Effect of exercise on depression and anxiety symptoms: systematic umbrella review with meta-meta-analysis

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ABSTRACT

Objective To synthesise meta-analytic outcomes from randomised controlled trials examining exercise effects on depression and anxiety across all population groups, including children and adults with both clinically diagnosed and subclinical symptoms, excluding those with pre-existing chronic physiological conditions.

Design Meta-meta-analysis (Preferred Reporting Items for Overviews of Reviews (PRIOR) framework).

Data sources Five electronic databases were searched for eligible meta-analyses published from inception to 31 July 2025.

Eligibility criteria for selecting studies Meta-analyses of randomised controlled trials examining exercise interventions for the management of depression and anxiety symptoms were included. To avoid contamination effects, meta-analyses exclusively focused on populations in which chronic physiological conditions were excluded. Study selection was undertaken in duplicate by two independent reviewers.

Results 63 studies (81 meta-analyses, 1079 component studies and 79 551 participants) were included. Exercise reduced depression (standardised mean difference (SMD)=−0.61, 95% CI −0.69 to −0.54) and anxiety (SMD=−0.47, 95% CI −0.59 to −0.36) symptoms, with aerobic exercise demonstrating the most substantial impact on both depression and anxiety symptoms. The greatest benefits by population group for depression were seen in emerging adults aged 18–30 and postnatal women. Greater reductions in depression were associated with exercise in group and supervised settings. Exercise of shorter duration and at lower intensity was most strongly associated with anxiety reduction.

Conclusion and relevance The findings of the study support that exercise based interventions, in all formats and parameters, can help mitigate depression and anxiety symptoms across all population categories. These results can help health professionals provide targeted, cost effective, evidence based support that aligns with individual profiles and preferences.

Trial registration PROSPERO CRD42020210651.

WHAT IS ALREADY KNOWN?

⇒ Exercise is an effective intervention for reducing symptoms of depression and anxiety, with prior research suggesting comparable benefits to psychotherapy and pharmacotherapy, but there is limited uptake of exercise as a first line treatment.

⇒ Previous studies have examined different exercise types, intensities, and population subgroups, but variability in study designs has made it challenging to synthesise findings for clinical application.

WHAT ARE THE NEW FINDINGS?

⇒ This meta-meta-analysis is the first to comprehensively isolate the effect of exercise on both depression and anxiety across clinically diagnosed and non-clinical populations, including children, emerging adults, older adults and perinatal women.

⇒ Exercise was effective across all population groups, with aerobic, group based and supervised formats showing the greatest benefits for depression.

⇒ Differences in the impact of exercise intensity, duration and frequency were revealed for depression and anxiety based symptoms

HOW THIS STUDY MAY IMPACT RESEARCH, PRACTICE OR POLICY?

⇒ Mental health professionals should prescribe exercise with the same confidence as traditional treatments, recognising that all exercise formats demonstrate positive effects while tailoring programmes to individual profiles and preferences (e.g., group-based/supervised formats show strongest effects for depression; shorter, lower-intensity programmes for anxiety).

⇒ Public health guidelines should position exercise as an accessible, evidence-based first-line intervention for mental health, particularly targeting emerging adults and perinatal populations where effects are strongest

INTRODUCTION

Depression and anxiety disorders represent significant global health challenges, affecting 7–25% of the population worldwide.[1–3] These conditions extend beyond psychological problems, impacting family and social functioning,[4–6] physical health[7 8] and carrying substantial economic costs.[8] Youth populations experience almost twice the rate of depression and anxiety disorders of adults,[9–11] with a particularly concerning incidence among women.[12]

While traditional treatments such as antidepressants[13 14] and psychotherapy[15] have become increasingly common, rising prevalence rates for depression and anxiety symptoms[16] suggest that these therapies alone are not sufficient.[17 18] Evidence consistently demonstrates that exercise represents a promising intervention, with empirical findings supporting its role in developing cognitive and neurobiological pathways that enhance mental health outcomes.[19 20] Research consistently indicates the positive impact of exercise on quality of life and psychological well-being in both clinically diagnosed[21 22] and non-clinically diagnosed populations.[23] While evidence for exercise interventions also shows positive effects on anxiety symptoms,[24–26] challenges remain regarding how to optimise exercise design to improve adherence rates.[27]

Meta-meta-analyses have indicated the potential for exercise to mitigate depression and anxiety symptoms,[23 28] while gaps remain in understanding its effectiveness across age ranges and within exercise parameters. Previous meta-meta-analyses have been limited to adult populations[23 28] or included populations with confounding factors, such as chronic diseases.[29] These were also conducted before the development of the Preferred Reporting Items for Overviews of Reviews (PRIOR) framework,[30] which provides comprehensive guidance to facilitate transparency for overviews of healthcare intervention reviews.

In this meta-meta-analysis, our aims were to: (1) provide comprehensive estimates of the impact of exercise on depression and anxiety symptoms across all age ranges, including clinical and non-clinical populations and (2) examine moderation effects of exercise parameters (type, duration, frequency, intensity, supervision and group based activity) and population groups, applying the PRIOR methodology.

