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https://doi.org/10.25903/vpfg%2Dhs61

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James Cook University – Master of Philosophy

The effect of exercise on depression and anxiety: A meta-meta-analysis

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Submission – 6th February 2025

Acknowledgements

I want to express my sincere gratitude and appreciation to the supervisory team, Professor James Dimmock, Dr Sam Teague, and Dr Klaire Somoray, for your consistent support, both formal and informal. James, your insight, sense of direction, good humour, and incisiveness have been a privilege to experience. Sam, your energy, positivity, engaging support, warmth and clarity have been inspirational. Klaire, you always bring genuine engagement, an ability to help clarify complexities into simple terms and a natural can-do energy at all stages. Successful students often comment on the importance of having a mixture of intellect and an engaging human touch with their supervisory team. This comes naturally to each of you and flows through in every conversation. Thank you. It is a genuine privilege to be on our team.

My wife, Fiona, and two children, Lachlan and Samuel, are always there with their love, support and sense of intrigue. You create a safe environment for me to disappear into my studies whilst constantly inspiring and testing me with real-world applicability questions. I can only make the study work with you beside me. Love you Fi, Lochie and Sammy.

I'd also like to express my sincere appreciation for a close friend, Dr Sathiya (Sam) Ramakrishnan, for your friendship, support, guidance and sense of humour in supporting me through the ups and downs of life, inside and outside academia. You are a real inspiration and a great friend, Sam.

Statement of the Contribution of Others

I'd also like to express my sincere appreciation to the following individuals for their specific contributions to the completion of this thesis.

Nature of Assistance	Contribution	Names, Titles and Affiliations
Primary intellectual support	Proposal guidance Project direction Research assistance Academic leadership Weekly consultation and support	Professor James Dimmock Dr Sam Teague Dr Klaire Somoray (All from James Cook University (JCU), Townsville, Australia)
Secondary intellectual support	Proposal consultation Academic insight	Associate Professor Amanda Rebar (University of South Carolina) Aaron Simpson Dr Timothy Budden Dr Ben Jackson (All from University of Western Australia (UWA and The Kids Research Institute, Perth, Australia)
Wider academic support	Administration support Checkpoint assessment Teaching masterclass Assessment marking appointment	JCU Graduate Research School team Dr Ylona Chun Tie Dr Florence Boulard Dr Emma Ward
Financial support	Stipend Publication grant Conference attendance grant (Society for Mental Health Research)	JCU
Data collection	Library management Software guidance and support Data review	Sam Rannard (JCU) Aaron Simpson (UWA)
Data analysis	Software guidance and support	Dr Klaire Somoray

	Statistical direction Data query resolution Data review	Associate Professor Amanda Rebar
Thesis review	Editorial assistance	Dr Timothy Budden (UWA) Dr Klaire Somoray Dr Sam Teague Professor James Dimmock

Statement of the use of Generative AI

While preparing this thesis, I acknowledge using two Generative AI tools, Grammarly (https://www.grammarly.com) and Claude (https://claude.ai). Both tools supported correct grammar and proofreading while helping edit text for suitability. The output from any prompts generated was reviewed, refined, and only used within the text if applicable. This thesis's substantial intellectual contributions, analyses, and conclusions are my original work.

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Abstract

Background: Depression and anxiety are estimated to impact 7-25% of the global population. Exercise offers potential as a practical, low-cost, and low-stigma therapy for depression and anxiety. Understanding what structures of exercise intervention can work best for depression and anxiety in various populations can help health practitioners guide patients to the most appropriate exercise solution.

Methods: Five databases were systematically searched (SCOPUS, PsycINFO, CINAHL, Ovid MEDLINE, SPORTDiscus) for all extant studies reporting meta-analytic outcomes of randomised controlled trials that investigated the effects of exercise on depression and/or anxiety. To avoid contamination effects, meta-analyses that exclusively examined populations with pre-existing and chronic physiological conditions were excluded. This review is unique in the inclusion of children, adults and older adults, clinical and sub-clinical depression and anxiety.

