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Review Article

The effects of aerobic exercise on cognitive function and depressive symptom in patients with depression: a systematic review and meta-analysis of randomized controlled trials

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Abstract: Objective: This study sought to comprehensively assess the impact of aerobic exercise on cognitive performance and depressive symptoms in individuals diagnosed with depression, in order to provide a more comprehensive evidence base for the clinic. Methods: PubMed, Embase, Web of Science, Cochrane Library, CNKI, Wanfang Data, and SinoMed were searched for randomized controlled trials (RCTs) published up to June 2025. Eligible studies included clinically diagnosed patients with depression receiving aerobic exercise as the intervention. Meta-analyses were conducted using RevMan 5.4. Standardized mean differences (SMD) were pooled as effect sizes. Heterogeneity was assessed using the I^2 statistic. The Cochrane Risk of Bias 1.0 tool was used to assess methodological quality. Results: A total of 17 RCTs were included. According to the results of the meta-analysis, aerobic exercise was associated with marked enhancements in working memory (Digit Span Backward, SMD = 0.16, P = 0.05) and executive function (Trail Making Test-B, SMD = -0.29, P = 0.03) in patients with depression. Notably, as comprehensive cognitive assessment tools, the Montreal Cognitive Assessment and the Mini-Mental State Examination demonstrated significant effects of aerobic exercise (SMD = 1.68, P = 0.0003). Regarding depressive symptoms, significant improvement was found with the Hamilton Depression Rating Scale (SMD = -0.87, P = 0.04). Additionally, four studies reported unique single-scale outcomes suggesting potential trends toward improvement in both cognitive and emotional domains. Conclusion: Engagement in aerobic exercise appears to support improvements in executive function and working memory among patients with depression, though its impact on other cognitive domains and mood-related outcomes remains inconclusive. These findings should be interpreted with caution.

Keywords: Aerobic exercise, depression, cognitive function, working memory, meta-analysis

Introduction

Depression is a common affective disorder characterized by loss of interest, persistent low mood, reduced energy, and other symptoms [1]. More than 280 million individuals globally are currently living with depression, and its prevalence continues to increase annually [2]. The detrimental impact of depression on quality of life and social integration, combined with its strong association with suicide, underscores its role as a major contributor to global disease burden and highlights the necessity for public health prioritization [3].

Besides affective manifestations, patients with depression are often accompanied by significant cognitive dysfunction, which is manifested as inattention, memory loss, impaired executive functioning, and weakened decision-making ability [4]. A study from China showed that more than 63% of patients with depression may have different degrees of cognitive impairment during acute episodes, and cognitive dysfunction persists in some patients even after their mood symptoms have been relieved, which becomes one of the major obstacles to their social function recovery [5]. Cognitive impairment aggravates patients' loss of social and

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occupational functioning and affects their adherence to treatment, thus influencing the long-term prognosis of the disease [6]. Therefore, cognitive function intervention for depressed patients has become a focus of clinical research in recent years.

In recent years, aerobic exercise has garnered increasing attention in the field of psychiatry as a low-cost, low-risk, non-pharmacological intervention [7]. It is believed that aerobic exercise may exert positive effects on emotional symptoms and cognitive function by promoting the expression of brain-derived neurotrophic factor (BDNF), and enhancing neuroplasticity [8]. Reports suggest that aerobic exercise can effectively alleviate anxiety and depression in both community populations and individuals with depression [9-11]. Aerobic exercise has been previously studied for its potential cognitive benefits in cognitively impaired individuals. A systematic review and meta-analysis indicated that aerobic exercise interventions may improve processing speed and attention to some extent [12]. However, not all studies have consistently demonstrated beneficial effects of aerobic exercise on cognitive function, resulting in substantial heterogeneity across findings. Meanwhile, previous meta-analyses still have some limitations in several aspects. First, one of the most recent meta-analyses included only English-language studies, which suffers from language bias and may have missed some of the higher-quality literature in Chinese or other languages, thus affecting the robustness of the conclusions [13]. Second, previous systematic evaluations and meta-analyses have limited the age of the study population in terms of inclusion criteria, only including literature from adult and elderly participants, and it is well known that depression affects adolescents in particular, making it difficult for these possible studies to provide a picture of the response to aerobic exercise in depression [12, 13]. Additionally, in meta-analyses, existing studies have primarily focused on indicators of cognitive functioning and have less frequently included secondary clinical outcome indicators, such as depressive symptom scores. This approach fails to comprehensively assess the combined benefits of exercise interventions.

Based on the above background, this study intends to conduct a systematic review and meta-analysis to assess the impact of aerobic exercise on the cognitive function of patients with depression of all ages and further explore its potential role in alleviating depressive symptoms. To reduce bias and enhance the generalizability of the conclusions, this study does not restrict the language of the literature and includes multiple assessment indicators such as cognitive scores and depression scales, thereby comprehensively evaluating the intervention effect of aerobic exercise. The implementation of this study aims to provide more sufficient evidence support for clinical practice and promote the standardized application of exercise intervention in the auxiliary treatment strategies for depression.

Methods

Literature search

A broad literature search covering Chinese and English sources was implemented to retrieve studies assessing the impact of aerobic exercise on cognitive outcomes in depression. This study has been registered with PROSPERO (CRD420251136360) and strictly adhered to the PRISMA guidelines to ensure the rigor of the study. The databases searched included PubMed, Embase, Web of Science, the Cochrane Library, CNKI, Wanfang Data, and the SinoMed database. Studies published from the inception of the respective databases until June 2025 were included in the search, with no language restrictions applied. A free-text search strategy was employed using terms such as: depression, attention, depressive disorder, cognitive impairment, major depressive disorder, cognitive function, executive function, working memory, memory, aerobic exercise, physical activity, physical exercise, and running, among others. Search terms and spellings were adjusted as needed throughout the retrieval process. The search strategy is as follows (Take PubMed as an example): #1: (“Depression”[MeSH] OR “Depressive Disorder”[MeSH] OR “Depressive Disorder, Major”[MeSH] OR depression[Title/Abstract] OR depressive disorder[Title/Abstract] OR major depressive disorder[Title/Abstract] OR attention[Title/Abstract]); #2: (“Cognition”[MeSH] OR “Cognition Disorders”[MeSH] OR “Executive Function”[MeSH] OR “Memory”[MeSH] OR “Memory, Short-Term”[MeSH] OR cognitive impairment[Title/Abstract] OR cognitive function[Title/Abstract] OR executive function[Title/Abstract] OR working memory[Title/Abstract] OR memory[Title/Abstract]); #3: ("Exercise"[MeSH] OR "Exercise Therapy"[MeSH] OR "Running"[MeSH] OR "Aerobic Exercise"[MeSH] OR aerobic exercise[Title/Abstract] OR physical activity[Title/Abstract] OR physical exercise[Title/Abstract] OR running[Title/Abstract]); #4: #1 AND #2 AND #3. To minimize the risk of omitting gray literature or studies not indexed in the selected databases, additional searches were conducted by tracking bibliography lists and using general search engines. Two researchers carried out the search and screening independently. Discrepancies were resolved through discussion or by involving a third reviewer.

