BMC Psychology

SYSTEMATIC REVIEW Open Access

The intervention effect of long-term exercise on depression and anxiety in college students: a three-level meta-analysis

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Abstract

Background Mental health issues, especially depression and anxiety, are prevalent among college students. Long-term exercise has been shown to improve depression and anxiety in college students. Therefore, this study aims to systematically and comprehensively evaluate the intervention effect of long-term exercise on depression and anxiety in college students using a three-level meta-analysis.

Methods A computer-based search was conducted in five databases—China National Knowledge Infrastructure (CNKI), PubMed, Embase, The Cochrane Library, and Web of Science—for randomized controlled trials (RCTs) investigating the effects of long-term exercise interventions on depression and anxiety in college students. The search covered all records from the inception of each database up to January 11, 2025. The quality of the included studies was assessed using the PEDro scale, and the evidence quality was evaluated using GRADEpro. A three-level meta-analysis with a random-effects model was performed using the metafor package in R 4.3.0.

Results In total, 36 studies were included in this meta-analysis. Long-term exercise significantly improved depression (g = -0.89, 95% CI [-1.23, -0.54], $p < 0.001$) and anxiety (g = -0.64, 95% CI [-0.96, -0.32], $p < 0.001$) in college students. Exercise type, time, frequency, cycle, and questionnaire type were not found to be moderators (all $p > 0.05$). The evidence quality, as assessed by GRADEpro, was rated as high.

Conclusion Long-term exercise can improve depression and anxiety in college students. However, future studies should use more rigorous methodologies and explore the intervention effects of various exercise parameters on depression and anxiety in this population.

Keywords Long-term exercise, College students, Depression, Anxiety, Meta-analysis

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Introduction

College students are in a critical transitional period from adolescence to adulthood, during which they face pressures related to academics, life, and social interactions [1, 2]. As a result, mental health issues are prevalent, with anxiety and depression being the most common. Studies have reported that approximately 62.9% of college students experienced anxiety in the past year, and 27.4% felt that anxiety hurt their academic performance [3]. In China, Italy, and the United States, the prevalence of depressive symptoms among college students is 24.71% [4], 27.8% [5], and 20% [6], respectively. Approximately 33.48% of depressed students engage in self-harm behaviors [7], with the prevalence of anxiety and depression continuously rising each year [8]. Mental health issues such as anxiety and depression not only severely impair the physical and mental well-being of college students but also increase the risk of dropout and suicide [9]. Physical inactivity is one of the largest public health issues of the 21st century [10], with college students showing significantly decreasing physical activity levels [11]. Insufficient physical activity is strongly associated with the development of mental health problems [12].

Long-term exercise not only enhances physical fitness but also improves mental health. Several studies have investigated the intervention effects of long-term exercise on depression and anxiety in college students. One study implemented a 6-week aerobic exercise intervention, with results indicating that long-term exercise can improve depression in college students, although the effects on anxiety were less pronounced [13]. Other research suggests that 8 weeks of exercise can improve anxiety in college students [14]. However, some studies have argued that 6 weeks of aerobic exercise may not be sufficient to alleviate depression in this population [15]. Currently, meta-analytic studies have also explored the effects of exercise on depression and anxiety in college students. A meta-analysis by Huang et al. indicated that exercise can improve both depression and anxiety in college students [16] but did not further investigate the effects of exercise type, duration, frequency, or other specific exercise parameters. Song's network meta-analysis focused only on the intervention effects of aerobic exercise and traditional Chinese exercises on depression in college students but did not explore other types of exercise, such as yoga or ball sports, or examine the effects on anxiety [17]. Similarly, Li et al. only investigated the impact of exercise type on depression in college students [18].

The three-level meta-analysis allows for the extraction of multiple effect sizes from the same study, such as data from different measurement tools and various time points, thereby maximizing information retention and improving statistical efficiency. This approach decomposes variance into three levels: sampling variance (Level 1), within-study variance (Level 2), and between-study variance (Level 3) [19].

A review of previous research reveals that the intervention effects of long-term exercise on depression and anxiety in college students remain controversial. Furthermore, some studies suggest that the effectiveness of long-term exercise interventions may be influenced by the exercise program itself, such as exercise intensity and duration [20]. Based on this, the present study uses a three-level meta-analysis to include all effect sizes related to depression and anxiety, systematically evaluating the intervention effects of long-term exercise on depression and anxiety in college students. Additionally, it further explores the moderating effects of exercise type, duration, frequency, and cycle.

Research methods

This study was conducted in strict accordance with the latest guidelines and requirements of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [21]. The study protocol has been registered with the International Prospective Register of Systematic Reviews (PROSPERO) under registration number CRD42025636691 (https://www.crd.york.ac.uk/PROSPERO/view/CRD42025636691).

Search strategy

Researchers conducted computer-based searches in five bilingual databases: China National Knowledge Infrastructure (CNKI), PubMed, Embase, The Cochrane Library, and Web of Science, for randomized controlled trials (RCTs) on the effects of long-term exercise interventions on depression and anxiety in college students. The search covered all records from the inception of each database up to January 11, 2025. This date was selected to ensure the inclusion of the most recent studies available at the time of manuscript preparation and to maintain consistency with the registration date of the review protocol in the PROSPERO database. Medical Subject Headings (MeSH) and keywords were combined using the logical operators OR and AND. The search terms included: "Exercise," "Physical Activity," "Tai Chi," "Jogging," "Qi Gong," "Walking," "Strength," "Aerobic Exercise" "Ba Duan Jin," "Dancing," "Tai Ji," "Cycling," "Swimming," "Running," "HIIT," "High-Intensity Interval Training," "Sport," "Yoga," "Ball," "College Students," "Youth," "Undergraduate," "University Student," "Adolescents," "Young Adults," "Depression," "Anxiety," "Depressive Emotion," "Depressed Mood," "Anxious Emotion," "Anxiety Symptoms," and "Randomized Controlled Trial." Relevant references from related systematic reviews were also consulted. A detailed description of the search strategy can be found in Appendix 1.

Inclusion and exclusion criteria

The study population consisted of college students, with no restriction on gender. The experimental group had to include at least one group that implemented exercise interventions, with a minimum exercise duration of 4 weeks. If multiple experimental groups involved exercise, all were included. The control group did not engage in any exercise, maintaining normal daily activities such as sedentary behavior or non-exercise interventions like health counseling. The outcome measures included depression and anxiety, assessed using scales such as the Beck Depression Inventory (BDI), State-Trait Anxiety Inventory (STAI), Depression Anxiety Stress Scales – 21 Items (DASS-21), Symptom Checklist-90 (SCL-90), Center for Epidemiologic Studies Depression Scale (CES-D), Self-Rating Depression Scale (SDS), Hamilton Depression Rating Scale (HAMD), Beck Anxiety Inventory (BAI), and Zung Self-Rating Anxiety Scale (SAS). The study design comprised RCTs.

The exclusion criteria were as follows: review studies, conference abstracts, or animal studies; articles published in languages other than Chinese or English; and articles for which the full text could not be accessed or data could not be obtained from the original authors after contact.

Literature selection process

First, two researchers imported the downloaded articles into EndNote X9 and used it to remove duplicate records. Second, the remaining articles were screened by reading the titles and abstracts to exclude irrelevant studies. Finally, relevant articles were downloaded in full and underwent a detailed review. In cases of disagreement between the two researchers, a third researcher was consulted, and consensus was reached through discussion. The specific screening process is shown in Fig. 1.

Data extraction and coding

Two researchers used a pre-established form to extract information from the included studies. The extracted data included author, year, country, sample size, type of intervention, intervention characteristics, and outcome measures. The extracted data consisted of the change scores for both the experimental and control groups. If multiple assessment time points present were during the intervention period, data from all time points were extracted. In cases of disagreement between the two researchers, a third researcher was consulted, and consensus was reached through discussion.

This study also explored potential moderating factors. The type of exercise was coded as aerobic exercise, resistance training, mind-body exercise, and multi-component exercise [22]. Dummy coding was applied to this categorical variable, with aerobic exercise chosen as the reference category. The remaining categories (resistance training, mind-body exercise, and multi-component exercise) were compared to the reference category, in the analysis. Multi-component exercise is defined as a composite form of exercise that integrates various types of physical activities, such as aerobic exercise, resistance training, flexibility training, and balance training. Examples include dance, which incorporates both aerobic and balance training, and ball sports, which combine aerobic exercise and strength training [23]. This study also performed dummy coding for the anxiety assessment tools, which were coded as: BAI, DASS-21, SAS, SCL-90, STAI, and other, with BAI as the reference category. Similarly, the depression assessment tools were dummy coded as: BDI, SDS, CES-D, DASS-21, SCL-90, HAMD, and other, with BDI as the reference category. The exercise cycle was categorized as <8 weeks or ≥ 8 weeks. The exercise time per session was coded as <60 min, ≥ 60 min, or unspecified. The frequency of exercise was classified as <3 days per week, ≥ 3 days per week, or unspecified. Due to the lack of clear reporting on exercise intensity in most studies, moderating factors related to exercise intensity were not explored.

Quality assessment and evidence grading

Two researchers evaluated the quality of the included articles. The methodological quality of the included studies was assessed using the PEDro scale. This scale consists of 11 items: "Eligibility Criteria," "Random Allocation," "Allocation Concealment," "Similarity of Baseline," "Blinding of Participants," "Blinding of Therapists," "Blinding of Outcome Assessment," "More than 85% Retention Rate," "Intention-to-Treat Analysis," "Inter-group Comparisons," and "Point and Variability Measures." The total score is out of 10, with "Eligibility Criteria" not contributing to the total score [24, 25]. A score of <4 points is considered poor quality, 4–5 points fair, 6–8 points good, and 9–10 points excellent.