Results: Fifty-seven meta-analyses (926 component trials and 66,707 participants) were included. All types of exercise were found to reduce depression (SMD =-0.60, 95% CI -0.68 to -0.52) and anxiety symptoms (SMD =-0.43, 95% CI -0.55 to -0.32). The largest benefits for depression were seen for emerging adults, adults aged over 18, and post-natal females. Greater reductions in depression were associated with exercise at higher intensity, over a longer duration, at higher frequency, and in group and supervised settings. Exercise of shorter duration and at lower intensity was most strongly associated with anxiety reduction. Relative to other forms of exercise, aerobic exercise had the most substantial impact on both depression and anxiety symptoms.

Conclusion: Exercise in multiple formats can help mitigate depression and anxiety symptoms across all populations, with aerobic forms of exercise being the most effective. These findings can inform clinical recommendations for exercise-based interventions. Gaps exist in meta-analytical understanding of the most significant impact of exercise on anxiety for youth and perinatal females.

Impact Statement: These results can help health professionals provide targeted, cost-effective, exercise-based support that aligns with individual profiles and preferences. This meta-meta-analysis offers the most comprehensive analysis of the impact of exercise on depression and anxiety to date.

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Introduction

Depression and anxiety symptoms are estimated to impact between 7-25% of the global population [1-3]. The debilitating burden of mental illness extends beyond personal psychological suffering; it also carries adverse downstream effects on family and social functioning [4-6], can lead to physical comorbidities and chronic physiological conditions [7 8], and has high economic costs[8]. Whilst comorbidities can exist between depression and anxiety, and both are considered within the broader spectrum of mental health disorders [9], key differences apply to symptomology and the effectiveness of treatments [10]. Varied prevalence ranges can also exist amongst age ranges and population groups, with youth populations experiencing almost double the rate of depression and anxiety disorders than adults [11 12 13]. Alarmingly, the growth rate of depressive symptoms for youth continues to grow [14], particularly for females [15]. Gender disparities are also observed among individuals of childbearing age, with females experiencing twice the level of prevalence of depression and anxiety than men [11 12].

The United Nations Sustainable Development Goals [16] sets global targets and calls upon the international community to build activities that help mitigate the impact of poor mental health [17]. Treatment of symptoms via antidepressants [18 19] and psychotherapy [20] has increased substantially, although the prevalence of depression and anxiety continues to rise [21]. This suggests that the burden on mental health requires additional support strategies and the exploration of alternative approaches for treatment [22 23]. Increasingly, evidence suggests that exercise can build cognitive and neurobiological pathways that improve mental health [24 25]. Research consistently indicates that exercise improves the quality of life and psychological well-being of people with diagnosed mental illness [26 27] and offers distraction from negative impulses [28]. Improved physical functioning is associated with a lower prevalence of depression and anxiety disorders [29] and

mitigating depressive and anxiety symptoms for non-clinically diagnosed populations [30]. Exercise within depressed populations has also shown promise in reducing suicide attempts [31] and can underpin biological mechanisms that mitigate depressive symptoms [32 33].

The implementation of structured exercise programs can be an effective treatment for the management of depression [34] , whilst proposals to investigate how different parameters of exercise programs can impact depression have been suggested [35-37]. Most of the research on depression has been conducted on adult populations, with recommendations made to investigate further the potential impact of exercise on depression for potentially vulnerable population groups, including youth [38 39] and perinatal women [40 41]. Therefore, whilst exercise offers evidence to support the mitigation of depression, there remain gaps in understanding what exercise formats are the most appropriate for different population groups. In addition to the abundant literature on the effects of exercise interventions on depression, research has also revealed the positive impact of exercise interventions on anxiety symptoms [42 43] and anxiety disorders [44]. Mixed results have been reported between different exercise modalities and their impact on anxiety [45 46], leading to recommendations for further analysis [47 48]. Furthermore, studies into exercise's impact on anxiety for specific population groups are also needed [49-52].

Research on the overall effects of exercise on depression and anxiety has accumulated at such a rate that reviews have been required to consolidate findings [53]. Meta-analyses and systematic reviews can help synthesise conclusions from individual studies into narratives that help inform policymakers in the healthcare community [54]. The rate of meta-analysis production continues to increase, with over 2,800 publications in healthcare sciences per year in 2008 [55], growing to 9,135 during 2014 [56], and an expected growth curve leading to over 1890,000 in the early 2020s [57]. This ever-increasing volume, with substantial variability in conclusive

understanding of what moderators have the most significant impact, [58] has led to calls for more robust methodologies to be applied within broader synthesis methods [56 59]. Whilst it has often been acknowledged that exercise can positively mitigate depression and anxiety overall[30 60], variations in component study quality, combined with the heterogeneity of exercise characteristics, suggest that further higher-quality and wider-ranging research may provide more conclusive evidence [61].

