferred Reporting Items for Overviews of Reviews (PRIOR) statement (Gates et al., 2022) and the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) statement (Page et al., 2021). Tables S1 and S2 show the specific location of this overview where each item in the PRIOR and PRISMA checklist was addressed. The review protocol was registered in the International Prospective Register of Systematic Review (PROSPERO) database (registration number: CRD42022307443).

Eligibility criteria

The eligibility criteria for this overview of MAs were:

(1) Population: Adults aged 50 and above diagnosed with MCI, as defined by the original meta-analyses, were identified based on the Peterson criteria, objective measures such as the Mini-Mental State Examination (score of 25 or below) and Montreal Cognitive Assessment, and others.
(2) Interventions: Any type of aerobic exercise and/or dance interventions. Meta-analyses that *exclusively* examined the effects of multi-modal interventions (e.g. the combination of physical activity and cognitive intervention), multi-component exercise

(the combination of two or more types of exercise), serious game, resistance training, or other types of mind–body exercise (e.g. tai chi, qigong, Pilates, yoga) were excluded, as it would be difficult to tease apart the independent benefits of the physical components of the interventions.

(3) Comparators: Any type of control group (e.g. waitlisted, standard care, health education, sham exercise training, alternative active treatment).

(4) Outcomes: At least one outcome measure of cognition (e.g. global cognition, memory, executive function, visuospatial ability, learning, attention).

(5) Study Design: Only MAs that exclusively examined randomized controlled trials (RCTs) were considered, because RCT is a rigorous method for investigating the efficacy of an intervention by reducing bias through randomization (Hariton & Locascio, 2018). Only MAs that specifically pooled effect sizes for the effects of aerobic exercise or dance on cognitive function in individuals with MCI were considered.

Search strategy

Five electronic databases in MEDLINE via Ovid (from 1946), EMBASE via Ovid (from 1974), PsycINFO via Ovid (from 1806), PubMed, and the Cochrane Central Register of Controlled Trials (CENTRAL) were searched from inception to 29 September 2022. An update search was implemented on 13 September 2023. A combination of MeSH terms and keywords (in title, abstract, subject heading, author keywords, and more) was used to search for MCI, aerobic exercise, dance, and meta-analysis. Searches were restricted to human participants and English language documents. The complete search strings and search results for all databases are given in Table S3. Reference lists of relevant overviews of reviews (Hu et al., 2022; Turner et al., 2021; Venegas-Sanabria et al., 2021) were also searched to identify additional reviews. Only meta-analyses that were published in peer-reviewed journals were considered.

Selection process

Search results from the databases were imported into Rayyan (Ouzzani et al., 2016), and duplicates were detected and removed. Based on the eligibility criteria, two authors (YQ and CYL) independently screened titles and abstracts for potentially eligible reviews. Full texts of all potential eligible reviews were then obtained and assessed in detail by the same two reviewers. Any discrepancies were discussed and resolved by consensus.

Data extraction

The following data were extracted from all eligible MAs: citation details (title, authors, year of publication), review registration identifier, objective, review conclusion, number of databases, date of search, number of included RCTs, number of RCT that examined interventions of interests (i.e. aerobic exercise and/or dance), total sample size, participants' characteristics (mean age, percentage of women, cognitive status), intervention details (type, duration of each session, frequency, length of the intervention), type of comparison, cognitive outcomes measures, pooled effect sizes of effects of aerobic exercise and/or dance on cognitive functions in MCI, tools to assess the risk of bias, and correspondence.

Since the same primary study may be included in more than one MA, primary studies in each MA were extracted, and the corrected covered area was calculated to determine the percentage of overlapped primary studies across MAs (Pieper et al., 2014). Using a predetermined standard data extraction tabular form in Microsoft Excel, all data were extracted by YQ and checked for accuracy by CYL.

Quality assessment

Two authors (YQ and CYL) independently assessed the methodology quality of each included MA using the 16-item 'A MeaSurement Tool to Assess systematic Reviews – 2 (AMSTAR 2)' critical appraisal tool (Shea et al., 2017). Any discrepancies were discussed and resolved by consensus. The AMSTAR 2 consists of domains of adherence to PICO (item 1), registration of a protocol (item 2), justification for the selection of study design (item 3), adequacy of literature search (item 4), duplication of study selection (item 5) and data extraction (item 6), the listing of and justification for excluding studies (item 7), detailed descriptions of included studies (item 8), satisfactory risk of bias (RoB) assessment (item 9), report of the source of fundings (item 10), appropriateness of statistical analysis methods (item 11), analysis of the impact of RoB on the results (item 12), interpretation of the impact of RoB on the results (item 13), explanation of heterogeneity (item 14), assessment and discussion of publication bias (item 15), and report of conflict of interest (item 16). Items were rated as 'yes', 'partial yes', or 'no'. Although all 16 items are relevant to the methodological quality of meta-analyses, Shea et al. (2017) recommended that a review should also consider whether there are weaknesses in certain *critical* domains. Items 2, 4, 9, 11, 13, and 15 were considered critical to the validity and conclusions of a MA. Item 7 was rated but not considered as a critical domain as Shea et al. suggested, because the included MAs excluded hundreds of studies, listing and justifying the exclusion of each study would be a highly intensive task. Once the two authors appraised the 16 items, the quality of each MA was categorized as 'high' (no or one non-critical weakness), 'moderate' (more than one non-critical weakness), 'low' (one critical weakness), or 'critically low' (more than one critical weakness).