GRADEpro software was used to evaluate the quality of outcome evidence. The evidence was downgraded or upgraded based on five factors: "Risk of Bias," "Inconsistency," "Indirectness," "Imprecision," and "Publication Bias." The evidence quality was categorized as "High," "Moderate," "Low," or "Very Low.

In cases of disagreement between the two researchers, a third researcher was consulted, and consensus was reached through discussion.

Statistical analysis

Since multiple effect sizes (ES) were extracted from the same study, a three-level random-effects meta-analysis was conducted using the metafor package in R 4.3.0 [26–28]. The pooled ES for the effects of long-term exercise on depression or anxiety was determined using Hedges' g with 95% confidence intervals (CI), employing

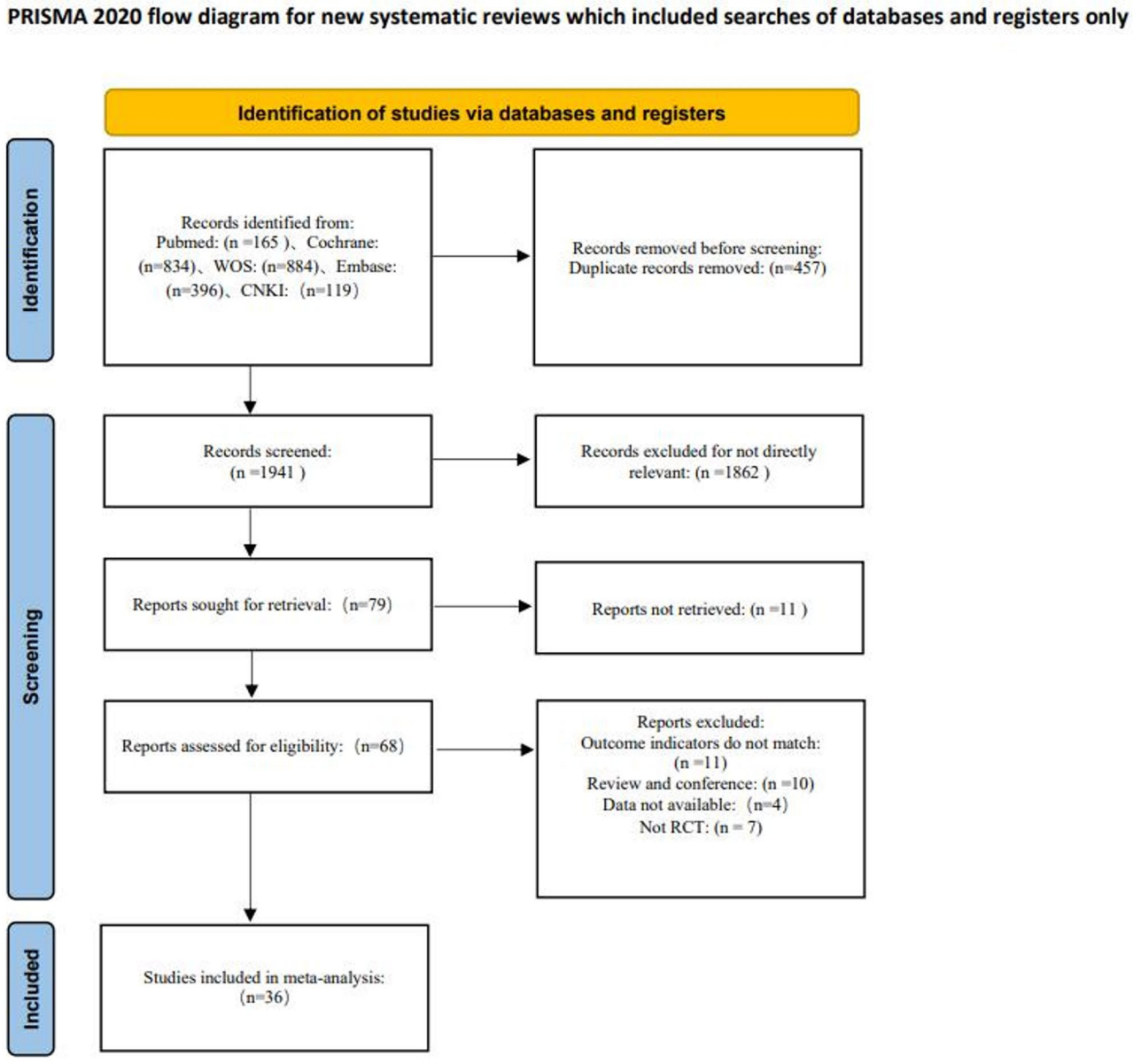

Fig. 1 Literature Selection Process

the restricted maximum-likelihood estimation (REML) method. A P-value < 0.05 was considered statistically significant. Hedges' g < 0.2 indicates a small effect, 0.2–0.49 a small-to-moderate effect, 0.5–0.79 a medium effect, and ≥ 0.8 a large effect [29]. Additionally, 95% prediction intervals (PIs) were calculated to estimate the range in which the ES of future identical studies would likely fall.

Statistical significance in Level 2 (within-study) and Level 3 (between-study) variances was assessed using the log-likelihood ratio test (LRT) [27]. The overall heterogeneity was evaluated using the Q test, with I^2 values of 25%, 50%, and 75% representing low, moderate, and high heterogeneity, respectively [30]. Influence analysis was conducted to identify any outliers. Egger's regression tests were performed to examine the potential for publication bias.

Results

Literature selection process

A total of 2,398 articles were retrieved, and 457 duplicates were removed, leaving 1,941 articles. Titles and abstracts of these remaining articles were screened, resulting in the exclusion of 1,862 irrelevant studies. The full texts of the remaining 79 articles were downloaded and reviewed in detail. As a result, 11 articles were inaccessible, 11 did not meet the outcome measure criteria, 10 were reviews or conference abstracts, four could not provide the necessary data, and seven were not RCTs,

leading to their exclusion. Ultimately, 36 studies were included in the final analysis [9, 14, 15, 31–63], as shown in Fig. 1.

Basic characteristics of the included studies

In total, 36 studies were included, with 27 studies focusing on depression and 22 on anxiety. The studies were conducted in countries such as Türkiye, Iran, and China. The total sample included 2,392 college students, with 14 studies exclusively involving female students. Interventions in the experimental groups included dance, aerobic exercise, ball games, Wuqinxi, Tai Chi, and other activities, while the control groups primarily maintained normal daily activities. The outcome measures were predominantly BDI, SAS, and SDS, as shown in Table 1.

Quality assessment of the studies

All 36 studies described "Eligibility Criteria," "Random Allocation," "Inter-group Comparisons," and "Point and Variability Measures." Seven studies reported "Allocation Concealment" and "Blinding of Participants." One study did not achieve "Similarity of Baseline," two studies achieved "Blinding of Therapists," and six studies implemented "Blinding of Outcome Evaluation." Two studies did not meet the "More than 85% Retention Rate" criterion. None of the studies used "Intention-to-Treat Analysis." The average score was 5.53. See Table 2.

Meta-analysis results

In total, 22 studies with 34 ES investigated the intervention effect of long-term exercise on anxiety in college students. The three-level random-effects model indicated that long-term exercise did not significantly improve anxiety in college students (g = -2.25, 95% CI [-5.49, 0.99], $p = 0.167$, 95% PI [-17.74, 13.24]). The two-level random-effects model also showed no significant improvement (g = -1.58, 95% CI [-3.62, 0.45], $p = 0.123$, 95% PI [-13.54, 10.37]). An influence analysis revealed one outlier [39]. After excluding the outlier, the ES was recomputed. The three-level random-effects model then showed that long-term exercise significantly improved anxiety in college students (g = -0.64, 95% CI [-0.96, -0.32], $p < 0.001$, 95% PI [-1.82, 0.54]). The two-level random-effects model also indicated a significant improvement (g = -0.59, 95% CI [-0.84, -0.34], $p < 0.001$, 95% PI [-1.57, 0.39]) (Figs. 2 and 3). To minimize the impact of outliers, heterogeneity tests, moderator analyses, and publication bias assessments were conducted after excluding the outlier.

S-AI for State anxiety inventory. T-AI for Trait Anxiety Inventory. SAS for Self-Rating Anxiety Scale. SCL-90 for Symptom Checklist-90. Low for Low-Intensity Exercise. Moderate for Moderate-Intensity Exercise. Group for Group games. Individuals for Individuals games.

Through a likelihood ratio test, the variance between studies (Level 3) was not significant ($\chi^2 = 4.41$, $p = 0.018$), indicating that the three-level model was not superior to the two-level model. The within-study variance (Level 2) was also not significant ($\chi^2 = 0.000$, $p = 0.5$), further confirming that the three-level model was not superior. Although the three-level model did not outperform the two-level model, its use remained meaningful. Specifically, the three-level structure better accounts for the nested data hierarchy (e.g., multiple ES nested within studies) and provides a more accurate estimation of between-study and within-study variance components. This approach aligns with recent methodological recommendations for meta-analyses involving complex data structures [28]. In the total variance, sampling variance (Level 1) accounted for 47.66%, within-study variance (Level 2) accounted for 5.96%, and between-study variance (Level 3) accounted for 52.34%.