Literature inclusion and exclusion criteria

Inclusion criteria: Randomized controlled trials (RCT) published in any language; no age restrictions for participants; participants must be diagnosed with depression, based on diagnostic standards, or selected using reliable depression scales and clear cut-off values; the experimental group must receive aerobic exercise intervention or combined with other therapies; the control group must undergo non-aerobic exercise, conventional treatment, placebo, waiting list, or no intervention; studies must report cognitive function-related indicators.

Exclusion criteria: Studies where both the experimental and control groups receive aerobic exercise intervention; studies where the intervention is yoga, resistance training, Tai Chi, or other non-aerobic exercises; studies where complete or clear data cannot be obtained; duplicate publications.

Data extraction and risk of bias assessment

The process of screening and extracting data was conducted separately by two reviewers, with extracted content comprising fundamental study information (first author's surname, year of publication, country, and language of publication) and study characteristics (sample size and details of interventions in both groups). For outcome measures, particularly those related to cognitive function and depressive symptoms, the names of the used assessment instruments were recorded. Mean values, standard deviations, and participant numbers for each outcome were also extracted. When discrepancies arose, they were discussed and resolved collaboratively, with input from a third reviewer when required to guarantee consistency and precision. The risk of bias in the included RCTs was evaluated using the Cochrane RoB 1.0 tool, following the guidelines provided by the Cochrane Collaboration. This tool evaluates the risk of bias across seven domains [14].

Statistical analysis

Review Manager (v5.4, Cochrane Collaboration) was used to conduct the meta-analysis. Since the outcome data were continuous, effect sizes were summarized as standardized mean differences (SMD) with 95% confidence intervals. Heterogeneity among the outcomes of each study was assessed using the I^2 statistic. I^2 values greater than 50% indicate moderate or greater heterogeneity. A fixed-effects model was used when $I^2 \leq 50\%$, and a random-effects model was used when $I^2 > 50\%$ to obtain more robust results. For outcomes with $I^2 > 50\%$, sensitivity analyses were further performed using leave-one-out procedures in R 4.4.3 to assess the stability of the findings. Since fewer than 10 studies were included for each outcome variable, funnel plotting and publication bias analysis were not performed to avoid instability in the interpretation of the results.

Meta-analysis results

Overview of included trials and risk of bias evaluation

Figure 1 presents the flow diagram of literature selection. As shown in **Table 1**, a total of 17 RCTs [15-31] involving 1,581 participants were included in this meta-analysis, with 755 participants in the control group and 826 in the intervention group. The publication years of the included studies ranged from 2001 to 2024. Specifically, eight studies [16, 17, 19, 26, 28-31] were conducted in China, three [23-25] in Denmark, two [20, 22] in the United States, two [15, 27] in Germany, one [21] in the Netherlands, and one [18] did not report the country of participant recruitment or trial implementation. In terms of publication language, eight studies [16, 17, 19, 26, 28-31] were published in Chinese, while the remaining nine [15,

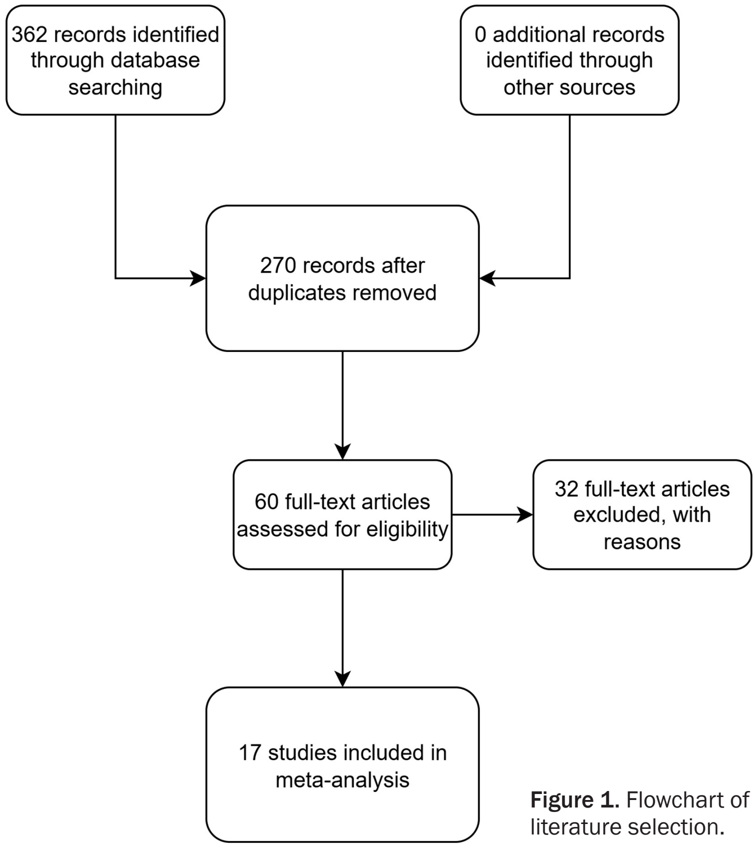


Figure 1. Flowchart of literature selection.

18, 20-25, 27] were in English. The intervention groups predominantly employed various forms of aerobic exercise, including running and cycling, with some studies combining aerobic exercise with pharmacotherapy, psychological interventions, or standard care. In contrast, the control groups typically received stretching exercises, usual care, placebo, or no intervention. All included studies reported at least one cognitive function-related outcome.

