Systematic Umbrella Review and Meta-Meta-Analysis: Effectiveness of Physical Activity in Improving Depression and Anxiety in Children and Adolescents

Ben Singh[a,*], PhD, Hunter Bennett[a], PhD, Aaron Miatke[a], BAppSci,
Dorothea Dumuid[a], PhD, Rachel Curtis[a], PhD, Ty Ferguson[a], PhD, Jacinta Brinsley[a], PhD,
Kimberley Szeto[a], BClinExPhys, Emily Eglitis[a], BPhty, Mason Zhou[a], MS,
Catherine E.M. Simpson[a], B Physio, MRes, Jasmine M. Petersen[b], PhD, Joseph Firth[c,d], PhD,
Carol A. Maher[a], PhD

Objective: Depression and anxiety are prevalent and rising in children and adolescents, prompting interest in exercise as a potential therapeutic intervention. The aim of this systematic umbrella review and meta-meta-analysis (a meta-analysis of meta-analyses) was to evaluate the effects of exercise on depression and anxiety symptoms in children and adolescents and to identify the most promising exercise-based approaches.

Method: This systematic umbrella review was preregistered (PROSPERO ID: CRD42024533558) and followed Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) and Preferred Reporting Items for Overviews of Reviews (PRIOR) guidelines. A search of 11 databases identified systematic reviews and meta-analyses of randomized controlled trials (RCTs) evaluating the effects of exercise (aerobic, resistance, mind–body exercise) on depression and anxiety symptoms in children and adolescents. Risk of bias was assessed using the A MeaSurement Tool to Assess systematic Reviews (AMSTAR-2) tool, and certainty of evidence was assessed using the Grading of Recommendations Assessment, Development and Evaluation (GRADE) tool. Meta-analyses were conducted to combine effect sizes, using random effects models. Subgroup analyses were performed to examine participant and intervention characteristics.

Results: A total of 21 systematic reviews (n = 375 RCTs, n = 38,117 participants 5-18 years of age) were included. Participants included those with various clinical conditions, including depression, psychosocial disorders, obesity, and cancer, as well as healthy individuals. The pooled analysis found moderate effect sizes favoring exercise for symptoms of depression (standardized mean difference [SMD] = −0.45, 95% CI = −0.59 to −0.31, I^2 = 71.37%, $p < .01$, 180 RCTs, n = 34,490 participants) and anxiety (SMD = −0.39, 95% CI = −0.61 to −0.17, I^2 = 68.1%, $p < .01$, n = 55 RCTs, n = 24,797 participants). Mixed exercise modes and moderate-intensity exercise had the largest effects on depression, whereas resistance exercise was most effective for symptoms of anxiety. Interventions that were <12 weeks were more effective for depression compared with those that were ≥12 weeks. Benefits were generally consistent across populations. The certainty of evidence was moderate for depression and low to moderate for anxiety.

Conclusion: This meta-meta-analysis finds that exercise reduces depression and anxiety symptoms in children and adolescents. These results suggest that structured exercise programs should be considered as part of comprehensive care approaches.

Plain language summary: This study reviewed evidence from 21 review articles, consisting of 375 randomized controlled trials involving over 38,000 children and adolescents, to examine the effects of exercise on symptoms of anxiety and depression. Results show that exercise significantly reduces symptoms of depression and anxiety, with moderate-intensity and resistance exercises being particularly effective. Shorter interventions (less than 12 weeks) had greater benefits for depression. These results highlight the potential of structured exercise programs as a valuable tool for improving youth mental health.

Clinical guidance
- Clinicians should consider incorporating structured exercise programs, particularly moderate-intensity and resistance training, as part of a comprehensive approach to managing depression and anxiety in children and adolescents.
- Shorter exercise interventions (<12 weeks) may provide greater benefits for depression and could be a practical starting point for integrating exercise into treatment plans.
- Given the broad effectiveness of exercise across various populations, healthcare providers can recommend physical activity interventions regardless of a child's clinical condition, tailoring programs to individual needs and preferences.

Study registration information: Effectiveness of physical activity in improving depression and anxiety in children and adolescents: a systematic umbrella review; https://www.crd.york.ac.uk/PROSPERO/view/CRD42024533558

Key words: depression; anxiety; exercise; adolescents; meta-analysis

J Am Acad Child Adolesc Psychiatry 2026;65(2):171-186.

Depression and anxiety are among the most prevalent mental health issues affecting children and adolescents worldwide.[1] Depression is characterized by persistent sadness, loss of interest in activities, changes in appetite and sleep patterns, low self-esteem, and feelings of hopelessness or worthlessness.[2] Anxiety disorders involve excessive worry, fear, and avoidance of situations that trigger these feelings, interfering with daily functioning.[2] These symptoms exist on a spectrum, and although a significant number of children receive clinical diagnoses, many more experience subclinical symptoms that also have an impact on their well-being and daily functioning.

The prevalence of depression and anxiety symptoms in youth is concerning. It has been estimated that approximately 25% of children and adolescents (≤18 years of age) have elevated depression symptoms, and 21% have elevated anxiety symptoms worldwide.[1] These figures likely underestimate the actual burden, as many children experience subclinical symptoms that affect their lives, and unreported or untreated cases are not included. Concerningly, the number of children diagnosed has increased exponentially over the last few years. From 2016 to 2020, the percentage of children in the United States ever diagnosed with depression or anxiety rose by 24% and 27%, respectively.[3] Both diagnosed disorders and subclinical symptoms of depression and anxiety are linked to poor educational and psychosocial functioning, increased substance use, and an elevated risk of suicide.[4-8] In addition, childhood-onset depression and anxiety often recur and persist into adulthood, amplifying their long-term disease burden.[9,10]

Addressing these mental health issues during childhood and adolescence is a crucial public health priority. Current evidence-based treatment guidelines recommend cognitive–behavioral therapy (CBT) and selective serotonin reuptake inhibitor (SSRI) antidepressants as first-line interventions for pediatric depression and anxiety.[11-13] Previous meta-analyses have shown that traditional treatments yield modest improvements in depression symptoms in children. Feeney *et al.*[14] reported a small effect size for antidepressants, with a standardized mean difference (SMD) of 0.12, whereas Cuijpers *et al.*[15] found a moderate effect for psychotherapy (SMD = 0.35). However, a significant portion of affected youth, ranging from 40% to 60%, either fail to receive these treatments or experience inadequate benefits from them.[16-19] Furthermore, adherence is often suboptimal because of adverse effects of medications, high costs, and accessibility barriers to psychotherapy.[20-22] These limitations underscore the critical need to explore additional interventions for managing depression and anxiety symptoms in children and adolescents. There is growing interest in cost-effective lifestyle interventions, particularly exercise, as a potential therapeutic approach for mental health symptoms.

The clinical guidance on using lifestyle interventions, such as physical activity, sleep hygiene practices, and a nutritious diet, for mental health conditions differs across nations and professional bodies within them. In the United States, the American Psychological Association clinical recommendations prioritize psychotherapy or pharmacotherapy as the initial treatment approaches for children and adults, considering lifestyle interventions as complementary alternatives only when psychotherapy and medication are deemed ineffective or unacceptable.[23] Conversely, in countries such as Australia, the Royal Australian and New Zealand College of Psychiatrists advocate lifestyle management as the first-line treatment strategy for children and adults, although, in practice, pharmacotherapy is often prescribed first.[24] This discrepancy between research evidence and clinical practice may stem from the vast volume of randomized controlled trials (RCTs) evaluating different forms of exercise, varying dosages, and different population subgroups, and using different comparator groups, which can pose challenges for clinicians in comprehending the overall body of evidence. This information could help refine clinical practice guidelines and inform the development of exercise-based interventions for managing the highly prevalent burden of depression and anxiety symptoms among youth.

Findings from a large umbrella review in adults demonstrated that exercise significantly reduces symptoms of depression (median SMD = −0.43) and anxiety (median SMD = −0.42).[25] Exercise benefits depression and anxiety through both psychological and neurobiological mechanisms. Psychologically, it enhances self-efficacy, provides distraction from negative thoughts, and improves mood via endorphin release.[26] Neurobiologically, exercise increases brain-derived neurotrophic factor, promoting neuroplasticity in mood-regulating regions such as the hippocampus.[27] Exercise also modulates the hypothalamic–pituitary–adrenal axis, reducing cortisol levels and stress responses,[28] and regulates serotonin, dopamine, and norepinephrine systems, which are critical for mood stabilization.[29] These mechanisms highlight exercise as a holistic intervention for mental health. Despite this compelling evidence in adults, there is comparatively less research among children and adolescents, and evidence syntheses to date[30,31] have had methodological limitations restricting the conclusions that can be drawn. For instance, Dale *et al.*[31] performed an umbrella review summarizing evidence from 2010 to 2017, encompassing 26 systematic reviews. Their findings indicated that physical activity reduced depression in 71% of the included reviews, and reduced anxiety symptoms. However, the absence of pooled analyses and the limited number of reviews on anxiety (only 2) led the authors to classify their overall findings as unclear.[31] Similarly, Purgato *et al.*[30] examined 18 meta-analyses from between 2010 and 2022, concluding that physical activity generally reduces

"psychological symptoms." However, this broad categorization encompassed various mental health outcomes (depression, anxiety, and emotional-related issues) making it challenging to discern specific effects on distinct mental health domains. Furthermore, their analysis combined various exercise types and populations without performing subgroup analyses to account for variations in exercise modes, intervention durations and intensities, and population characteristics. Furthermore, findings are often inconsistent because of variability in exercise types, intervention characteristics, and population subgroups evaluated, making it difficult for stakeholders to draw actionable conclusions.

