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# The effect of exercise on depression and anxiety symptoms: A systematic umbrella review with meta-meta-analysis

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**Summary box**

**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. Yet, 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 females.
- Exercise is 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 are revealed for depression and anxiety-based symptoms.

## 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 (PRIOR framework [1]).

### Data sources

Five electronic databases were searched for eligible meta-analyses published from inception to 30 September 2024.

### 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 with chronic physiological conditions were excluded. Study selection was undertaken in duplicate by two independent reviewers.

### Results

Sixty-three studies (81 meta-analyses, 1,079 component studies, 79,551 participants) were included. Exercise reduced depression (SMD =-0.61, 95% CI -0.69 to -0.54) and anxiety symptoms (SMD =-0.47, 95% CI -0.59 to -0.36), 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 to 30 and post-natal females. 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**

Findings 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.

**PROSPERO registration number** CRD42020210651.

## Introduction

Depression and anxiety disorders represent significant global health challenges, affecting 7-25% of the population worldwide [2-4]. These conditions extend beyond psychological suffering, impacting family and social functioning [5-7], physical health [8 9], and carrying substantial economic costs[9]. Youth populations experience almost twice the rate of depression and anxiety disorders of adults [10 11 12], with particularly concerning incidence among females [13].

While traditional treatments such as antidepressants [14 15] and psychotherapy [16] have become increasingly common, rising prevalence rates for depression and anxiety symptoms [17] suggest that these therapies alone are not sufficient [18 19]. 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 [20 21]. Research consistently indicates the positive impact of exercise on quality of life and psychological well-being in both clinically diagnosed [22 23] and non-clinically diagnosed populations [24]. Whilst evidence for exercise interventions also shows positive effects on anxiety symptoms [25 26 27], challenges remain regarding how to optimise exercise design to improve adherence rates [28].

Meta-meta-analyses have indicated the potential for exercise to mitigate depression and anxiety symptoms [24 29], whilst gaps remain in understanding its effectiveness across age ranges and within exercise parameters. Previous meta-meta-analyses have been limited to adult populations [24 29]or included populations with confounding factors, such as chronic diseases[30]. These were also conducted before the development of the PRIOR framework [1], which provides comprehensive guidance to facilitate transparency for overviews of healthcare intervention reviews.

In this meta-meta-analysis, we aim to: 1) provide comprehensive estimates of the impact of exercise on depression and anxiety symptoms across all age ranges, including clinical/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) with the identification number CRD42020210651. 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 [1].

### 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 programs, and were limited to English language peer-reviewed journal articles (Appendix 1).

Search results were exported to the Colandr tool [31] for duplicate removal. Two independent reviewers (NM 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 (NM and AS), with additional discussion from the supervisory team (JD, KS, ST) and reached100% 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].

Patient/Population: 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 (e.g., heart disease, cancers, HIV, Parkinson's disease) were excluded to avoid potential confounding effects on the relationship between motivation to exercise and mental health [35].

Intervention: 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.

Comparison: Only meta-analyses of randomised controlled trials (RCTs) comparing exercise to an active control, placebo, or no intervention (e.g., waitlist) were included. Meta-analyses that incorporated non-randomised studies or cohort designs were excluded.

Outcome: 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.

Study type: Eligible studies were systematic reviews that included meta-analyses of RCTs meeting the above PICO criteria. Narrative, umbrella, and systematic reviews without 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) randomised controlled trial (RCT) and control group features; (4) depression or anxiety characteristics and assessment scales employed; (5) effect scores on depression or anxiety symptoms as standardised mean difference (SMD) or Hedges' g, confidence intervals (CI), p-values, heterogeneity measures ($I^2$ statistic [39] ), and standard errors; (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 sub-section, although some reviews may include more than one meta-analysis.

The primary author (NM) assessed the risk of bias in the included systematic reviews and reviewed with the supervisory panel (JD, ST, KS) to reach complete agreement on AMSTAR-2 categorisation [41]. Each included meta-analysis was classified as high, moderate, low, or critically low quality (Supplementary table 2). Sixteen items are considered within AMSTAR-2, each

scoring as yes, partial, or no. Seven items are considered critical, and eleven 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. Standardised mean differences (SMD) [37 44] with 95% confidence intervals (CIs) were used as the effect size (ES) 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 under 18 years of age, emerging adults between 18 to 30, adults aged 18 and over, adults aged 55 and over, and females 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 employed 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 United Kingdom, one from the United States, 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 PRISMA flowchart [48] (Figure 1). The initial database search yielded 2,517 records, of which 57 met the eligibility criteria.