To investigate the impact of outliers, subgroup analyses were conducted both before and after the removal of outliers. The results indicated significant changes in ES for the following subgroups: "mind-body exercise (g = -2.62 → -0.47)," "multi-component exercise (g = -2.65 → -0.79)," "< 60 min (g = -2.31 → -0.58)," "≥ 60 min (g = -2.39 → -0.73)," "< 8 weeks (g = -2.36 → -0.41)," "≥ 8 weeks (g = -2.19 → -0.75)," "≥ 3 days a week (g = -5.15 → -0.56)," "SAS(g = -4.50 → -1.29)," and "other (g = -4.07 → -0.87)." After removing outliers, exercise type, exercise time, exercise cycle, exercise frequency, and questionnaire type were not significant moderators ($p > 0.05$ for all). Among exercise types, only multi-component exercise significantly improved anxiety in college students (g = -0.79, 95% CI [-1.20, -0.37], $p = 0.001$). Both exercise time of < 60 min (g = -0.58, 95% CI [-1.03, -0.13], $p = 0.013$) and ≥ 60 min (g = -0.73, 95% CI [-1.19, -0.28], $p = 0.003$) were effective in improving anxiety. In terms of the exercise cycle, long-term exercise for ≥ 8 weeks significantly improved anxiety (g = -0.75, 95% CI [-1.12, -0.38], $p < 0.001$). Regarding exercise frequency, both < 3 days per week (g = -0.77, 95% CI [-1.32, -0.23], $p = 0.013$) and ≥ 3 days per week (g = -0.56, 95% CI [-0.98, -0.15], $p = 0.009$) improved anxiety in college students. In terms of questionnaire type, statistical significance was observed only for "SAS (g = -1.29, 95% CI [-1.86, -0.73], $p < 0.001$)" and "other (g = -0.87, 95% CI [-1.45, -0.28], $p = 0.005$)" (Table 3).

The Egger test indicated no publication bias in the studies (t = -0.17, $p = 0.871$) (Fig. 4).

Intervention effect of long-term exercise on depression in college students

A total of 27 studies with 44 ES examined the intervention effect of long-term exercise on depression in college students. The three-level random-effects model indicated

Table 1 Basic information of the included studies

Reference	Country	Number (E/C), Sex(F/M)	Age (Y)	Exercise intervention	Content of the Control Group	Outcomes
Akandere 2011	Turkey	60/60; F/M: 60/60	20–24	Dancing, 12 weeks, 3 days a week, 110 min	Daily life	BDI
Abavisani 2019	Iran	31/31, None	Total: 23.7 ± 2.69	Pilates, 8 weeks, 2 days a week, 60 min	Daily life	OAHA
Alsaraireh 2017	Jordan	90/91, F/M:112/69	None	Strength exercises combined with aerobics exercises, 10 weeks, 3 days a week, 60 min	Meditation	CESD-R
Asci 2003	Turkey	20/20, F/M:40/0	21.35 ± 0.88/ 21.20 ± 1.67	Aerobic exercise combined with dance, 10 weeks, 3 days a week, 60–80%HRR, 50 min	Daily life	STAI
Bargı 2022	Turkey	15/16, F/M:28/3	Total: 19.97 ± 1.14	Physical activity, 4 weeks, 30–60 min, at least 3days a week,	Daily life	BAI, BDI
Eather 2018	Australia	22/31, F/M:35/18	20.48 ± 2.01/20.23 ± 1.72	HIIT, 8 weeks, 3 days a week, 8–12 min, 85%HRmax	Waiting Group	STAI
Ghorbani 2014	Iran	15/15, F/M:30/0	26.06 ± 1.18/26.33 ± 1.30	Aerobic Exercises, 6weeks, 3 days a week, 60 min,	Daily life	GHQ-28
Hemat-Far 2012	Iran	10/10 F/M:20/0	18–25	Aerobic exercises, 8 weeks, 3 days a week, 40–60 min, 60–65%HRmax	Daily life	BDI
Ji 2022	China	78/78/79, F/M:82/113	E1:21.42 ± 2.4, E2:22.31 ± 3.1, C:21.9 ± 2.1	E1: Team Sports, E2: Individual Sports, 6 weeks, 2 days a week, 45 min, Moderate/high intensity	Daily life	SAS
Li 2022	China	13/14, F/M:27/0	22.6 ± 2.5/22.5 ± 2.0	Resistance training, 8 weeks, 2 days a week, 50 min, 70%RM	Daily life	SAS
Kim 2004	South Korea	24/28, F/M:52/0	19–26	Meridian exercise, 6 weeks, 2 days a week, 30 min	Daily life	STAI, DSI
Mailey 2010	USA	24/23, F/M:32/15	None	Internet-delivered physical activity, 10 weeks, 7days a week	Health Counseling	STAI, BDI

Table 1 (continued)

Reference	Country	Number (E/C), Sex(F/M)	Age (Y)	Exercise intervention	Content of the Control Group	Outcomes
Paolucci 2018	Canada	18/19/18, F/M:39/16	Total: 21 ± 2	E1: HIIT, E2: MCT, 6 weeks, 3 days a week, E1:25 min, E2:32.5 min, E1: 174 ± 2 beats/min, E2: 142 ± 2 beats/min	Daily life	BDI, BAI
Papp 2019	Sweden	21/23, F/M:48/6	Median age:25	High-intensity yoga, 6 weeks, 1 day a week, 50–60 min	Daily life	HADS
Philippot 2022	Germany	13/15, F/M:25/3	20.69 ± 1.44/20.93 ± 1.94	High-Intensity Interval Training, 4 weeks, 3 days a week, 80%HRmax	Daily life	DASS-21
Roth 1987	USA	18/19/18, F/M:28/27	Total: 18.9 ± 1.3	E1: Aerobic exercises, E2: Progressive Relaxation Training, 11 weeks, 3 days a week, 30 min, E1:75%HRmax; E2: None	Daily life	BDI, STAI
Sadeghi 2016	Iran	16/14, F/M:6/24	20.93 ± 1.06/20.92 ± 1.20	Aerobic exercise, 8 weeks, 45–60 min, 60-80%Heart rate	Daily life	BDI
Saltan 2020	Turkey	29/28/35, F/M:75/17	E1:18.82 ± 1.07, E2:18.85 ± 2.50; C:19.42 ± 1.38	E1: Pilates, E2: Therapeutic exercise, 12 weeks, 3 days a week	Daily life	BDI
Xiao 2021	China	31/31/34,F/M:25/71	E1:19.21 ± 1.02, E2:18.95 ± 0.89, C:19.71 ± 1.72	E1: Baduanjin, E2: Basketball, 12 weeks, 3 days a week, 90 min, moderate intensity(120–150 beats/minute)	Daily life	SRAS
Zhang JW 2023	China	9/9, F/M:13/5	24.2 ± 4.07/22.50 ± 5.95	Taichi, 8 weeks, 5 days a week, 60 min	Daily life	SAS, SDS
Yiğiter 2017	Turkey	30/30, F/M:60/0	18.93 ± 5.8/19.20 ± 1.09	Tennis exercise, 8 weeks, 3 days a week, 60 min	Daily life	BDI,
Zhang YQ 2023	China	39/39; F/M:78	Average age of 19.2	Baduanjin, 12 weeks, 3 days a week, 60 min	Daily life	SCL-90
Zhao 2023	China	29/29/28; F/M:61/25	E1:20.72 ± 2.05 E2:21.66 ± 1.97 C:21.21 ± 2.25	E1: Aerobic exercise, E2: Resistance training, 12 weeks, 3 days a week, 40–60 min, E1: 50–90%HRR, E2: 20 RM	Waiting Group	SDS

Table 1 (continued)

Reference	Country	Number (E/C), Sex(F/M)	Age (Y)	Exercise intervention	Content of the Control Group	Outcomes
Zheng 2021	China	91/90, F/M:95/86	19.67 ± 1.39/19.45 ± 1.21	Dance, 8 weeks, 90 min 2 days a week, 65%HRmax	Daily life	SRCQ
Chen 2019	China	18/18, F/M:36/0	None	Taichi, 16 weeks, 3 days a week, 60 min, 65–75%HRmax	Daily life	CES-D
Chen 2020	China	20/19, F/M:39/0	None	Pilates, 3 days a week, 60 min, 16 weeks, 65–75%HRmax	Daily life	CES-D
Cheng 2016	China	15/15, F/M:15/15	21.2 ± 1.4/21.0 ± 1.6	Wuqinxi, 12 weeks, 3 days a week, 40–60 min, Moderate intensity	Daily life	BDI、HAMD
Gong 2019	China	34/36, F/M:70/0	Total:22.85 ± 1.26	Aerobic exercise and yoga, 8 weeks, 3 days a week, 40 min, 60–69%HRmax	Daily life	SAS
Guan 2008	China	15/15, F/M:30/0	20.97 ± 2.09/20.18 ± 2.37	Resistance training, 8 weeks, 3 days a week, 50–70%RM	Daily life	CES-D
Hua 2021	China	67/60/63/20, F/M:177/33	E1:20.29 ± 0.84, E2:20.38 ± 0.80, E3:20.24 ± 1.00, C:21.15 ± 1.04	E1: Yoga, E2: Taichi, E3: Dance, 12 weeks, 1 day a week, 80 min	Daily life	DASS-21
Li Gang 2008	China	20/18, F/M:38/0	Total:20.35 ± 0.88	Taichi, 8 week, 3 days a week, 60 min, 60–70%HRmax	Daily life	POMS
Li Ke 2023	China	24/24/24,F/M:72/0	None	E1: Wuqinx, E2: Mix Wuqinxi, 12 week, 7 days a week, 30–50 min	Health Counseling	HAMD, SCL-90, STDS
Li QL 2009	China	15/15, F/M:30/0	20.22 ± 2.15/ 20.18 ± 2.37	Aerobic exercise, 8 weeks, 5days a week, 50 min, 70–80%HRmax	Daily life	CES-D
Ren 2023	China	35/35, None	Total:22.85 ± 1.26	Running and HIIT, 8weeks, 3 days a week, 50 min, Moderate intensity	Daily life	SDS