Synthesis methods

The characteristics of the included MAs are presented in tabular forms and narratively summarized. Given that the MAs assessed the effects on different cognitive domains, the effectiveness is synthesized for each cognitive domain for aerobic exercise and dance separately. The quantitative analysis was conducted using the *metafor* R package.

Standardized mean differences (SMD) and their corresponding 95% confidence intervals were extracted from each MA. For MAs that reported mean differences, SMD was calculated using the original data provided in the MA. A positive SMD indicated improvement. Only effect sizes based on at least two primary studies were included. In cases where a MA synthesized multiple effect sizes for one cognitive outcome, these estimates were aggregated into a single effect size, so each MA contributed only one effect size to the meta-meta-analysis. When a cognitive domain was only synthesized in one MA, the statistics from that MA were reported but not subjected to analysis.

The meta-meta-analysis method followed that of Mingebach et al. (2018) to correct for the primary study overlap, which was based on Munder et al. (2013). This involved calculating the uniqueness of each primary study and the adjusted number of included primary studies (k_{adj}) for each MA. Effect sizes of MAs were weighted by the k_{adj} to obtain the overall effect sizes that account for the overlap of primary studies. According to Cohen (1988), effect sizes were interpreted as small (0.2–0.5), moderate (0.5–0.8), and large (>0.8). Heterogeneity was estimated using the Q-test and I^2, with I^2 of 25%, 50%, and 75% indicating low, medium, and high heterogeneity, respectively. Publication bias was assessed for analyses involving at least ten MAs through the visual inspections of funnel plots and Egger's tests. Sensitivity analyses were conducted through excluding outliers (defined as those whose confidence interval does not overlap with the confidence interval of the pooled effect; Harrer et al., 2021) and MAs with low methodological quality.

Results

MAs selection

Figure 1 presents the PRIOR flow diagram. A total of 806 studies were identified by the initial database search. After removing duplicates, 424 titles and abstracts were screened, resulting in 61 remaining eligible studies. Sixteen additional MAs were identified from relevant

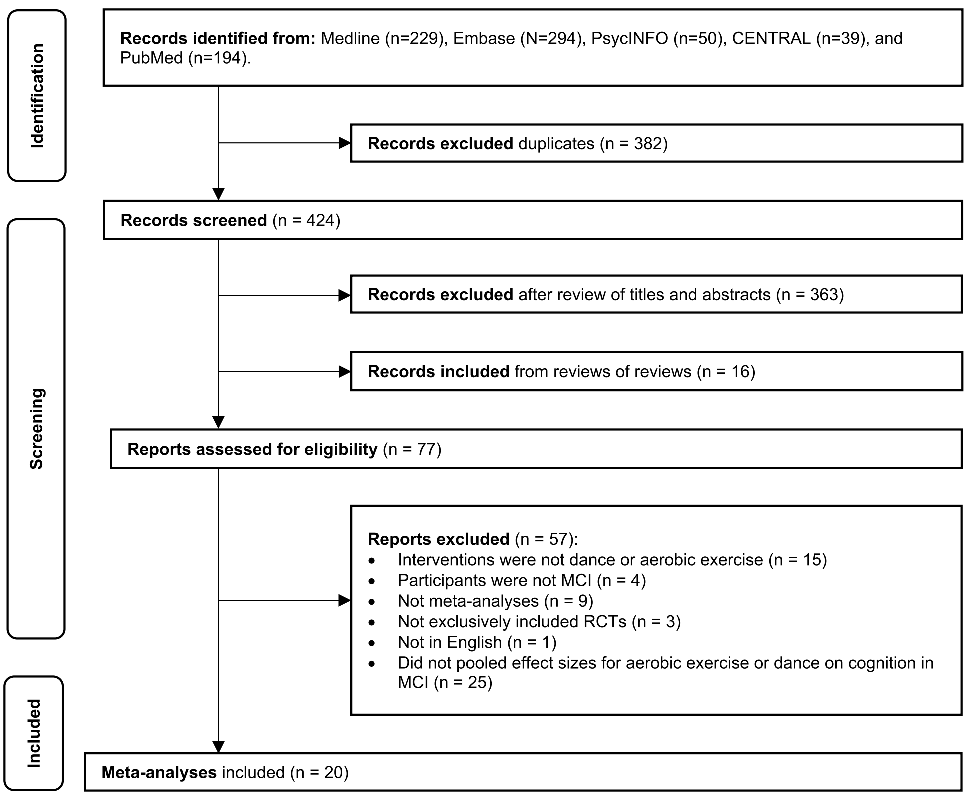

Figure 1. PRIOR flow diagram.

overviews of reviews. The full texts of 77 studies were reviewed, and 20 met the eligibility criteria and were included in this overview. The list of excluded studies and reasons for exclusion are provided in Table S4. The inter-rater reliability for screening full texts was $k = 0.76$.