Syntheses of meta-analyses, named "meta-meta analyses" or "overviews of reviews", can collate data and conclusions from multiple meta-analytic reviews and offer a pathway towards more conclusive, balanced and broader findings [62]. Between 2000 and 2020, over 1,500 meta-meta-analyses were published in the healthcare sciences field, with 57% of these published between 2017 and 2020 [63]. Whilst some consistencies arise in meta-meta-analyses that point towards exercise mitigating depression and anxiety symptoms, there remain conflicting conclusions in specific impacts and some gaps in population inclusions. One meta-meta review that synthesised findings from 6 meta-analyses, which in turn consolidated data from 399 studies of over 14,000 adult participants with non-clinically diagnosed symptoms, concluded that physical activity could reduce symptoms of depression significantly and to a lesser extent for symptoms of anxiety [30]. This study, however, did not include children with clinical or sub-clinical depression and/or anxiety, nor adults diagnosed with clinical levels of depression or anxiety, and was limited in providing clear evidence for what types of exercise provide the most effective mental health outcomes. A further and wider-ranging meta-meta-analysis conducted across a core population of over 125,000 adult participants concluded that higher intensity physical activity could be more effective than more prolonged duration exercise for mild to moderate depression; however, the data did not fully assess more severe or clinically diagnosed

disorders [60] [61]. This study also included populations experiencing a form of chronic physiological disease, which may provide additional variables that impact motivation levels to exercise or act as a confounding factor [64-66].

Taken together, these meta-meta-analyses indicate the potential of exercise to be effective at mitigating depression and anxiety disorders. However, challenges remain in understanding how this applies across age ranges, what types of exercise are effective against depression and anxiety specifically, and what are the most appropriate methodologies that should be applied when conducting meta-meta-analyses. It is important to measure the impact against diagnosed and non-diagnosed depression-based conditions, as definitions may be open to interpretation [67] and, at times, underdiagnosed [68]. Similar challenges remain in the diagnosis of anxiety conditions [69] and the appropriateness of guidelines provided to medical professionals [70]. Conducting a meta-meta-analysis that encompasses clinically diagnosed and non-diagnosed participants may help identify the broader potential of exercise's impact on depression and anxiety. By integrating the wealth of existing evidence, we can explore how variations in exercise characteristics affect depression and anxiety outcomes.

A consistent challenge with conducting meta-meta-analyses has been clarity surrounding study design frameworks that guide subjective and objective components [71]. Building robust and best practice protocols for meta-meta-analysis can help to ensure transparency of valid conclusions [72] [73] and assist future researchers and clinicians in research and policy design [74]. The inevitable increases in power and effect sizes from larger meta-meta-analyses increase the demand for revision of governance and protocols to help substantiate the reliability of conclusions [75]. Whilst general and well-established principles of good practice, similar to those used within meta-analysis reviews, have mainly been applied [76] and have included PRISMA-P

guidelines [77], Cochrane reporting standards [78], and risk of bias [79], an all-encompassing and widely recognised consensus of methodology for meta-meta-analyses has been lacking [80]. This has led to the development of the PRIOR framework, which aims to establish reporting protocols for meta-meta-analyses of healthcare-based interventions [81]. The emergence of the PRIOR framework represents a significant advancement in establishing standardised reporting protocols for meta-meta-analyses of healthcare-based interventions. This framework provides robust and comprehensive guidance for researchers conducting overviews of reviews, integrating the most appropriate synthesis methods into a cohesive structure that enhances trustworthiness and accessibility for healthcare professionals. This study is one of the first to apply the PRIOR protocol for analyses in the impact of exercise on depression and anxiety symptoms. It is a distinctive contribution to the field that addresses previous methodological gaps. Previous meta-meta-analyses on the effects of exercise on anxiety and depression were undertaken before the release of the PRIOR framework, representing an essential opportunity for subsequent reviews in this area.