Table 1 (continued)

Reference	Country	Number (E/C), Sex(F/M)	Age (Y)	Exercise intervention	Content of the Control Group	Outcomes
Yao 2013	China	20/20, None	20.25 ± 1.0	Physical activity, 8 weeks, 2 days a week, 80 min, 60–75%HRmax,	Daily life	STAI, SAS
Zhu 206	China	28/29/30,F/M:87/0	None	E1: Low Basketball, E2: Moderate Basketball, 10 weeks, 3 days a week, 30 min, E1:90–110 beats/minute, E2:135-150beats/minute	Daily life	SCL-90

Note BDI, Beck Depression Scale; HRR, Heart Rate Reserve; STAI, State-Trait Anxiety Scale; HIIT, High-Intensity Interval Training; HRmax, Maximum Heart Rate; SAS, Zung's Self-Rating Anxiety Scale; MCT, Moderate-Intensity Continuous Training; BAI, Beck Anxiety Inventory; SRAS, Self-Rating Anxiety Scale; SDS, Self-Rating Depression Scale; OAHA, Obvious and Hidden anxiety; DSI, Depression Status Inventory Scale; HADS, Hospital Anxiety and Depression Scale; DASS-21, Depression Anxiety Stress Scales −21 Items; SCL-90, Symptom Checklist-90; SRCQ, Stress Response Characteristic Questionnaire; CES-D, Center for Epidemiologic Studies Depression Scale; POMS, Profile of Mood States; STDS, Self-subthreshold Depression Scale; HAMD, Hamilton Depression Rating Scale; F, Female; M, Male.; Y, Years; RM, Repetition maximum

that long-term exercise did not significantly improve depression (g = -2.38, 95% CI [-5.36, 0.60], $p = 0.115$, 95% PI [-18.09, 13.34]). The two-level random-effects model showed that long-term exercise could improve depression (g = -1.91, 95% CI [-3.67, -0.15], $p = 0.034$, 95% PI [-13.65, 9.83]). An influence analysis was conducted, revealed one outlier [39]. After excluding the outlier, the ES was recomputed. The three-level random-effects model indicated that long-term exercise significantly improved depression (g = -0.89, 95% CI [-1.23, -0.54], $p < 0.001$, 95% PI [-2.48, 0.71]). The two-level random-effects model also showed that long-term exercise significantly improved depression (g = -0.99, 95% CI [-1.30, -0.69], $p < 0.001$, 95% PI [-2.64, 0.65]) (Figs. 5 and 6). To minimize the impact of outliers, heterogeneity tests, moderator analyses, and publication bias assessments were conducted after excluding the outlier.

Through a likelihood ratio test, the variance between studies (Level 3) was not significant ($\chi^2 = 4.49$, $p = 0.017$), indicating that the three-level model was superior to the two-level model. However, the within-study variance (Level 2) was not significant ($\chi^2 = 2.25$, $p = 0.067$), suggesting that the three-level model was not superior to the two-level model. In the total variance, sampling variance (Level 1) accounted for 34.35%, within-study variance (Level 2) accounted for 25.87%, and between-study variance (Level 3) accounted for 39.79%.

To investigate the impact of outliers, subgroup analyses were conducted both before and after the removal of outliers. The results indicated that significant changes in ES were observed in the following subgroups: "resistance exercise (g = -0.74 → -1.07)," "mind-body exercise (g = -3.26 → -1.23)," "multi-component exercise (g = -2.71 → -0.49)," "< 60 min (g = -4.07 → -1.09)," "≥ 60 min (g = -0.85 → -0.69)," "< 8 weeks (g = -2.40 → -0.53)," "≥ 8 weeks (g = -2.37 → -0.99)," "< 3 days a week (g = -9.03 → -0.84)," "BDI (g = -2.31 → -0.73)," "HAMD (g = -3.63 → -1.15)," "SCL-90 (g = -2.34 → 0.17)," and "other (g = -4.99 → -1.28)." After the removal of outliers, exercise type, exercise time, exercise cycle, exercise frequency, and questionnaire type were not found to be significant moderators ($p > 0.05$ for all) ($p > 0.05$ for all). Among exercise types, aerobic exercise (g = -0.90, 95% CI [-1.54, -0.27], $p = 0.007$), resistance exercise (g = -1.07, 95% CI [-2.09, -0.06], $p = 0.039$), and mind-body exercise (g = -1.23, 95% CI [-1.77, -0.70], $p < 0.001$) all significantly improved depression in college students. Regarding exercise time, both < 60 min (g = -1.09, 95% CI [-1.57, -0.61], $p < 0.001$) and ≥ 60 min (g = -0.69, 95% CI [-1.25, -0.13], $p = 0.016$) of long-term exercise significantly improved depression in college students. In terms of exercise cycle, only long-term exercise for ≥ 8 weeks significantly improved depression (g = -0.99, 95% CI [-1.36, -0.61], $p < 0.001$). For exercise frequency, only long-term exercise for ≥ 3 days a week significantly improved depression (g = -0.89, 95% CI [-1.28, -0.51], $p < 0.001$). In the questionnaire type, statistical significance was observed for BDI (g = -0.73, 95% CI [-1.38, -0.09], $p = 0.026$), CES-D (g = -1.42, 95% CI [-2.38, -0.45], $p = 0.005$), HAMD (g = -1.15, 95% CI [-2.19, -0.11], $p = 0.021$), SDS (g = -1.32, 95% CI [-2.49, -0.14], $p = 0.029$), and other (g = -1.28, 95% CI [-2.20, -0.36], $p = 0.008$) (Table 4).

The Egger test indicated the presence of publication bias in the studies (t = -6.07, $p < 0.001$). After applying the imputation method, the ES did not change significantly (g = 1.28, 95% CI [-1.59, -0.97], $p < 0.001$), suggesting that the results are robust (Fig. 7).

Table 2 PEDro scores

Included Literature	1	2	3	4	5	6	7	8	9	10	11	TS
Akandere 2011	1	1	0	1	0	0	0	1	0	1	1	5
Abavisani2019	1	1	1	0	0	0	0	1	0	1	1	5
Alsaraireh 2017	1	1	1	1	0	0	0	1	0	1	1	6
Asci 2003	1	1	0	1	0	0	0	1	0	1	1	5
Barğı 2022	1	1	0	1	1	0	0	1	0	1	1	6
Eather 2018	1	1	0	1	1	0	0	1	0	1	1	6
Ghorbani 2014	1	1	1	1	0	0	0	1	0	1	1	6
Hemat-Far 2012	1	1	0	1	0	0	0	1	0	1	1	5
Ji 2022	1	1	0	1	0	0	0	0	0	1	1	4
Kim 2004	1	1	0	1	0	0	1	1	0	1	1	6
Mailey 2010	1	1	0	1	1	0	0	1	0	1	0	6
Paolucci 2018	1	1	0	1	0	0	0	1	0	1	1	5
Papp 2019	1	1	0	1	1	1	1	0	0	1	1	7
Philippot 2022	1	1	1	1	1	1	1	1	0	1	1	9
Roth 1987	1	1	0	1	0	0	0	1	0	1	1	5
Sadeghi 2016	1	1	0	1	0	0	0	1	0	1	1	5
Saltan 2020	1	1	0	1	1	0	1	1	0	1	1	7
Yiğiter 2017	1	1	0	1	0	0	0	1	0	1	1	5
Zhang JW2023	1	1	1	1	0	0	1	1	0	1	1	7
Zhang YQ 2023	1	1	1	1	0	0	1	1	0	1	1	7
Zhao 2023	1	1	1	1	1	0	0	1	0	1	1	7
Zheng 2020	1	1	0	1	0	0	0	1	0	1	1	5
Chen 2019	1	1	0	1	0	0	0	1	0	1	1	5
Chen 2020	1	1	0	1	0	0	0	1	0	1	1	5
Cheng 2016	1	1	0	1	0	0	0	1	0	1	1	5
Gong 2019	1	1	0	1	0	0	0	1	0	1	1	5
Guan 2008	1	1	0	1	0	0	0	1	0	1	1	5
Hua 2021	1	1	0	1	0	0	0	1	0	1	1	5
Li Gang 2008	1	1	0	1	0	0	0	1	0	1	1	5
Li Ke 2023	1	1	0	1	0	0	0	1	0	1	1	5
Li QL 2009	1	1	0	1	0	0	0	1	0	1	1	5
Ren 2023	1	1	0	1	0	0	0	1	0	1	1	5
Yao 2013	1	1	0	1	0	0	0	1	0	1	1	5
Zhu 206	1	1	0	1	0	0	0	1	0	1	1	5
Xiao 2021	1	1	0	1	0	0	0	1	0	1	1	5
Li Ran 2022	1	1	0	1	0	0	0	1	0	1	1	5