The overall risk of bias in the included studies is presented in **Figure 2**. Several studies were judged as having unclear or high risk of bias in domains such as "blinding of participants and personnel", "allocation concealment", and "selective reporting", indicating notable limitations in the design of some trials.

Analysis of executive function

As shown in **Figure 3**, these results analyzed the therapeutic potential of aerobic exercise on three executive function-related scales in patients with depression [32-34]. As depicted in **Figure 3A**, a total of five studies [16, 19, 22-24] included Trail Making Test B (TMT-B) scores, with a total sample size of 504 individuals. The meta-analysis demonstrated a significant advantage of the intervention group over the control group in TMT-B with a moderate effect size (SMD = -0.29, P = 0.03), suggesting that aerobic exercise is beneficial for enhancing executive function. Notably, there was moderate heterogeneity in this result (I^2 = 54%), so a random-effects model was used for the analysis. Meanwhile, as shown in **Figure 3B**, the Stroop Color-Word Test was used in three studies [20, 22, 24] with a total sample size of 352 individuals. Results from the meta-analysis indicated that the performance difference between the aerobic exercise and control groups in this task was marginal (SMD = -0.00, P = 0.97), and the heterogeneity among studies was low (I^2 = 15%). Additionally, as shown in **Figure 3C**, the Verbal Fluency Test (VFT) was included in four studies [16, 20, 23, 24], involving 483 participants. Verbal fluency outcomes slightly favored the aerobic exercise group over controls (SMD = 0.22); however, the difference did not reach statistical significance (P = 0.28), and heterogeneity among studies was high (I^2 = 78%). In addition, **Figure 3D** and **3E** present the sensitivity analyses for TMT-B and VFT, respectively. The results indicated that the heterogeneity of TMT-B was not driven by any single study. For VFT, the study by Krogh (2009) [23] might have exerted some influence on the pooled effect, but it did not alter the overall direction of the effect.

Analysis of attention and processing speed

As illustrated in **Figure 4**, this study examined the effects of aerobic exercise on attention and processing speed in patients with depression, based on relevant assessment scales [35, 36]. In **Figure 4A**, a total of five studies [19, 22-24, 27], comprising 393 participants, reported outcomes using the TMT-A. The results indicated

Table 1. Characteristics of included studies

Author	Year	Country	Language	Control Sample Size	Intervention Sample Size	Control Treatment	Intervention Treatment	Outcomes
Buschert	2019	Germany	English	15	15	Occupational or art therapy	Outdoor walking, Nordic walking, or running	WMS-R (digit span forward), WMS-R (digit span backwards), BDI-II
Chen	2021	China	Chinese	62	63	Conventional drug therapy	Conventional drug therapy + jogging, ball games or square dancing	WMS-R (Digit Span-Sequential Order), WMS-R (Digit Span-Reversed Order), TMT-B, Verbal Fluency Test
Du	2019	China	Chinese	30	30	Sertraline	Sertraline + aerobic exercise	HAMD-17, MoCA
Foley	2008	Not reported	English	5	8	Stretching	Aerobic exercise	BDI-II
Fu	2022	China	Chinese	45	45	Escitalopram	Escitalopram + fitness running	HAMD-24, TMT-A, TMT-B, WMS-RC (Digit Span-Reversed Order)
Hoffman	2008	USA	English	49	104	Placebo	Supervised or home-based aerobic exercise	WAIS-R, Stroop Color and Word Test, Verbal Fluency Test
Imboden	2020	Switzerland	English	20	22	Stretching	Indoor bicycles	BDI, TAP V 2.3
Khatri	2001	USA	English	42	42	Sertraline	Aerobic exercise	WAIS-R, Color and Word Test, TMT-A, TMT-B
Krogh	2009	Denmark	English	42	48	Relaxation exercise	Cycling, running, stepping, abdominal exercises, and rowing	BDI, HAMD-17, TMT-A, TMT-B, Buschke Test, Rey Complex Figure Test, Verbal Fluency Test
Krogh	2012	Denmark	English	59	56	Stretching	Aerobic exercises	HAMD-17, BDI, Buschke Test, WAIS-R, TMT-A, TMT-B, Stroop Color and Word Test, Rey Complex Figure Test, Verbal Fluency Test
Krogh	2014	Denmark	English	38	41	Stretching	Stationary bikes	Buschke Test, Rey Complex Figure Test
Liu	2024	China	Chinese	49	51	Conventional therapy	Conventional therapy + Ball games, jogging, square dancing	HAMD-24, MoCA
Oertel-Knöchel	2014	Germany	English	6	8	Cognitive training	Cognitive training + aerobic exercises	TMT-A, BDI-II
Qian	2024	China	Chinese	42	42	Routine rehabilitation training	Routine rehabilitation training + aerobic exercises	MMSE
Wang	2024	China	Chinese	51	51	Repetitive transcranial magnetic stimulation	Repetitive transcranial magnetic stimulation + aerobic exercises	MoCA
Zhang	2023	China	Chinese	50	50	Paroxetine	Aerobic exercise + paroxetine	SDS, MMSE
Zhu	2019	China	Chinese	150	150	Citalopram + repetitive transcranial magnetic stimulation	Citalopram + repetitive transcranial magnetic stimulation + aerobic exercises	HAMD-17, Wisconsin card sorting test

