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The Effect of Exercise Interventions on Depressive Symptoms in College Students: A Meta-Analysis and Systematic Review

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A B S T R A C T

Background: This meta-analysis investigates the effects of different types and doses of exercise interventions on depressive symptoms among college students, aiming to provide scientific evidence for exercise prescription.

Methods: A total of 22 empirical studies were included through searching databases such as Web of Science, PubMed, Cochrane Library, Google Scholar and CNKI.

Result: Results showed that flexibility training had the most significant effect on alleviating depressive symptoms (g = 1.09, P < 0.01), followed by traditional Chinese health exercises (g = 0.80, P < 0.01), anaerobic exercise (g = 0.78, P < 0.01) and aerobic exercise (g = 0.70, P < 0.01). Subgroup analysis indicated that the most effective intervention consisted of low-intensity exercise (g = 0.95), performed 3-4 sessions per week (g = 0.79), ≥90 minutes per session (g = 0.77), lasting for 4-8 weeks (g = 0.90). Meta-regression revealed that exercise intensity and intervention duration were negatively associated with effect size, while session length and frequency were positively associated.

Conclusion: These findings suggest that exercise interventions are effective in alleviating depressive symptoms among college students, with flexibility training of low intensity and high frequency demonstrating the greatest efficacy.

Keywords: Depression, College students, Exercise intervention, Flexibility training, Meta-analysis

1. Introduction

Depression is one of the most common mental disorders among adults worldwide, characterized by a high prevalence, significant treatment costs and serious health consequences[1]. In recent years, the risk of depression among college students has been increasing annually and has even surpassed that of other age groups, becoming a global concern[2]. An epidemiological study involving 22,022 college students worldwide found that the prevalence of depression was 11.8% in the Americas, 13.7% in Africa and as high as 32.9% in Asia[3]. From the perspective of social identity, college students are in a transitional stage

between high school and university; physiologically, they are also transitioning from adolescence to adulthood[4]. During this period, changes in daily routines, adjustments in interpersonal relationships and academic and career-related pressures may all act as risk factors for the development of depression.

Currently, the treatment of depression primarily includes pharmacotherapy, psychotherapy and physical therapy. However, due to factors such as stigma, side effects of medications and high treatment costs, many patients tend to avoid seeking help[5]. Exercise is easy to implement, has minimal side effects and enjoys relatively high acceptance-particularly for alleviating certain symptoms of depression-with numerous studies demonstrating its significant positive effects[6]. Exercise helps reduce depressive symptoms through multiple mechanisms, including the regulation of neurotransmitters[7], enhancement of brain function[8], reduction of stress hormones[9], increased release of endorphins[10] and improved self-efficacy[11]. However, the type, intensity, frequency and duration of exercise can vary greatly, which may lead to differing levels of intervention effectiveness[12]. Different exercise modalities may produce distinct outcomes in alleviating depressive symptoms; therefore, selecting an appropriate and effective exercise intervention strategy is especially important[13,14]. This study conducts a meta-analysis to evaluate the effectiveness of exercise interventions in treating depressive symptoms among college students and to explore the optimal exercise dosage for intervention.

2. Methods

2.1. Inclusion and exclusion criteria

2.1.1. Inclusion criteria for studies:

- The study must be a randomized controlled trial (RCT);
- The participants must be college students aged 18 years or older diagnosed with depression;
- The intervention must involve various types of exercise training in the experimental group, while the control group receives either standard treatment or no treatment;
- The primary outcome must be depressive symptoms.

2.1.2. Exclusion criteria:

- Animal studies, conference abstracts, patents and review articles;
- Studies that cannot be retrieved even after contacting the authors;
- Duplicate publications;
- Studies not published in Chinese or English.

This study strictly adheres to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines[15]. The systematic review has been registered in the International Prospective Register of Systematic Reviews (PROSPERO) under the registration number CRD42024540518.

2.2. Literature search strategy

A computerized search was conducted by two independent researchers (LM and HZ) in the following databases: Web of Science, PubMed, Cochrane Library, Google Scholar and China National Knowledge Infrastructure (CNKI) to identify randomized controlled trials (RCTs) on exercise interventions for depressive symptoms in college students. The search

covered literature from database inception to March 28, 2025. English search terms included: "anxiety disorders" "Neuroses" "Anxiety state" "Exercise" "Physical activity" "Acute exercise" "Isometric exercises" "Aerobic exercise" "Exercise training" "Students" "Randomized controlled trial". Any disagreements in the search process were resolved through discussion or, if necessary, by consulting a third researcher. An example of the detailed search strategy used for PubMed is shown in **(Table 1)**.

Table 1: PubMed search strategy.

Step	Search query
#1	"Anxiety disorders" OR "anxiety disorder" OR "neuroses" OR "anxiety state"
#2	"exercise" OR "physical" OR "activity" OR "acute exercise" OR "isometric exercises" OR "aerobic exercise" OR "exercise training"
#3	"College students" OR "university students" OR "undergraduates"
#4	"Randomized controlled trial" OR "RCT"
#5	#1 AND #2 AND #3 AND #4

2.3. Literature screening and data extraction

The two authors (LM and HZ) who performed the search strategy in the Methods section of our manuscript. They independently screened the retrieved studies to ensure consistency and accuracy. Any disagreements between the two reviewers (LM and HZ) were resolved through discussion. If a consensus could not be reached, a third researcher (RF) served as a referee to make the final decision. During the initial screening stage, EndNote 20.6 software was used for reference management. Titles and abstracts of the exported articles were reviewed to exclude those that did not meet the inclusion criteria and reasons for exclusion were documented. In the second screening stage, Excel 2024 was used for data recording. The full texts of the remaining studies were carefully read to determine eligibility based on inclusion criteria. The extracted data included the following:

- Title, first author, publication date and journal information of the included studies;
- Baseline characteristics of the participants, such as sample size and age;
- Detailed information on the intervention, including type of exercise, duration, frequency and session length;
- Outcome indicators meeting the inclusion criteria and related results;
- Information relevant to the risk of bias assessment of the included studies.