The evidence base in this field is rapidly expanding, with an ever-increasing number of RCTs providing the highest level of experimental evidence. We set out to conduct the most comprehensive and rigorous umbrella review, incorporating a comprehensive quantitative synthesis. Thus, this systematic umbrella review and meta-meta-analysis aims to systematically evaluate all existing systematic reviews and to provide a comprehensive overview of the evidence on the effects of exercise on symptoms of depression and anxiety in children and adolescents. In addition, this review will examine these effects across diverse populations and exercise characteristics.

METHOD

Protocol and Registration
This review is reported in accordance with Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)[32] and Preferred Reporting Items for Overviews of Reviews (PRIOR)[33] guidelines. The protocol was pre-registered on PROSPERO (ID: CRD42024533558).

Selection Criteria and Search Strategy
The eligibility criteria were developed using the Participant, Intervention, Comparator, Outcome, Study type (PICOS) framework: The population comprised children and adolescents under 18 years of age, with or without medical conditions, including those currently on medications. Reviews including adults were eligible if over 75%[25] of the included RCTs focused on children or adolescents, or if separate meta-analysis results for children or adolescents were reported. For the intervention, reviews evaluating exercise interventions were eligible. The following definition of exercise was used: "is a type of physical activity consisting of planned, structured, and repetitive bodily movement done to improve and/or maintain one or more components of physical fitness."[34] Reviews were included if ≥75%[25] of the trials evaluated exercise interventions, such as aerobic training, resistance training, team sports, yoga, dance, tai chi, or exergames, without

combining with other interventions. Exercise reviews were considered regardless of mode, supervision, delivery, or dose. Reviews with >25% acute RCTs (single bouts of exercise) were excluded. In regard to the comparator, reviews were eligible if ≥75%[25] of the trials compared exercise to no intervention (eg, waitlist), usual care, a sham intervention, an equal-attention nonexercise intervention (ie, a level of attention and interaction similar to that of the exercise intervention, but without involving any physical activity), or a lesser exercise intervention (eg, exercise vs. stretching). Outcomes included any assessment of depression or anxiety. With regard to study type, systematic reviews with meta-analyses were eligible if >75% of the trials were RCTs or involved meta-analyses of RCTs only.

Comprehensive searches were conducted across 11 databases including CINAHL, The Cochrane Library, Embase, MEDLINE, Emcare, ProQuest Central, ProQuest Nursing and Allied Health Source, PsycINFO, Scopus, Sport Discus, and Web of Science. The searches used subject headings, keywords, and Medical Subject Headings (MeSH) terms related to "systematic review," "meta-analysis," "depression," "anxiety," and "exercise" (Table S1 provides the full search strategy). Searches were limited to peer-reviewed journal articles published in the English language up to April 8, 2024.

Data Management and Extraction
Search results were imported into EndNote (Version 20, Clarivate, Philadelphia, PA), and duplicates were removed. Results were then exported to Covidence (Veritas Health Innovation, Melbourne, Australia), and title/abstract screening, full-text screening, data extraction, and risk of bias scoring were performed. Reference lists of eligible reviews were also screened for potentially eligible review articles. All screening was completed in duplicate by 2 reviewers (BS, HB, AM, DD, RC, TF, JB, KS, EE, MZ, CEMS, and JMP), and discrepancies were resolved by a third reviewer.

Data extraction and risk of bias assessments were completed in duplicate by 2 reviewers (BS, HB, AM, DD, RC, TF, JB, KS, EE, MZ, CEMS, and JMP), and discrepancies were resolved by a third reviewer. A standardized Covidence data extraction form was used to extract information on study characteristics, population characteristics, intervention characteristics, outcomes of interest, and results. Risk of bias of the included reviews was evaluated in duplicate by 2 reviewers using the A MeaSurement Tool to Assess systematic Reviews (AMSTAR-2) tool.[35] This tool involves 16 items that are scored as "yes," "partial yes," or "no." Of the AMSTAR-2 items, 7 are considered "critical" and 9 items "noncritical."[35] The "critical" items include protocol registration, search strategy, study exclusions, risk of bias assessment, meta-analysis methods, risk of bias interpretation, and publication

bias. The noncritical items include duplicate study selection and data extraction, comprehensive literature searching, justification for excluded studies, details of included studies, appropriate statistical methods, assessment of heterogeneity, consideration of study funding sources, and conflict of interest assessment. Reviews were scored as follows: "critically low confidence" (>1 critical weakness and ≥3 noncritical weaknesses); "low confidence" (>1 critical weakness and <3 noncritical weaknesses); "moderate confidence" (1 critical weakness and <3 noncritical weaknesses); or "high confidence" (no critical weakness and <3 noncritical weaknesses).[35]

Umbrella Review Synthesis Methods

The degree of overlap of the trials that were included in each systematic review and meta-analysis was assessed using the Corrected Covered Area (CCA) method.[36] A CCA score of 0% indicates that every included review consisted of entirely unique trials, and 100% indicates that every review consists of entirely the same trials. CCA was quantified as follows: 0% to 5%, "slight" overlap; 6% to 10%, "moderate" overlap; 11% to 15%, "high" overlap; and >15%, "very high" overlap.[37] If overlap was >15%, recommended methods to reduce overlap[36] were undertaken before proceeding to meta-meta-analysis.

To synthesize the findings on symptoms of depression and anxiety, meta-analyses were performed by combining the effect sizes, 95% confidence intervals, and sample sizes reported in each review, using a random effects model. Standardized effect sizes (ie, SMDs) with 95% CIs were used as the effect measure for the meta-analyses. For subgroup analyses, we extracted subgroup-specific effect sizes and corresponding data (eg, CIs and *p* values) as reported in the included systematic reviews, and pooled these results across reviews. The following subgroup analyses were performed: (1) age group (≤12 years, >12 years); (2) population (general population, diagnosis of depression, attention-deficit/hyperactivity disorder [ADHD], clinical condition, or chronic disease status); (3) exercise mode (aerobic, resistance, mixed mode, mind–body [yoga and tai chi], dance, exergames, other); (4) exercise intensity (low, moderate, moderate-to-vigorous, vigorous); (5) intervention length (1-3 months, 4-6 months, >6 months); (6) session frequency (1-2/wk, 3-5/wk, 6-7/wk); (7) session duration (<30 minutes, 30-60 minutes, >60 minutes); and (8) risk of bias score (critically low, low, moderate confidence). For each meta-analysis, the proportion of the overall outcome that was attributed to variability was quantified using the I^2 statistic.[38] The following cutoffs were used to assess heterogeneity: 0% to 29%, low; 30% to 49%, moderate; 50% to 74%, substantial; and 75% to 100%, considerable.[39] The magnitude of the effect sizes were categorized as follows: <0.20, small effect; 0.20 to 0.50, medium effect; and >0.50, large effect.[40] Statistical