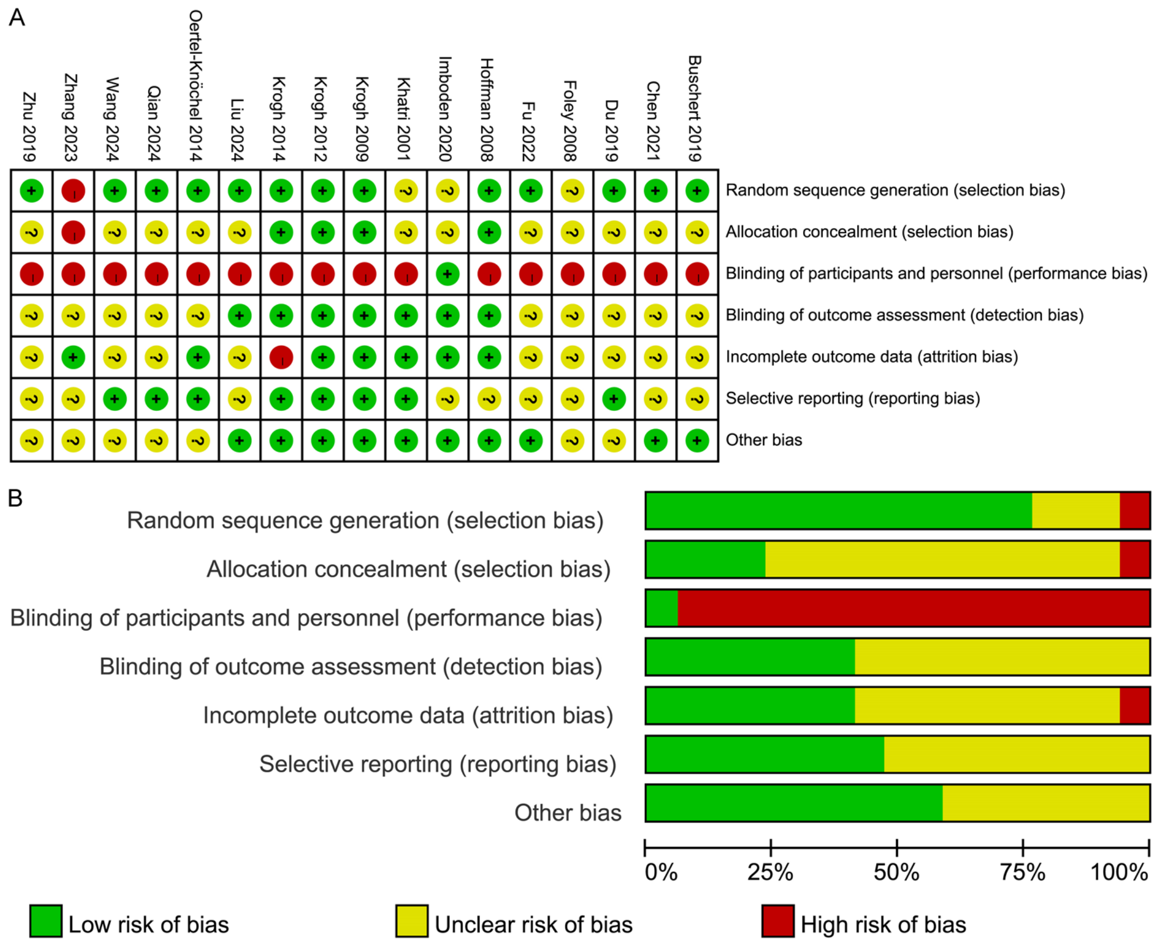


Figure 2. Risk of bias assessment. A: Risk of bias for each included study; B: Summary of risk of bias across studies.

that the aerobic exercise group performed slightly better than the control group on the TMT-A (SMD = -0.11, P = 0.27). The heterogeneity among studies was low to moderate (I^2 = 29%). Additionally, as shown in **Figure 4B**, five studies [15, 16, 20, 22, 24] involving 507 participants assessed performance using the Digit Span Forward test. The pooled analysis showed negligible differences between groups (SMD = 0.04, P = 0.64), accompanied by low heterogeneity (I^2 = 0%).

Analysis of working memory

As shown in **Figure 5**, six studies [15, 16, 19, 20, 22, 24], comprising a total of 597 participants, used the Digit Span Backward test to assess working memory capacity [37]. The meta-analysis demonstrated a statistically significant advantage for the intervention group over the control group in the Digit Span Backward task with a small effect size (SMD = 0.16, P = 0.05). Given the low heterogeneity among studies (I^2 = 0%), a fixed-effects model was applied.

Analysis of memory function

Figure 6 presents the meta-analysis results of the Wechsler Memory Scale (WMS) Logical Memory subtest, the Rey Complex Figure Test, and the Buschke Selective Reminding Test, which are commonly used to assess verbal and visuospatial memory functions [38-40]. As shown in **Figure 6A**, the pooled analysis of the WMS Logical Memory subtest included two studies [20, 22] with a total of 237 participants. A slight performance advantage was observed in the aerobic exercise group compared to the control group; however, this difference was not statistically significant (SMD = 0.21, P = 0.11), with minimal heterogeneity detected across