**Characteristics of included reviews**

Supplementary Table 1 presents the characteristics of all included reviews. The selected meta-analyses for depression (n=57) encompassed 800 component studies, totaling 57,930 participants aged from 10 to 90 years, either diagnosed with clinical levels of depression or experiencing depressive symptoms. Exercise interventions for depression analyses were categorised into aerobic (e.g. running, walking, and cycling) (n=19) encompassing 181 component studies, totaling 9,941 participants, resistance (e.g. strength training), (n=8)

encompassing 93 component studies, totaling 4,770 participants, mind-body (e.g. yoga, tai-chi, qigong), (n=16) encompassing 90 component studies, totaling 7,257 participants, or mixed exercise modalities (n=39) encompassing 631 component reviews, totaling 48,696 participants. For anxiety, the selected meta-analyses (n=24) comprised 258 component studies, totaling 19,368 participants aged from 18 to 67 years. Exercise interventions for anxiety analyses were categorised into aerobic (n=7), encompassing 32 component studies, totaling 1,235 participants, resistance (n=1), encompassing 5 component reviews, totaling 300 participants, mind-body (n=9), encompassing 74 component studies, totaling 5,175 participants, or mixed exercise modalities (n=13) encompassing 170 component studies, totaling 14,208 participants.

The overall CCA rating was 1.16% for depression reviews and 0.52% for anxiety reviews, indicating slight overlap. Characteristics of all depression reviews are shown in Supplementary Table 3, with anxiety reviews shown in Supplementary 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 (Supplementary Table 2). A sensitivity analysis revealed minimal inter-group differences for both depression (Supplementary Table 3) and anxiety (Supplementary 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). (Figures 2a and 2b)

## Depression

### Depression - overall analysis

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

### Depression - sub-group analyses

Exercise was effective in reducing depression symptoms across all population sub-groups. It demonstrated the most pronounced effect for emerging adults, represented by four reviews [49-52] (4 meta-analyses, 54 component studies, 4,180 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, encompassing twenty-three reviews [22 53-74] (27 meta-analyses, 428 component studies, 24,154 participants); SMD -0.53 (95% CI −0.81 to −0.24) for youth aged younger than 18 years analysed in six reviews [75-80] (6 meta-analyses, 79 component studies, (7,474 participants); SMD -0.81 (95% CI -1.06 to -0.57) for emerging adults aged 18 to 30 analysed in four reviews [49 81-83] (4 meta-analyses, 54 component studies, 4,180 participants), and SMD -0.41(95% CI −0.51 to −0.30) for late adulthood, represented by six reviews [66 84-88] (8 meta-analyses, 72 component studies, 5,860 participants).

Postnatal populations, represented by four reviews [89-92] (4 meta-analyses, 42 component studies, 3,437 participants) demonstrated 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 [93-96] (4 meta-analyses, 42 component studies, 4,717 participants), and for the broader perinatal category SMD of -0.52 (95% CI −0.66 to −0.39) encompassing eleven reviews [89-99] (11 meta-

analyses, 150 component studies, 15,518 participants). The perinatal group incorporated prenatal and postnatal populations and reviews explicitly designated as perinatal. These three categories exhibited high to very high interpretations in the combined covered area (CCA) analysis: postnatal (26.92%). prenatal (18.67%), and perinatal (12.76%).

Exercise modes for depression

Aerobic exercise exhibited the most substantial impact, with SMD of -0.81 (95% CI −1.01 to −0.60) based on fifteen reviews [52 55 63 65-67 70 74 75 79 80 86 92 98 100] (19 meta-analyses, 181 component studies, 9,941 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 86] (12 meta-analyses, 93 component studies, 4,770 participants); -0.53 (95% CI: -0.66 to -0.39) for mind-body interventions, from eleven reviews [51 52 56 60 62 64 69 80 87 88 92 93 98] (16 meta-analyses, 90 component studies, 7,257 participants), and -0.60 (95% CI: -0.68 to -0.52) for mixed exercise modalities, based on thirty-five reviews [22 49 50 52-55 57-59 61 66 68 70 72 73 75-80 84-86 89-92 94-99] (39 meta-analyses, 631 component studies, 48,696 participants).

Group-based exercise appeared more effective with SMD of -0.71 (95% CI -0.93 to -0.47) based upon seven reviews [66 68 70 79 80 89 98] (7 meta-analyses, 70 component studies, 4,858 participants), compared to individual performed exercise with SMD of -0.38 (95% CI: -0.65 to -0.11) reported for from five reviews [66 68 70 79 98] (5 meta-analyses, 41 component studies, 2,253 participants).