2.4. Risk of bias assessment and methodological quality evaluation

The Cochrane Risk of Bias Tool[16] was used to assess the risk of bias in the included studies. The following domains were evaluated: random sequence generation (selection bias), allocation concealment (selection bias), blinding of participants (performance bias), blinding of outcome assessors (detection bias), incomplete outcome data (attrition bias), selective reporting (reporting bias) and other potential sources of bias. Each item was rated as "low risk," "unclear risk," or "high risk" of bias.

The Physiotherapy Evidence Database (PEDro) scale[17] was employed to evaluate the methodological quality of the included studies. The scale consists of 11 items: D1. Eligibility criteria;

D2. Random allocation; D3. Allocation concealment; D4. Similarity at baseline; D5. Blinding of subjects; D6. Blinding of therapists; D7. Blinding of assessors; D8. Adequate follow-up (≥85% retention); D9. Intention-to-treat analysis; D10. Between-group statistical comparisons; D11. Point estimates and variability measures. Only items D2–D11 are scored, with 1 point for each, resulting in a total possible score of 0 to 10. According to PEDro scoring criteria, studies are classified as low quality (≤3 points), moderate quality (4-5 points) or high quality (≥6 points).

Additionally, the Grading of Recommendations Assessment, Development and Evaluation (GRADE) approach[18] was used to assess the certainty of evidence. The certainty of evidence was classified as: High: Further research is very unlikely to change confidence in the estimate of effect. Moderate: Further research may have an important impact on confidence in the estimate and may change the estimate. Low: Further research is very likely to have an important impact on the confidence in the estimate and is likely to change the estimate. Very low: The estimate of effect is very uncertain.

The risk of bias and methodological quality of the included studies was independently assessed by two researchers (LM and HZ). Each assessment domain was thoroughly analyzed and any discrepancies were resolved through consultation with a third researcher (RF).

2.5. Statistical analysis

Statistical analysis was conducted using the "meta" and "metafor" packages in R version 4.4.2 (R Foundation for Statistical Computing, Vienna, Austria). The DerSimonian-Laird random-effects model was employed and the inverse-variance method was used to pool the primary effect sizes. To reduce bias caused by small sample sizes, Hedges' g was adopted as the corrected indicator for the standardized mean difference (SMD). The interpretation of effect size was as follows: negligible effect ($|g| < 0.2$), small effect ($0.2 \leq |g| < 0.5$), medium effect ($0.5 \leq |g| < 0.8$) and large effect ($|g| > 0.8$)[19].

$$\text{Hedge's } g = \frac{M_1 - M_2}{S_p} \times 1 - \frac{3}{4(n_1 + n_2 - 2) - 1} \quad (1)$$

Where M_1 and M_2 are the means of the intervention and control groups, n_1 and n_2 are the respective sample sizes and S-> is the pooled standard deviation.

Where S_1 and S_2 are the standard deviations of the intervention and control groups, respectively.

Heterogeneity among studies was assessed using the I^2 statistic, categorized as follows: low heterogeneity: 0-30%, moderate heterogeneity: 31-50%, substantial heterogeneity: 51-75%, considerable heterogeneity: 76-100%[20]. Subgroup analyses were conducted based on predefined exercise characteristics, including type, intensity, duration, frequency and intervention period. All subgroup analyses used a random-effects model. To explore the dose-response relationship between exercise dose and effect size, both linear and quadratic polynomial meta-regression models were established. Sensitivity analysis was conducted using the leave-one-out method, whereby each study was sequentially removed and the pooled effect size was recalculated to assess the robustness of the results. Publication bias was evaluated using funnel plots in combination with Egger's test. A P-value ≥ 0.05 was considered indicative of no publication bias ($\alpha = 0.05$).