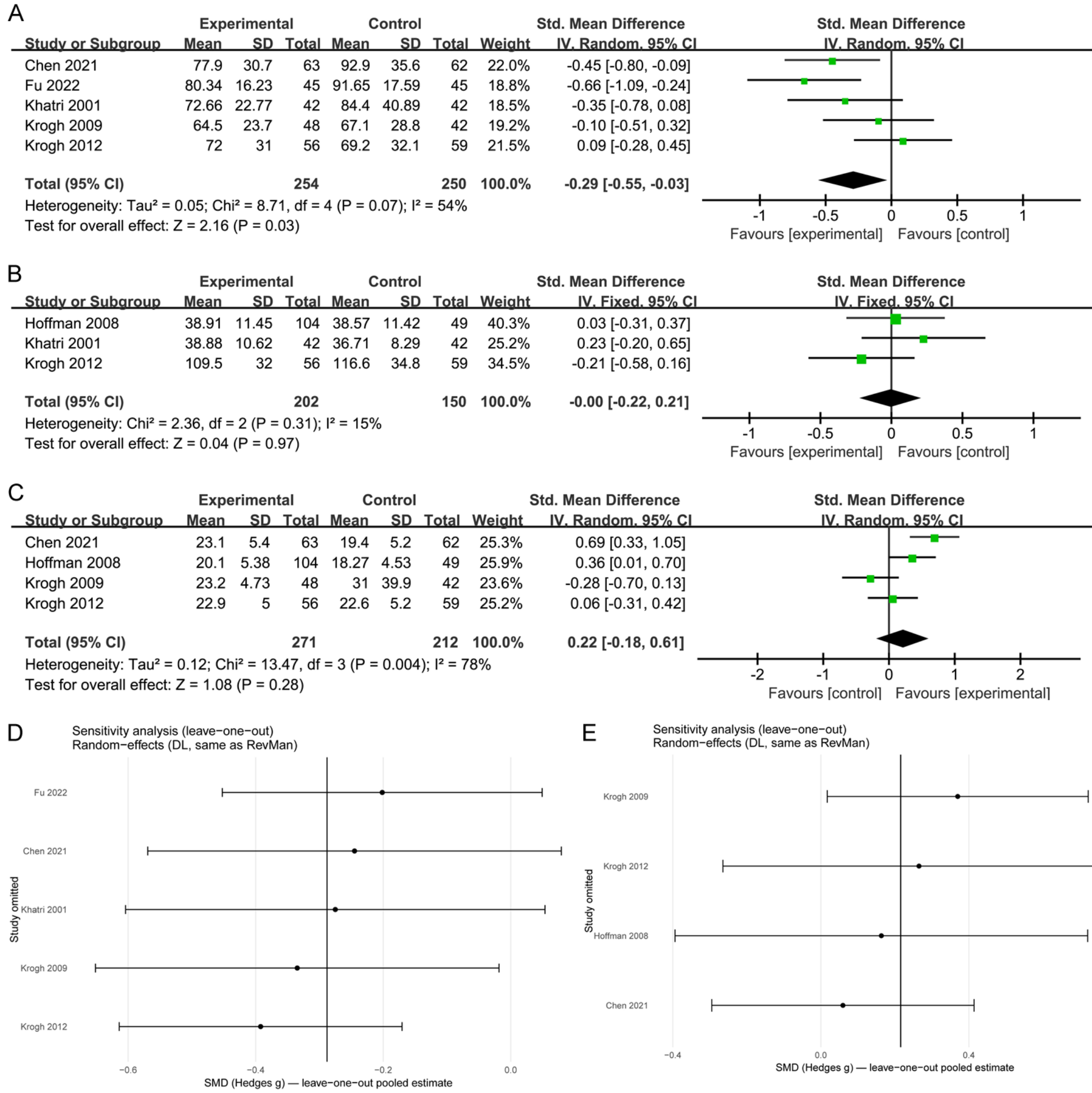


Figure 3. Meta-analysis results of executive function. A: Trail Making Test Part B; B: Stroop Color-Word Test; C: Verbal Fluency Test; D: Sensitivity analysis of the Trail Making Test Part B; E: Sensitivity analysis of the Verbal Fluency Test.

studies (I^2 = 0%). Similarly, **Figure 6B** shows the pooled analysis of the Buschke test based on three studies [23-25], including 284 participants, which revealed minimal differences between groups (SMD = -0.05, P = 0.68) and no significant heterogeneity (I^2 = 0%). In **Figure 6C**, the analysis of the Rey Complex Figure Test, also based on three studies [23-25] with 284 participants, indicated a modest advantage for the aerobic exercise group (SMD = 0.31, P = 0.12), although the difference was not statistically significant and moderate heterogeneity was observed (I^2 = 63%). **Figure 6D** presents the sensitivity analysis of the Rey Complex Figure Test. The results suggested that the study by Krogh (2009) [23] might be a potential source of heterogeneity; however, it did not alter the overall direction of the effect.

Analysis of global cognitive function

Figure 7 presents the meta-analysis results of the Montreal Cognitive Assessment (MoCA) and the Mini-Mental State Examination (MMSE), both of which are commonly used tools for the assessment of global cognitive function. As shown in **Figure 7A**, the pooled analysis of MoCA included three studies [17, 26, 29], MMSE based on two studies [28, 30], including 446 participants, which revealed a significant

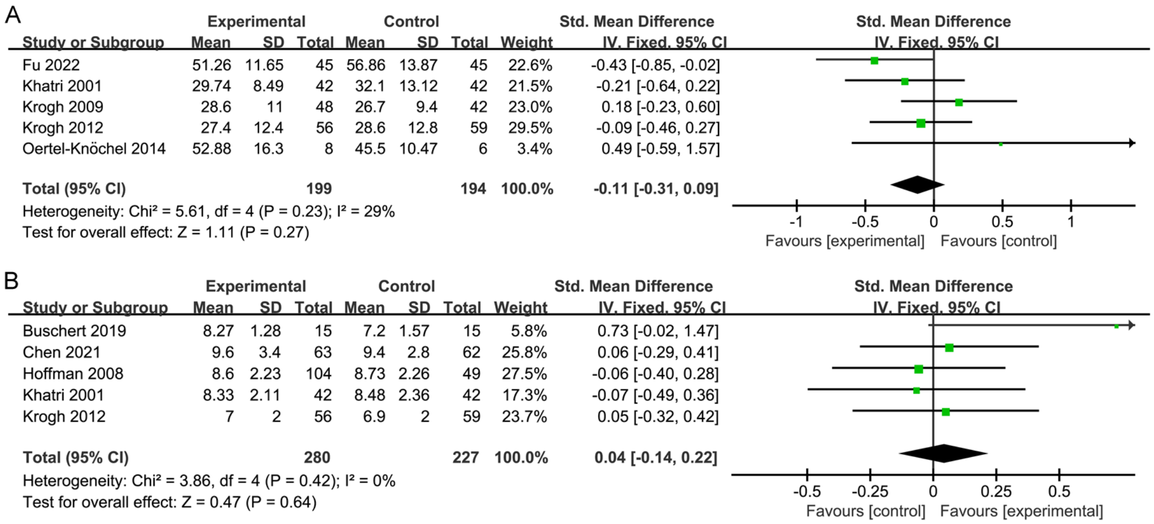


Figure 4. Meta-analysis results of attention. A: Trail Making Test A; B: Digit Span Forward.

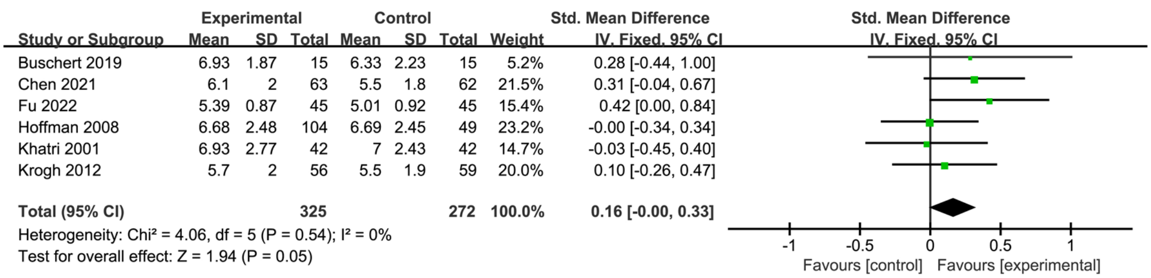


Figure 5. Meta-analysis result of working memory (Digit Span Backward).