METHODS

Protocol and registration

This meta-meta-analysis was conducted following a prospectively registered protocol published in the International Prospective Register of Systematic Reviews (PROSPERO). The only deviations from the protocol were to include additional authors. Our methodological approach adheres to the protocol as described in PROSPERO and with the Reporting Guideline for Overviews of Reviews of Healthcare Interventions.[30]

Search strategy and selection criteria

Five electronic databases were searched: SCOPUS, PsycINFO, CINAHL, OVID Medline and SPORTDiscus. The search was conducted in October 2023 with no restrictions, and repeated in September 2024 to capture more recent literature. A further search was conducted in July 2025 with all five databases, and two additional databases, Embase and Cochrane Library, were included. Manual searches were also performed. Search terms covered constructs related to depression, anxiety, randomised controlled trial designs, meta-analyses and exercise programmes, and were limited to English language peer reviewed journal articles (online supplemental appendix 1).

Search results were exported to the Colandr tool[31] for duplicate removal. Two independent reviewers (NRM and AS) screened the titles and abstracts of the identified studies. Disagreements were resolved through discussion between the reviewers and the broader author team. The full text assessment was performed in duplicate (NRM and AS), with additional discussion from the supervisory team (JD, KS and ST) and reached 100% agreement for studies to be included in the final data extraction. In cases where full texts were unavailable or data clarity was required (five instances), study authors were contacted for clarification.

The PICOS (Patient/Population, Intervention, Comparison, Outcome, Study design) framework was used to define the inclusion and exclusion criteria.[32] Eligible studies included those with participants of any age who were assessed for depression and anxiety symptoms or diagnosed with depression or anxiety disorders according to DSM-5,[33] ICD-10[34] or validated self-reported measures. Studies that explicitly stated the inclusion of individuals with physiological conditions (eg, heart disease, cancers, HIV, or Parkinson's disease) were excluded to avoid potential confounding effects on the relationship between motivation to exercise and mental health.[35]

Exercise interventions were defined as planned, structured, repetitive and purposeful physical activities to improve physical and mental health.[36] All exercise modalities, intensities, frequencies and settings (individual or group) were considered eligible. Studies that combined exercise with psychotherapy, nutrition, pharmacotherapy treatments or manual therapies, and any other non-exercise based interventions were excluded unless the independent effect of exercise could be isolated.

Only meta-analyses of randomised controlled trials (RCTs) comparing exercise with an active control, placebo or no intervention (eg, waitlist) were included. Meta-analyses that incorporated non-randomised studies or cohort designs were excluded. Eligible meta-analyses assessed the impact of exercise on depression or anxiety symptoms using validated self-report or clinician rated measures. Only meta-analyses reporting standardised mean difference (SMD)[37] or Hedges g[38] were eligible. Eligible studies were systematic reviews that included meta-analyses of RCTs meeting the PICO criteria. Narrative, umbrella and systematic reviews without a meta-analysis were excluded.

Data extraction and quality assessment

Data extraction was performed using a systematic template and subjected to further independent audits of potential errors by two additional researchers (KS and AR) to reach 100% verification. The following data were collected: (1) demographic information (age range, sample size, gender distribution and participant characteristics); (2) intervention characteristics (exercise category, intensity, duration, frequency, group or individual exercise format and specific sports); (3) RCT and control group features; (4) depression or anxiety characteristics and assessment scales used; (5) effect scores on depression or anxiety symptoms as SMD or Hedges' g, confidence intervals (CIs), p values, heterogeneity measures (I^2 statistic[39]) and standard errors; and (6) meta-analysis study characteristics, including certainty of evidence using assessment[40] and risk of bias analyses. For clarity in reporting results, we state the number of meta-analyses collected for each subsection, although some reviews may include more than one meta-analysis.

The primary author (NRM) assessed the risk of bias in the included systematic reviews and reviewed with the supervisory panel (JD, ST and KS) to reach complete agreement on AMSTAR-2 categorisation.[41] Each included meta-analysis was classified as high, moderate, low or critically low quality (online supplemental table 2). Sixteen items are considered within AMSTAR-2, each scoring as yes, partial or no. Seven items are considered critical and 11 non-critical. To assess for publication bias, additional funnel plots were conducted to review asymmetries.

Data synthesis

Data synthesis was conducted using R Studio software[42] and the Metafor package.[43] Random effects meta-analyses were conducted to examine the overall effect of exercise interventions on depression and anxiety symptoms. SMDs[37 44] with 95% CIs were used as the effect size measure, interpreted according to Cohen's *d* conventions.[45] Heterogeneity was assessed using I^2, with values of 25%, 50% and 75% indicating low, moderate and high heterogeneity, respectively.

To evaluate the robustness of findings, sensitivity analyses were conducted to compare the synthesis of overall depression and anxiety outcomes across studies categorised by AMSTAR[41] ratings (critically low, low, moderate and high). Subgroup analyses were performed to explore differences by population category (youth aged <18 years, emerging adults aged 18–30 years, adults aged ≥18 years and adults aged ≥55 years, and women in prenatal, postnatal and perinatal stages), clinical depression or anxiety status and exercise modality, provided at least two studies reported the effect estimates for the same population, intervention and outcome.