significance was determined using a *p* value threshold of .05. To evaluate potential publication bias, funnel plots were generated and examined for asymmetries or gaps indicating missing reviews for each meta-analysis. In addition, trim-and-fill analyses were conducted on meta-analyses containing at least 10 reviews to account for potential unpublished research.[41] In addition, we calculated the corrected true effect size (theta [θ]) using the trim-and-fill method to provide an adjusted estimate that accounts for potentially missing reviews due to publication bias. This corrected estimate (θ) represents the effect size after adjusting for publication bias, providing a more conservative and potentially more accurate estimate of the true effect. All meta-analyses were performed using Stata/MP (v16, Stata Corp, College Station, TX).
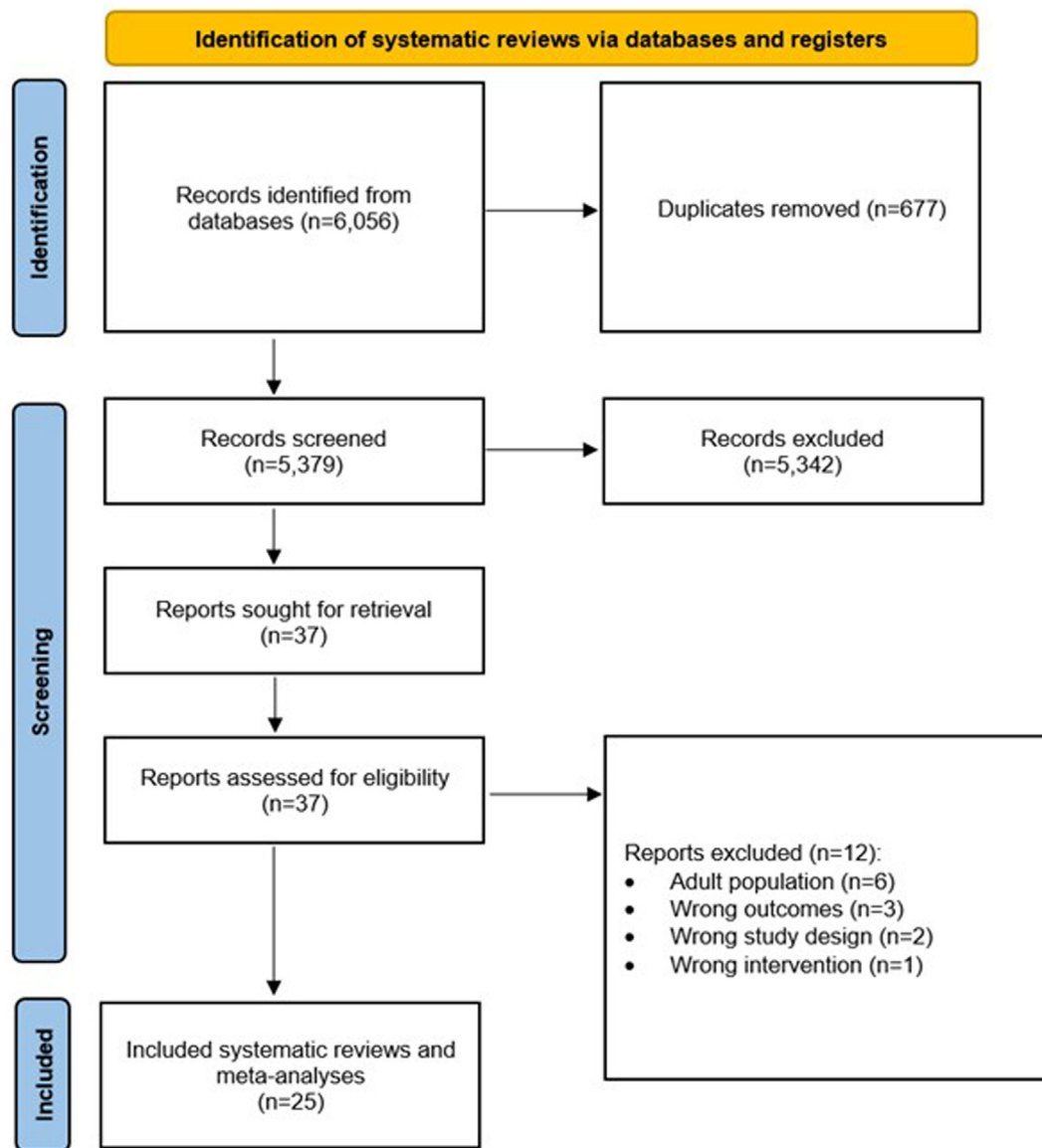
The certainty of evidence was assessed using the Grading of Recommendations, Assessment, Development, and Evaluations (GRADE) approach.[42] Five domains were considered: risk of bias, inconsistency, indirectness, imprecision, and publication bias. Each outcome (depression and anxiety symptoms) was assigned a certainty rating of high, moderate, low, or very low, based on these criteria.

Changes to Preregistered Protocol

After conducting the database search, we modified our inclusion criteria to enhance comprehensiveness while maintaining methodological rigor. We included reviews in which at least 75% of included RCTs focused solely on exercise, allowing reviews with a small proportion (<25%) of included RCTs that combined exercise with other interventions to remain eligible. To ensure robustness, we conducted sensitivity analyses excluding all reviews with combined interventions, analyzing only those with 100% exercise-only RCTs. Sensitivity analyses were also conducted by excluding reviews with large effects based on visual inspection, to ensure that the results were not influenced by outliers. Furthermore, because of insufficient data, it was not possible to use the ≥12 weeks and <12 weeks groupings for the anxiety intervention duration subgroup analysis. As a result, we used >8 weeks and ≤8 weeks as the cutoff for this analysis.

RESULTS

After the database search, 7,614 search results were identified. Of those, 21 systematic reviews and meta-analyses met the eligibility criteria and were included. The PRISMA flowchart, including reasons for exclusions, is shown in Figure 1. A list of the reasons for exclusion after the full-text review can be found in Table S2. The 21 included reviews comprised 375 RCTs and a total of 38,117 participants. The overall CCA was 4.1% for depression (slight overlap) and 8.8% for anxiety (moderate overlap).

FIGURE 1 PRISMA Flow Chart

A summary of the participant demographics, such as ages and population groups as well as characteristics of the exercise interventions, is provided in Table 1.[43-63] Mean participant age in most reviews (n = 16, 76%) ranged between 5 and 18 years, and all reviews (n = 21, 100%) included both female and male participants. The samples involved children or adolescents with depression or depressive symptoms (n = 6[44,45,54,56,60,62]), healthy/general population (ie, not diagnosed with any health or medical conditions, including no mental health conditions, n = 7[43,47,48,51,53,57,63]), ADHD (n = 3[49,58,59]), various psychosocial disorders or neurodevelopmental disorders (n = 2[46,52]), obesity (n = 1[50]), cancer (n = 1[61]), or a mix of various clinical conditions (n = 1[55]). All systematic reviews

and meta-analyses examined a mix of various exercise modes, except for one that specifically focused on aerobic exercise[52]) (Table 1). The included reviews had a moderate (n = 4[44,51,53,61]), low (n = 14[43,45-47,50,52,54-60,62]), or critically low (n = 3[39,49,63]) AMSTAR-2 score (Table S3). Common limitations included not describing the funding sources of the included reviews (n = 21) and not providing a list of full-text exclusions (n = 17).

Meta-Analyses Results: Depression

Pooled analysis of 20 meta-analyses (180 RCTs, n = 34,490 participants) using SMD showed a significant effect of exercise for improving symptoms of depression in children and adolescents (SMD = −0.45, 95% CI = −0.59

TABLE 1 Overview of All Included Systematic Reviews and Meta-Analyses

First author, year, reference	No. of studies	Total sample	Population or condition Sex Age, y, mean (SD) or range	Exercise mode, intensity, and intervention duration	Outcomes of interest
Andermo 2020[43]	31	16,089	School children Female and male participants Age range: 6-19	Type: mixed mode; school-based interventions to increase PA or reduce sedentary behavior (including active breaks, policies, and environmental changes promoting PA) Intensity: low to vigorous Duration: 4 wk to 1 y Frequency: 15-45 min, 2-5 times/wk	Depression Anxiety
Axelsdóttir 2021[44]	4	159	Children and adolescents with depression Female and male participants Age range: 14-18	Type: mixed mode; circuit training, pool walking, walking, running, resistance training Intensity: low to moderate Duration: 6-9 wk Frequency: 20-45 min, 2-4 times/wk	Depression
Bailey 2018[45]	17	771	Adolescents and/or young with depression Female and male participants Mean age range: 15.4-25.8	Type: mixed mode; stationary cycling, circuit and strength training, treadmill, dance, walking, jogging, soccer, volleyball, swimming, football, athletics, yoga Intensity: low to vigorous Duration: 6-15 wk Frequency: 30-75 min, 1-5 times/wk	Depression
Barahona-Fuentes 2021[46]	9	768	Adolescents with psychosocial disorders Female and male participants Mean age range: 11.0-17.9	Type: mixed mode; aerobic, HIIT, Cross Fit, resistance exercise, Pilates, treadmill, stationary cycling, ergometer Intensity: low to high Duration: 4-22 wk Frequency: 20-60 min, 1-5 times/wk	Depression Anxiety
Brown 2013[47]	9	581	Children and adolescents Female and male participants Age range: 5-19	Type: mixed mode; aerobic, physical education classes, yoga, sports Intensity: low to vigorous Duration: 9-40 wk Frequency: 20-90 min, 2-5 times/wk	Depression
Carter 2016[48]	11	1449	Adolescents Female and male participants Mean age range: 13.7-17	Type: mixed mode; aerobic, running, sports, circuit training, treadmill, stationary bike, dance, yoga, Frisbee, kickball, pool exercises Intensity: low to vigorous Duration: 6-40 wk Frequency: 15-90 min, 2-4 times/wk	Depression

(continued)