Note: 1 = Eligibility Criteria; 2 = Random Allocation; 3 = Allocation Concealment; 4 = Similarity Baseline; 5 = Blinding of Participants; 6 = Blinding of Therapists; 7 = Blinding of Outcome Evaluation; 8 = More than 85% Retention Rate; 9 = Intention-to-Treat Analysis; 10 = Inter-group Comparisons; 11 = Point and Variability Measures; TS, Total score

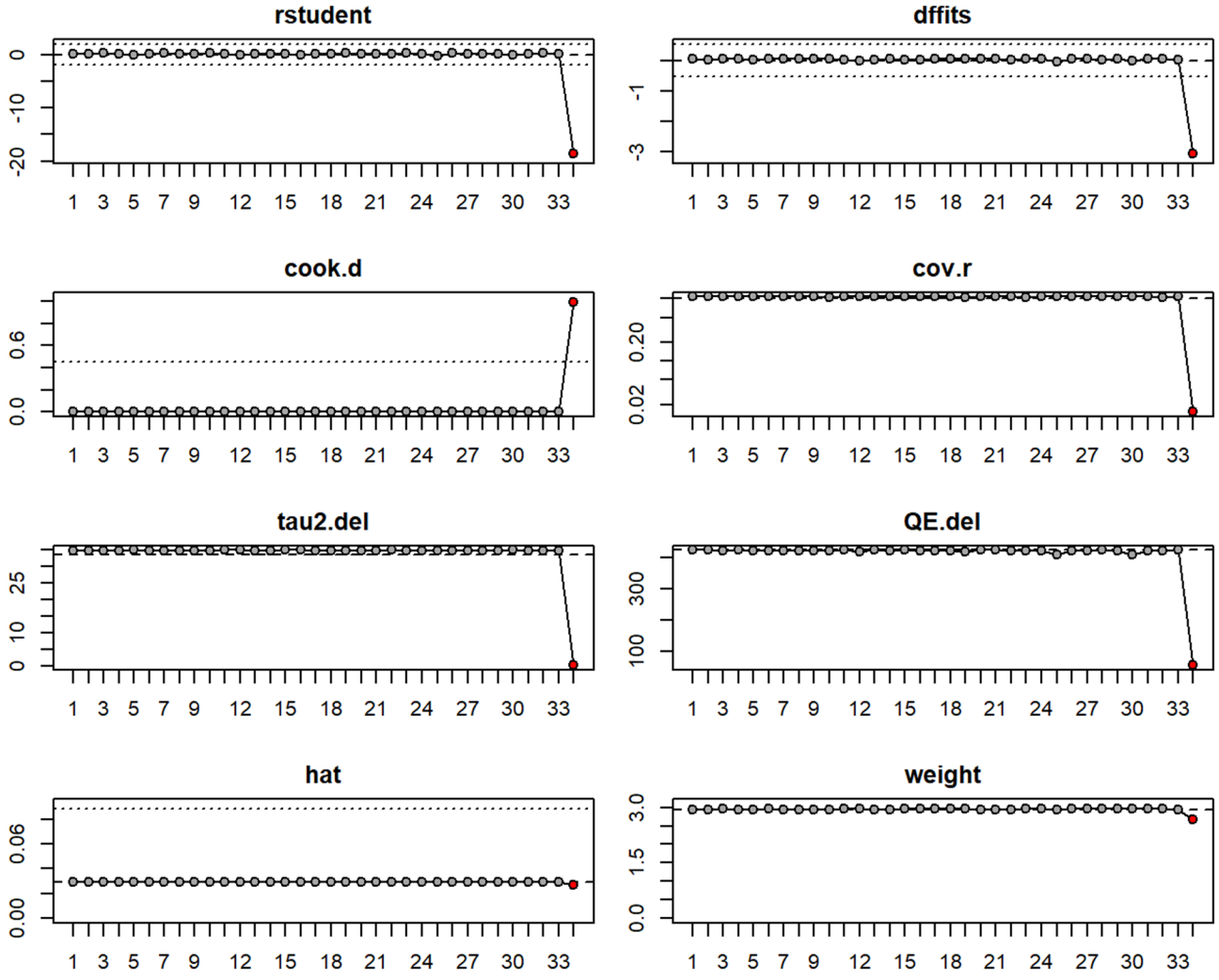

Fig. 2 Influence Analysis of the Effects of Long-Term Exercise on Anxiety in College Students

GRADEpro evidence quality assessment

This study employed GRADEpro to assess the quality of evidence regarding the effects of long-term exercise interventions on depression and anxiety in college students. Since all the included studies were randomized controlled trials, the default evidence level in GRADEpro was high. No downgrades were made in the domains of "Study limitations," "Inconsistency," "Indirectness," "Imprecision," and "Publication bias," as the evidence for both depression and anxiety remained classified as high quality.

Discussion

This study used a three-level meta-analysis to explore the intervention effects of long-term physical exercise on depression and anxiety in college students and conducted an influence analysis to investigate potential outliers. After removing the outliers, the overall ES and ES in most subgroup analyses were significantly reduced, indicating that the original results were influenced by some extreme data points. The results became more robust and reliable after removing these outliers, suggesting that the outcomes may better reflect the true intervention effect. The influence analysis indicated that the outliers originated from Kim [39]. The intervention in this study involved meridian exercise, a form of exercise based on Traditional Chinese Medicine (TCM) meridian theory, which may have varying effects on individuals. As this exercise emphasizes internal energy flow and the regulation of qi and blood, psychological and physiological responses could differ significantly between individuals. For example, some participants might have a strong cultural identification and psychological acceptance of this exercise, resulting in more pronounced effects, while others may not experience the same benefits. Moreover, the outliers may stem from inconsistencies in the implementation of meridian exercise in the studies.

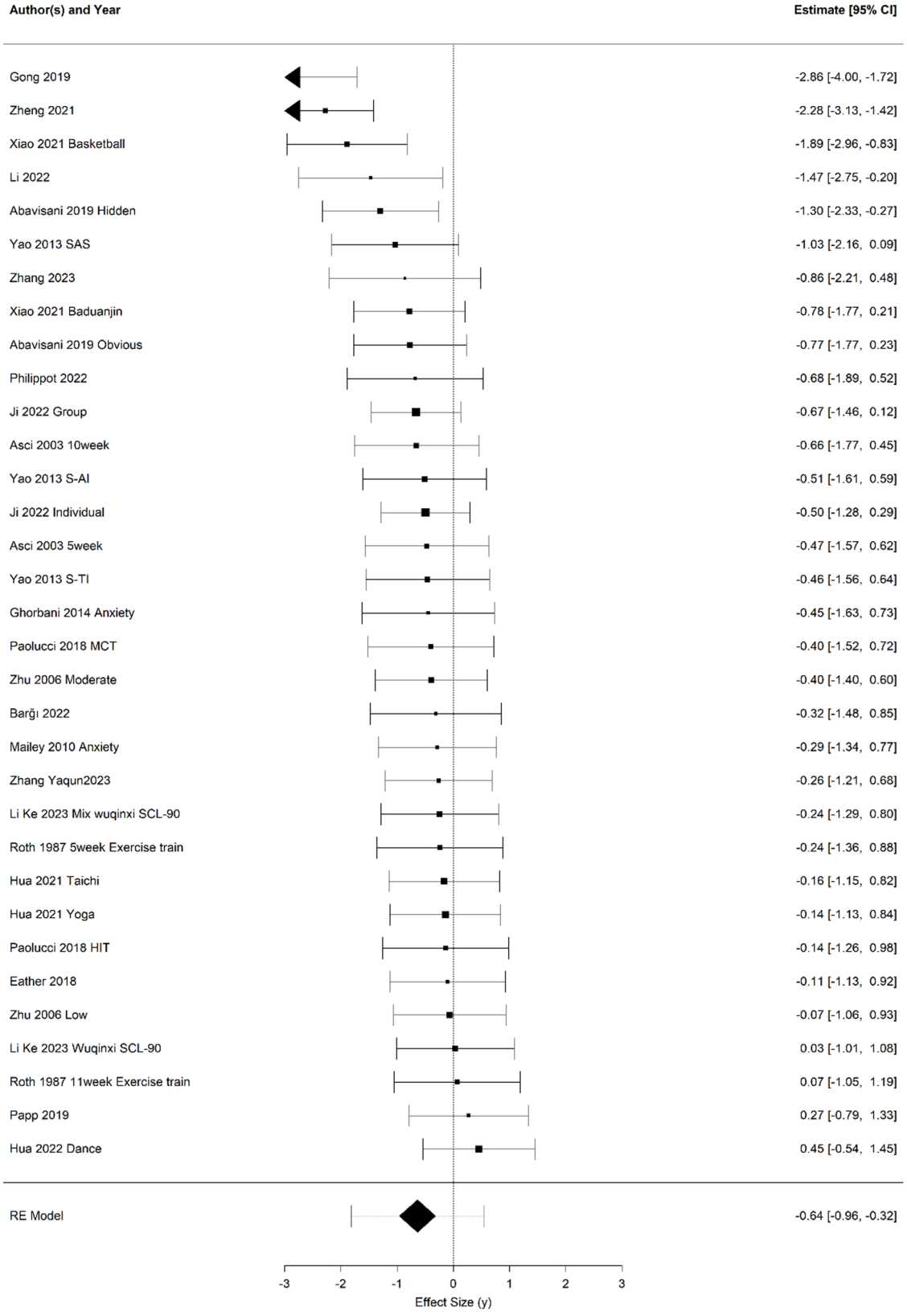

Fig. 3 Forest Plot of the Effects of Long-Term Exercise on Anxiety in College Students' Intervention. Note: RE model for Random Effects Model. HIT for High-intensity interval training. MICT for Moderate-intensity continuous training. Obvious for Obvious anxiety. Hidden for Hidden anxiety