The corrected covered area (CCA) method was used to evaluate the degree of overlap in component studies across all reviews.[46] This approach quantifies the extent of primary research duplication among systematic reviews, with a CCA of 0% indicating complete uniqueness of component studies across meta-analyses and 100% signifying complete duplication. CCA calculations are interpreted as slight (0–5%), moderate (6–10%), high (11–15%) or very high (>15%). The evidence classification system developed by the Oxford Centre for Evidence Based Medicine (GRADE)[47] was used to provide additional certainty of evidence.

Equity, diversity and inclusion statement

Our research and author team included three women and five men, consisting of junior, mid-career and senior researchers from different countries. Four of the team members were initially from Australia, two from the UK, one from the US and one from the Philippines. As a meta-meta-analysis, the populations within the component studies span across countries globally. From a financial and time resourcing perspective, we sourced the contributing meta-analyses to those published in English and, in turn, recognise the potential limitation in the applicability of findings to non-English speaking populations.

RESULTS

The study selection process and rationale are outlined in the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) flowchart[48] (figure 1). The initial database search gave 2517 records, of which 57 met the eligibility criteria.

Characteristics of included reviews

Online supplemental table 1 presents the characteristics of all of the included reviews. The selected meta-analyses for depression (n=57) included 800 component studies, with a total of 57 930 participants aged 10–90 years, diagnosed with clinical levels of depression or experiencing depressive symptoms. Exercise interventions for depression analyses were categorised as aerobic (eg, running, walking and cycling; n=19), with 181 component studies of 9941 participants, resistance (eg, strength training; n=8) with 93 component studies of 4770 participants, mind–body (eg, yoga, tai-chi and qigong; n=16) with 90 component studies of 7257 participants or mixed exercise modalities (n=39), with 631 component reviews of 48 696 participants. For

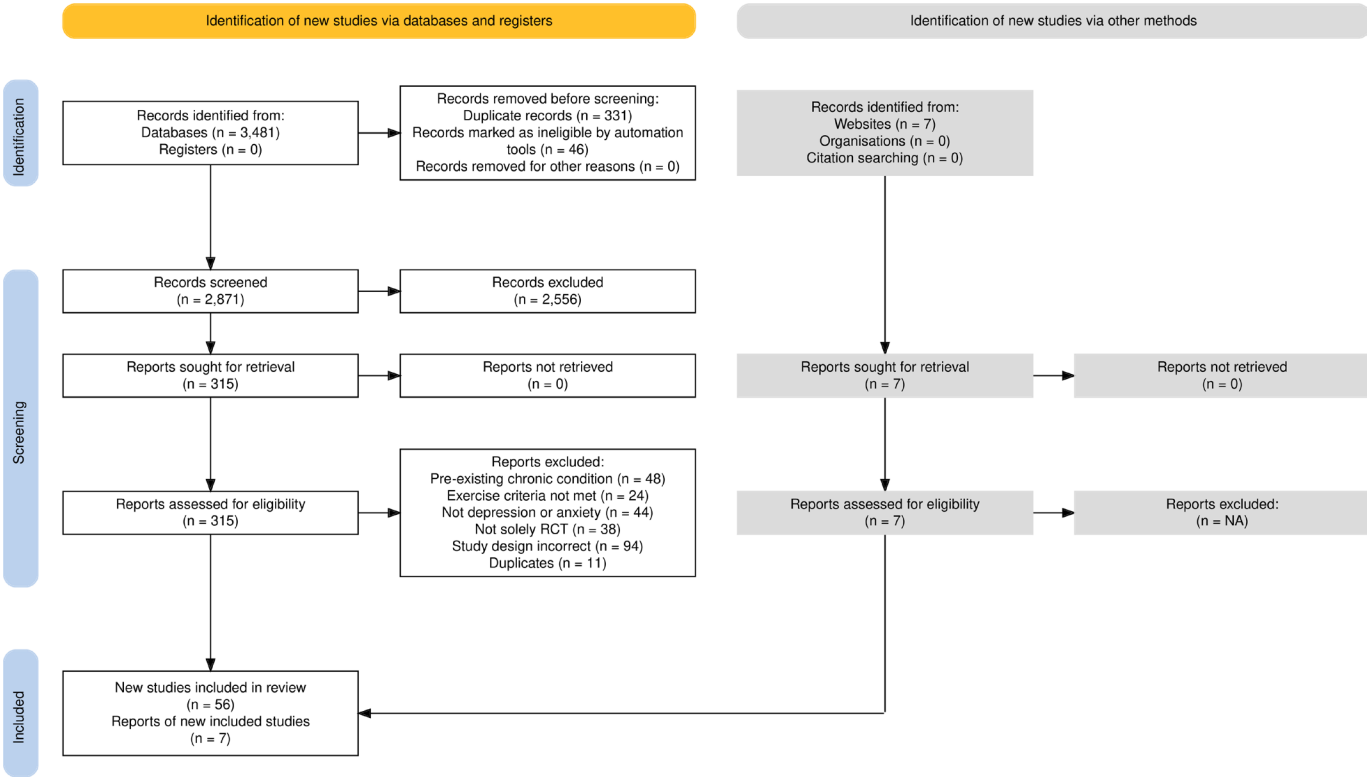

Figure 1 Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) flowchart of study selection process. NA, not available; RCT, randomised controlled trial.