TABLE 1 Continued

First author, year, reference	No. of studies	Total sample	Population or condition / Sex / Age, y, mean (SD) or range	Exercise mode, intensity, and intervention duration	Outcomes of interest
Cerrillo-Urbina 2015[49]	8	249	Children with ADHD Female and male participants Mean age range: 8.4-15.8	Type: mixed mode; treadmill, running, sports, yoga Intensity: low to moderate Duration: 1-20 wk Frequency: 20-90 min, 1-5 times/wk	Anxiety
Chen 2024[50]	25	2188	Children and adolescents with obesity Female and male participants Mean age range: 8.3-18.44	Type: mixed mode; aerobic exercise, walking, ergometer, rowing, dance, strength training, soccer, sports Intensity: low to vigorous Duration: 4-32 wk Frequency: 20-135 min, 1-5 times/wk	Depression Anxiety
Larun 2006[51]	16	1191	Children and young people Female and male participants Age range: 11-19	Type: mixed mode; aerobic exercise, walking, running, strength training Intensity: low to vigorous Duration: 6-40 wk Frequency: 20-70 min, 1-5 times/wk	Depression Anxiety
Liu 2024[52]	76	3007	Children and adolescents with neurodevelopmental disorders Female and male participants Age range: 5-17	Type: aerobic exercise Intensity: low to vigorous Duration: 2-52 weeks Frequency: 5-90 min, 1-7 times/wk	Depression Anxiety
Neill 2020[53]	13	1928	Adolescents Female and male participants Age range: 10-18	Type: mixed mode; aerobic exercise, walking, cycling, rowing, yoga, running, dance, stepping, circuit training, resistance training, sports Intensity: low to vigorous Duration: 4-22 wk Frequency: 15-120 min, 1-5 times/wk	Depression Anxiety
Oberste 2020[54]	10	491	Adolescents with depression Female and male participants Age range: 12-18	Type: mixed mode; aerobic exercise, walking, running, softball, resistance training, circuit interval training, cycle ergometer, dance, swimming, track and field, football Intensity: low to vigorous Duration: 6-12 wk Frequency: 20-90 min, 2-4 times/wk	Depression
Peng 2022[55]	31	1255	Children and adolescents with neurodevelopment disorders, depression, or obesity Female and male participants Mean age range: 6.9-16.9	Type: mixed mode; various aerobic exercise, running, team sports, pool exercise, walking, resistance exercise, yoga Intensity: low to vigorous Duration: 6-78 wk Frequency: 15-90 min, 1-5 times/wk	Depression

TABLE 1 Continued

First author, year, reference	No. of studies	Total sample	Population or condition Sex Age, y, mean (SD) or range	Exercise mode, intensity, and intervention duration	Outcomes of interest
Radovic 2017[56]	8	297	Adolescents with depressive symptoms Female and male participants Mean age range: 15.9-17	Type: mixed mode; aerobic and resistance exercises Intensity: low to vigorous Duration: 4-20 wk Frequency: 20-90 min, 2-5 times/wk	Depression
Recchia 2023[57]	21	2441	Children and adolescents Female and male participants Mean age range: 8.1-18.9	Type: aerobic exercise; sports, dance, soccer, basketball, track practice and volleyball, stepping, cycling, rowing, dance mat, and walking, treadmill, elliptical machine, cycle ergometer, Wii Sports, ergometer Intensity: low to vigorous Duration: 6-144 wk Frequency: 20-150 min, 2-5 times/wk	Depression
Sun 2024[58]	18	627	Children and adolescents with ADHD Female and male participants Age range: 6-14	Type: mixed mode; aerobic, treadmill, resistance exercises, jump rope, HIIT, water aerobics Intensity: low to vigorous Duration: 3-12 wk Frequency: 30-90 min, 2-3 times/wk	Depression Anxiety
Sun 2022[59]	15	734	Children with ADHD Female and male participants Mean age range: 8-14.5	Type: mixed mode; aerobic, resistance exercise, water aerobics, yoga, Taekwondo, table tennis, horseback riding, sports, orienteering Intensity: low to vigorous Duration: 5 wk-1.5 y Frequency: 25-90 min, 1-5 times/wk	Depression
Wang 2022[60]	15	1331	Adolescents with depression Female and male participants Mean age: 15.9	Type: mixed mode; aerobic, resistance exercise, yoga, jogging, water exercise, dance, cycling, whole-body muscle vibration training Intensity: low to vigorous Duration: 6-40 wk Frequency: 30-120 min, 2-4 times/wk	Depression
Zang 2023[61]	9	371	Children with paediatric cancer Female and male participants Mean age range: 7.6-13.4	Type: mixed mode; aerobic, resistance exercise, jogging, cycle ergometer, sports Intensity: low to vigorous Duration: 6-26 wk Frequency: 15-60 min, 2-5 times/wk	Depression

TABLE 1 Continued

First author, year, reference	No. of studies	Total sample	Population or condition / Sex / Age, y, mean (SD) or range	Exercise mode, intensity, and intervention duration	Outcomes of interest
Zhang 2022[62]	13	433	Adolescents with depression / Female and male participants / Mean age: 10-18	Type: mixed mode; aerobic, resistance, sports, yoga / Intensity: Low to vigorous / Duration: 6-18 wk / Frequency: 20-60 min, 2-4 times/wk	Depression
Zhang 2022[63]	16	1757	Students / Female and male participants / Mean age range: 10.7-21.4	Type: mixed mode; aerobic, sports, tai chi, jogging, cycling, physical education classes, yoga, dance, sports / Intensity: low to vigorous / Duration: 5 days-20 wk / Frequency: 15-120 min, 1-14 times/wk	Anxiety

Note: ADHD = attention-deficit/hyperactivity disorder; HIIT = high-intensity interval training; PA = physical activity.

to -0.31, $I^2 = 71.37\%$, $p < .01$) (Figure 2). There were insufficient data to perform meta-analyses using mean differences for individual depression instruments.

The certainty of evidence for exercise improving depression symptoms was rated as moderate (Table S4). Although the effect size was moderate (SMD = -0.45), risk of bias was a concern because of the inclusion of systematic reviews with low or critically low AMSTAR-2 ratings. In addition, publication bias was detected in funnel plot analyses, although the corrected effect size ($\theta = -0.41$) remained similar to the original estimate, suggesting minimal impact.

Anxiety

Pooled results from 8 meta-analyses (n = 55 RCTs, n = 24,797 participants) using SMD showed a significant effect of exercise for improving symptoms of anxiety in children and adolescents (SMD = -0.39, 95% CI = -0.61 to -0.17, $I^2 = 68.1\%$, $p = .01$) (Figure 3). There were insufficient data to perform meta-analyses using mean differences for individual anxiety instruments.

The certainty of evidence for exercise improving anxiety symptoms was rated as low to moderate (Table S4). The observed effect (SMD = -0.39) was statistically significant, but the limited number of meta-analyses and included RCTs, along with moderate heterogeneity ($I^2 = 68.1\%$), contributed to imprecision and inconsistency, lowering confidence in the findings.
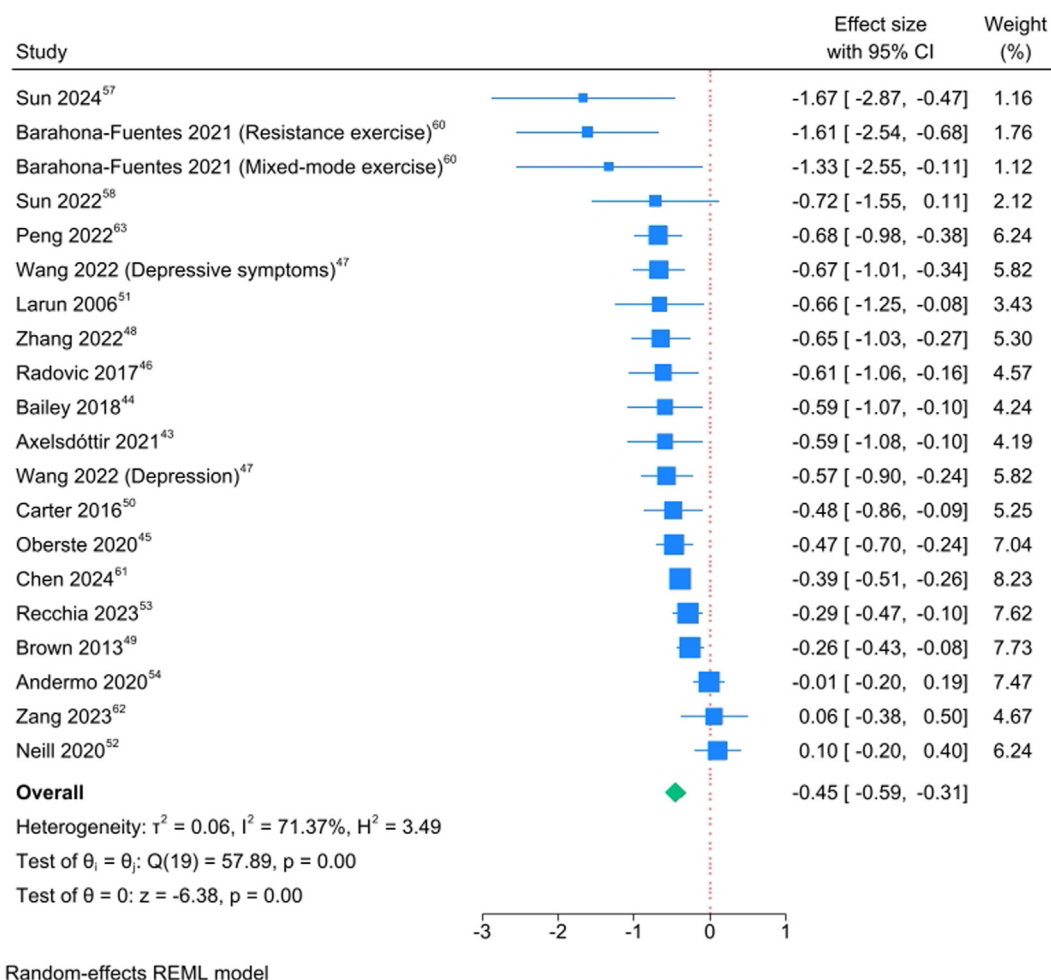
Subgroup Analyses

Results of subgroup analyses for depression and anxiety are shown in Table S5 and Table S6, respectively.