3. Results

3.1. Literature search results

A total of 2,908 relevant articles were initially retrieved. After removing duplicates and screening by article type, 2,534 articles remained. Following full-text review and exclusion of studies not meeting the inclusion criteria, 22 articles were finally included. The literature screening process is shown in **(Figure 1)**.
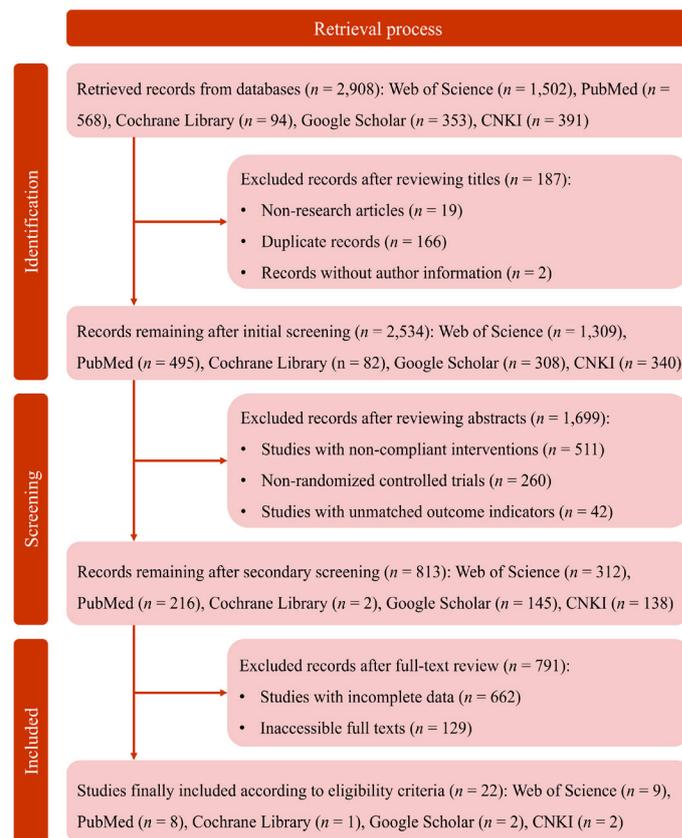

Figure 1: Literature screening flowchart.

3.2. Basic characteristics of included studies

A total of 2,167 participants were included in the studies, with 1,098 in the intervention groups and 1,069 in the control groups. Among them, 872 were male and 1,132 were female. Some studies did not report participants' age [21-28] or sex [21,29,30]. All included studies compared exercise intervention groups with non-exercise control groups. Interventions were administered by professionals with relevant expertise or physical education teachers, conducted in settings such as school playgrounds, gymnasiums, laboratories and home environments.

Most studies explicitly excluded participants with chronic diseases. In a few studies, participants had obesity[22] or a history of COVID-19 infection[21,31,32]. Several studies reported that, besides depressive symptoms, participants also experienced anxiety[22,24,32-36], obsessive-compulsive symptoms[25] or sleep disorders[30] Exercise interventions covered aerobic metabolism exercises, anaerobic metabolism exercises, traditional health-preserving practices and flexibility training. Single session durations ranged from 30 to 90 minutes, with intervention frequency from 1 to 6 times per week, lasting 4 to 32 weeks.

Exercise intensity was categorized as low, moderate or high. Assessment tools included the Symptom Checklist-90 (SCL-90), Self-Rating Depression Scale (SDS) and Beck Depression Inventory (BDI), which measured the severity of depressive symptoms in participants. The basic characteristics of the included studies are summarized in **(Table 2)**.

Table 2: Basic characteristics of included studies.

Included study	country	Age (E/C) (mean ± SD, years)	Sample Size (E/C) (male/female, n)	Health status	Comorbidities	Exercise type	Session Duration (min)	Frequency (times/week)	Total Duration (weeks)	Intervention personnel	Intervention site	Exercise intensity	Measurement tool	PEDro Score
Sadeghi et al., 2016[37]	Iran	20.93±1.06/20.92±1.20	16(13/3)/14(11/3)	Healthy	None	Aerobic	50	2	8	Researchers	School playground	Moderate	BDI	6
Zhang，2021[21]	China	-	30(-/-)/30(-/-)	COVID-19	None	Aerobic	60	5	12	PE Coach	Home	Low	SDS	5
Bang et al., 2017[38]	Korea	24.8±4.66/23.8±3.60	51(26/25)/48(21/27)	Healthy	None	Aerobic	60	1	6	Researchers	Outdoor park	Low	SDS	6
Wang et al., 2009[22]	China	-	176(0/176)/164(0/164)	Obese	Anxiety	Aerobic	60	3	12	Researchers	School playground	Moderate	SCL-90	6
Zhao et al., 2023[31]	China	20.72±2.05/21.21±2.25	29(8/21)/28(8/20)	COVID-19	None	Aerobic	30	3	12	PE Coach	Home	Low	SDS	4
Ahmad et al., 2021[23]	Iran	-	10(0/10)/10(0/10)	Healthy	None	Aerobic	50	3	8	Researchers	Laboratory	Moderate	BDI	5
Hu et al., 2019[33]	China	19.18±2.94/19.83±2.18	387(252/135)/390(259/141)	Healthy	Anxiety	Anaerobic	60	3	12	Researchers	School playground	High	SCL-90	7
Viana et al., 2019[24]	Brazil	-	18(0/18)/18(0/18)	Healthy	Anxiety	Anaerobic	30	3	8	Researchers	Laboratory	High	BDI	5
Ma，2017[39]	China	21.43±1.46/21.43±1.46	31(15/16)/31(15/16)	Healthy	None	Anaerobic	50	3	24	PE Coach	School playground	Moderate	SDS	5
Liu et al., 2009[25]	China	-	20(16/4)/20(17/3)	Healthy	Obsessive-compulsive	Anaerobic	90	2	32	Researchers	School playground	Moderate	SCL-90	7
Lucibello et al., 2020[40]	Canada	19.8±2.2/19.8±2.2	30(11/19)/31(11/20)	Healthy	None	Anaerobic	60	3	11	Researchers	Laboratory	Moderate	BDI	6
Paolucci et al., 2018[41]	Canada	21±2/21±2	18(5/13)/17(6/12)	Healthy	None	Anaerobic	50	3	6	Researchers	Laboratory	High	BDI	6
Yolanda et al., 2021[32]	Spain	25.22±5.23/27.19±8.88	36(15/21)/31(7/24)	COVID-19	Anxiety	Anaerobic	40	6	6	PE Coach	Home	Moderate	BDI	5
Zhang et al., 2012[29]	China	19.23±0.98/19.16±1.05	34(-/-)/39(-/-)	Healthy	None	Traditional exercise	60	3	12	PE Coach	School playground	Low	SCL-90	5
Shen et al., 2018[30]	China	20.53±1.60/20.44±2.26	26(-/-)/15(-/-)	Healthy	Sleep disorders	Traditional exercise	45	5	8	PE Coach	School playground	Low	SDS	6
Sun et al., 2022[42]	China	22±1.5/22±1.5	30(15/15)/30(15/15)	Healthy	None	Traditional exercise	90	2	16	PE Coach	School playground	Low	SCL-90	7
Zhang et al., 2023[34]	China	24.20±4.07/22.50+5.95	9(2/7)/9(3/6)	Healthy	Anxiety	Traditional exercise	45	3	18	Researchers	Laboratory	Low	SDS	6
Cheng et al., 2016[43]	China	21.1±1.4/21.0±1.6	15(7/8)/15(8/7)	Healthy	None	Traditional exercise	45	3	12	Researchers	School playground	Low	BDI	4
Yazdani et al., 2014[26]	Iran	-	19(19/0)/19(19/0)	Healthy	None	Flexibility training	60	2	4	Researchers	Gymnasium	Low	SDS	5
Xiong et al., 2014[35]	China	21.5±1.1/21.2±1.0	30(0/30)/27(0/27)	Healthy	Anxiety	Flexibility training	70	3	8	Researchers	Laboratory	Low	BDI	7
Akandere et al., 2011[27]	Turkey	-	60(30/30)/60(30/30)	Healthy	None	Flexibility training	60	3	12	PE Coach	Gymnasium	Moderate	BDI	6
Falsafi，2016[36]	USA	-	23(4/19)/23(4/19)	Healthy	Anxiety	Flexibility training	75	3	12	Researchers	Gymnasium	Low	BDI	5