anxiety, the selected meta-analyses (n=24) comprised 258 component studies of 19 368 participants aged 18–67 years. Exercise interventions for anxiety analyses were categorised as aerobic (n=7), with 32 component studies of 1235 participants, resistance (n=1), with five component reviews of 300 participants, mind–body (n=9), with 74 component studies of 5175 participants or mixed exercise modalities (n=13), with 170 component studies of 14 208 participants.

The overall CCA rating was 1.16% for depression reviews and 0.52% for anxiety reviews, indicating slight overlap. The characteristics of all of the depression reviews are shown in online supplemental table 3, with anxiety reviews in online supplemental table 4. Most reviews (n=34) received a critically low AMSTAR-2 score, while the remainder were distributed between low rated (n=21) and high rated (n=8) reviews (online supplemental table 2). A sensitivity analysis revealed minimal inter-group differences for both depression (online supplemental table 3) and anxiety (online supplemental table 4) by AMSTAR-2 quality level. Using the GRADE framework,[47] all included reviews were classified as level 1 (meta-analyses of RCTs) and graded as high quality.

Analysis of funnel plots for the incorporated reviews revealed no discernible evidence of publication bias due to the overall symmetrical appearance of the plot for reviews that examined depression. However, a slight sign of asymmetry was observed for the reviews that examined anxiety, as indicated by an imbalance in the distribution of reviews, with more reviews on the left side (adverse effects) than the right side (positive effects) (figure 2a, b).

Depression

Overall analysis

The overall analysis of 50 reviews (57 meta-analyses, 800 component studies and 57 930 participants) showed a significant medium sized SMD[37 44] of −0.61 (95% CI −0.69 to −0.54).

Subgroup analyses

Exercise was effective in reducing depression symptoms across all population subgroups. Exercise showed the most pronounced effect for emerging adults, represented by four reviews[49–52] (four meta-analyses, 54 component studies and 4180 participants) with SMD of −0.81 (95% CI −1.06 to −0.57). Exercise interventions across all age groups were effective: SMD −0.66 (95% CI −0.79 to −0.54) for adults, from 23 reviews[21 53–74] (27 meta-analyses, 428 component studies and 24 154 participants); SMD −0.53 (95% CI −0.81 to −0.24) for youths aged <18 years analysed in six reviews[75–80] (six meta-analyses, 79 component studies and 7474 participants); SMD −0.81 (95% CI −1.06 to −0.57) for emerging adults aged 18–30 analysed in four reviews[49 50 81 82] (four meta-analyses, 54 component studies and 4180 participants); and SMD −0.41 (95% CI −0.51 to −0.30) for late adulthood, represented by six reviews[66 83–87] (eight meta-analyses, 72 component studies and 5860 participants).

Postnatal populations, represented by four reviews[88–91] (four meta-analyses, 42 component studies and 3437 participants) showed the most pronounced effect of exercise on depression within perinatal groups, with an SMD −0.70 (95% CI −0.92 to −0.48). Exercise was also effective for prenatal populations with SMD −0.46 (95% CI −0.59 to −0.32), analysed in four reviews[92–95] (four meta-analyses, 42 component studies and 4717 participants) and for the broader perinatal category SMD of −0.52 (95% CI −0.66 to −0.39) analysed in 11 reviews[88–98] (11 meta-analyses, 150 component studies and 15 518 participants). The perinatal group incorporated prenatal and postnatal populations and reviews explicitly designated as perinatal. These three categories showed high to very high interpretations in the CCA analysis: postnatal (26.92%), prenatal (18.67%) and perinatal (12.76%).

Exercise modes for depression

Aerobic exercise showed the most substantial impact, with SMD of −0.81 (95% CI −1.01 to −0.60) based on 15 reviews[52 55 63 65–67 70 74 75 79 80 85 91 97 99] (19 meta-analyses, 181 component studies and 9941 participants). All other exercise modes were effective: −0.62 (95% CI −0.93 to −0.31) for resistance training derived from eight reviews[52 55 65 67 70 71 74 80 85] (12 meta-analyses, 93 component studies and 4770 participants); −0.53 (95% CI −0.66 to −0.39) for mind–body interventions, from 11 reviews[51 52 56 60 62 64 69 80 86 87 91 92 97] (16 meta-analyses, 90 component studies and 7257 participants) and −0.60 (95% CI −0.68 to −0.52) for mixed exercise modalities, based on 35 reviews[21 49 50 52–55 57–59 61 66 68 70 72 73 75–80 83–85 88–91 93–98] (39 meta-analyses, 631 component studies and 48 696 participants).