Age Group and Population

Depression. Significant subgroup effects were observed for age and population. Greater effects were observed in studies involving participants >12 years of age (SMD = -0.35, 95% CI = -0.19 to 0.06, $I^2 = 0\%$) compared with those ≤12 years of age (SMD = -0.06, 95% CI = -0.51 to -0.19, $I^2 = 0\%$; test of subgroup differences: $Q_b(1) = 7.47$, $p = .01$). There was a significant subgroup effect for population (test of subgroup differences: $Q_b(7) = 56.86$, $p < .01$) (Table S5). For children with ADHD, the effect size was SMD = -1.09 (95% CI = -2.00 to -0.18, $I^2 = 38.6\%$), and for those with various mental illnesses, SMD = -1.07 (95% CI = -1.67 to -0.46, $I^2 = 48.7\%$). In the general population, individuals with depression or depressive symptoms, overweight and obesity, and other clinical conditions, the SMD ranged from -0.59 to 0.06.

Anxiety. There were insufficient studies to perform subgroup analyses for age for symptoms of anxiety. There was

FIGURE 2 Meta-Analysis Results for the Effects of Exercise on Depression

Note: REML = restricted maximum likelihood. Please note color figures are available online.

no significant difference between different populations for symptoms of anxiety (test of subgroup differences: $Q_b(2) = 0.49$, $p = .78$) (Table S6).
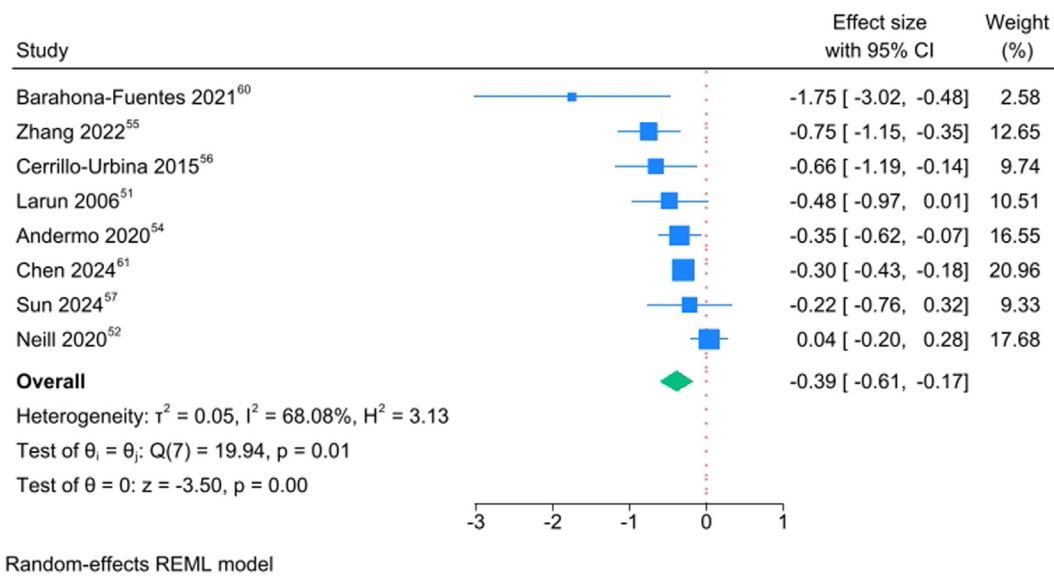
Exercise Mode
Depression. There was a significant subgroup effect of exercise mode on depression (test of subgroup differences: $Q_b(3) = 16.91$, $p < .01$) (Table S5). Among exercise types, mixed-mode training showed the largest effect (SMD = −1.20, 95% CI = −1.76 to −0.65; $I^2 = 0\%$), followed by resistance training (SMD = −1.05, 95% CI = −2.01 to −0.09; $I^2 = 66.9\%$). Aerobic exercise demonstrated a moderate effect (SMD = −0.43, 95% CI = −0.74 to −0.13; $I^2 = 67.9\%$), whereas yoga showed the smallest effect (SMD = −0.12, 95% CI = −0.31 to 0.07; $I^2 = 0\%$).

Anxiety. Resistance exercise had a greater reduction in symptoms of anxiety (SMD = −0.90, 95% CI = −1.52 to −0.27, $I^2 = 0\%$) compared with aerobic exercise (SMD = −0.19, 95% CI = −0.44 to −0.06, $I^2 = 0\%$; test of subgroup differences: $Q_b(1) = 4.27$, $p = .04$) (Table S6).

Exercise Intensity
Depression. Moderate-intensity exercise (SMD = −0.91, 95% CI = −1.56 to −0.26, $I^2 = 78.2\%$) and moderate-to-vigorous physical activity (SMD = −1.06, 95% CI = −1.71 to −0.41, $I^2 = 0\%$) had larger effects compared with low-intensity (SMD = −0.20, 95% CI = −0.41 to 0.01, $I^2 = 0\%$) and high-intensity (SMD = −0.38, 95% CI = −0.71 to −0.05, $I^2 = 87.8\%$; test of subgroup differences: $Q_b(3) = 9.41$, $p = 0.02$) exercise (Table S5).

FIGURE 3 Meta-Analysis Results for the Effects of Exercise on Anxiety

Note: REML = restricted maximum likelihood. Please note color figures are available online.

Anxiety. Low-intensity exercise (SMD = −2.35, 95% CI = −3.86 to −0.84, I^2 = 0%) had the largest effect on symptoms of anxiety (moderate: SMD = −0.45, 95% CI = −0.85 to −0.04, I^2 = 0%; high: SMD = 0.16, 95% CI = −0.31 to 0.63, I^2 = 0%; test of subgroup differences: $Q_b(2)$ = 11.19, $p < .01$) (Table S6).

Intervention Length
Depression. Interventions that were <12 weeks had a greater effect on symptoms of depression (SMD = −0.53, 95% CI = −0.69 to −0.38, I^2 = 26.7%) compared with longer-term interventions (≥12 weeks; SMD = −0.21, 95% CI = −0.33 to −0.09, I^2 = 18.5%; test of subgroup differences: $Q_b(1)$ = 10.24, $p < .01$) (Table S5).

Anxiety. There was no difference in effect between short-term (≤8 weeks) and longer-term (>8 weeks) interventions (test of subgroup differences: $Q_b(1)$ = 2.59, p = 0.11) (Table S6).

Session Frequency
Depression and Anxiety. There was no difference in effect between performing exercise 1 to 3 times/wk compared with >3 times/wk for depression symptoms (test of subgroup differences: $Q_b(1)$ = 2.23, p = .72) (Table S5) or anxiety (test of subgroup differences: $Q_b(1)$ = 1.56, p = 0.21) (Table S6).

Session Duration
Depression and Anxiety. There was no difference in effect between shorter- or longer-duration exercise sessions for symptoms of depression (<60 minutes or ≥60 minutes; test of subgroup differences: $Q_b(1)$ = 0.66, p = .42) (Table S5) or anxiety (≤30 minutes vs >30 minutes; test of subgroup differences: $Q_b(1)$ = 2.27, p = .13) (Table S6).

Intervention Components
Depression and Anxiety. There was no difference in effect between systematic reviews involving RCTs of exercise alone and those involving RCTs of exercise combined with other interventions for depression ($Q_b(1)$ = 0.52, p = .47) and anxiety ($Q_b(1)$ = 0.01, p = .94).

Risk of Bias Score
Depression and Anxiety. There was no difference in effects based on study risk of bias score according to the AMSTAR-2 tool for symptoms of depression ($Q_b(2)$ = 2.50, p = .29) (Table S5) or anxiety ($Q_b(1)$ = 0.96, p = .33) (Table S6).

Sensitivity Analyses and Publication Bias
For depression, removing reviews with an SMD >1.2 resulted in an SMD of −0.44 (95% CI = −0.57 to −0.31, I^2 = 73.1%, p = .01). Similarly, for anxiety, excluding reviews with an SMD >1.2 led to an SMD of −0.35 (95% CI = −0.55 to −0.14, I^2 = 65.9%, p = .01). After excluding reviews that combined exercise with other interventions, the SMDs for exercise-only interventions were −0.52 (95% CI = −0.70 to −0.34, I^2 = 77.58%, $p < .01$) for depression and −0.40 (95% CI = −0.71 to −0.09, I^2 = 69.55, $p < .01$) for anxiety. Visual inspection of the funnel plots for symptoms of depression

(Figure S1) displayed a degree of asymmetry with a gap in the bottom left quadrant, suggesting a lack of smaller reviews reporting negative effect sizes. After accounting for these potentially missing unpublished reviews, the corrected effect size ($\theta = -0.41$) was only slightly smaller than the original estimate (SMD $= -0.45$), suggesting that publication bias had minimal impact on our findings. There was an insufficient number of reviews (<10) to create a funnel plot for anxiety. Taken together, the sensitivity analyses and publication bias assessments corroborate the robustness of moderate beneficial effects of exercise on depression and anxiety symptoms.