Note: E, Experimental group; C, Control group; SCL-90, Symptom Checklist-90; SDS, Self-Rating Depression Scale; BDI, Beck Depression Inventory; PEDro, Physiotherapy Evidence Database scale; "-" indicates the information was not reported in the article.

3.3. Quality assessment of included studies

The included studies reported complete outcome data, with no evidence of selective reporting or other significant sources of bias. Overall, the risk of bias in the included studies was low; however, due to the nature of exercise interventions, double-blinding was difficult to implement, resulting in a certain risk of bias related to blinding. PEDro scale scores ranged from 4 to

7 points, including 12 high-quality studies and 10 moderate-quality studies. Overall, the included literature demonstrated a relatively high quality. The risk of bias assessment is shown in **(Figure 2)**.
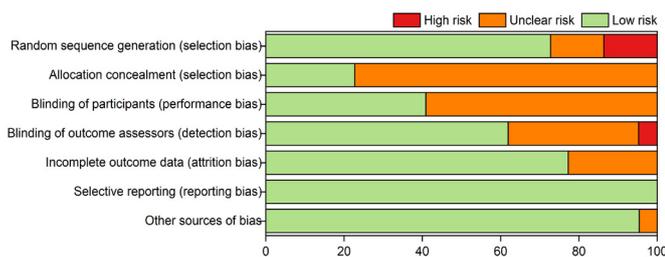

Figure 2: Risk of bias assessment of included studies.

3.4. Meta-analysis results

The effects of 13 exercise interventions across 4 exercise types on the improvement of depressive symptoms were analyzed. After pooling the effect sizes, flexibility training showed the best intervention effect (g = 1.09, 95% CI = 0.57–1.60, P < 0.01). Traditional health-preserving exercises (g = 0.80, 95% CI = 0.15–1.44, P < 0.01), anaerobic exercises (g = 0.78, 95% CI = 0.63–1.38, P < 0.01) and aerobic exercises (g = 0.70, 95% CI = 0.19–1.20, P < 0.01) all showed varying degrees of improvement in depressive symptoms. Among different exercise modalities, cycling (g = 1.60, 95% CI = 1.23–2.19, P < 0.05) and yoga (g = 1.26, 95% CI = 0.70–1.82, P < 0.01) significantly improved depressive symptoms, while ball games showed a weaker effect (g = 0.16, 95% CI = -0.15–0.47, P < 0.01). The main pooled effect sizes are presented in **(Figure 3)**.
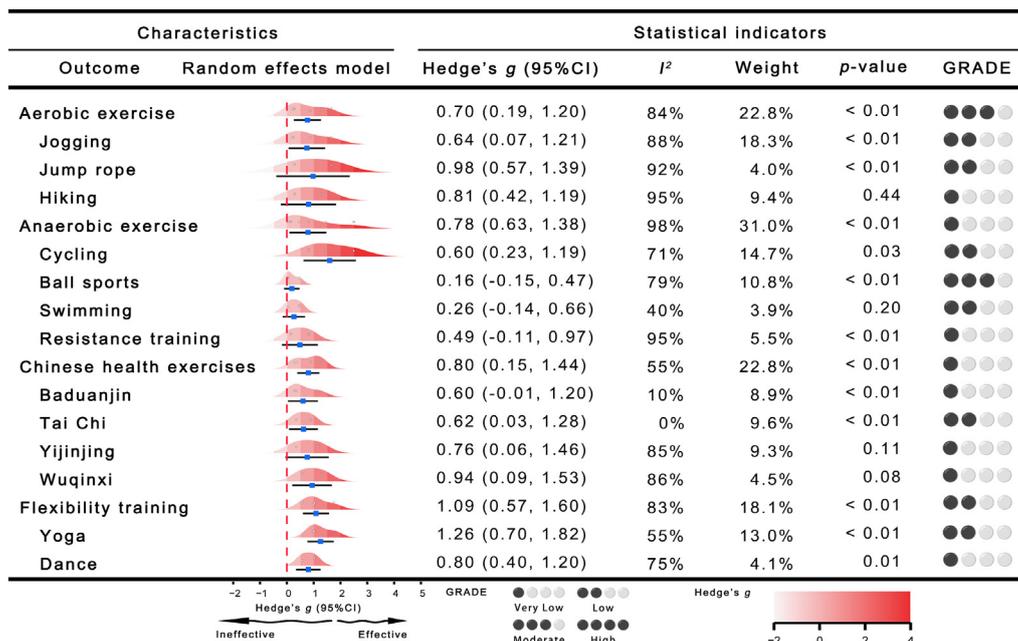