Group based exercise appeared more effective with SMD of −0.71 (95% CI −0.93 to −0.47) based on seven reviews[66 68 70 79 80 88 97] (seven meta-analyses, 70 component studies and 4858 participants), compared with individual performed exercise with SMD of −0.38 (95% CI −0.65 to −0.11) reported from five reviews[66 68 70 79 97] (five meta-analyses, 41 component studies and 2253 participants).

Exercise intensity for depression

From four reviews[70 72 79 99] (four meta-analyses, 17 component studies and 1063 participants), low intensity exercise showed SMD of −0.69 (95% CI −1.09 to −0.30). Four reviews[68 70 72 99] for moderate intensity interventions (four meta-analyses, 43 component studies and 3217 participants) showed a more substantial impact with SMD of −1.02 (95% CI −1.68 to −0.35). Moderate to vigorous intensity, from two reviews[68 79] (two meta-analyses, 11 component studies and 591 participants), showed a comparable effect with SMD of −0.78 (95% CI −1.26 to −0.31). Vigorous intensity, from three reviews[70 74 99] (three meta-analyses, 17 component studies and 981 participants), showed a comparable effect with SMD of −0.65 (95% CI −0.99 to −0.31).

Exercise duration for depression

Longer term exercise over 24 weeks showed the most substantial impact from two reviews[69 85] (two meta-analyses, 20 component studies and 987 participants) reporting SMD of −1.11 (95% CI −2.01 to −0.21). Medium term exercise, lasting 9–24 weeks, showed a more modest effect, from four reviews[52 69 85 86] (seven meta-analyses, 45 component studies and 2874 participants) reporting SMD of −0.44 (95% CI −0.57 to −0.31). Short-term exercise of up to 8 weeks demonstrated a medium effect from four reviews[50 52 79 95] (four meta-analyses, 21 component studies and 958 participants) with SMD of −0.76 (95% CI: −1.07 to −0.45).

Exercise frequency for depression

Exercise with a higher frequency, ≥3 days per week, reported SMD of −0.52 (95% CI −0.75 to −0.29) from four reviews[50 52 71 79] (six meta-analyses, 39 component studies and 2270 participants), with a similar impact to exercise with lower frequency, occurring 1 or 2 days per week, with SMD of −0.43