DISCUSSION

This systematic umbrella review and meta-meta-analysis aimed to evaluate the effects of exercise on symptoms of depression and anxiety in children and adolescents. The analysis included 21 systematic reviews comprising 375 unique trials with a total of 38,117 participants. The findings provide evidence supporting the therapeutic potential of exercise for improving mental health in this demographic. Specifically, the pooled analysis revealed moderate effect sizes favoring exercise interventions for reducing symptoms of both depression (SMD $= -0.45$) and anxiety (SMD $= -0.39$). Notably, in terms of exercise modality, mixed-mode exercise and resistance training appeared to have the greatest benefits for depression, whereas resistance training showed the largest effect for anxiety. Regarding exercise intensity, moderate-intensity exercise was most effective for depression, whereas lower-intensity exercise demonstrated the greatest impact on anxiety symptoms. Furthermore, shorter intervention durations (<12 weeks) were more beneficial for depression compared to longer interventions.

Our findings align with and expand upon previous research in adult populations, in which exercise has been conclusively shown to alleviate symptoms of depression and anxiety. The effect sizes observed in our analysis were remarkably similar to those reported in adults (SMD $= -0.45$ in children vs -0.43 in adults, and SMD for anxiety $= -0.39$ in children vs -0.42 in adults),[25] underscoring the therapeutic potential of exercise across age groups. Broadly speaking, our findings regarding the beneficial effects of physical activity on youth mental health are consistent with those in previous umbrella reviews; however, our separate meta-analyses for depression and anxiety and our extensive subgroup analyses considerably extend understanding compared with earlier umbrella reviews by Dale *et al.*[31] and Purgato *et al.*[30] Moreover, our findings extend those of a 2022 umbrella review[64] that examined the impact of organized activities (not necessarily exercise-based) on children's mental health, and noted a small positive impact of organized sports on child/adolescent mental health, independent of sport type, but did not conduct pooled analyses. By integrating these analyses, our study provides clearer, more actionable insights for optimizing exercise interventions to improve mental health outcomes in children and adolescents.

Several notable findings emerged from the subgroup analyses that can help guide the development and optimization of exercise interventions for youth mental health. For symptoms of depression, the effects of exercise were more pronounced in adolescents >12 years of age compared to younger children. This aligns with the understanding that adolescents generally have lower baseline physical activity levels than children, potentially providing more room for improvement through increased exercise. The larger effects in adolescents could also reflect greater symptom severity, changes in exercise preferences, or psychological factors such as motivation that may influence intervention engagement and outcomes at different developmental stages. Our findings also highlighted the variability in the effectiveness of exercise-based on the type of population and existing mental health conditions. The most substantial improvements in depressive symptoms were observed in children with ADHD and various mental illnesses, suggesting that exercise might serve as an effective treatment option for these groups. In contrast, the effects of exercise on symptoms of anxiety did not differ significantly across different populations, indicating a more uniform benefit. This distinction suggests that while exercise is broadly beneficial for symptoms of anxiety, more targeted approaches might be necessary to optimize the effects on depressive symptoms, particularly in populations with co-occurring conditions. The findings underscore the importance of considering individual differences, developmental stages, and comorbidities when designing exercise interventions for mental health improvement in youth. Accounting for factors such as baseline activity levels and tailoring interventions to specific populations may enhance the therapeutic potential of exercise for managing mental health conditions in young people.

Regarding exercise characteristics, resistance training appeared to be particularly beneficial for both depression and anxiety, with mixed-mode exercise (combining aerobic and resistance training) also showing strong effects for depression. In terms of intensity, moderate-intensity exercise was most effective for depression, whereas lower-intensity exercise showed the greatest impact on

anxiety symptoms. These findings suggest that resistance training may be a valuable component of exercise interventions for mental health, and that vigorous intensity is not necessary for benefits. A combined approach incorporating both aerobic and resistance training may be particularly useful for individuals experiencing both depression and anxiety. Therefore, tailoring a balanced program that incorporates both types of exercise may optimize mental health outcomes for individuals with comorbid anxiety and depression. It is also important to consider that blinding participants in exercise studies is not feasible, which may influence outcomes because of participants' awareness of the intervention, potentially affecting their expectations and behavior when interpreting the effects of exercise on mental health. Consistent with previous research in adults,[25] shorter interventions <12 weeks yielded larger effects on symptoms of depression compared to longer programs. This could indicate a higher initial motivation and engagement that wanes over time, or the tendency for short-term effects to diminish as the novel effects of exercise dissipate. However, no significant differences were observed regarding the frequency of exercise sessions per week or the duration of individual exercise sessions for symptoms of either depression or anxiety. This suggests that the weekly frequency and session length may be approached with flexibility, allowing for adaptations to fit individual schedules and preferences.

This comprehensive umbrella review has significant clinical implications for managing depression and anxiety in children and adolescents. The moderate effect sizes for exercise interventions indicate that exercise is a valuable treatment, particularly for youth who do not respond well to psychotherapies or pharmacotherapies, have limited access to these treatments, or prefer nonpharmacological options because of medication side effects. The findings suggest that mixed exercise modalities at moderate intensities are beneficial for depression, whereas resistance exercise at lower intensities is effective for anxiety. Even brief interventions of <12 weeks were effective in reducing depression symptoms. These insights support the integration of tailored exercise programs into clinical care, as a primary lifestyle intervention. By optimizing exercise prescriptions based on specific parameters, clinicians can enhance therapeutic outcomes for youth depression and anxiety within a multimodal treatment approach.

Strengths of this review include its adherence to PRISMA and PRIOR guidelines, a comprehensive search across multiple databases, and a focus on RCTs, enhancing the robustness of the findings. The inclusion of a large number of reviews and participants increases the generalizability of the results. RCT overlap analysis using Corrected Covered Area (CCA) demonstrated minimal redundancy, with values of 4.1% for depression and 8.8% for anxiety—both well below the established threshold of 15% that would indicate problematic overlap. The relatively low overlap observed in our meta-meta-analysis is due to the broad scope of included systematic reviews and meta-analyses, which examined diverse populations (eg, children with ADHD, obesity, or pediatric cancer, or healthy children) and varied exercise interventions (eg, aerobic-only, mixed-mode, or school-based programs), resulting in little overlap in our meta-analyses. This low degree of overlap further strengthens the reliability and validity of our results, increasing our confidence in the conclusions drawn from the data.

Several limitations warrant consideration. We were unable to systematically report sociodemographic information, such as race/ethnicity, for participants across the included studies, as these data were inconsistently reported in the systematic reviews and meta-analyses. This limitation highlights the need for future research to prioritize the standardized reporting of sociodemographic characteristics to better assess the generalizability of findings. The methodological quality of the included reviews varied, with only 4 reviews demonstrating moderate quality, highlighting the need for more rigorous reviews. Substantial heterogeneity was observed (as reflected in high I^2 values) likely due to variations in participant characteristics, exercise interventions, and outcome measures, necessitating cautious interpretation of pooled effect sizes. Publication bias analysis suggested an underrepresentation of smaller studies with negative findings, potentially inflating effect sizes. However, when a correction was applied, the adjusted effect estimate ($\theta = -0.41$) remained very similar to the original estimate (SMD = -0.45), suggesting minimal impact of publication bias. In addition, the lack of sufficient data in the included systematic reviews and meta-analyses prevented us from conducting subgroup analyses comparing self-reported and objective measures of depression or anxiety, which is a limitation given the potential influence of outcome measurement methods on the results and their interpretation. To maximize comprehensiveness, we included reviews in which a small proportion (<25%) of RCTs combined exercise with other interventions. Importantly, our sensitivity analyses excluding these combined intervention studies showed similar or slightly larger effects for exercise-only interventions (SMD = -0.52 for depression; SMD = -0.40 for anxiety), supporting the robustness of our primary findings and suggesting that the inclusion of reviews with some combined interventions did not inflate our effect estimates.

Furthermore, the generalizability of our findings may be limited by the inclusion of only English-language articles, as the exclusion of studies published in other languages could introduce language bias.

Future research should address the gaps highlighted by our umbrella review, emphasizing the importance of exercise as a treatment for depression and anxiety and integrating it into the healthcare system. This includes exploring the long-term effects of exercise on mental health, identifying optimal exercise parameters for different subgroups, and developing practical and cost-effective strategies for implementing exercise interventions in real-world settings. Although the inclusion of studies with low or critically low confidence ratings highlights the need for higher-quality research, the consistency of our findings across sensitivity analyses underscores the reliability of the observed benefits of exercise for depression and anxiety in youth. It is also important to acknowledge that AMSTAR-2 is a conservative tool, and some criteria—such as reporting of funding sources—may unduly affect confidence ratings in behavioral research, despite being more critical in pharmaceutical studies. Raising the profile of exercise as a mental health treatment and embedding it within health care can better support the mental health of children and adolescents. Furthermore, by combining participants with symptoms of depression or anxiety and those diagnosed at baseline, we cannot distinguish whether the observed effect size reflects treatment or prevention. Some exercise interventions may be more effective for treating existing symptoms, whereas others may be better suited for prevention. Future research should separate these groups to better understand the specific benefits of exercise in treating vs preventing depression and anxiety, which could lead to more targeted and effective interventions.