This meta-meta-analysis aims to synthesise high-quality evidence from meta-analyses of randomised controlled trials evaluating exercise programs for depression and anxiety comprehensively across the lifespan and clinical and non-clinical symptomatology. More specifically, this meta-meta-analytic review's aims are twofold: 1) to provide meta-meta-analytic estimates of the impact of exercise programs on depression and anxiety mood and symptoms, conducted on a populace encompassing all age ranges, including those with and without clinical depression or anxiety diagnoses, and; 2) to examine any moderation effects for exercise parameters, including exercise type, duration, frequency, intensity, levels of supervision and group-based activity, as well as population groups. Applying the relatively recently developed

PRIOR methodology to this meta-meta-analysis will add to the existing literature by providing insights that aim to understand the impact of exercise on depression and anxiety symptoms, analysed within a robust framework. This paper will synthesise results from eligible and appropriate meta-analytic reviews to build cohesive conclusions that indicate the broad applicability of relevant exercise interventions in the mitigation of depression and anxiety symptoms.

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. Minor amendments were made to the protocol to ensure two additional co-authors, KS and AS were recognised. These were both approved by PROSPERO, with the record updated accordingly. Our methodological approach adheres to the protocol as described in PROSPERO and with the Reporting Guideline for Overviews of Reviews of Healthcare Interventions (PRIOR Statement) [81].

Search strategy and selection criteria

The PICOS (Patient/Population, Intervention, Comparison, Outcome, Study design) approach was employed to define the inclusion and exclusion criteria [82]. Studies eligible for this meta-meta-analysis included:

Patient/Population

Participants included children and adults assessed for depression and anxiety symptoms or diagnosed with depression or anxiety disorders as specified in DSM-5 [83] or ICD-10 [84] or on a self-reported basis. While no restrictions were placed on population age or characteristics,

studies involving participants with existing physiological conditions (e.g., heart disease, cancers, HIV, Parkinson's disease) were excluded due to the potential confounding impact on exercise motivation [85].

Intervention

Exercise interventions were defined as planned, structured, repetitive, and purposeful physical activities to improve physical and mental health [86]. Exclusion criteria encompassed:

- Interventions combining exercise with psychotherapy, nutrition, or drug-based treatments, unless the impact of exercise alone could be isolated.

Inclusion criteria encompassed:

- All exercise modalities and parameters (intensity, duration, frequency).
- All levels of supervision and settings (individual or group).

Comparison

Included meta-analyses comprised solely of randomised controlled trials (RCTs) comparing exercise activity against:

- Active control
- Placebo-control
- No-intervention/waitlist

Exclusion criteria:

- Prospective or cohort studies
- Meta-analyses incorporating non-randomised controlled trials

Outcome

Eligible meta-analyses examined the impact of exercise on depression or anxiety symptoms:

- Diagnosed using self-report mechanisms or clinician-rated assessment

- Measured on a pre-and post-trial basis
- Reported results using standardised mean difference (SMD) [87] or Hedges g [88] basis

Study type

Inclusion criteria:

- Explicit meta-analyses of component studies based on the PICO (above) criteria

Exclusion criteria:

- Systematic, narrative, or thematic reviews without meta-analysis
- Meta-meta-analyses or umbrella reviews

Databases

Database Search

Five electronic databases were searched: Scopus, PsychINFO, CINAHL, OVID Medline, and SPORTSDiscus. The search was conducted in October 2023 with no restrictions and repeated in April 2024 to capture more recent literature prior to data synthesis. The search strategy covered constructs related to depression, anxiety, randomised controlled trial designs, meta-analyses, and exercise programs (Appendix 1 – Search terms).

Study Selection Process

Search results were exported to the Colandr tool [89] for duplicate removal. Two reviewers (NM and AS) independently screened the title and abstract. Disagreements were resolved through discussion between the reviewers and consultation with the supervisory team. The full-text assessment was performed for studies that reached a consensus during the initial screening.

The full-text evaluations underwent a panel review process (JD, ST, KS). Selected studies were subsequently examined to ensure data collection utilised the pertinent meta-analyses

within each study. In cases where full texts were unavailable, or data elements proved inconclusive (five instances), study authors were contacted for clarification.