Characteristics of the MAs

Table 1 summarizes the characteristics of the included MAs. The included MAs were based on literature searches conducted between 2014 and 2023. The number of RCTs in the 20 MAs ranged from five to 73, resulting in a total of 510 RCTs being identified. In 15 MAs, 162 RCTs examined the effects of aerobic exercise in MCI, of which 59 were unique RCTs. In five MAs, 27 RCTs examined the effects of dance in MCI, with 12 being unique RCTs. The corrected covered areas indicated a 12% (high) and 31% (very high) overlap in the primary studies included across different MAs for aerobic exercise and dance, respectively.

The number of participants in the MAs ranged from 358 to 5682. The ages of participants ranged from 50 to 93 years. Thirteen MAs reported gender proportions or the number of males/females in each included study. Intervention characteristics varied across MAs with respect to duration (2.5–150 min per session), frequency (1–17 sessions per week), and intervention length (4–104 weeks). Control comparators in the included MAs can be categorized into three types: (a) no contact (i.e. not engaged in additional activities): no treatment, usual care, or waitlist control; (b) active controls: health education, education program, social visits, or recreational activities; (c) low-intensity physical exercise: balance, tone, stretching, sham exercise, low-intensity exercise, relaxation with light movements, or other forms of low-intensity exercise.

A variety of cognitive domains were assessed. Table S5 lists cognitive outcome measures and their corresponding cognitive domains as indicated by the included MAs. The table highlights substantial clinical heterogeneity. First, the same cognitive domain was often assessed using different measurements. For example, global cognition was assessed by nine scales, such as ADAS-Cog, MMSE, and MoCA. Second, the same cognitive measurements were sometimes categorized under different cognitive domains in different MAs. For instance, the Trial Making Test – A was categorized as executive function ($N = 4$), attention ($N = 1$), and visuospatial ability ($N = 1$); the Verbal Fluency Test was categorized as executive function ($N = 5$), language (N = 3), and working memory ($N = 1$).

Based on a cross-disciplinary taxonomy created by Webb et al. (2018) and the measures for attention (e.g. Test of Everyday Attention), language (e.g. Verbal Fluency Test), verbal learning (e.g. Rey Auditory Verbal Learning Test), and working memory (e.g. Digit Span), these three domains were categorized into the memory domain in this review. Therefore, four cognitive domains were considered in the current overview of reviews: global cognition, executive function (including cognitive flexibility and processing speed), memory (including attention, immediate and delayed recall, language, recognition, verbal learning, and working memory), and visuospatial ability.

Table S6 summarizes the reported effect sizes from each MA exclusively for aerobic exercise or dance on cognition in people with MCI. It should be noted that only two studies pooled the effects of dance on visuospatial ability (Chan et al., 2020; Wu et al., 2021), while Chan incorrectly categorized the Trial Making Test – A as a measure of visuospatial ability. This means that only Wu et al. (2021) actually investigated the effects on visuospatial ability, so the meta-meta-analysis did not synthesize this specific effect.

Table 1. Characteristics of included MAs.