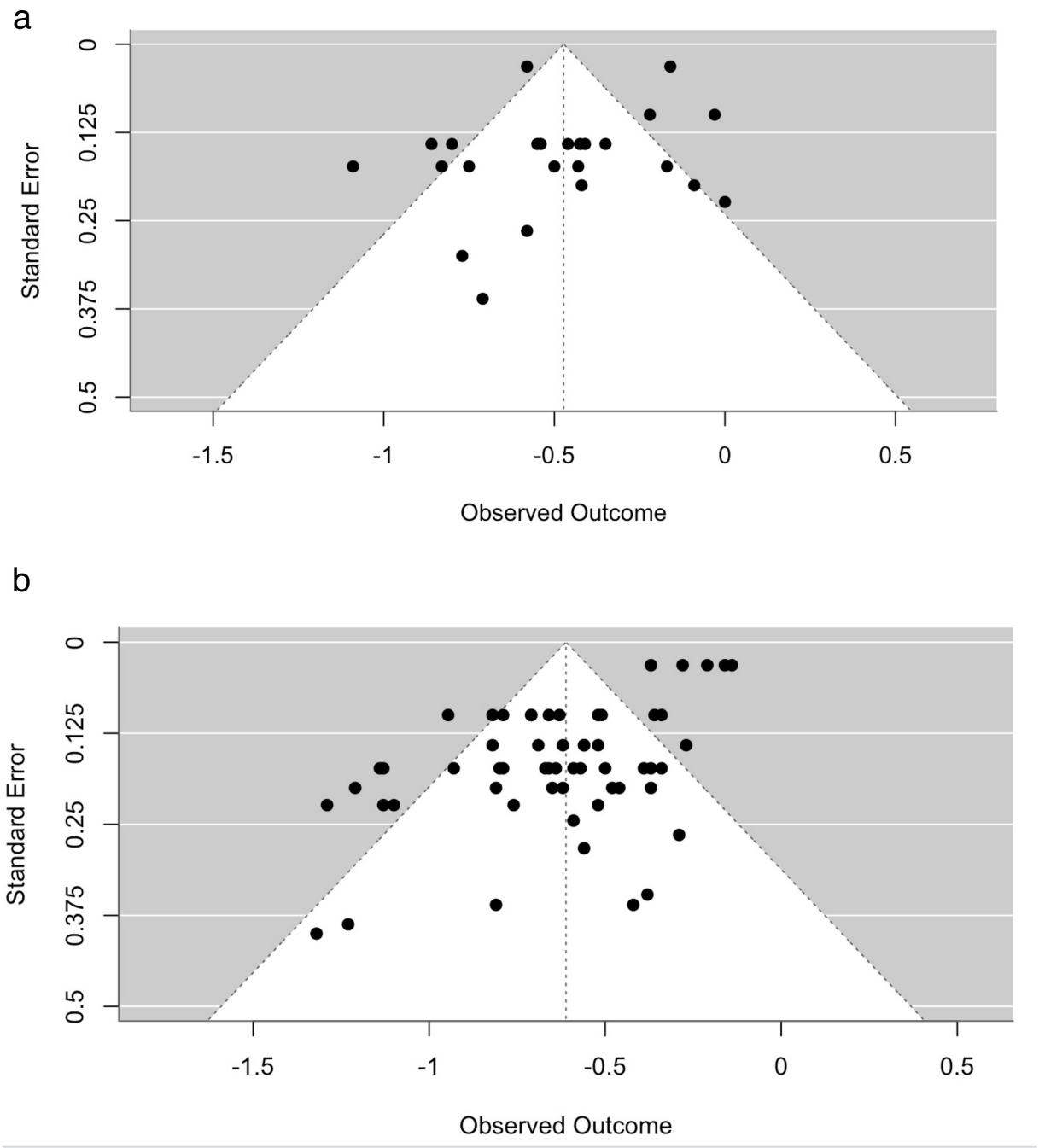

Figure 2 Funnel plot analysis of publication bias for anxiety. (A) Funnel plot analysis of publication bias for depression. (B) Funnel plot analysis of publication bias for anxiety.

(95% CI −0.73 to −0.13) from three reviews[71 81 100] (three meta-analyses, 30 component studies and 1820 participants).

Exercise supervision for depression

Supervised exercise showed a more pronounced impact with SMD of −0.69 (95% CI −1.08 to −0.30) from three reviews[57 66 70] (three meta-analyses, 93 component studies and 4624 participants) than unsupervised activity SMD of −0.46 (95% CI −0.66 to −0.26) from three reviews[57 66 70] (three meta-analyses, 35 component studies and 1698 participants).

Exercise for clinical and non-clinical depression

For populations with clinically diagnosed depression, eight reviews[21 54 58 63 68 75 78 95] (eight meta-analyses, 79 component studies and 4960 participants) reported SMD of −0.73 (95% CI −0.93 to −0.53) with a slightly larger impact SMD of −0.81 (95% CI −0.98 to −0.64) reported in populations explicitly identified as non-clinically diagnosed from two reviews[75 78] (two meta-analyses, 24 component studies and 1617 participants).

Anxiety

Overall analysis

The impact of exercise on anxiety symptoms, derived from 23 reviews (24 meta-analyses, 258 component studies and 19 368 participants) showed a small to moderate SMD[37 44] of −0.47 (95% CI −0.59 to −0.36).

Subgroup analyses

Exercise was effective in reducing depression symptoms across all anxiety subgroups. For emerging adults, four reviews[50–52 101] (four meta-analyses, 48 component studies and 4186 participants) showed a moderate reduction in anxiety symptoms, with SMD of −0.59 (95% CI −0.65 to −0.53). The adult population, examined in 17 reviews[56 58 60 62 72 74 102–112] (18 meta-analyses, 184 component studies and 13 186 participants), showed a slightly smaller effect size with SMD of −0.40 (95% CI −0.52 to −0.27).

Exercise modes for anxiety

Aerobic exercise showed the most substantial effect on anxiety symptoms with SMD of −0.60 (95% CI −0.87 to −0.33) from five reviews[52 74 102 104 107] (five meta-analyses, seven component studies and 1235 participants). All other exercise modes were effective: resistance based exercise SMD of −0.56 (95% CI −0.84 to −0.28) based on one review[52] (one meta-analysis, five component studies and 300 participants); mind–body exercise SMD of −0.50 (95% CI −0.67 to −0.32) from eight reviews[56 60 62 81 82 106 108 111] (nine meta-analyses, 74 component studies and 5175 participants); and mixed exercise SMD of −0.45 (95% CI −0.60 to −0.30) from 12 reviews[50 58 72 81 98 101 103 105 109 110 112 113] (13 meta-analyses, 170 component studies and 14 208 participants). One group based exercise review[104] showed effectiveness with SMD of −0.60 (95% CI −0.94 to −0.26) from one review (one meta-analysis, two component studies and 72 participants), and no meta-analysis data were available for individual performed exercise on anxiety.

Exercise intensity for anxiety

Low intensity exercise showed a more substantial impact with SMD of −0.68 (95% CI −1.21 to −0.14) from two studies[72 110] (two meta-analyses, nine component studies and 903 participants) compared with the effect of moderate intensity exercise with SMD of −0.06 (95% CI −0.22 to 0.09) reported from the same two studies[72 110] (two meta-analyses, 13 component studies and 2069 participants). No data were available for moderate to vigorous exercise for anxiety, although data for vigorous exercise showed SMD of −0.17 (95% CI −0.53 to 0.19) from one review[74] (one meta-analysis, five component studies and 225 participants).