Exercise intensity for depression

From four reviews [70 72 79 100] (4 meta-analyses, 17 component studies, 1,063 participants), low-intensity exercise exhibited SMD of -0.69 (95% CI: -1.09 to -0.30). Four reviews [68 70 72 100] for moderate-intensity interventions (4 meta-analyses, 43 component studies, 3,217 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] (2 meta-analyses, 11 component studies, 591 participants), demonstrated a comparable effect with SMD of -0.78 (95% CI: -1.26 to -0.31). Vigorous intensity, from three reviews [70 74 100] (3 meta-analyses, 17 component studies, 981 participants), demonstrated 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 demonstrated the most substantial impact from two reviews [69 86] (2 meta-analyses, 20 component studies, 987 participants) reporting SMD of -1.11 (95% CI: -2.01 to -0.21). Medium-term exercise, lasting 9 to 24 weeks, showed a more modest effect, from four reviews [52 69 86 87] (7 meta-analyses, 45 component studies, 2,874 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 96] (4 meta-analyses, 21 component studies, 958 participants) with SMD of -0.76 (95% CI: -1.07 to -0.45).

Exercise frequency for depression

Exercise with a higher frequency, three or more days per week, SMD of -0.52 (95% CI: -0.75 to -0.29) from four reviews [50 52 71 79] (6 meta-analyses, 39 component studies, 2,270 participants), presented a similar impact to exercise with lower frequency, occurring one or two days per week, SMD of -0.43; (95% CI: -0.73 to -0.13) from three reviews [81 101 102] (3 meta-analyses, 30 component studies, 1,820 participants with SMD of = -0.43; 95% CI: -0.73 to -0.13).

Exercise supervision for depression

Supervised exercise demonstrated a more pronounced impact with SMD of -0.69 (95% CI: -1.08 to -0.30) from three reviews [57 66 70] (3 meta-analyses, 93 component studies, 4,624 participants),

than unsupervised activity SMD of -0.46 (95% CI: -0.66 to -0.26) from three reviews [57 66 70] (3 meta-analyses, 35 component studies, 1,698 participants).

Exercise for clinical and non-clinical depression

For populations with clinically diagnosed depression, eight reviews [22 54 58 63 68 75 78 96] (8 meta-analyses, 79 component studies, 4,960 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] (2 meta-analyses, 24 component studies, 1,617 participants).

**Anxiety**

Anxiety - overall analysis

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

Anxiety sub-group analyses

Exercise was effective in reducing depression symptoms across all anxiety sub-groups. For emerging adults, four reviews [50-52 103] (4 meta-analyses, 48 component studies, 4,186 participants) demonstrated a moderate reduction in anxiety symptoms, with SMD of −0.59 (95% CI: −0.65 to −0.53). The adult population, examined in seventeen reviews [56 58 60 62 72 74 104-114] (18 meta-analyses, 184 component studies, 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 exhibited the most substantial effect on anxiety symptoms with SMD of -0.60 (95% CI: −0.87 to −0.33) from five reviews [52 74 104 106 109] (5 meta-analyses, 7 component studies,

1,235 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] (1 meta-analysis, 5 component studies, 300 participants); mind-body exercise SMD of -0.50 (95% CI: -0.67 to -0.32) from eight reviews [60 81 82 110 115-118] (9 meta-analyses, 74 component studies, 5,175 participants), and mixed exercise SMD of -0.45 (95% CI: -0.60 to -0.30) from twelve reviews [58 72 81 83 99 103 107 114 119-122] (13 meta-analyses, 170 component studies, 14,208 participants). One group-based exercise review [106] showed effectiveness with SMD of -0.60 (95% CI -0.94 to -0.26) from one review (1 meta-analysis, 2 component studies, 72 participants), and no meta-analysis data were available for individual-performed exercise on anxiety.

Exercise intensity for anxiety

Low-intensity exercise demonstrated a more substantial impact with SMD of -0.68 (95% CI: -1.21 to -0.14) from two studies [72 112] (2 meta-analyses, 9 component studies, 903 participants), compared to the effect of moderate-intensity exercise with SMD of -0.06 (95% CI: -0.22 to 0.09) reported from the same two studies [72 112] (2 meta-analyses, 13 component studies, 2,069 participants). No data were available for moderate to vigorous exercise for anxiety, although data for vigourous exercise showed SMD of -0.17 (95% CI: -0.53 to 0.19) from one review [74] (1 meta-analysis, 5 component studies, 225 participants).

Exercise duration for anxiety

Short-term exercise, up to 8 weeks, demonstrated the most substantial impact with SMD of -0.70 (95% CI: -0.92 to -0.47) from two reviews [50 52] (2 meta-analyses, 12 component studies, 267 participants) compared to 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 [52 112] (4 meta-analyses, 23 component

studies, 2,285 participants), and longer-term exercise, lasting over 24 weeks, SMD of -0.03 (95% CI: -0.18 to 0.13) from one review [112] (1 meta-analysis, 7 component studies, 1,013 participants).