Meta-analyses	Databases searched	Language restrictions	N RCTs	Population	Interventions	Control comparisons	Cognitive outcomes
Ahn and Kim (2023)	Date: May 2022 15 databases	No restrictions	22 (10AE)	N: 2210 Age: 64–78 Women: NR CS: MCI	Types: aerobic exercise, multicomponent, resistance, neuromotor exercise Duration: 30–90 min Frequency: 1–7/week Length: 6–48 weeks	No treatment, usual care, health education, stretching	Global cognition
Biazus-Sehn et al. (2020)	Date: January 2020 5 databases	English	27 (12 AE)	N: 2,077 Age: 65–78 Women: NR CS: MCI	Types: aerobic exercise, resistance exercise, multicomponent interventions, others (tai chi, baduanjin, dance, handball) Volume: 72–210 min/week Length: 6–52 weeks	No treatment, balance, tone or stretching programs, social or mental activities	Global cognition, cognitive speed, verbal fluency, immediate recall, delayed recall, working memory, executive function or attention
Chan et al. (2020)	Date: July–Aug 2019 7 databases	English	5 (5 dance)	N: 358 Age: 66–75 Women: 48–76% CS: MCI	Types: dance Duration: 25–60 min Frequency: 1–3 /week Length: 12–40 weeks	Waitlist control, health education	Global cognition, attention, recall, working memory, language, mental flexibility, visuospatial ability
Ding et al. (2023)	Date: June 2022 6 databases	English	65 (11 AE in MCI)	N: 5682 Age: 72.4 Women: 65.7% CS: MCI, dementia	Types: diet, stress management, exercise (aerobic exercise, resistance training, walking, tai chi, multicomponent training), multimodal intervention Duration: 10–150 min Frequency: 1–7/week Length: 5–104 weeks	Social programs, sham interventions, care-as-usual, waiting list	Global cognition, attention, executive function, language, non-verbal memory, processing speed, verbal learning and memory, visuospatial skills, and working memory
Han (2023)	Date: March 2022 3 databases	English	18 (7 AE)	N: 1700 Age: 60–80 Women: 0–86% CS: MCI	Types: conventional aerobic exercise, mind-body exercise, multicomponent aerobic exercise Duration: 21–80 min Frequency: 1–5/week Length: 6–52 weeks	Stretching, health education, routine care, daily lifestyle, social recreation	Global cognition
Hewston et al. (2021)	Date: August 2020 4 databases	Not mentioned	11 (4 dance in MCI)	N: 1,412 Age: 60–80 Women: NR CS: healthy, MCI	Type: dance Duration: 60–120 min/week Frequency: 1–3/week Length: 14–48 weeks	Any control group (e.g. education, walking, waitlisted, no physical activity)	Global cognitive function, executive function, learning and memory, complex attention, language
Hu et al. (2022)		English and Chinese	42 (11 AE)	N: 4401 Age: 55–80	Types: physical activity (aerobic, muscle-strengthening, mind-body	Inactive and active control	Cognition

	Date: June 2020 7 databases			Women: 20–100% CS: MCI	activity), cognitive intervention, multicomponent intervention, nutrition intervention Duration: 16–120 min Frequency: 1–7/week Length: 4–104 weeks		
Huang et al. (2022)	Date: September 2019 6 databases	English	73 (12 AE in MCI)	N: 5,606 Age: 58–89 Women: 30–100% CS: MCI, dementia	Types: aerobic exercise (walking, running, cycling), resistance exercise (elastic bands, weight machines), multicomponent exercise, mind-body exercise (tai chi, yoga, dance), whole-body vibration, finger exercise Duration: 2.5–120 min Frequency: 1–17/week Length: 6–93 weeks	No intervention, usual care, health education, sham exercise training, other forms of exercise	Global cognition, executive function, memory function
Li et al. (2022)	Date: November 2021 4 databases	English	12 (7 AE in MCI)	N: 708 Age: 60–86 Women: 38–100% CS: MCI, dementia	Types: aerobic exercise (bicycle, treadmill, walking), resistance exercise, multimodal exercise Duration of AE: 30–60 min Frequency of AE: 1–3/week Length of AE: 6–26 weeks	Waiting list, maintaining lifestyle routine, a strength or balance tone, muscle-stretching exercises, social visits	Global cognition, immediate recall, working memory, delayed recall, processing speed, attention, executive function, recognition
Lin et al. (2022)	Dates: February 2021 9 databases	No restrictions	24 (11 AE)	N: 2278 Age: 60–85 Women: NR CS: MCI	Types: aerobic exercise, resistance exercise, mind body exercise, or multicomponent training Duration: 30–120 min Frequency: 1–7/week Length: 6–48 weeks	No contact (e.g. maintain current lifestyle), positive (e.g. balancing, stretching, and toning), education (e.g. health lectures or educational consulting), or social (e.g. social activities, social meeting groups)	Executive function: working memory, switching, inhibition control and executive planning
Lin (2023)	Date: July 2023 8 databases	English and Chinese	14 (14 AE)	N: 560 Age: 55–80 Women: NR CS: MCI	Types: walking or brisk walking Duration: 25–60 min Frequency: 2–5/week Length: 24–48 weeks	Hand/face exercises, stretching, activities of daily living, social activities, health education, motion exercises, balance exercises, usual care, relaxation techniques, flexibility, and postural exercise	Global cognition, verbal learning, processing speed
Liu (2023)	Date: May 2022 5 databases	English	21 (5 dance)	N: 1743 Age: 50–85 Women: NR CS: MCI	Types: dance, handball training, multicomponent exercise, Ruesi Dadton, resistance exercise, dumbbell training, Taiji, limbs	Usual care, health education, waitlist, relation exercise, and placebo control	Global cognition

(*Continued*)

Table 1. Continued.