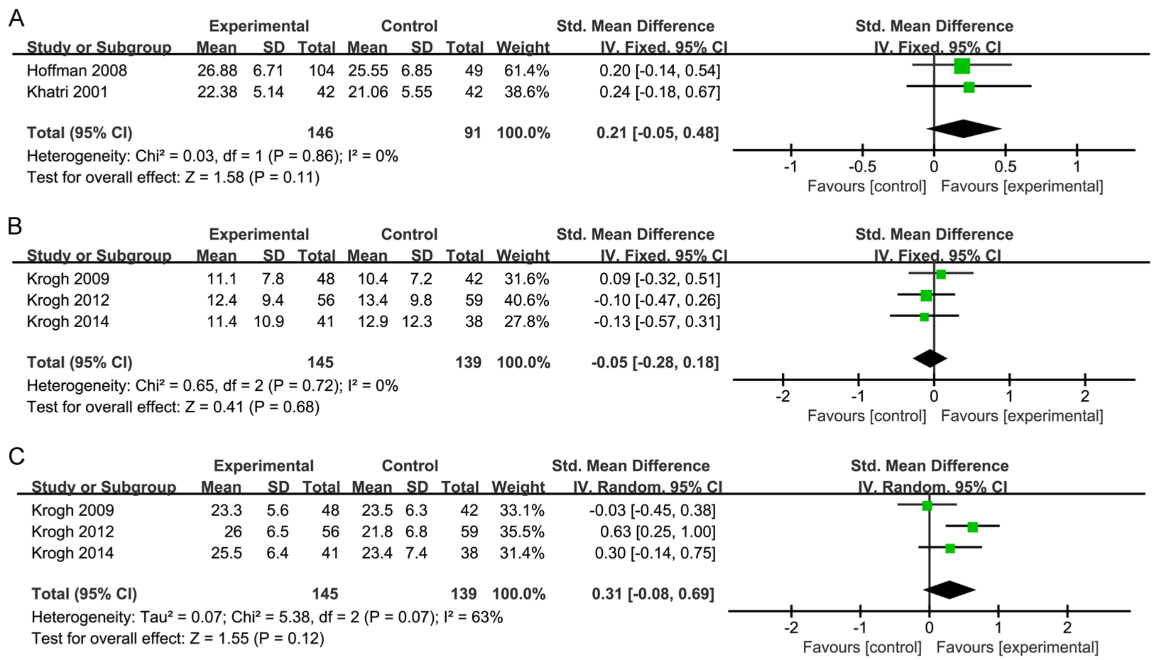
improvement in cognitive performance in the aerobic exercise group with a large effect size (SMD = 1.68, P = 0.0003) with high heterogeneity (I^2 = 94%). **Figure 7B** displays the sensitivity analysis of MoCA and MMSE, suggesting that although Liu's study [26] may have influenced the pooled effect to some extent, the overall direction of the effect remained consistent, indicating the robustness of the finding.

Analysis of depressive symptoms

To evaluate the severity of depressive symptoms, three types of scales were included: the 17-item and 24-item Hamilton Depression Rating Scale (HAMD-17, HAMD-24), and the Beck Depression Inventory (BDI, BDI-II) [41]. A total of six studies [17, 19, 23, 24, 26, 31] employed the HAMD scale, among which two [19, 26] used HAMD-24, and four [17, 23, 24, 31] used HAMD-17. As shown in **Figure 8A**, the meta-analysis of HAMD indicated that a significant reduction in depressive symptoms was observed with a large effect size (SMD = -0.87, P = 0.04), although the presence of substantial heterogeneity (I^2 = 96%) led to the adoption of a random-effects model. Additionally, as shown in **Figure 8B**, the results of BDI, BDI-II did not reveal any statistically significant improvements following aerobic exercise interventions (SMD = 0.08, P = 0.47). **Figure 8C** presents the sensitivity analysis of the HAMD. The analysis showed that omitting any single study did not substantially alter the pooled effect size or its direction, indicating the robustness of the overall findings.

Qualitative results of other cognitive and mood assessments

In addition to quantitative analyses, some studies were included in this review that used independent assessment tools. These tools appeared only once in the included literature



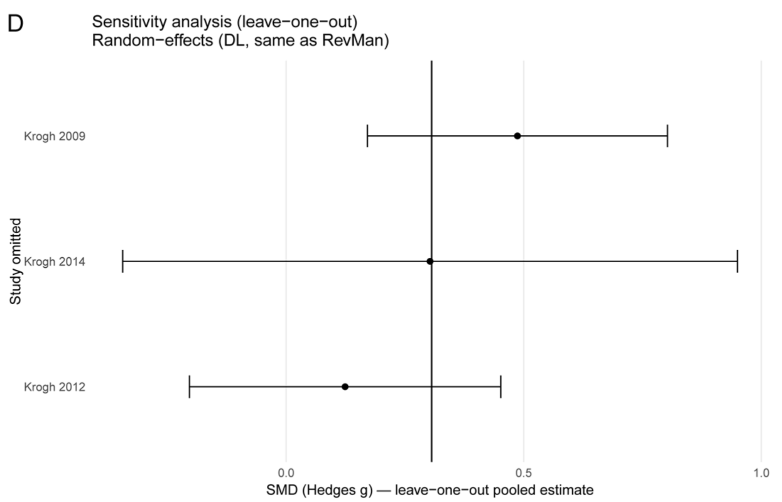
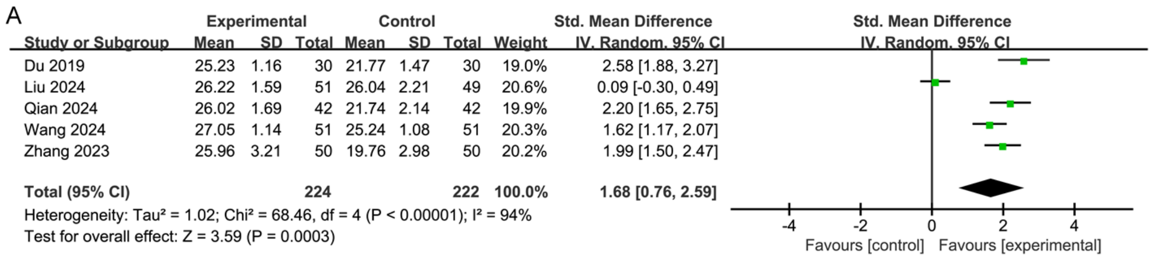