Exercise frequency for anxiety

Lower-frequency exercise, one or two days per week, was examined in one review [52] (1 meta-analysis, 6 component studies, 293 participants) with SMD of -0.71 (95% CI: -0.95 to -0.47), which showed more impact than higher-frequency exercise of three or more days per week, with SMD of -0.50 (95% CI: -0.71 to -0.30) from two reviews [50 52] (4 meta-analyses, 18 component studies, 1,573 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 [109 111] (1 meta-analysis, 19 component studies, 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 females. Exercise has 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 demonstrated 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 demonstrated notably higher effect sizes than individual-based activities for depression, suggesting that social components play a crucial role in the antidepressant effects of exercise. These outcomes align with research demonstrating exercise's social support benefits [123], indicating that the psychological sense of belonging may contribute additional value at both biological and psychosocial levels [124] [125] [126]. 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 [127]. 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 [128]. 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 [24] [129] [130].

The effectiveness of exercise interventions appears comparable to pharmacological treatments (SMD = -0.36) and psychotherapies (SMD = -0.34) for managing depression and anxiety symptoms [131]. 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 [19] [132]. Early interventions of exercise have been shown to enhance recovery from physiological conditions [133] [134] , and there is evidence that early interventions, from an age-related or diagnosis-timing perspective, can support recovery from ICD-10 [135] or DSM-5

diagnosed mental health conditions [136]. As exercise also stimulates neurobiological mechanisms, including increased growth of brain neurotrophins and protection against neurotoxic damage [137] [138], our findings further support public health guidance beyond the immediate impact of alleviating depression and anxiety symptoms.

Our findings suggest that exercise interventions show 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)[29]. These divergent findings may reflect the impact of pre-existing severe medical conditions on motivation and ability to exercise [139] [140] , alongside potential participation bias for physically healthier populations [141]. While the overall effect of exercise on all age groups is positive, the analysis of subgroups suggests 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 [142] 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 [143], underscoring the potential of exercise as a low-risk, high-benefit strategy for improving maternal mental health during this vulnerable period [144] [145].

For anxiety management, lower intensity and shorter duration (up to 8 weeks) interventions appear more efficacious, although a wide range of definitions are 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 [146]. 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's important to acknowledge that physical and mental health characteristics contribute significantly to exercise adoption [147]. Incorporating intrinsic motivational factors into exercise program design can significantly influence intervention adherence and participation rates [36 148 149]. Therefore, future research on intervention design and exercise prescription should prioritise the consideration of individual circumstances and needs, thereby supporting increased motivation and responses. [150]

**Strengths and Limitations**

The primary strength of this study lies in 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 enhances the robustness of these findings [1]. Our research distinguishes itself by encompassing clinically diagnosed and non-clinical populations across diverse demographics, including children and young people, emerging adults, older adults, and perinatal females. 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 [35 151].

The inspection of 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 [152 153]. Analyses of data from studies of depression for perinatal and youth populations yielded high to very high Corrected Covered Area [46] (CCA) 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 (e.g., one thousand participants) will contribute the same level of input calculation to CCA as a study with a smaller sample size (e.g., ten 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 Supplementary Table 3 and Supplementary 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 overall results. The substantial volume of meta-analyses available for depression studies engenders high confidence in the results across the analysed subgroups.

The heterogeneous interpretations of exercise parameters employed within constituent studies present a significant challenge in reporting exercise intensity and duration results with precise boundaries. Meta-analyses examining exercise intensity utilised 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 is 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 [154]. Several factors are crucial for successful implementation, including co-designed approaches and individually tailored interventions [155] [156]. Enhancing clinicians' knowledge base and developing pragmatic guidelines could promote broader adoption of exercise interventions in clinical practice [157-159].

## Conclusion

This meta-meta-analysis provides robust evidence that exercise effectively reduces depression and anxiety symptoms across all age groups, comparable to or exceeding traditional pharmacological or psychological interventions. Group and supervised formats yield 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 programs 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.

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NM, 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. NM, JD, ST, KS, AR and AS undertook investigation, methodology, and project administration. Data curation involved NM, KS and AS. NM, KS, AS and AR directly accessed and verified the underlying data reported in the manuscript. The lead statistician was KS, with NM, JD, ST, AS and AR also assisting with formal analysis. The manuscript was drafted by NM, 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 NM) 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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**Availability of data, code and other materials**

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**Patient and Public Involvement**

There has been no patient and public involvement in research from patients or members of the public in the research design, conduct, reporting, or dissemination plans.

**Ethics approval**

Ethics approval is not applicable, as there has been no patient and public involvement in research from patients or members of the public in the research design, conduct, reporting, or dissemination plans.

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