Meta-analyses	Databases searched	Language restrictions	N RCTs	Population	Interventions	Control comparisons	Cognitive outcomes
					exercise, aerobic exercise, physical activity, virtual kayak paddling exercise Duration: 30–90 min Frequency: 1–5/week Length: 6–52 weeks		
Shao (2022)	Date: June 2020 7 databases	English and Chinese	42 (14 AE)	N: 4401 Age: 50–85 Women: 20–100% CS: MCI	Types: cognitive intervention, physical exercise (kayak paddling, dance, elastic band, walking, running, tai chi), multicomponent intervention, nutrition intervention Duration: 30–90 min Frequency: 1–6/week Length: 6–48 weeks	Any intervention different from the intervention group or the control group with less impact on cognitive function	Cognition
Song et al. (2018)	Date: October 2017 6 databases	English and Chinese	14 (6 AE)	N: 929 Age: 50–93 Women: NR CS: MCI	Types: aerobic exercise, resistance exercise, multi-modal exercise Duration: 30–90 min Frequency: 1–4/week Length: 6–48 weeks	Health education, placebo stretching, social visits, social recreational activities, blank control	Global cognition, executive function, memory
Talar (2022)	Date: December 2021 3 databases	English	53 (19 AE in MCI)	N: 3427 Age: 65–86 Women: 62.9% CS: healthy older adults, MCI, dementia	Type: aerobic exercise Duration of AE: 46 min Frequency of AE: 1–7/week Length of AE: 1–60 weeks	Stretching, balance and tone, usual care, no intervention, health education, recreational activities, low intensity activity	Global cognition, working memory, executive function
Wang et al. (2014)	Date: January 2014 4 databases	English	18 (5 AE)	N: 1,125 Age: 68–86 Women: 44–78.9% CS: MCI	Types: cognition-based intervention and physical exercise (aerobic, resistance exercise, walking, biking) Length: 6–48 weeks	Recreational activities, education classes, stretching and toning, low-intensity exercises	Global cognition, executive function, working memory, processing speed, memory
Wang (2019)	Date: December 2018 6 databases	English and Chinese	18 (5 AE)	N: 1,364 Age: 50–78 Women: 0–100% CS: MCI	Types: aerobic exercise, resistance exercise, mind-body exercise, exergame Duration: 21–90 min Frequency: 1–6/week Length: 6–48 weeks	Usual lifestyle, health education, placebo	Global cognition
Wu et al. (2021)		English	8 (8 dance)	N: 680 Age: 65–81	Type: dance Duration: 35–60 min	Usual care, health education, music, physical therapy	Global cognition, memory, attention, executive function,

	Date: March 2020 7 databases			Women: 46–83% CS: MCI	Frequency: 1–3/week Length: 12–40 weeks		processing speed, visuospatial function, language
Zheng et al. (2016)	Date: January 2015 7 databases	No restrictions	18 (18 AE)	N: 1,497 Age: 66–85 Women: 27–100% CS: MCI	Types: aerobic exercises (regular walking, handball training, tai chi, jogging combined with tai chi, cycling, dance-based aerobics, multicomponent, aerobic exercises) Duration: 30–60 min Frequency: 2–5/week Length: 6–48 weeks	Non-intervention, stretching or tone exercise, social activities, health education	Global cognition, immediate and delayed recall, attention, executive function, verbal fluency, visuospatial function
Zhu et al. (2020)	Date: February 2019 4 databases	English	5 (5 dance)	N: 842 Age: 65–77 Women: 50–80% CS: MCI	Types: aerobic dance (salsa, rumba, waltz, cha-cha, blues, jitterbug, tango, tai chi) Duration: 30–90 min Frequency: 1–3/week Length: 12–52 weeks	Health education, exercise but not aerobic dance	Global cognition, executive function, immediate and delayed recall

Abbreviations: CS = cognitive status; MA = meta-analysis; MCI = mild cognitive impairment; NR = not reported; RCT = randomized controlled trial.

Quality assessments in meta-analyses

Details of the AMSTAR-2 ratings for each MA are presented in Table S7. The overall quality was moderate in five MAs, low in five MAs, and critically low in 10 MAs. The inter-rater reliability was $k = 0.67$. Among the 10 critically-low-quality MAs, one MA (Ding et al., 2023) had four weaknesses in the critical domains, and one MA (Hewston et al., 2021) had three weaknesses. The remaining eight MAs only had two weaknesses in the critical domains, mainly failing to consider the influence of risk of bias on the findings and investigating publication bias.