Table 3 Moderators of the intervention effect of Long-term exercise on anxiety in college students

Moderator	B: k,g(95%CI), *P*	A: k,g(95%CI), *P*	A: Test of Moderators
Exercise type			F (3,29) = 1.00, *p* = 0.407
Aerobic exercise	5, -0.27(-9.52,8.98),0.953	5, -0.25 (-1.09,0.60),0.552	
Resistance exercise	1, -1.47(-17.52,14.57),0.853	1, -1.47(-3.21,0.26),0.093	
Mind-body exercise	11, -2.62(-6.44,1.21),0.172	10, -0.47(-0.10,0.05),0.074	
Multi-component exercise	17, -2.65(-6.45,1.16),0.165	17, -0.79(-1.20, -0.37),0.001	
Exercise time			F (2,30) = 0.24, *p* = 0.788
<60 min	17, -2.31(-5.77,1.14),0.182	16, -0.58(-1.03, -0.13),0.013	
≥ 60 min	16, -2.39(-5.87,1.08),0.170	16, -0.73(-1.19, -0.28),0.003	
Unclear	1, -0.29(15.93,15.36),0.971	1, -0.29(-1.91,1.34),0.772	
Exercise cycle			F (1,31) = 1.27, *p* = 0.269
<8 weeks	11, -2.36(-5.67,0.96),0.158	10, -0.41(-0.93,0.11),0.121	
≥ 8 weeks	23, -2.19(-5.45,1.07),0.182	23, -0.75(-1.12,-0.38),<0.001	
Exercise frequency			F (1,31) = 0.39, *p* = 0.54
<3 days a week	14, -0.60(-4.58,3.38),0.762	13, -0.77(-1.32, -0.23),0.007	
≥ 3 days a week	20, -5.15(-10.44,0.13),0.056	20, -0.56(-0.98, -0.15),0.009	
Questionnaire type			F (5,27) = 2.06, *p* = 0.102
BAI	3, -0.29(-12.06,11.47),0.960	3, -0.29(-1.27,0.69)0.551	
DASS-21	4, -0.32(-12.08,11.45),0.956	4, -0.20(-1.12,0.72)0.662	
SAS	8, -4.50(-9.58,0.58),0.081	8, -1.29(-1.86,-0.73)<0.001	
SCL-90	5, -0.20(-9.80,9.40)0.966	5, -0.20(-0.93,0.53)0.586	
STAI	6, -0.26(-8.58,8.06)0.949	6, -0.27(-0.94,0.40)0.417	
Other	8, -4.07(-9.15,1.00)0.111	7, -0.87(-1.45,-0.28)0.005	

Note: B, Before the outliers are removed; A, After excluding outliers; SAS, Zung's Self-Rating Anxiety Scale; STAI, State-Trait Anxiety Inventory; BAI, Beck Anxiety Inventory; SCL-90, Symptom Checklist-90; DASS-21, Depression Anxiety Stress Scales – 21 Items

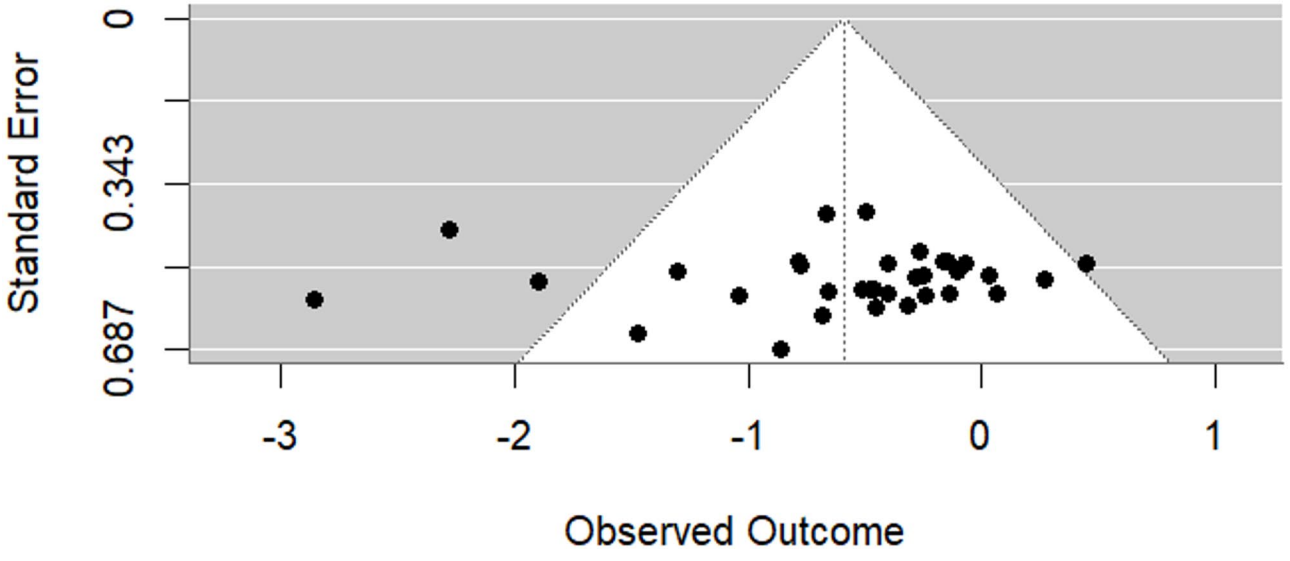

Fig. 4 Funnel Plot of the Effects of Long-Term Exercise on Anxiety in College Students' Intervention

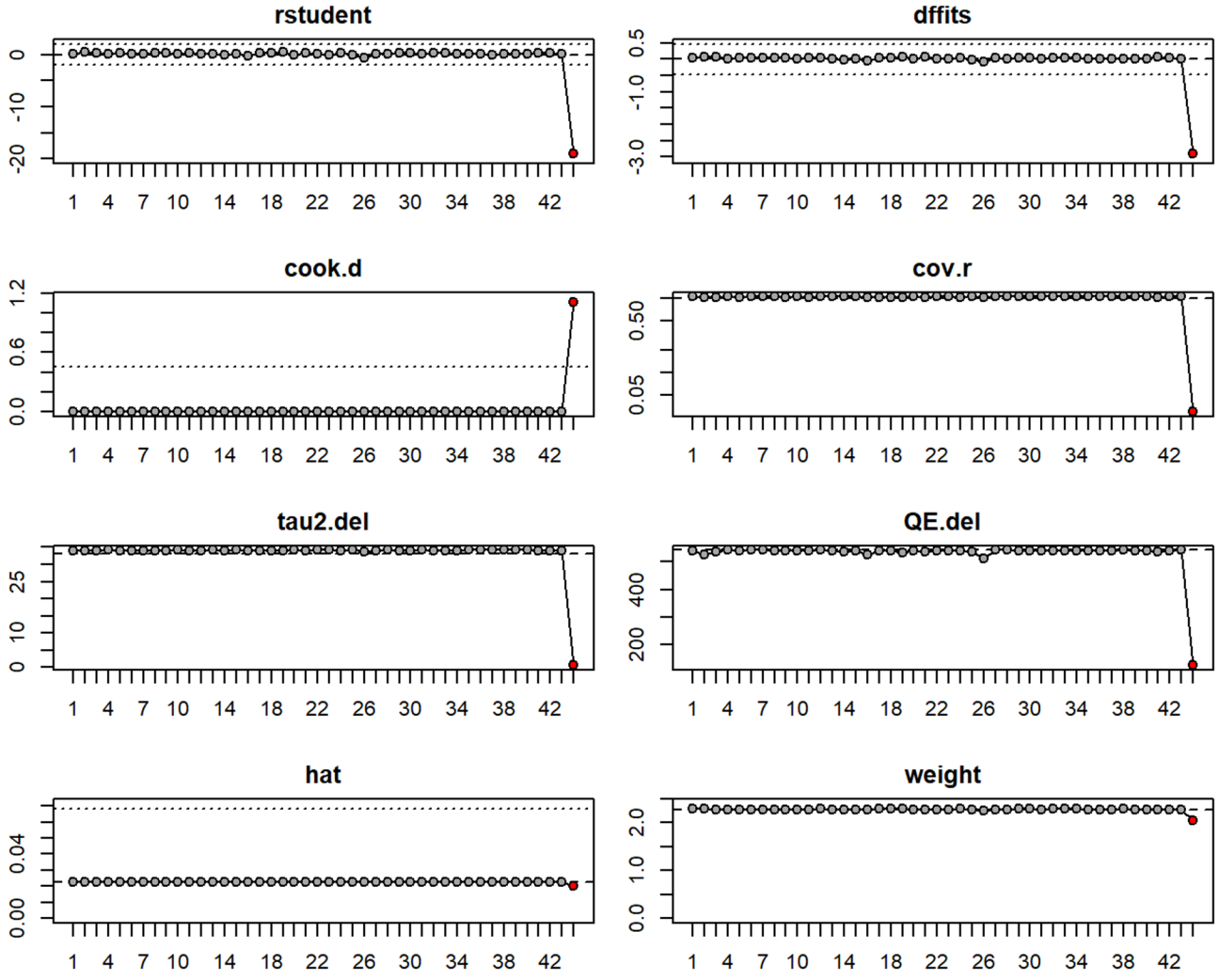

Fig. 5 Influence Analysis of the Effects of Long-Term Exercise on Depression in College Students

In some studies, variations in exercise intensity, frequency, or duration could lead to different adaptation levels among participants, which, in turn, may have affected the outcomes. Additionally, the cultural background and nature of meridian exercise may have caused certain participants to have inflated expectations or emotional reactions, further contributing to the variability in results [39]. Future research could conduct subgroup analyses on different types of exercises. Specifically, when employing meridian exercise, intensity, frequency, and participants' cultural backgrounds should be controlled to reduce the effects of individual differences. Furthermore, researchers should ensure standardization in intervention design to improve the reliability and consistency of the results, and whenever possible, use more standardized and unified assessment tools to avoid heterogeneity caused by different instruments.