Figure 6. Meta-analysis results of memory function. A: Logical Memory from the Wechsler Memory Scale; B: Buschke Selective Reminding Test; C: Rey-Osterrieth Complex Figure Test; D: Sensitivity analysis of Rey-Osterrieth Complex Figure Test.

and could not be included in meta-analyses. However, we felt it was necessary to organize these data qualitatively. Imboden et al. [21] used TAP-V 2.3 to assess cognitive function and found that aerobic exercise significantly improved the working memory performance of depressed patients. The study by Zhang et al. [30] demonstrated that aerobic exercise intervention significantly reduced the scores on the Self-Rating Depression Scale in elderly patients with depression. In addition, the study by Zhu et al. [31] indicated that aerobic exercise effectively reduced the number of random errors on the Wisconsin Card Sorting Test in patients with depression. Additionally, a study by Foley et al. [18] demonstrated that aerobic exercise can significantly improve episodic memory in individuals with depression. These results partially support the potential improvement of aerobic exercise on depressive symptoms and cognitive functioning.

Discussion

This study systematically evaluated the effects of aerobic exercise on cognitive function and depressive symptoms in patients with depression, including 13 randomized controlled trials that covered multiple cognitive domains and emotional outcomes. We did not impose any restrictions on the languages included in the study or the age of participants, thereby



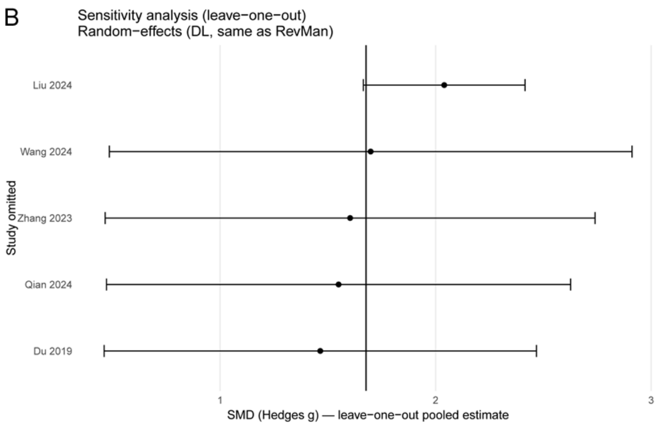
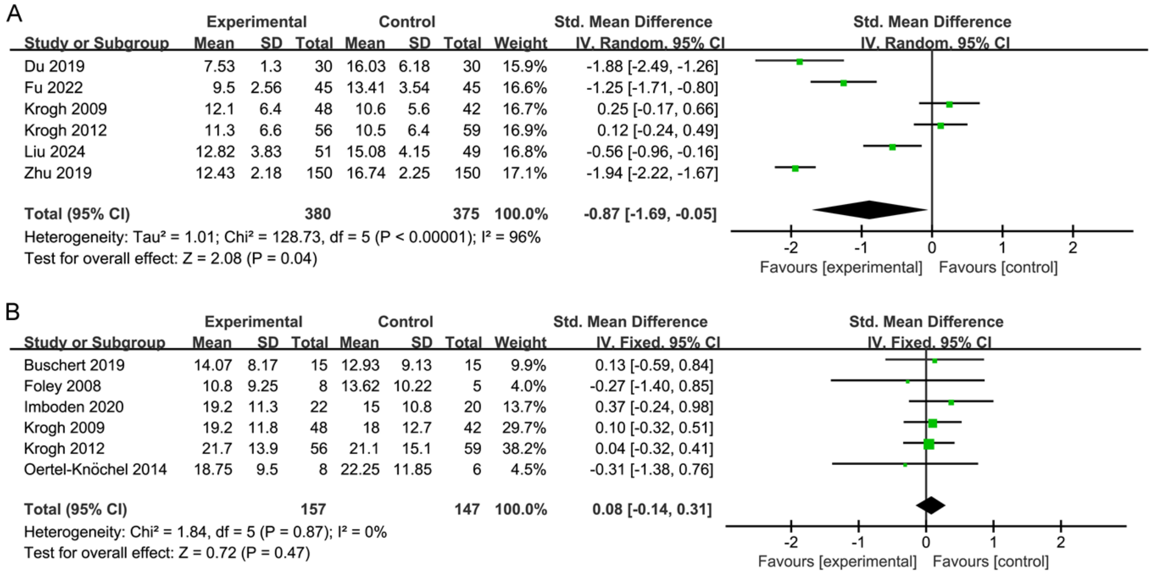


Figure 7. Meta-analysis results of global cognitive function. A: Montreal Cognitive Assessment and Mini-Mental State Examination; B: Sensitivity analysis.

addressing shortcomings in previous research. This meta-analysis revealed that aerobic exercise may moderately improve executive function, working memory, and depressive symptoms in individuals with depression. However, no significant differences were found in other cognitive domains such as attention, information processing speed, verbal fluency, or logical memory. It is worth noting that some of the included studies exhibited methodological limitations, particularly in aspects such as blinding and allocation concealment, which suggests that the current findings should be interpreted with caution.

Executive function is one of the most complex components of cognitive function, encompassing abilities such as planning, inhibition, and cognitive flexibility. It is also a crucial factor affecting the quality of life in patients with depression and is commonly assessed using tasks such as the TMT-B, the Stroop Color-Word Test, and the VFT [4, 5]. In this meta-analysis, the TMT-B results suggest that aerobic exercise may exert a positive effect on executive function, with statistically significant differences observed. The improvement in executive function may be attributed to mechanisms such as the upregulation of BDNF and enhanced functional connectivity between the cortex and hippocampus [8, 42]. However, the results from the Stroop Color-Word Test and VFT did not reach statistical significance, which may be related to limitations in test sensitivity and the heterogeneity of included study populations. The Stroop task relies heavily on response inhibition and is influenced by executive load and language background, whereas VFT performance may be affected by cultural and educational factors, potentially compromising the stability of effect sizes [43]. Notably, this part of the meta-analysis showed relatively high heterogeneity, indicating the need for future studies to improve standardization of interventions and better control of participant characteristics. It is also worth noting that the current findings differ from those of a previous meta-analysis, which reported no significant improvement in executive function following aerobic exercise. This discrepancy may be due to differences in inclusion and exclusion criteria between the two studies [12].