For the critical domains, 15 MAs registered the protocol (item 2), none of the MAs used a comprehensive literature search strategy such as searching the reference lists of included studies or study registries (item 4), 17 MAs evaluated the RoB with satisfactory technique (item 9), all included MAs used appropriate methods to statistically combine results (item 11), 8 MAs interpreted the impact of RoB on the results (item 13), and 7 MAs assessed and discussed publication bias (item 15). Additionally, most MAs did not provide a list of excluded studies and provide a justification for the exclusion (item 7, $N = 20$), report the funding sources for the individual studies (item 10, $N = 20$), justify the inclusion of particular study designs (item 3, $N = 13$), and assess the potential impact of bias on the meta-analysis (item 12, $N = 13$). Although such shortcomings must be borne in mind when interpreting findings, it is important to note that the criteria for evaluating the MAs do not reflect on the quality of the individual RCTs included in the analysis but rather on how closely the MAs adhered to the reporting protocols for conducting and reporting a MA. The included MAs summarized RCTs published in peer-reviewed journals, and most of them employed appropriate data synthesis approaches, so they still provide valuable data to assess the cognitive benefits of aerobic exercise and dance relative to control conditions.

Syntheses of results

Table 2 summarizes the meta-meta-analysis outcomes for aerobic exercise and dance in each cognitive domain. Forest plots illustrating these outcomes are displayed in Figure S1–8. For aerobic exercise, the result showed a significant and small effect on cognition (SMD = 0.28 [.13, .43]) with a high heterogeneity ($I^2 = 84\%$). The effect size on global cognition was small-to-moderate (SMD = 0.42 [.21, .64], $I^2 = 81\%$). No significant effects on

Table 2. Meta-meta-analysis outcomes.

Outcome	MA	SMD	*SE*	95% *CI*	*p*	*Q*	I^2 (%)	tau^2
Aerobic exercise								
Overall	15	0.28	0.08	[0.13, 0.43]	0.0002	$Q(14) = 71.1, p < .0001$	83.89	0.06
Global cognition	9	0.42	0.11	[0.21, 0.64]	0.0001	$Q(8) = 33.43, p < .0001$	81.26	0.06
Executive function	7	0.01	0.11	[−0.21, 0.23]	0.91	$Q(6) = 20.12, p = .003$	72.41	0.05
Memory	8	0.03	0.06	[−0.09, 0.14]	0.67	$Q(7) = 11.23, p = .13$	36.79	0.008
Dance								
Overall	5	0.39	0.05	[0.28, 0.49]	<.0001	$Q(4) = 4.48, p = .34$	27.21	0.002
Global cognition	5	0.4	0.16	[0.01, 0.09]	0.01	$Q(4) = 23.99, p < .0001$	83.32	0.095
Executive function	4	0.18	2.42	[0.03, 0.32]	0.02	$Q(3) = 0.93, p = .82$	0	0
Memory	4	0.46	0.08	[0.32, 0.61]	<.0001	$Q(3) = 3.86, p = .28$	34.96	0.003

Abbreviations: MA = number of included meta-analyses; SMD = standardized mean difference; SE = standard error; CI = confidence interval; Q = test statistic for heterogeneity; I^2 = the degree of heterogeneity; tau^2 = the amount of true heterogeneity between studies.

executive function (SMD = 0.01 [−.21, .23], I^2 = 72%) and memory (SMD = 0.03 [−.09, .14], I^2 = 37%) were observed for aerobic exercise. For dance, the results revealed a small-to-moderate effect on cognition (SMD = 0.39 [.28, .49]) with relatively low heterogeneity (I^2 = 27%). The specific cognitive domains, global cognition (SMD = 0.4 [.01, .09], I^2 = 83%), executive function (SMD = 0.18 [.03, .32], I^2 = 0%), and memory (SMD = 0.46 [.32, .61], I^2 = 35%) were all improved by dance. There was only one MA that examined the effect of dance on visuospatial ability (Wu et al., 2021), which revealed a small-to-moderate effect size supporting the effectiveness of dance (SMD = 0.42 [.08, .76]) based on results from three primary studies.

Subgroup analyses revealed that the type of intervention significantly moderated the effects on memory (Q = 21.38, p < .0001), with dance showing larger effect sizes than aerobic exercise. However, intervention type did not moderate the effects on overall cognition (Q = 0.1, p = .75), global cognition (Q = 0.01, p = .92), or executive function (Q = 1.52, p = .22). Publication bias was assessed only for the overall effect of aerobic exercise on cognition, as this analysis included more than ten MAs. The funnel plot (Figure S9) and Egger's test (b = −0.14 [−.57, .29]) indicated no signs of asymmetry. Table S8 summarizes the results of sensitivity analyses. Excluding outliers did not impact the effect sizes but reduced the heterogeneity level. Excluding studies with critical low and/or low quality generally did not change the results, except that the effect of aerobic exercise on global cognition became marginally significant (.05 < p < .10).