Figure 3: Main pooled effect sizes of the results.

3.5. Subgroup analysis results

The optimal exercise intervention dose for improving depressive symptoms in college students was a single session duration of ≥90 minutes (g = 0.77, 95% CI = 0.41–1.13, P < 0.01), exercising 3-4 times per week (g = 0.79, 95% CI = 0.38–1.20, P < 0.01), a total intervention period of 4–8 weeks (g = 0.90, 95% CI = 0.21–1.59, P < 0.01) and low-intensity exercise interventions (g = 0.95, 95% CI = 0.39–1.51, P < 0.01). The subgroup analysis results are shown in **(Figure 4)**.

3.6. Meta-regression results

The linear regression results showed that exercise intensity (y = -0.389x + 2.094) and intervention duration (y = -0.001x + 0.801) were negatively correlated with Hedge's g; whereas session length (y = 0.008x + 0.339) and exercise frequency (y = 0.022x + 0.716) were positively correlated with Hedge's g. The quadratic polynomial regression results indicated a U-shaped relationship between exercise intensity (y = 2.409 - 1.664x + 0.754 x^2) and intervention duration (y = 0.561 - 0.003x + 0.014 x^2) with Hedge's g; meanwhile, intervention duration (y = 0.654 + 0.021x - 6.412 x^2) and exercise frequency (y = -1.274 + 1.168x - 0.153 x^2) showed an inverted U-shaped relationship

with Hedge's g. The fitted curves are presented in **(Figure 5)**.

3.7. Sensitivity analysis and publication bias risk

Sensitivity analyses were performed using a leave-one-out method for exercise intensity, intervention duration, session length and exercise frequency. The results identified that heterogeneity mainly originated from the study by Hu, et al.[33], whose sample size was significantly larger than those of other studies. After excluding this study, heterogeneity within subgroups was markedly reduced and the pooled effect size remained stable (P < 0.05). Funnel plots and Egger's test indicated no significant publication bias in terms of exercise type (P > 0.05), while some publication bias was detected regarding intervention methods (P < 0.05). However, the distribution of study points on both sides of the funnel plot was generally symmetrical. The publication bias assessment is shown in **(Figure 6)**.

4. Discussion

This study employed meta-analysis to systematically evaluate the effects of different types of exercise interventions on improving depressive symptoms among college students. Subgroup analyses were conducted to explore the associations between intervention variables and intervention outcomes.

Building on this, meta-regression models were constructed to analyze the dose–response relationships between four key variables-exercise intensity, intervention duration, session length and frequency-and the intervention effect. Linear regression results indicated that exercise intensity and intervention duration were negatively correlated with intervention effects, suggesting that higher intensity and longer intervention periods were associated with smaller improvements in depressive symptoms. In contrast, session length and exercise frequency were positively correlated with intervention effects, implying that longer exercise sessions and higher frequency contributed to enhanced intervention outcomes. In the quadratic polynomial models, exercise intensity and intervention duration exhibited U-shaped relationships with the intervention effect, indicating that lower or higher levels of intensity and duration yielded better outcomes, while moderate levels were associated with relatively weaker effects. Meanwhile, session length and exercise frequency showed inverted U-shaped relationships, suggesting that moderate levels of single-session duration and exercise frequency were most beneficial for alleviating depressive symptoms, whereas too low or too high doses might have counterproductive effects.
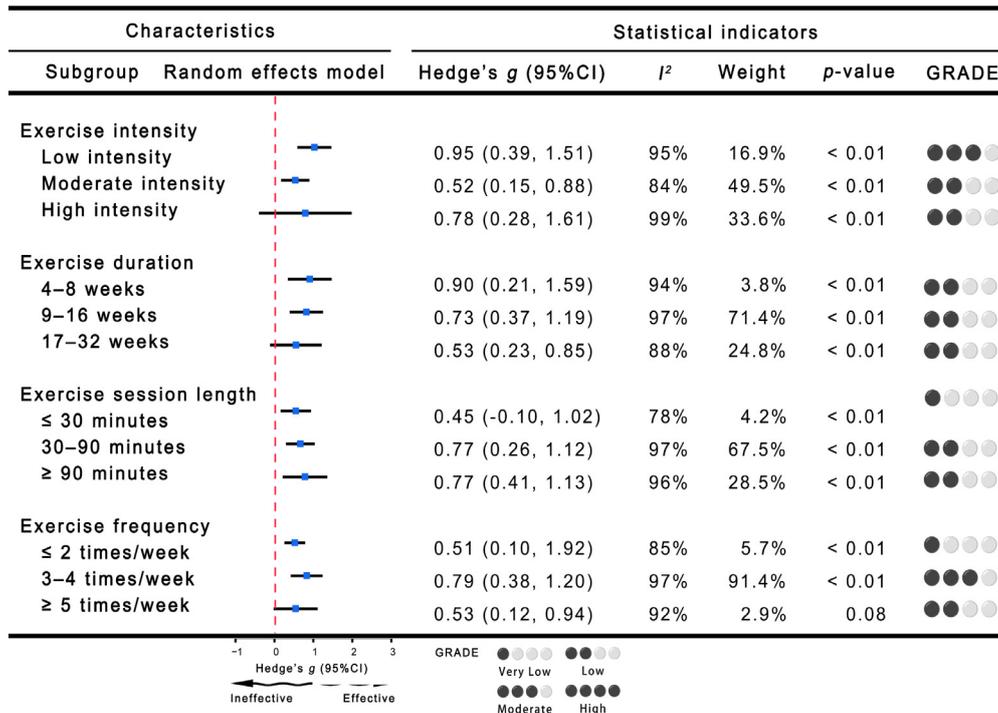