The TMT-A and Digit Span Forward are widely used to assess attentional capacity and processing speed. Digit Span Forward primarily reflects short-term attention span, while TMT-A captures task-switching ability and visual scanning performance [35, 36]. In the present study, no significant differences were observed between the intervention and control groups on either measure. This finding diverges from prior



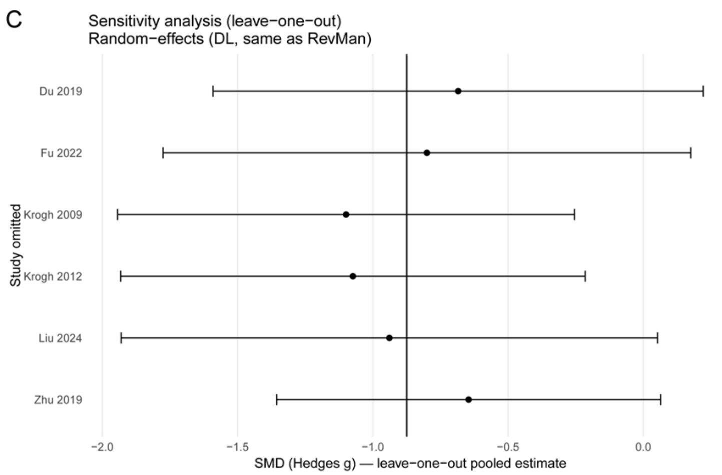


Figure 8. Meta-analysis results of depressive symptom rating scales. A: Hamilton Depression Rating Scale 17 and 24; B: H Beck Depression Inventory and Beck Depression Inventory-II; C: Sensitivity analysis of Hamilton Depression Rating Scale.

evidence, a systematic review suggesting that aerobic exercise can effectively enhance attention in patients with depression [12]. One possible explanation is that Digit Span Forward may exhibit considerable variability across studies due to differences in language versions and testing conditions, particularly between the Wechsler Adult Intelligence Scale-Revised (WAIS-R) and the WMS-R, which, despite using the same task format, differ in scoring methods and norms [44]. In contrast, Digit Span Backward - a representative measure of working memory - places higher demands on information storage, manipulation, and updating abilities [37]. In our analysis, scores on Digit Span Backward were significantly higher in the aerobic exercise group compared to controls. This result warrants attention, as working memory impairment is a persistent and common cognitive deficit in depression. Such impairment is closely related to dysfunction in the hippocampus and amygdala, and it is hypothesized that aerobic exercise may enhance working memory through promoting hippocampal function [45]. However, it should be noted that although the effect size was statistically significant, it remained modest, suggesting that its clinical relevance needs to be interpreted with caution in the context of functional improvement.

This study included several memory-related tasks, such as the WMS Logical Memory, Buschke test, and Rey Complex Figure Test; however, none showed statistically significant differences between groups. Prior reviews have suggested that regular aerobic exercise may enhance memory in older adults with mild cognitive impairment [46], whereas a systematic review by Guo et al. reported no memory benefits for patients with depression [12]. The lack of observed effects in both our analysis and Guo's study may be partly attributed to heterogeneity in baseline cognitive function and limited sample sizes. Moreover, the Rey Complex Figure Test relies heavily on visual constructive and executive abilities, which may require longer intervention periods to yield measurable improvements [47]. The Buschke test, though well-designed, is prone to practice effects and is highly language-dependent, making it susceptible to variations in participants' cultural and educational backgrounds.

Although emotional outcomes were not the primary focus of this review, many included studies that employed depression rating scales to assess symptom changes. A statistically significant reduction was observed in HAMD. No significant improvements were found in BDI and BDI-II scores, which contrasts with the findings of most prior research. For example, earlier meta-analyses have reported that aerobic exercise is effective in reducing depressive symptoms among adolescents and adults experiencing mild to moderate depression [11, 48]. This inconsistency might be attributed to the fact that our inclusion criteria specifically mandated the reporting of cognitive outcomes. As a result, a number of high-quality RCTs focusing exclusively on the antidepressant effects of exercise may have been excluded, introducing potential selection bias.

In addition to quantitative results, this review also incorporated several studies [18, 21, 30, 31] that employed standalone assessment tools to provide supplementary evidence. Although these studies could not be included in the meta-analysis due to methodological differences, their findings lend indirect support to the main conclusions of this review. Moreover, they underscore the importance of expanding the range of cognitive assessment instruments in future research, particularly when evaluating populations from diverse cultural backgrounds.

This study's strengths include coverage of both Chinese and English literature, reduction of language bias, systematic assessment of multiple cognitive dimensions and emotional outcomes, and comprehensive examination of the effects of aerobic exercise interventions. Additionally, we used SMD for merging, which solved the problem of scale version differences more effectively. However, we must acknowledge the limitations of the present study. First, the number of included studies was limited. On some scales, there were only two to three papers, which reduced statistical efficacy. Second, many of the studies involved combined interventions, making it difficult to distinguish the independent effects of aerobic exercise. Publication bias analysis could not be performed because fewer than 10 studies were available for each outcome. Potential publication bias may affect the reliability of the results. Therefore, this issue deserves further resolution in subsequent studies. The current work inevitably exhibits high heterogeneity. Although we ensured the robustness of our results through the leave-one-out method, subsequent researchers should conduct further subgroup analyses once sufficient literature becomes available in the field. Additionally, since subgroup analyses of intervention modality, frequency, and duration were not conducted in this study, future studies could explore differential response patterns between intervention dosage and individual characteristics. Finally, it is worth noting that this systematic review was not pre-registered, which introduces a certain degree of bias.

Conclusions

Aerobic exercise effectively improves executive function and working memory in patients with depression. However, the effects on other cognitive dimensions and mood outcomes are unclear, and the results should be interpreted with caution. Future high-quality RCT with large samples, a high degree of intervention standardization, and longer intervention durations are needed to further clarify the cognitive and emotional benefits of aerobic exercise interventions for depression.

Disclosure of conflict of interest

None.

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