Discussion

This overview of meta-analyses synthesized the effect of aerobic exercise and dance interventions on cognitive functions in people with MCI using data from previous MAs. Only MAs that exclusively examined RCTs were included to minimize the risk of bias and provide the best available evidence. Among the 20 included MAs, 15 focused on aerobic exercise and five on dance. By quantitatively synthesizing effect sizes that exclusively addressed our current purpose, the meta-meta-analyses showed that both aerobic exercise and dance had positive effects on overall cognition. Aerobic exercise exhibited high heterogeneity, while dance showed relatively low heterogeneity, suggesting that the finding for dance is more consistent across MAs. For specific cognitive domains, aerobic exercise enhanced global cognition, and dance improved global cognition, executive function, and memory. Only one MA that examined and found a small-to-moderate effect of dance on visuospatial ability, which was not included in the quantitative synthesis. Moderator analysis suggested that dance appears to have a larger positive effect on memory than aerobic exercise.

This overview study suggests that aerobic exercise improves global cognition in adults aged 50 and above with MCI. Four reasons can explain the cognitive benefits. First, aerobic exercise changes vascular functions, including the increase of cerebral blood flow and oxygen saturation and the promotion of angiogenesis, which enhances neurotransmitter availability and neural efficiency (Lojovich, 2010; Song et al., 2018). It has been shown that the increase of maximal oxygen uptake during aerobic exercise mediates the improvement of executive function (Stern et al., 2019). Second, aerobic exercise induces the release of neurotrophic factors, such as insulin-like growth factors, vascular endothelial growth factors, and BDNF, which regulate cell growth and specialization in the developing central nervous system (Lojovich, 2010; Moriarty et al., 2019). Third, according to the catecholamine hypothesis, aerobic exercise stimulates the synthesis of norepinephrine in the prefrontal cortex, leading to enhanced arousal and attention (Moriarty et al., 2019). Fourth, aerobic exercise mitigates cardiovascular or cerebrovascular risk factors related to cognitive impairment, preventing further declines in cognitive function and delaying the onset of dementia (Cammisuli et al., 2017; Song et al., 2018). Furthermore, Stern et al. (2019) found that the benefit of aerobic exercise on executive function increased with age, suggesting that aerobic exercise may be particularly beneficial for those experiencing age-related decline in executive function, such as those with MCI.

It should be acknowledged that the included MAs on aerobic exercise did not explicitly mention the presence or absence of music – an unfortunate omission that motivated this review. However, we noticed that most of their included RCTs on aerobic exercise did not involve music (e.g. Law et al., 2019; Tarumi et al., 2019). In other words, RCTs for aerobic exercise rarely featured music whereas RTCs for dance always included music.

Our findings suggest that dance is beneficial for global cognition, executive function, and memory in adults aged 50 and above with MCI. One included MA also indicated the beneficial effects of dance on visuospatial ability. It is not surprising that dance conferred benefits that were observed for aerobic exercise, given that dance is a form of aerobic exercise. However, compared to aerobic exercise, dance was significantly more effective than aerobic exercise in improving memory. The unique combination of music and exercise in dance may play a vital role in improving memory for MCI. Beyond the aerobic benefits, dance also involves detailed, repetitive, and purposeful body movements that must be remembered and executed in precise synchrony with the music (Hewston et al., 2021; Wu et al., 2021). These features of dance place high demands on memory and timing mechanisms that may supplement the general benefits associated with aerobic exercise.

More generally, the *Therapeutic Music Capacities Model* describes how music interventions interact with cognitive-motor functions and can lead to a range of benefits for people with neurological impairment (Brancatisano et al., 2020). For example, the emotional capacity of music in inducing and modulating emotional states might enrich the emotional experience of dance, thus boosting one's motivation to continue engaging in the intervention and amplifying the cognitive benefits of exercise. The music in dance can also serve as a memory cue for learning new movement sequences, and individuals with cognitive decline often retain the ability to move in response to music, making it a valuable tool for treating MCI (Brancatisano et al., 2020; Brancatisano & Thompson, 2019; Särkämö, 2019). The changing tempi of music and the need to remember the choreography with music provide a challenging but aesthetically pleasing environment that maximizes the therapeutic benefits of dance on memory (Fritz, 2021; Hansen & Kenny, 2019; Leisman & Aviv, 2020; Rehfeld et al., 2018). Furthermore, when individuals perform the dance choreography, they are required to visually track objects and continuously adjust their body positions and orientations in relation to the surrounding environment (Chan et al., 2020; Ho et al., 2020; Lazarou et al., 2017; Zhu et al., 2020), which may explain the improvement of visuospatial ability. Dancing is also a social activity in which individuals interact by synchronizing movement with one another and interact through movements (Lossing et al., 2017; Tarr et al., 2014; Wu et al., 2022). The social rewards of dance may enhance adherence to dance programs and confer additional benefits beyond that of exercise alone.