Data extraction and risk of bias assessment

Data extraction was performed using a systematic template and subjected to independent review by two additional researchers (KS and AR) for inclusion. The following data were collected: (1) demographic information (age range, sample size, sex, effect sizes, and participant characteristics); (2) intervention characteristics (exercise category, intensity, duration, frequency, group or individual exercise format, and specific sports); (3) randomised controlled trial (RCT) percentage and control group features; (4) depression or anxiety categories and assessment scales employed; (5) effect scores on depression or anxiety symptoms, utilising standardised mean differences (SMD) or Hedges' g, confidence intervals (CI), p-values, heterogeneity measures (I^2 statistic [90]), and standard errors; (6) meta-analysis study characteristics, including certainty of evidence using assessment [91] and risk of bias analyses. For clarity in reporting results, we state the number of meta-analyses collected for each sub-section. Some reviews may include more than one meta-analysis.

The study inclusion process is illustrated in the PRISMA flowchart (Figure 1). Risk of bias assessment involved the AMSTAR-2 tool [92], with each included meta-analysis classified as high, moderate, low, or critically low quality. Funnel plots were conducted to assess for publication bias.

Data synthesis

Data synthesis was conducted using R Studio software [93] and the Metafor package [94]. Two independent reviewers (NM and KS) reassessed each candidate article to extract each meta-analytic effect. The supervisory team reviewed each output, resolving any necessary

clarifications through team discussions. Standardised mean differences (SMD), confidence intervals (CI), sample sizes, weightings, overall heterogeneity and p-value calculations were collected from each selected meta-analysis. Sensitivity analyses were performed to compare the synthesis of overall depression and anxiety outcomes across studies categorised by AMSTAR [92] ratings (critically low, low, moderate, and high).

The Corrected Covered Area (CCA) method was employed to evaluate the degree of overlap in component studies across all reviews [95]. 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)[96] was used, which employs a hierarchical structure ranging from Grade A to D. Grade A represents the highest level of evidence, comprising consistent Level 1 studies, specifically systematic reviews of randomized controlled trials (RCTs) and individual RCTs. Grade B encompasses consistent Level 2 studies (systematic reviews or individual cohort studies) and Level 3 studies (systematic reviews or individual case-control studies), as well as extrapolations from Level 1 studies. Grade C includes Level 4 studies (case series) and extrapolations from Level 2 or 3 studies. Finally, Grade D represents the lowest level, consisting of Level 5 evidence (expert opinion without explicit critical appraisal) or studies of any level that demonstrate troubling inconsistency or inconclusive results.