Characteristics		Statistical indicators				
Subgroup Random effects model		Hedge's g (95%CI)	I^2	Weight	p-value	GRADE
Exercise intensity						
Low intensity		0.95 (0.39, 1.51)	95%	16.9%	< 0.01	●●●○
Moderate intensity		0.52 (0.15, 0.88)	84%	49.5%	< 0.01	●●○○
High intensity		0.78 (0.28, 1.61)	99%	33.6%	< 0.01	●●○○
Exercise duration						
4–8 weeks		0.90 (0.21, 1.59)	94%	3.8%	< 0.01	●●○○
9–16 weeks		0.73 (0.37, 1.19)	97%	71.4%	< 0.01	●●○○
17–32 weeks		0.53 (0.23, 0.85)	88%	24.8%	< 0.01	●●○○
Exercise session length						●○○○
≤ 30 minutes		0.45 (-0.10, 1.02)	78%	4.2%	< 0.01	
30–90 minutes		0.77 (0.26, 1.12)	97%	67.5%	< 0.01	●●○○
≥ 90 minutes		0.77 (0.41, 1.13)	96%	28.5%	< 0.01	●●○○
Exercise frequency						
≤ 2 times/week		0.51 (0.10, 1.92)	85%	5.7%	< 0.01	●○○○
3–4 times/week		0.79 (0.38, 1.20)	97%	91.4%	< 0.01	●●●○
≥ 5 times/week		0.53 (0.12, 0.94)	92%	2.9%	0.08	●●○○

Figure 4: Subgroup analysis of exercise intensity, intervention duration, session length and exercise frequency.
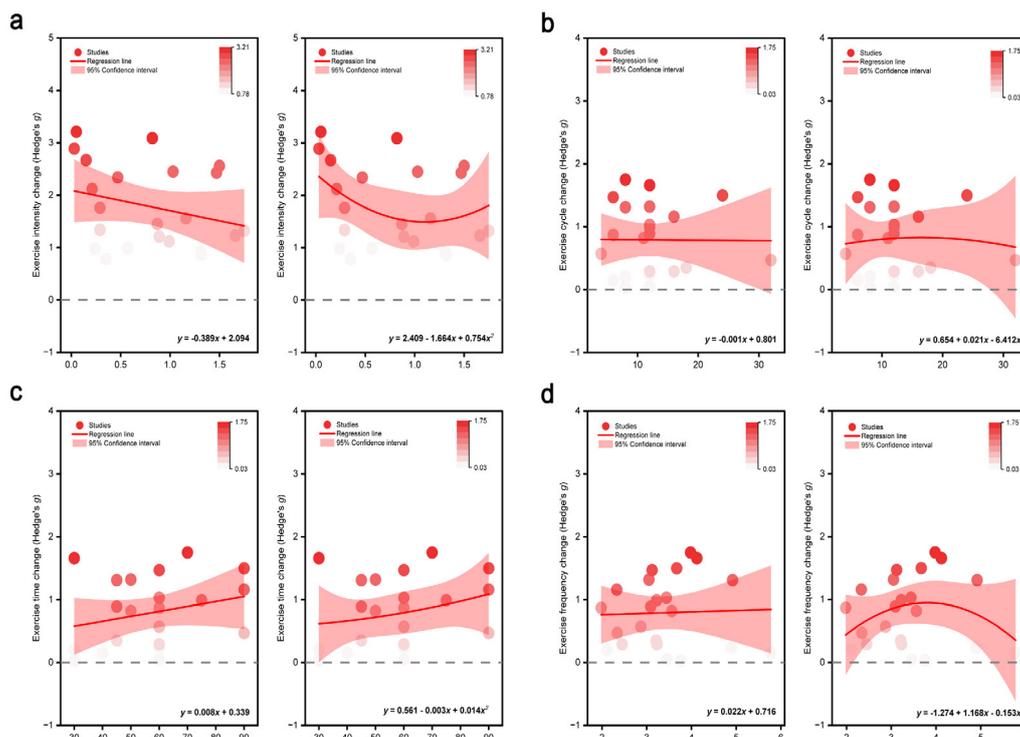