In conclusion, this umbrella review and meta-meta-analysis shows that exercise interventions significantly reduce depression and anxiety symptoms in children and adolescents. The analysis found moderate effect sizes favoring exercise for both depression (SMD = −0.44) and anxiety (SMD = −0.39). Mixed exercise modes and moderate-intensity exercise had the largest effects on depression, whereas resistance exercise and light-intensity exercise were most effective for anxiety. Short-term interventions (<12 weeks) reduced depressive symptoms more effectively than longer programs. Benefits were consistent across different populations, with children with ADHD and other diagnoses showing the greatest improvements. These findings indicate that structured exercise programs could be an essential component of comprehensive mental health care. Future research should examine the long-term impacts of exercise and identify effective strategies for integrating exercise interventions within health care settings, reinforcing exercise as a valuable option for supporting mental well-being in young people.

CRediT authorship contribution statement

Ben Singh: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Hunter Bennett:** Writing – review & editing, Methodology, Investigation. **Aaron Miatke:** Writing – review & editing, Methodology, Investigation. **Dorothea Dumuid:** Writing – review & editing, Methodology, Investigation. **Rachel Curtis:** Writing – review & editing, Methodology, Investigation. **Ty Ferguson:** Writing – review & editing, Methodology, Investigation. **Jacinta Brinsley:** Writing – review & editing, Methodology, Investigation. **Kimberley Szeto:** Writing – review & editing, Methodology, Investigation. **Emily Eglitis:** Writing – review & editing, Project administration, Methodology, Conceptualization. **Mason Zhou:** Writing – review & editing, Methodology, Investigation. **Catherine E.M. Simpson:** Writing – review & editing, Methodology, Investigation. **Jasmine M. Petersen:** Writing – review & editing, Methodology, Investigation. **Joseph Firth:** Writing – review & editing, Methodology, Investigation. **Carol A. Maher:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Terrace and Frome Rd, Adelaide, South Australia 5001, Australia; e-mail: Ben. Singh@unisa.edu.au

REFERENCES

1. Racine N, McArthur BA, Cooke JE, Eirich R, Zhu J, Madigan S. Global prevalence of depressive and anxiety symptoms in children and adolescents during COVID-19: a meta-analysis. JAMA Pediatr. 2021;175(11):1142-1150. https://doi.org/10.1001/jamapediatrics.2021.2482

2. Gleason MM, Thompson LA. Depression and anxiety disorder in children and adolescents. JAMA Pediatr. 2022;176(5):532. https://doi.org/10.1001/jamapediatrics.2022.0052

3. Lebrun-Harris LA, Ghandour RM, Kogan MD, Warren MD. Five-year trends in US children's health and well-being, 2016-2020. JAMA Pediatr. 2022;176(7):e220056. https://doi.org/10.1001/jamapediatrics.2022.0056

4. Mofatteh M. Risk factors associated with stress, anxiety, and depression among university undergraduate students. AIMS Public Health. 2021;8(1):36-65. https://doi.org/10.3934/publichealth.2021004

5. Mullen S. Major depressive disorder in children and adolescents. Ment Health Clin. 2018;8(6):275-283. https://doi.org/10.9740/mhc.2018.11.275

6. Carballo JJ, Llorente C, Kehrmann L, et al. Psychosocial risk factors for suicidality in children and adolescents. Eur Child Adolesc Psychiatry. 2020;29(6):759-776. https://doi.org/10.1007/s00787-018-01270-9

7. Li J, Zhang Y, Chan BSM, et al. Associations between anxiety, depression, and risk of suicidal behaviors in Chinese medical college students. Front Psychiatry. 2022;13:1-10. https://doi.org/10.3389/fpsyt.2022.1012298

8. Nepon J, Belik SL, Bolton J, Sareen J. The relationship between anxiety disorders and suicide attempts: findings from the National Epidemiologic Survey on Alcohol and Related Conditions. Depress Anxiety. 2010;27(9):791-798. https://doi.org/10.1002/da.20674

9. Powell V, Lennon J, Bevan Jones R, et al. Following the children of depressed parents from childhood to adult life: a focus on mood and anxiety disorders. JCPP Adv. 2023;3(4):e12182. https://doi.org/10.1002/jcv2.12182

10. Fergusson DM, Boden JM, Horwood LJ. Recurrence of major depression in adolescence and early adulthood, and later mental health, educational and economic outcomes. Br J Psychiatry. 2007;191(4):335-342. https://doi.org/10.1192/bjp.bp.107.036079

11. National Institute for Health and Care Research. Mental health care for children and teenagers: introduction. 2022. https://evidence.nihr.ac.uk/collection/antidepressants-for-children-and-teenagers-what-works-anxiety-depression/

12. Dwyer JB, Bloch MH. Antidepressants for pediatric patients. Curr Psychiatry. 2019;18(9):26-42.

13. Strawn JR, Vaughn S, Ramsey LB. Pediatric psychopharmacology for depressive and anxiety disorders. Focus (Am Psychiatr Publ). 2022;20(2):184-190. https://doi.org/10.1176/appi.focus.20210036

14. Feeney A, Hock RS, Fava M, Hernández Ortiz JM, Iovieno N, Papakostas GI. Antidepressants in children and adolescents with major depressive disorder and the influence of placebo response: a meta-analysis. J Affect Disord. 2022;305:55-64. https://doi.org/10.1016/j.jad.2022.02.074

15. Cuijpers P, Karyotaki E, Eckshtain D, et al. Psychotherapy for depression across different age groups: a systematic review and meta-analysis. JAMA Psychiatry. 2020;77(7):694-702. https://doi.org/10.1001/jamapsychiatry.2020.0164

16. Wang S, Li Q, Lu J, et al. Treatment rates for mental disorders among children and adolescents: a systematic review and meta-analysis. JAMA Netw Open. 2023;6(10):e2338174. https://doi.org/10.1001/jamanetworkopen.2023.38174

17. Centers for Disease Control and Prevention. Data and statistics on children's mental health. 2023. https://www.cdc.gov/childrensmentalhealth/data.html

18. Bennett K, Manassis K, Duda S, et al. Treating child and adolescent anxiety effectively: overview of systematic reviews. Clin Psychol Rev. 2016;50:80-94. https://doi.org/10.1016/j.cpr.2016.09.006

19. Cuijpers P, Karyotaki E, Ciharova M, et al. The effects of psychological treatments of depression in children and adolescents on response, reliable change, and deterioration: a systematic review and meta-analysis. Eur Child Adolesc Psychiatry. 2023;32(1):177-192. https://doi.org/10.1007/s00787-021-01884-6

20. Edgcomb JB, Zima B. Medication adherence among children and adolescents with severe mental illness: a systematic review and meta-analysis. J Child Adolesc Psychopharmacol. 2018;28(8):508-520. https://doi.org/10.1089/cap.2018.0040

21. Schwalbe C, Gearing R. The moderating effect of adherence-promoting interventions with clients on evidence-based practices for children and adolescents with mental health problems. Am J Orthopsychiatry. 2012;82(1):146-155. https://doi.org/10.1111/j.1939-0025.2011.01133.x

22. Meredith LS, Stein BD, Paddock SM, et al. Perceived barriers to treatment for adolescent depression. Med Care. 2009;47(6):677-685.

23. American Psychological Association. APA clinical practice guideline for the treatment of depression across three age cohorts. 2019. https://www.apa.org/depression-guideline

24. Malhi GS, Bell E, Bassett D, et al. The 2020 Royal Australian and New Zealand College of Psychiatrists clinical practice guidelines for mood disorders. Aust N Z J Psychiatry. 2021;55(1):7-117. https://doi.org/10.1177/0004867420979353

25. Singh B, Olds T, Curtis R, et al. Effectiveness of physical activity interventions for improving depression, anxiety and distress: an overview of systematic reviews. Br J Sports Med. 2023;57(18):1203-1209. https://doi.org/10.1136/bjsports-2022-106195

26. Craft LL, Perna FM. The benefits of exercise for the clinically depressed. Prim Care Companion J Clin Psychiatry. 2004;6(3):104-111. https://doi.org/10.4088/pcc.v06n0301

27. Duman RS, Aghajanian GK, Sanacora G, Krystal JH. Synaptic plasticity and depression: new insights from stress and rapid-acting antidepressants. Nat Med. 2016;22(3):238-249. https://doi.org/10.1038/nm.4050

28. Hamer M, Steptoe A. Cortisol responses to mental stress and incident hypertension in healthy men and women. J Clin Endocrinol Metab. 2012;97(1):E29-E34. https://doi.org/10.1210/jc.2011-2132

29. Lin TW, Kuo YM. Exercise benefits brain function: the monoamine connection. Brain Sci. 2013;3(1):39-53. https://doi.org/10.3390/brainsci3010039

30. Purgato M, Cadorin C, Prina E, et al. Umbrella systematic review and meta-analysis: physical activity as an effective therapeutic strategy for improving psychosocial outcomes in children and adolescents. J Am Acad Child Adolesc Psychiatry. 2024;63(2):172-183. https://doi.org/10.1016/j.jaac.2023.04.017

31. Dale LP, Vanderloo L, Moore S, Faulkner G. Physical activity and depression, anxiety, and self-esteem in children and youth: an umbrella systematic review. Ment Health Phys Act. 2019;16:66-79. https://doi.org/10.1016/j.focus.2023.100074

32. Page MJ, McKenzie JE, Bossuyt PM, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ. 2021;372:n71. https://doi.org/10.1136/bmj.n71

33. Gates M, Gates A, Pieper D, et al. Reporting guideline for overviews of reviews of healthcare interventions: development of the PRIOR statement. BMJ. 2022;378:e070849. https://doi.org/10.1136/bmj-2022-070849

34. Caspersen CJ, Powell KE, Christenson GM. Physical activity, exercise, and physical fitness: definitions and distinctions for health-related research. Public Health Rep. 1985;100(2):126-131.