Differences between protocol and review

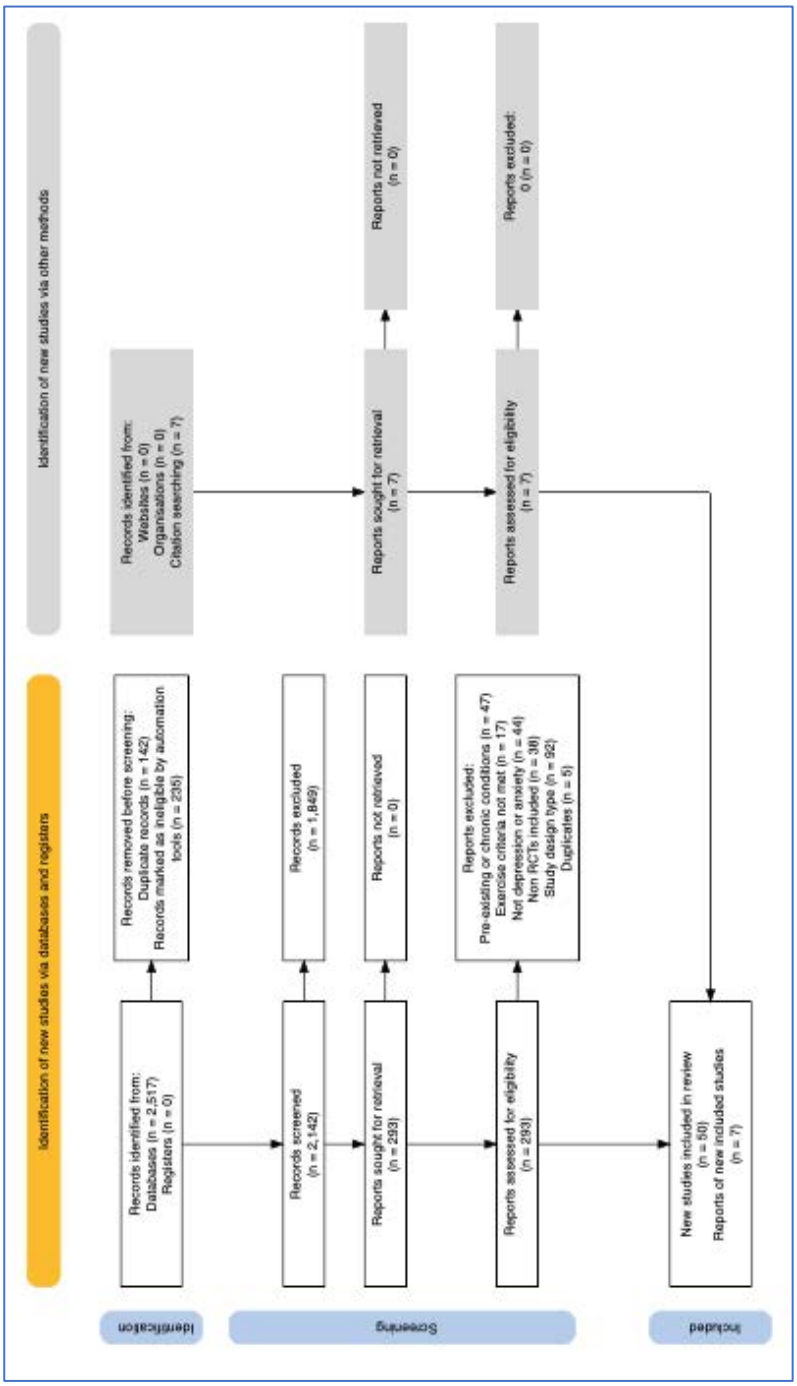
Minor amendments were made to the protocol to ensure two additional co-authors, KS and AS were recognised. These were both approved by PROSPERO.

Results

The study selection process and rationale are outlined in the PRISMA flowchart [97] (Figure 1). The initial database search yielded 2,517 records, of which 50 met the eligibility criteria for inclusion. Supplementary citation screening identified an additional seven reviews that satisfied the eligibility criteria.

Figure 1

PRISMA flowchart of study selection process



Characteristics of included reviews

Supplementary Table 1 presents the characteristics of all included reviews. The selected meta-analyses for depression (n=52) encompassed 712 component reviews, totaling 50,970 participants. For anxiety, the selected meta-analyses (n=20) comprised 214 component reviews, totaling 15,737 participants.

The degree of component study overlap across all included meta-analyses was assessed using the Corrected Covered Area[95] (CCA). The overall CCA rating for all included reviews fell within the slight overlap range, with component depression reviews at 1.30% and anxiety reviews at 0.82%. Sub-analysis level CCA categorisation confirmed slight overlap for depression-based sub-analyses, with exceptions noted for youth, female perinatal, and depression non-clinical populations (moderate rating), and female prenatal and postnatal populations (very high rating) (Supplementary Table 3). Anxiety-based sub-analyses predominantly exhibited slight overlap for CCA, with clinical populations being the sole exception, rated as moderate (Supplementary Table 4).

The majority of reviews (n=31) received a critically low AMSTAR-2 score, while the remainder were distributed between low-rated (n=20) and high-rated (n=6) reviews (Supplementary Table 2). A sensitivity analysis conducted to assess Standardized Mean Difference (SMD) for each AMSTAR-2 category revealed minimal inter-group differences for both depression (Supplementary Table 3) and anxiety (Supplementary Table 4).

Using the GRADE framework [96], all included reviews were classified as level 1 (meta-analyses of RCTs) and graded as high quality.

Population

In depression-focused reviews, meta-analytic data encompassed population groups spanning ages 10 to 90. This included meta-analyses (n=8) categorised for late adulthood (aged 55 and above)

[98-103], for adults (n=20) (aged 18 and above) [26 101 104-121], for emerging adults (n=4) (aged between 18 and 30) [122-125] , for youth (n=6) (aged 18 and under) [126-131], and for perinatal populations (n=10)[40 41 132-139].