Figure 5: Meta-regression equations based on linear and quadratic polynomial models. (a) Exercise Intensity; (b) Intervention Duration; (c) Session Length; (d) Exercise Frequency.
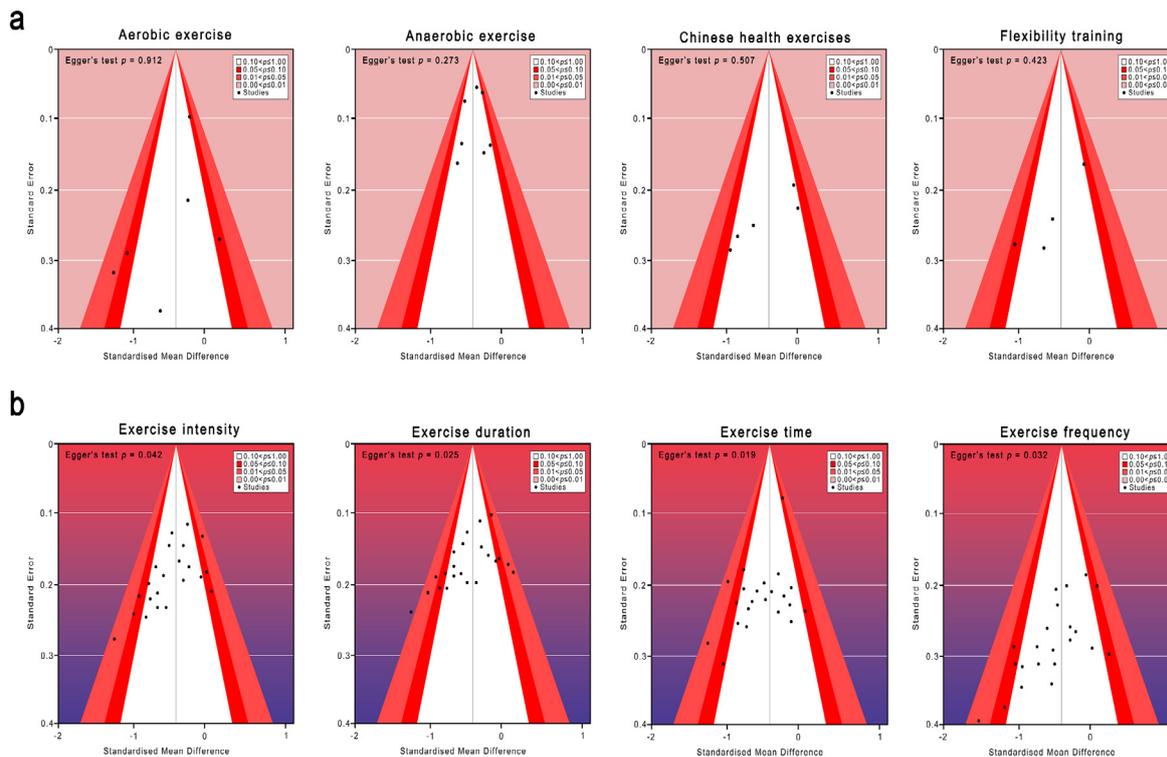
Figure 6: Publication bias funnel plots. (a) Exercise type; (b) Intervention methods.

This finding shows some similarity to previous studies conducted on adolescents[28] and middle-aged and older adults[44], though significant differences exist in the manifestation of depressive symptoms across these populations. Adolescents typically exhibit externalized emotional symptoms[45] and tendencies toward self-harm[46], with fluctuations in depressive symptoms closely linked to dramatic hormonal changes[47]. In contrast, college students more commonly present with somatic symptoms[48], difficulties in decision-making[49] and social anxiety[50], often showing a chronic progression. Middle-aged and older adults tend to display more concealed symptoms, characterized mainly by physical discomfort[51], cognitive decline[52] and social withdrawal[53], frequently accompanied by degenerative physiological changes. Therefore, exercise intervention programs for college students should be tailored to their unique psychological and behavioral characteristics to achieve more precise and effective outcomes.

Exercise intervention, as an important non-pharmacological treatment for depression, has been widely applied in rehabilitation practices and has been confirmed to significantly alleviate depressive symptoms[54]. Based on the current study's findings, combined with the dose–response relationships and characteristics of the college student population, the following evidence-based exercise recommendations are proposed:

- **Exercise type:** Mind-body integrated flexibility exercises demonstrate multidimensional regulatory effects in depression interventions. Compared to traditional aerobic or resistance training, these exercises not only modulate the secretion of mood-related neurotransmitters but also alleviate motor dysfunction associated with depression by improving body awareness and motor coordination, thereby achieving a synergistic mind–body intervention effect. They are recommended as the preferred intervention for college students.

- **Exercise intensity:** Low-intensity exercise has significant advantages during the initial intervention phase due to its high safety and low execution threshold, making it especially suitable for college students with severe depressive symptoms or weak exercise foundations. As the intervention progresses, moderate-intensity exercise can be gradually introduced to enhance neuroplasticity regulation, while high-intensity exercise should be selectively applied as an adjunct for individuals with good tolerance, forming a "low–moderate–high" stepwise intensity adaptation system.