High evidence quality indicates that long-term exercise can improve depression and anxiety in college students. This is consistent with the findings of previous studies. Huang et al.'s systematic review explored the effects of exercise on the mental health of college students, including 20 studies on anxiety and 14 studies on depression, and found that exercise could reduce symptoms of anxiety and depression [16]. Song et al.'s network meta-analysis compared the effects of aerobic exercise, traditional Chinese exercise, and meditation on improving depression symptoms in college students [17]. The results showed that aerobic exercise, traditional Chinese exercise, and meditation all improved depression symptoms, but aerobic exercise had a more significant effect on anxiety, while traditional Chinese exercise was more suitable for alleviating stress in college students. Li et al.'s network meta-analysis examined the intervention effects of music, massage, exercise, and acupuncture on depression in college students, and concluded that HIIT exercise was the most effective intervention for depression in college students [18].These studies suggest that the role

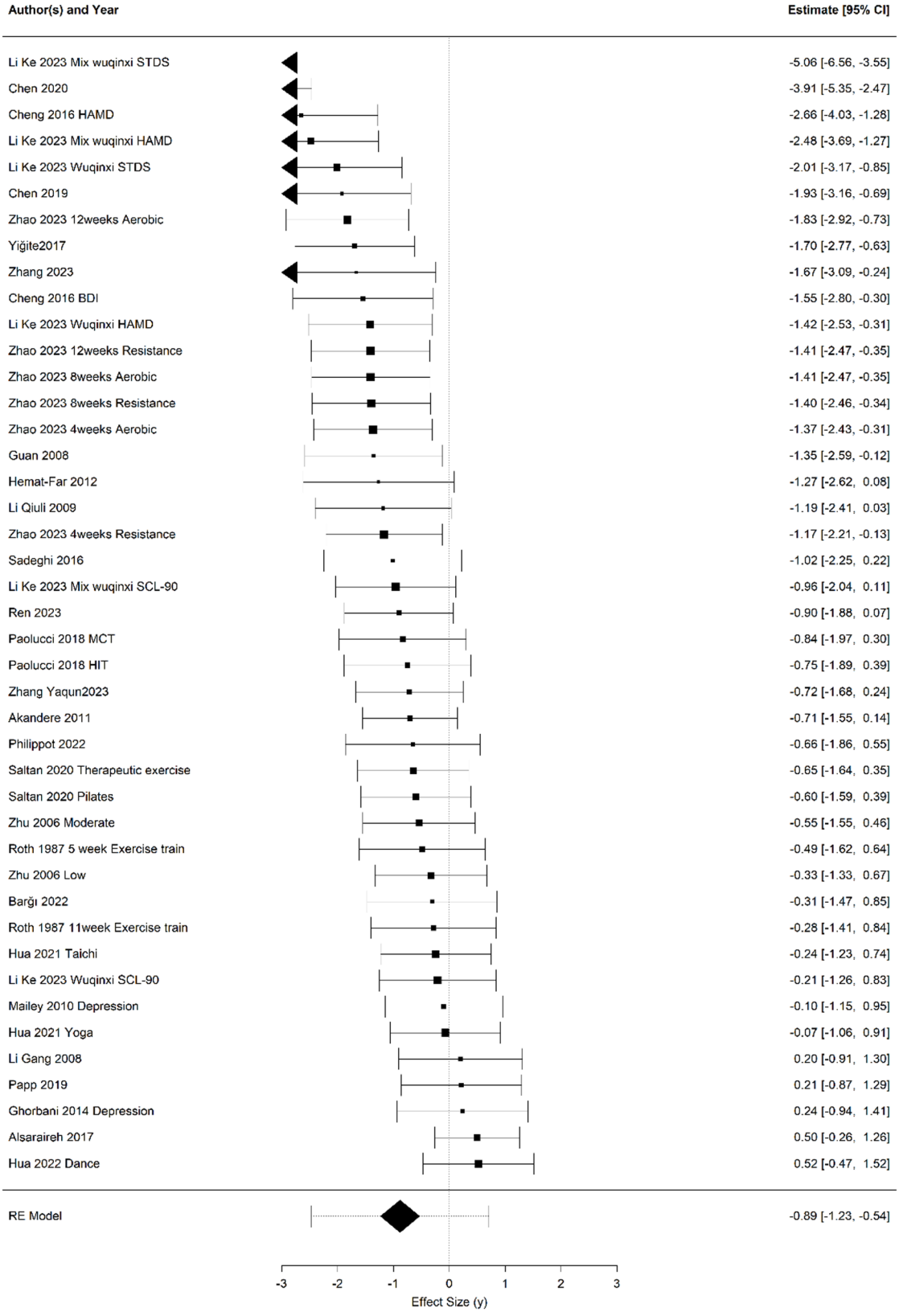

Fig. 6 The Forest Plot of the Effects of Long-Term Exercise on Depression in College Students' Intervention. Note: RE, Random-Effects Model; HIT, High-Intensity Interval Training; MICT, Moderate-Intensity Continuous Training; BDI, Beck Depression Inventory; HAMD, Hamilton Depression Rating Scale; STDS, Subthreshold Depression Scale; SCL-90, Symptom Checklist-90; Low, Low-Intensity Exercise; Moderate, Moderate-Intensity Exercise; Group, Group games; Individuals, Individual games

Table 4 Moderators of the intervention effect of Long-term exercise on depression in college students

Moderator	B: k,g(95%CI)	A: k,g(95%CI)	A: Test of Moderators
Exercise type			F (3, 39) = 1.42, $p = 0.253$
Aerobic exercise	11, -0.97(-6.46,4.58),0.733	11, -0.90(-1.54, -0.27),0.007	
Resistance exercise	4, -0.74(-6.36,4.89),0.792	4, -1.07(-2.09, -0.06),0.039	
Mind-body exercise	18, -3.26(-6.91,0.39),0.079	17, -1.23(-1.77,-0.70),<0.001	
Multi-component exercise	11, -2.71(-6.38, -0.96),0.144	11, -0.49(-1.05,0.0.07),0.084	
Exercise time			F (2, 40) = 0.71, $p = 0.498$
<60 min	27, -4.07(-8.46,0.33),0.069	26,-1.09(-1.57,-0.61),<0.001	
≥ 60 min	13, -0.85(-5.63,3.92),0.720	13, -0.69(-1.25, -0.13),0.016	
Unclear	4, -0.69(-9.83,8.44),0.879	4, -0.66(-1.68,0.36),0.200	
Exercise cycle			F (1, 41) = 1.78, $p = 0.189$
<8 weeks	10, -2.40(-5.51,0.71),0.127	9, -0.53(-1.17,0.12),0.108	
≥ 8 weeks	34, -2.37(-5.36,0.63),0.118	34,-0.99(-1.36,-0.61),<0.001	
Exercise frequency			F (1, 41) = 0.01, $p = 0.919$
<3 days a week	7, -9.03(-15.50, -2.57),0.007	6, -0.84(-1.77,0.08),0.074	
≥ 3 days a week	37, -0.87(-3.93, 2.19),0.569	37, -0.89(-1.28,-0.51),<0.001	
Questionnaire type			F (6, 36) = 2.28, $p = 0.058$
BDI	13, -2.31(-6.27,1.64)0.243	13, -0.73(-1.38,-0.09)0.026	
CES-D	5, -1.57(-8.67,5.52)0.656	5, -1.42(-2.38,-0.45)0.005	
DASS-21	4, -0.30(-11.51,10.91)0.958	4, -0.24(-1.66,1.18)0.730	
HAMD	3, -3.63(-7.65,0.39)0.075	3, -1.15(-2.19,-0.11)0.021	
SCL-90	5, -2.34(-6.43,1.74)0.253	5, 0.17(-0.77,1.11)0.721	
SDS	8, -1.33(-10.49,7.82)0.770	8, -1.32(-2.49,-0.14)0.029	
Other	6, -4.99(-9.08,-0.91)0.018	5, -1.28(-2.20,-0.36)0.008	

Note: B for Before the outliers are removed. A for After excluding outliers. BDI for Beck Depression Scale. DASS-21 for The Depression, Anxiety, and Stress scales-21 Items. SCL-90 for the symptom checklist-90. CES-D for Center for epidemiological survey, depression scale. SDS for self-rating depression scale. HAMD for Hamilton Depression Scale