Exercise duration for anxiety

Short term exercise, up to 8 weeks, showed the most substantial impact with SMD of −0.70 (95% CI −0.92 to −0.47) from two reviews[50 52] (two meta-analyses, 12 component studies and 267 participants) compared with the impact of medium term exercise, between 9 to 24 weeks, with SMD of −0.50 (95% CI −0.64 to −0.37) from two reviews[52 110] (four meta-analyses, 23 component studies and 2285 participants), and longer term exercise, lasting >24 weeks, with SMD of −0.03 (95% CI −0.18 to 0.13) from one review[110] (one meta-analysis, seven component studies and 1013 participants).

Exercise frequency for anxiety

Lower frequency exercise, 1 or 2 days per week, was examined in one review[52] (one meta-analysis, six component studies and 293 participants) with SMD of −0.71 (95% CI −0.95 to −0.47), which showed more impact than higher frequency exercise of ≥3 days per week, with SMD of −0.50 (95% CI −0.71 to −0.30) from two reviews[50 52] (four meta-analyses, 18 component studies and 1573 participants).

Exercise supervision for anxiety

No meta-analyses were available that reported explicitly on exercise supervision levels for anxiety.

Exercise for clinical and non-clinical anxiety

Two reviews[107 109] (one meta-analysis, 19 component studies and 935 participants) on clinically diagnosed anxiety were analysed, reporting an SMD of −0.42 (95% CI −0.61 to −0.22). No data were available for the non-clinical anxiety population.

DISCUSSION

This meta-meta-analysis is the first to comprehensively isolate the effect of exercise, by excluding pre-existing physiological conditions, on both depression and anxiety across clinically diagnosed and non-clinical populations, including children, emerging adults, older adults and perinatal women. Exercise had a medium sized effect on depression symptoms and a small-to-medium effect on anxiety symptoms, with the most substantial effects found for emerging adults and perinatal populations, particularly in the postnatal period. All exercise modalities showed positive effects, with aerobic, group based and supervised formats appearing to be the most effective for depression symptoms. Aerobic, resistance, mind–body and mixed exercise modalities showed a medium impact for the mitigation of anxiety symptoms.

Group based and supervised interventions showed notably higher effect sizes than individual based activities for depression, suggesting that social components have a crucial role in the antidepressant effects of exercise. These outcomes align with research demonstrating exercise's social support benefits,[114] indicating that the psychological sense of belonging may contribute additional value at both biological and psychosocial levels.[115–117] Psychological interventions conducted within groups can be more successful than interventions targeted at an individual level, and it is possible that articulating intentions in a group setting may increase motivation to persevere with behaviour change.[118] Furthermore, expectations surrounding the impact of exercise can increase when participants elaborate on their expectations, thereby increasing the possibility of rating the intervention as successful.[119] Mental health professionals should consider strategies for promoting exercise as a cost effective intervention and examine how contextual factors, particularly social and physical environments, can positively influence outcomes.[23 120 121]

The effectiveness of exercise interventions appeared comparable with pharmacological treatments (SMD=−0.36) and psychotherapies (SMD=−0.34) for managing depression and anxiety symptoms.[122] Given the cost effectiveness, accessibility and additional physical health benefits of exercise, these results underscore the potential for exercise as a first line intervention, particularly in settings where traditional mental health treatments may be less accessible or acceptable.[18 123] Early interventions of exercise have been shown to enhance recovery from physiological conditions,[124 125] and there is evidence that early interventions, from an age related or diagnosis timing perspective, can support recovery from ICD-10[126] or DSM-5 diagnosed mental health conditions.[127] As exercise also stimulates neurobiological mechanisms, including increased growth of brain neurotrophins and protection against neurotoxic damage,[128 129] our findings further support public health guidance beyond the immediate impact of alleviating depression and anxiety symptoms.

Our findings suggested that exercise interventions showed enhanced effectiveness in ameliorating depressive symptoms when implemented in populations without comorbid physiological conditions, relative to outcomes reported in a previous systematic review examining populations that did not specifically exclude such comorbidities (SMD=−0.43).[28] These divergent findings may reflect the impact of pre-existing severe medical conditions on motivation and ability to exercise,[130 131] alongside potential participation bias for physically healthier populations.[132] While the overall effect of exercise on all age groups was positive, the analysis of subgroups suggested that there may be nuanced differences in the impact of exercise based on specific population characteristics. For instance, we found particularly strong effects for emerging adults, an age that can typically signify the onset of mental health conditions[133] and postnatal women cohorts. That postnatal women may particularly benefit from exercise is especially significant given the high prevalence and potential severity of postpartum depression,[134] underscoring the potential of exercise as a low risk, high benefit strategy for improving maternal mental health during this vulnerable period.[135 136]

For anxiety management, lower intensity and shorter duration (up to 8 weeks) interventions seemed more efficacious, although a wide range of definitions was provided for intensity parameters. This pattern suggests that the prescription of more immediate and shorter time frame exercise regimens may offer substantial benefits for individuals with anxiety. Early stage interventions for anxiety disorders have been shown to mitigate the onset of secondary mental health disorders.[137] Promotion of briefer exercise interventions may, therefore, support populations with anxiety symptoms.