- **Session length:** The duration of a single exercise session should balance psychological benefits and physiological load. Sessions that are too short may insufficiently activate physiological mechanisms for mood regulation, while excessively long sessions may exacerbate stress responses and inflammation, reducing intervention effectiveness. Based on current evidence, it is recommended to control single-session duration around 90 minutes to ensure optimal psychological benefits.

- **Exercise frequency:** Higher frequency is not always better and must avoid physical and mental fatigue caused by overtraining. Low-frequency interventions with fewer than two sessions per week are insufficient to maintain stable biological effects, while high-frequency interventions exceeding five sessions per week may increase dropout risk. A frequency of 3-4 sessions per week achieves an optimal balance between adherence and intervention effect and is recommended for depressed college students. Intervention duration: The intervention period should consider both short-term adaptation and long-term neuroplastic remodeling needs. Short-term programs of less than 4 weeks may improve some psychological indicators but struggle to achieve lasting neural function optimization; interventions longer than 12 weeks may face a plateau in effects due to adaptation.

Clinically, a mid-term intervention of 4–8 weeks can establish exercise habits and activate key neuroregulatory mechanisms, making it the ideal duration for depression exercise interventions. A phased strategy is recommended, focusing on adaptive training in the first 4 weeks and consolidation and reinforcement in the subsequent 4 weeks.

The neurobiological mechanisms underlying exercise-induced antidepressant effects involve the coordinated action of multiple systems[55].

- **Regulation of neurotrophic factors:** Exercise upregulates the expression of neurotrophic factors such as brain-derived neurotrophic factor (BDNF) and insulin-like growth factor-1 (IGF-1), promoting neurogenesis in the hippocampus and increasing gray matter volume in the prefrontal cortex, thereby significantly enhancing neural plasticity[56];

- **HPA axis function regulation:** Exercise modulates the hypothalamic-pituitary-adrenal (HPA) axis, reducing the excessive secretion of corticotropin-releasing hormone (CRH) and glucocorticoids (GC), thus improving neuroendocrine dysregulation caused by chronic stress[57];

- **Inhibition of inflammatory response:** Exercise suppresses the expression of pro-inflammatory cytokines such as IL-1β and TNF-α, optimizing the kynurenine metabolic pathway and thereby alleviating neuroinflammation[58];

- **Antioxidant effects:** Exercise enhances the activities of antioxidant enzymes including superoxide dismutase (SOD) and glutathione peroxidase (GPx), maintaining the balance of the oxidative-antioxidative system and reducing oxidative stress-induced damage to the nervous system[59];

- **Neurotransmitter regulation:** Exercise helps regulate the functions of monoamine neurotransmitters such as serotonin (5-HT), dopamine (DA), norepinephrine (NE), as well as the glutamate/GABAergic systems, restoring neurotransmitter homeostasis[60].

This study found that, compared with other exercise interventions, flexibility training produced more significant improvements in depressive symptoms. This phenomenon may mainly be attributed to the unique social interaction properties of flexibility training. During the coordinated performance of movements, participants establish immediate social connections through nonverbal communication such as eye contact and synchronized body movements. This interaction pattern not only effectively alleviates feelings of loneliness but also significantly reduces social anxiety levels[61]. However, some researchers have pointed out that the antidepressant effects of exercise might be overstated, with benefits limited to symptom relief rather than cure[62]. Therefore, treatment for depression should comprehensively consider multiple interventions-including pharmacotherapy, exercise therapy and psychotherapy-to achieve more ideal therapeutic outcomes[63].

This study has several limitations. It included only accessible literature, lacking full-text articles that could not be retrieved due to database access restrictions, language barriers and other factors, which may have compromised the comprehensiveness of the review. The evaluation methods used in the study involve a certain degree of subjectivity, potentially leading to bias. Additionally, the study did not account for the potential influence of gender on depression severity. Future research could be expanded in the following directions:

Investigating the differential effects of low-intensity exercise interventions on various subtypes of depression (e.g., depression with anxious features, atypical depression);

Exploring the synergistic effects of low-intensity exercise in combination with other treatment approaches, such as psychotherapy or pharmacotherapy;

Conducting in-depth studies on the neurobiological mechanisms underlying the antidepressant effects of exercise, particularly its impact on the hypothalamic-pituitary-adrenal (HPA) axis function, levels of neurotrophic factors and neuroplasticity.

5. Conclusion

In summary, exercise interventions can effectively alleviate depressive symptoms among college students. Based on the effect sizes, different forms of exercise interventions that improve depressive symptoms include flexibility training, traditional health-preserving exercises, anaerobic exercise and aerobic exercise. Among these, consistent low-intensity flexibility training shows the most significant effect in reducing depressive symptoms. It is recommended that the intervention period last for 4-8 weeks, with a frequency of 3-4 sessions per week and each session lasting no less than 90 minutes.

6. Declarations

6.1. Ethics approval and consent to participate

Not applicable.

6.2. Consent for publication

Not applicable.

6.3. Availability of data and materials

All data generated or analyzed during this study are included in this published article.

6.4. Competing interests

The authors declare that they have no competing interests.

6.5. Funding

6.6. Authors' contributions

Lidian Meng: Conceptualization, Data curation, Formal analysis, Project administration, Methodology, Visualization, Writing - original draft, Writing - review & editing. Ruhui Fang: Conceptualization, Methodology. He Zheng: Conceptualization, Methodology, Supervision, Validation, Project administration, Writing - review & editing. All authors read and approved the final version of the manuscript.

6.7. Acknowledgements

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