While music interventions in the absence of exercise were not considered in this overview of reviews, evidence suggests that dance is more effective than passive music interventions. For example, participants in a dance performance group outperformed those in a passive music listening group when recognition memory was measured (Cross et al., 2012). A dance program significantly improved story memory performance in patients with MCI, while active music engagement had no significant result (Doi et al., 2017). Additionally, a recent MA (Ito et al., 2022) examined the effect of music-based intervention on cognition in people with MCI. The aggregated effect sizes for global cognition and executive function are smaller than that of dance. Although the comparison is indirect, it appears that dance may have superior cognitive benefits than a music intervention alone. Therefore, based on existing evidence, it can be inferred that dance may offer cognitive benefits beyond aerobic exercise or music listening, which are two important components of dance. It is likely that the integration and interaction of aerobic exercise and music with additional elements such as emotional and social engagement underpin the additional benefits of dance.

Although this study provided a robust overview of the best currently available evidence and synthesized the data using the meta-meta-analysis approach, some limitations should be considered when interpreting the results. First, the heterogeneity was higher for aerobic exercise than dance, likely due to the wide variety of exercise types classified under aerobic exercise, as opposed to the relatively more uniform category of dance. High levels of heterogeneity were also observed in the results for global cognition across both interventions, probably because of the variability in the measures of global cognition. However, given the challenges of categorizing the wide range of exercise types and outcome measures covered in the included meta-analyses, it is not feasible to analyze the heterogeneity of exercise types and measures using moderator analysis. Second, some MAs categorized and synthesized dance as aerobic exercise (e.g. Zheng et al., 2016). Third, half of the included MAs were rated as critically low quality based on the AMSTAR-2. However, this tool primarily assesses the completeness of reporting, so a 'critically low quality' MA does not necessarily indicate that its pooled effect sizes are not trustworthy. In fact, these MAs employed appropriate approaches to synthesize the effects, but still, most of them failed to analyze the impact of studies' risk of bias on results and failed to assess publication bias. Fourth, only English peer-reviewed MAs were included in this overview, which could lead to the omission of relevant studies in other languages and reduce the generalizability of the current findings. However, some of the included MAs (Ahn & Kim, 2023; Lin et al., 2022; Zheng et al., 2016) did not have language restrictions, which might partially mitigate this limitation.

The need for high-quality MAs is highlighted to improve the validity and reliability of evidence and enable researchers to reach more definitive conclusions based on the findings. Only four out of 15 MAs on aerobic exercise and one out of five MAs on dance were of moderate quality. Future MAs in this field should include a comprehensive search of the literature and critically interpret the meta-analysis results by considering the influence of risk of bias and publication bias. In addition, we cannot categorically conclude that it is the presence of music that contributes to the additional cognitive benefit of dance, as there are no RCTs to date comparing the impact of dance-movement interventions with and without accompanying music. A valuable next step would be to conduct a network meta-analysis on the primary studies identified by this overview, comparing the effectiveness of dance, aerobic exercise with music, and aerobic exercise without music. Such a network meta-analysis would help to refine our understanding of the most effective exercise-based interventions for improving cognitive function in adults with MCI. This further exploration would also shed greater light on the mechanisms that underpin the benefits of music and exercise on cognitive function.

The stabilization of cognitive status is a crucial objective in treating adults with MCI (see also Wolff et al., 2023). This overview of MAs suggests that aerobic exercise and dance can achieve this goal by effectively improving cognitive functions. Specifically, aerobic exercise has been shown to improve global cognition, while dance benefits a broader range of cognitive domains, including global cognition, executive function, memory, and visuospatial ability. Notably, dance appears to offer benefits in enhancing memory beyond aerobic exercise, potentially attributed to its unique integration of aerobic exercise and music. This comparison suggests that the benefits of aerobic exercise may be amplified by accompanying music, and illustrates the potential of music-supported exercise to maintain and improve cognitive function in adults with MCI. Although these findings should be interpreted with caution because of the high heterogeneity and the lack of high-quality MAs, the consistency in sensitivity analyses suggests that the results are stable and reliable. Efforts can be made to raise public awareness of the positive cognitive benefits of aerobic exercise and dance. Intervention programs designed for patients with MCI can consider incorporating aerobic exercise, especially dance, into their intervention protocols.

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Authors' contributions

YQ conceived the study, searched databases, selected studies, assessed study quality, extracted data, synthesized data, and drafted the manuscript. CYL selected studies, assessed study quality, and checked the accuracy of the data extraction. KNO and WFT conceived the study and critically reviewed the manuscript. All authors read and approved the final manuscript.

Data availability statement

The data that support the findings of this overview of reviews are available from the corresponding author, YQ, upon reasonable request.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Registration and protocol

The review protocol was registered in the International Prospective Register of Systematic Review (PROSPERO) database (registration number: CRD42022307443). Different from the protocol, meta-meta-analysis was performed to synthesize the results from the included meta-analyses, to provide more robust evidence.

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