Anxiety-based meta-analyses comprised meta-analyses for adults (n=16) (18 and above) [45 107 109 111 113 140-149] and for emerging adults (n=3) [123-125].

Exercise interventions

For depression, the analysis encompassed meta-analytic reviews across three primary exercise modalities: aerobic (n=14) [41 100 101 106 114 116 117 120 125 126 130 131 139], resistance (n=8) [100 106 116 117 120 121 125 131], and mind-body exercise (n=16). The mind-body category included yoga, tai-chi, qigong, pilates and wushusanda [41 102 103 107 111 113 115 119 124 125 131 133 139]. A fourth category, mixed exercise, [26 40 41 98-101 104-106 108-110 112 118 120 122 123 125-132 134-139] comprised meta-analyses (n=36) with multiple or undefined exercise interventions.

The anxiety-based analysis similarly categorised meta-analytic reviews (n=6) into aerobic [45 125 140 142], or resistance (n=1) [125], for mind-body (n=9) [107 111 113 124 125 145 148 150], and mixed exercise modalities (n=10) [50 109 123 125 141 143 146 147 149].

Depression

Depression-based population overall analysis

The analyses of depression outcomes (Supplementary Table 3) demonstrated a positive effect of exercise on depressive symptoms across all subgroups, including age categories, perinatal status, exercise modalities, exercise parameters, and levels of supervision. The overall analysis, encompassing forty-five reviews (comprising 52 meta-analyses, 712 component reviews, and 50,970 participants), revealed a significant medium-sized SMD [87 151] effect of -0.60 (95% CI:

−0.68 to −0.52). The narrow 95% confidence interval (−0.68 to −0.52) suggests a high degree of precision in the estimate, further strengthening the reliability of the findings.

Depression-based population sub-group analyses

Analysis of age-specific subgroups revealed varying impacts of exercise on depressive symptoms. Exercise demonstrated the most pronounced effect for emerging adults, represented by four reviews [122-125] (4 meta-analyses, 54 component reviews, 4,180 participants) with a SMD of −0.81 (95% CI −1.06 to −0.57). Exercise for adults, encompassing twenty reviews [26 101 104-121] (55 meta-analyses, 382 component reviews, 20,235 participants) exhibited an SMD of -0.67, (95% CI −0.81 to −0.53). Exercise for youth aged under 18, analysed in six reviews [126-131] (6 meta-analyses, 79 component reviews, 7,474 participants) showed an SMD of -0.44 (95% CI −0.66 to −0.33). Exercise for late adulthood, represented by six reviews [98-103] (8 meta-analyses, 72 component reviews, 5,860 participants), demonstrated an SMD of −0.41 (95% CI −0.51 to −0.50).

Analysis of perinatal populations revealed varying impacts of exercise on depressive symptoms across different stages. Postnatal populations, represented by four reviews [132 135 136 139] (4 meta-analyses, 42 component reviews, 3,437 participants) demonstrated the most pronounced effect of exercise on depression with an SMD of −0.70, (95% CI −0.92 to −0.48). Prenatal populations, analysed in four reviews [133 134 137 138] (4 meta-analyses, 42 component reviews, 4,717 participants) exhibited a medium SMD of −0.46, (95% CI −0.59 to −0.32). The broader perinatal category, encompassing nine reviews [40 41 132-134 136-139] (10 meta-analyses, 120 component reviews, 13,045 participants) showed a medium SMD of −0.49, (95% CI −0.63 to −0.35).

The perinatal group incorporated prenatal and postnatal populations and reviews explicitly designated as perinatal. Notably, these three categories exhibited high to very high interpretations in the combined covered area (CCA) analysis: perinatal (13.78%), prenatal (18.67%), and postnatal (26.92%). These elevated CCA values suggest substantial overlap in component reviews across these categories.