35. Shea BJ, Reeves BC, Wells G, et al. AMSTAR 2: a critical appraisal tool for systematic reviews that include randomised or non-randomised studies of healthcare interventions, or both. BMJ. 2017;358:j4008. https://doi.org/10.1136/bmj.j4008

36. Hennessy EA, Johnson BT. Examining overlap of included studies in meta-reviews: guidance for using the corrected covered area index. Res Synth Methods. 2020;11(1):134-145. https://doi.org/10.1002/jrsm.1390

37. Pieper D, Antoine S-L, Mathes T, Neugebauer EAM, Eikermann M. Systematic review finds overlapping reviews were not mentioned in every other overview. J Clin Epidemiol. 2014;67(4):368-375. https://doi.org/10.1016/j.jclinepi.2013.11.007

38. Deeks JJ, Higgins JPT, Altman DG; on behalf of the Cochrane Statistical Methods Group. Analysing data and undertaking meta-analyses. In: Higgins JPT, Thomas J, Chandler J, et al., eds. Cochrane Handbook for Systematic Reviews of Interventions. 2019. https://training.cochrane.org/handbook/current/chapter-10

39. Higgins JPT, Thomas J, Chandler J, et al., eds. Cochrane Handbook for Systematic Reviews of Interventions. Cochrane; 2023. Version 6.4. https://training.cochrane.org/handbook

40. Lakens D. Calculating and reporting effect sizes to facilitate cumulative science: a practical primer for t-tests and ANOVAs. Front Psychol. 2013;4:863. https://doi.org/10.3389/fpsyg.2013.00863

41. Egger M, Smith GD, Schneider M, Minder C. Bias in meta-analysis detected by a simple, graphical test. BMJ. 1997;315(7109):629-634. https://doi.org/10.1136/bmj.315.7109.629

42. Schünemann H, Brożek J, Guyatt G, Oxman A, eds. GRADE Handbook for Grading Quality of Evidence and Strength of Recommendations. The GRADE Working Group; 2013. https://doi.org/10.1136/bmj.39500.677199.AE. Updated October 2013.

43. Andermo S, Hallgren M, Nguyen T-T-D, *et al*. School-related physical activity interventions and mental health among children: a systematic review and meta-analysis. Sports Med Open. 2020;6(1):25. https://doi.org/10.1186/s40798-020-00254-x

44. Axelsdóttir B, Biedilae S, Sagatun Å, Nordheim LV, Larun L. Review: exercise for depression in children and adolescents—a systematic review and meta-analysis. Child Adolesc Ment Health. 2021;26(4):347-356. https://doi.org/10.1111/camh.12438

45. Bailey AP, Hetrick SE, Rosenbaum S, Purcell R, Parker AG. Treating depression with physical activity in adolescents and young adults: a systematic review and meta-analysis of randomised controlled trials. Psychol Med. 2018;48(7):1068-1083. https://doi.org/10.1017/S0033291717002653

46. Barahona-Fuentes G, Huerta Ojeda Á, Chirosa-Ríos L. Effects of training with different modes of strength intervention on psychosocial disorders in adolescents: a systematic review and meta-analysis. Int J Environ Res Public Health. 2021;18(18):1-15. https://doi.org/10.3390/ijerph18189477

47. Brown HE, Pearson N, Braithwaite RE, Brown WJ, Biddle SJ. Physical activity interventions and depression in children and adolescents: a systematic review and meta-analysis. Sports Med. 2013;43(3):195-206. https://doi.org/10.1007/s40279-012-0015-8

48. Carter T, Morres ID, Meade O, Callaghan P. The effect of exercise on depressive symptoms in adolescents: a systematic review and meta-analysis. J Am Acad Child Adolesc Psychiatry. 2016;55(7):580-590. https://doi.org/10.1016/j.jaac.2016.04.016

49. Cerrillo-Urbina AJ, García-Hermoso A, Sánchez-López M, Pardo-Guijarro MJ, Santos Gómez JL, Martínez-Vizcaíno V. The effects of physical exercise in children with attention deficit hyperactivity disorder: a systematic review and meta-analysis of randomized control trials. Child Care Health Dev. 2015;41(6):779-788. https://doi.org/10.1111/cch.12255

50. Chen L, Liu Q, Xu F, *et al*. Effect of physical activity on anxiety, depression and obesity index in children and adolescents with obesity: a meta-analysis. J Affect Disord. 2024;354:275-285. https://doi.org/10.1016/j.jad.2024.02.092

51. Larun L, Nordheim LV, Ekeland E, Hagen KB, Heian F. Exercise in prevention and treatment of anxiety and depression among children and young people. Cochrane Database Syst Rev 2006;(3):CD004691. https://doi.org/10.1002/14651858.CD004691.pub2

52. Liu C, Liang X, Sit CHP. Physical activity and mental health in children and adolescents with neurodevelopmental disorders: a systematic review and meta-analysis. JAMA Pediatr. 2024;178(3):247-257. https://doi.org/10.1001/jamapediatrics.2023.6251

53. Neill RD, Lloyd K, Best P, Tully MA. The effects of interventions with physical activity components on adolescent mental health: systematic review and meta-analysis. Ment Health Phys Act. 2020;19:100359. https://doi.org/10.1016/j.mhpa.2020.100359

54. Oberste M, Medele M, Javelle F, *et al*. Physical activity for the treatment of adolescent depression: a systematic review and meta-analysis. Front Physiol. 2020;11:185. https://doi.org/10.3389/fphys.2020.00185

55. Peng S, Fang Y, Othman AT, Liang J. Meta-analysis and systematic review of physical activity on neurodevelopment disorders, depression, and obesity among children and adolescents. Front Psychol. 2022;13:940977. https://doi.org/10.3389/fpsyg.2022.940977

56. Radovic S, Gordon MS, Melvin GA. Should we recommend exercise to adolescents with depressive symptoms? A meta-analysis. J Paediatr Child Health. 2017;53(3):214-220. https://doi.org/10.1111/jpc.13426

57. Recchia F, Bernal JDK, Fong DY, *et al*. Physical activity interventions to alleviate depressive symptoms in children and adolescents: a systematic review and meta-analysis. JAMA Pediatr. 2023;177(2):132-140. https://doi.org/10.1001/jamapediatrics.2022.5090

58. Sun F, Fang Y, Chan CKM, *et al*. Structured physical exercise interventions and children and adolescents with attention deficit hyperactivity disorder: a systematic review and meta-analysis. Child Care Health Dev. 2024;50(1):e13150. https://doi.org/10.1111/cch.13150

59. Sun W, Yu M, Zhou X. Effects of physical exercise on attention deficit and other major symptoms in children with ADHD: a meta-analysis. Psychiatry Res. 2022;311:114509. https://doi.org/10.1016/j.psychres.2022.114509

60. Wang X, Cai ZD, Jiang WT, Fang YY, Sun WX, Wang X. Systematic review and meta-analysis of the effects of exercise on depression in adolescents. Child Adolesc Psychiatry Ment Health. 2022;16(1):16. https://doi.org/10.1186/s13034-022-00453-2

61. Zang W, Fang M, Chen H, *et al*. Effect of concurrent training on physical performance and quality of life in children with malignancy: a systematic review and meta-analysis. Front Public Health. 2023;11:1127255. https://doi.org/10.3389/fpubh.2023.1127255

62. Zhang CS, Cheng L, Chen X, Wang Y, Wei S, Sun J. The strategies of exercise intervention for adolescent depression: a meta-analysis of randomized controlled trials. Front Psychol. 2022;13:974382. https://doi.org/10.3389/fpsyg.2022.974382

63. Zhang X, Li W, Wang J. Effects of exercise intervention on students' test anxiety: a systematic review with a meta-analysis. Int J Environ Res Public Health. 2022;19(11):1-15. https://doi.org/10.3390/ijerph19116709

64. Boelens M, Smit MS, Raat H, Bramer WM, Jansen W. Impact of organized activities on mental health in children and adolescents: an umbrella review. Prev Med Rep. 2022;25:101687. https://doi.org/10.1016/j.pmedr.2021.101687