While our study excluded populations affected by factors that might influence exercise engagement and did not explicitly examine motivational factors, it is important to acknowledge that physical and mental health characteristics contribute significantly to exercise adoption.[138] Incorporating intrinsic motivational factors into exercise programme design can significantly influence intervention adherence and participation rates.[36 139 140] Therefore, future research on intervention design and exercise prescription should prioritise the consideration of individual circumstances and needs, thereby supporting increased motivation and responses.[141]

Strengths and limitations of this study

The primary strength of this study was its comprehensive synthesis of data from 72 meta-analyses, incorporating 926 component randomised controlled studies and involving 66 707 participants. Applying the PRIOR framework's complete recommendations enhanced the robustness of these findings.[30] Our research distinguished itself by encompassing clinically diagnosed and non-clinical populations across diverse demographics, including children and young people, emerging adults, older adults and perinatal women. To isolate the precise impact of exercise, we excluded meta-analyses that included populations with pre-existing physiological conditions. This methodological decision mitigated the confounding effects of physiological illness related motivations on exercise engagement and its subsequent psychological outcomes.[35 142]

Inspection of the funnel plots suggested subtle asymmetry in anxiety focused studies, potentially indicating mild publication bias or true effect heterogeneity. Additionally, heterogeneous interpretations of exercise parameters across constituent studies present challenges in reporting precise exercise intensity and duration boundaries.[143 144] Analyses of data from studies of depression for perinatal and youth populations gave high to very high CCA[46] ratings, indicative of substantial duplication among component studies. This finding underscores the necessity for additional, diverse studies focusing on these specific demographic groups. Implementing the CCA method in the analysis facilitated the quantification of component study overlap across meta-analyses, thereby elucidating potential result distortion due to the double counting of duplicate studies. This methodological approach enhances the synthesis of multiple meta-analyses; however, it does not account for the relative sample sizes of individual component studies. Consequently, research with a substantial sample size (eg, 1000 participants) will contribute the same level of input calculation to CCA as a study with a smaller sample size (eg, 10 participants). While the CCA is not deployed to calculate the overall SMD within this meta-meta-analysis, it is imperative to interpret each output in conjunction with the corresponding CCA to contextualise potential levels of component study duplication (as illustrated in online supplemental table 3 and online supplemental table 4).

Despite most meta-analyses being categorised as critically low or low quality according to AMSTAR-2, sensitivity analyses across quality domains showed minimal impact on the overall results. The substantial volume of meta-analyses available for depression studies engendered high confidence in the results across the analysed subgroups.

The heterogeneous interpretations of exercise parameters used within constituent studies presented a significant challenge in reporting exercise intensity and duration results with precise boundaries. Meta-analyses examining exercise intensity used disparate source definitions for intensity, while exercise duration parameters showed wide variations within component studies. This limitation underscores the need for standardised intensity classifications in future investigations to facilitate more precise comparisons.

A notable limitation of this analysis was the need for more anxiety based meta-analytic data for wider ranging population groups, including late adulthood, youth and perinatal populations. This gap in the literature highlights the need for further research to comprehensively understand the effects of exercise on anxiety across the entire lifespan.

Clinical implications

These findings support exercise as a viable and effective intervention for depression and anxiety symptoms across diverse populations. However, clinical adoption of exercise based interventions remains limited.[145] Several factors are crucial for successful implementation, including co-designed approaches and individually tailored interventions.[146 147] Enhancing clinicians' knowledge base and developing pragmatic guidelines could promote broader adoption of exercise interventions in clinical practice.[148–150]

CONCLUSIONS

This meta-meta-analysis provides robust evidence that exercise effectively reduced depression and anxiety symptoms across all age groups, comparable with or exceeding traditional pharmacological or psychological interventions. Group and supervised formats gave the most substantial benefits, underscoring the importance of social factors in mental health interventions. With evidence that different characteristics of exercise appear to impact depression and anxiety at varying magnitudes, tailored exercise programmes must be prescribed. Exercise is

an accessible and cost effective treatment option for depression and anxiety, so these findings must be translated into clear, actionable guidelines for ensuring widespread adoption and long term impact.

Contributors NRM, JD, ST and BJ conceptualised the study, and consulted with AR to build upon the previous meta-meta-analysis conducted in this field. JD was responsible for the acquisition and provision of resources. NRM, JD, ST, KS, AR and AS undertook investigation, methodology and project administration. Data curation involved NRM, KS and AS. NRM, KS, AS and AR directly accessed and verified the underlying data reported in the manuscript. The lead statistician was KS, with NRM, JD, ST, AS and AR also assisting with formal analysis. The manuscript was drafted by NRM, with guidance from JD, KS and ST. JD, ST and KS provided supervision. All authors had full access to all the data in the study, reviewed and edited the manuscript, and had final responsibility for the decision to submit for publication. The guarantor (primary author NRM) accepts full responsibility for the finished work and/or the conduct of the study, had access to the data, and controlled the decision to publish.

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