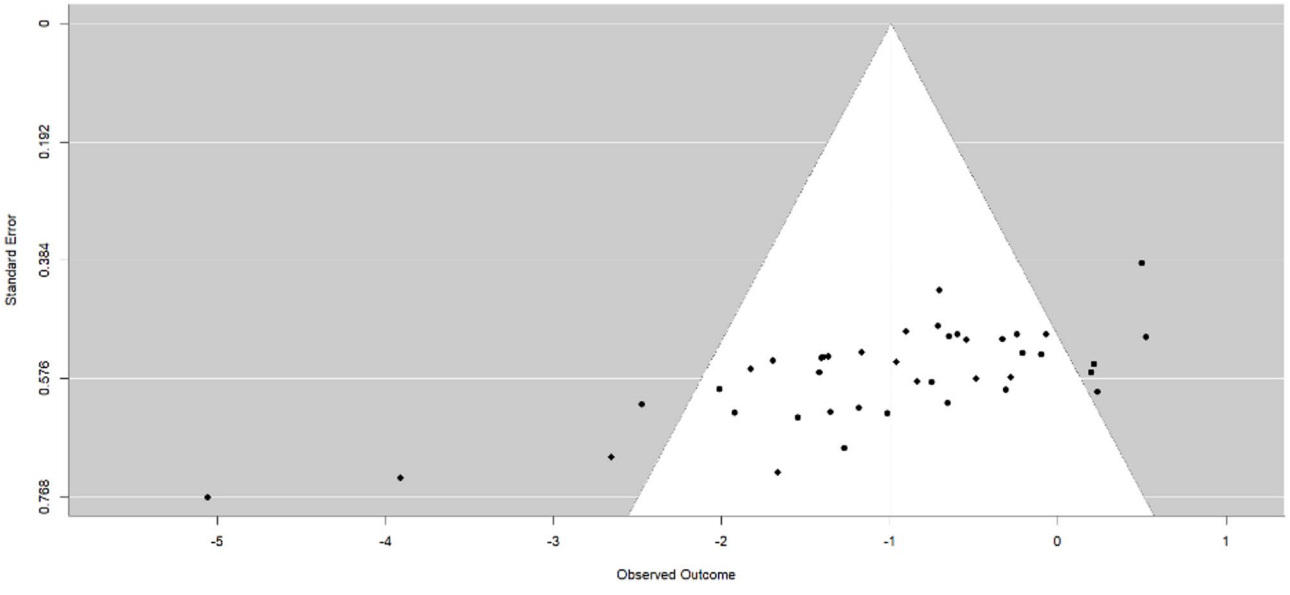

Fig. 7 The Funnel Plot of the Effects of Long-Term Exercise on Depression in College Students' Intervention

of exercise in alleviating depression and anxiety in college students is not limited to a specific type of exercise, but rather involves a comprehensive intervention through various forms of physical activity to promote mental health. Moreover, some studies indicate that moderate-intensity exercise is more effective than high-intensity exercise in alleviating anxiety, particularly in college student populations [64]. Research has shown that exercise may intervene in depression and anxiety through multiple biological and psychological mechanisms. First, the mechanisms of depression are often closely related to neurotransmitters (such as serotonin and dopamine) and endocrine responses (such as cortisol levels). Studies have found that aerobic exercise can improve depressive symptoms by increasing serotonin and dopamine levels, while also enhancing the functionality of brain regions such as the prefrontal cortex and hippocampus [65]. In contrast, anxiety is more strongly associated with the autonomic nervous system, sympathetic nervous activity, and stress response systems (such as the HPA axis). Exercise, especially aerobic exercise and yoga, can regulate anxiety symptoms by reducing sympathetic nervous activity and enhancing parasympathetic nervous function [66]. Additionally, exercise helps alleviate anxiety by improving emotional regulation and enhancing psychological resilience.

This study also found that exercise type, exercise cycle, exercise frequency, exercise time, and questionnaire type are not significant moderators of depression and anxiety in college students. However, Huang et al. suggested that the high heterogeneity in exercise interventions for college students' mental health may stem from exercise prescription elements (such as exercise type, exercise cycle, session duration, frequency, and intensity) [16]. They also proposed that the varying results of exercise interventions on depression and anxiety in college students might be attributed to differences in these exercise elements. Our study reached similar conclusions. In terms of exercise type, mixed exercise improved anxiety in college students, while aerobic exercise, resistance training, and mind-body exercise improved depression. Regarding exercise time, both <60 min and ≥ 60 min of exercise were effective in reducing depression and anxiety. In terms of exercise frequency, long-term exercise of <3 days a week and ≥ 3 days a week improved anxiety, but only ≥ 3 days a week improved depression. For the exercise cycle, long-term exercise lasting ≥ 8 weeks improved both depression and anxiety in college students. However, Li et al. indicated that other forms of mixed exercise, such as ball sports and dance, could also improve depression in college students [18]. Furthermore, studies have also investigated the effects of resistance training on anxiety, with results indicating that resistance training can alleviate anxiety, independent of factors such as intensity and duration [67]. The difference in results may be due to this study coding ball sports, dance, and similar activities as multi-component exercises. After reviewing previous research, this study did not find any systematic reviews discussing the impact of exercise cycle, duration, and frequency on exercise interventions for depression and anxiety in college students. The findings of this study provide new insights into the development of exercise guidelines for addressing depression and anxiety in college students, suggesting that not all exercise doses are effective in improving these mental health issues. Exercise interventions should be designed based on the specific psychological problem (depression or anxiety) to be addressed, as the study indicates that a minimum exercise cycle of eight weeks is necessary to improve both depression and anxiety in college students. Due to the lack of reporting on exercise intensity in some included studies, we were unable to incorporate exercise intensity as a moderator in the subgroup analyses. However, among studies that did report this information, the majority of interventions involved moderate (e.g., 60–75% of maximum heart rate [HRmax]) or moderate-to-vigorous intensity (e.g., 50–90% of heart rate reserve [HRR]), which aligns with the recommendations of the American College of Sports Medicine (ACSM). To improve comparability and interpretation across studies, future research should clearly report exercise intensity, preferably using standardized metrics such as metabolic equivalents (METs), HRmax, or HRR. Moreover, although questionnaire type is not a moderator, future research should aim to standardize the use of more objective and unified assessment tools to minimize heterogeneity.

This study has several advantages. First, it is the first to apply a three-level meta-analysis to explore the effects of long-term exercise on depression and anxiety in college students, thereby avoiding the omission of ES related to depression and anxiety and enhancing statistical power. Second, it is the first to comprehensively examine the moderating effects of exercise prescription elements (such as exercise type, exercise cycle, session duration, and exercise frequency) on depression and anxiety in college students, providing new insights for the development of future exercise interventions for improving depression and anxiety in this population. This study also investigated the impact of outliers, and after removing them, conducted ES aggregation, moderator analysis, heterogeneity testing, and publication bias assessment, along with predicting 95% CI. The research design is more rigorous, and the results are more reliable.

This study has several limitations that need to be acknowledged. First, the literature reviewed was limited to studies published in Chinese and English, which may introduce language bias. Additionally, the majority of the included studies were conducted in China and

other Asian countries, with relatively few from Europe and North America. This geographical imbalance could lead to reporting bias and may limit the generalizability of the findings on a global scale. Second, while moderating factors were explored, the coding of these factors was not sufficiently detailed. For example, activities such as dance and ball sports were grouped under "mixed exercise," which may not accurately capture their unique effects. This categorization might explain some of the discrepancies between our results and those of previous studies. Another important limitation is the exclusion of unpublished studies, often referred to as gray literature. The failure to incorporate gray literature may have introduced publication bias, as studies with null or negative results are less likely to be published. This could potentially skew the findings and affect the robustness of the conclusions. Finally, a significant limitation is the lack of detailed reporting on exercise dosage, including factors such as intensity and cumulative exercise time. Most studies did not provide sufficient information on these aspects, preventing us from exploring exercise dosage as a potential moderating factor. This oversight could have influenced the results and warrants further attention in future research.

Future research should consider including publications in additional languages, adopting diverse research designs, and incorporating more studies from European and North American regions. This would allow for a more comprehensive evaluation of the effects of long-term exercise interventions on depression and anxiety among college students and enhance the global representativeness of the findings. Furthermore, more detailed classifications of exercise type, exercise cycle, exercise duration, and exercise frequency should be made to further explore the influence of exercise components. In addition, future research should adopt larger sample sizes and more rigorous methods to investigate the intervention effects of long-term exercise on depression and anxiety in college students.

Conclusions

Long-term exercise can improve depression and anxiety in college students. Based on the findings of this study, we recommended that college students incorporate regular exercise as part of their mental health management strategies. Future research should employ more rigorous methodologies and explore the intervention effects of different exercise components on depression and anxiety in college students.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s40359-025-03009-z.

Supplementary Material 1

Supplementary Material 2

Acknowledgements
None.

Author contributions
J L wrote the manuscript. J L, L Z, and F Y extracted data, analyzed data, and produced pictures. F Y constructed the framework of the study and revised the manuscript.

Funding
Study on the living inheritance mechanism and path of sports intangible cultural heritage in Shandong along the Yellow River from the perspective of rural revitalization(23CWYJ27).

Data availability
The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
This article does not contain any studies with human participants or animals performed by any of the authors.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Received: 10 February 2025 / Accepted: 10 June 2025
Published online: 01 July 2025

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