Exercise modes for depression

Various exercise modalities demonstrated efficacy in alleviating depression symptoms. Aerobic exercise interventions exhibited the most substantial impact, with SMD of −0.75 (95% CI −0.98 to −0.53) based on thirteen reviews [41 100 101 106 114 116 117 120 125 126 130 131 139] (14 meta-analyses, 154 component reviews, 8,352 participants). Resistance training also showed positive effects, with an SMD of -0.62 (95% CI -0.93 to -0.31), derived from eight reviews [100 106 116 117 120 121 125 131] (12 meta-analyses, 93 component reviews, 4,770 participants). Mind-body interventions yielded an SMD of -0.53 (95% CI: -0.66 to -0.39), as evidenced by thirteen reviews [41 102 103 107 111 113 115 119 124 125 131 133 139] (16 meta-analyses, 90 component reviews, 7,257 participants). Mixed exercise modalities demonstrated an SMD of -0.59 (95% CI: -0.67 to -0.31), based on thirty-two reviews [26 40 41 98-101 104-106 108-110 112 118 120 122 123 125-132 134-139] (36 meta-analyses, 559 component reviews, 42,669 participants).

Group-based exercise interventions appeared more effective than individual-based programs. Seven reviews [41 101 118 120 130-132] (7 meta-analyses, 70 component reviews, 4,858 participants) yielded an SMD of -0.71 (95% CI -0.93 to -0.47). In contrast, five reviews [41 101 118 120 130] explicitly examining individual-based exercise (5 meta-analyses, 41 component reviews, 2,253 participants) showed a lower SMD of -0.38 (-0.65 to -0.11).

Exercise intensity for depression

Differential effects were also found for the level of exercise intensity on depression symptoms. Low-intensity exercise interventions, reported in two reviews [120 130] (2 meta-analyses, 7 component reviews, 327 participants), exhibited a relatively modest effect with an SMD of -0.30 (95% CI: -0.57 to -0.02). In contrast, moderate-intensity interventions, documented in two reviews [118 120] (2 meta-analyses, 28 component reviews, 1,759 participants), showed a more substantial impact with an SMD of -0.74 (95% CI: -1.51 to -0.04). Similarly, moderate to vigorous intensity interventions, reported in two reviews [118 130] (2 meta-analyses, 11 component reviews, 591 participants), demonstrated a comparable effect with an SMD of -0.78 (95% CI: -1.26 to -0.31). Differences in definitions of intensity parameters prevented further reviews from being included.

Exercise duration for depression

The duration of exercise interventions appeared to influence their efficacy in alleviating depression symptoms. Long-term interventions spanning over 24 weeks demonstrated the most substantial impact. Two reviews [100 119] examining this duration (2 meta-analyses, 20 component reviews, 987 participants) reported a standardized mean difference (SMD) of -1.11 (95% CI: -2.01 to -0.21). Medium-term interventions, lasting 9 to 24 weeks, showed a more modest effect. Four reviews [100 102 119 125] investigating this duration (7 meta-analyses, 45 component reviews, 2,874 participants) yielded an SMD of -0.44 (95% CI: -0.57 to -0.31). Short-term interventions of up to 8 weeks demonstrated a medium effect. Four reviews [123 125 130 138] focusing on this duration (4 meta-analyses, 21 component reviews, 958 participants) reported an SMD of -0.76 (95% CI: -1.07 to -0.45).

Exercise frequency for depression

The frequency of exercise interventions demonstrated a modest influence on their effectiveness in mitigating depression symptoms. Interventions with higher frequency, specifically three or more days per week, in four reviews [121 123 125 130] (6 meta-analyses, 39 component reviews, 2,270 participants) reported a standardised mean difference (SMD) of -0.52 (95% CI: -0.75 to -0.29). Interventions with lower frequency, occurring one or two days per week, showed similar medium effects in three reviews (3 meta-analyses, 30 component reviews, 1,820 participants; SMD = -0.43; 95% CI: -0.73 to -0.13).

Exercise supervision for depression

The level of supervision in exercise interventions for depression appeared to influence their effectiveness. Supervised exercise programs demonstrated a more pronounced impact on depressive symptoms compared to unsupervised interventions. Three reviews [101 108 120] examining supervised exercise activities (3 meta-analyses, 93 component reviews, 4,624 participants) reported a standardised mean difference (SMD) of -0.69 (95% CI: -1.08 to -0.30). This effect size indicates a medium to large reduction in depressive symptoms. In contrast, three reviews [101 108 120] specifically investigating unsupervised exercise interventions (3 meta-analyses, 35 component reviews, 1,698 participants) yielded a lower SMD of -0.46 (95% CI: -0.66 to -0.26). While still demonstrating a positive effect, this suggests a small to medium reduction in depressive symptoms.

Exercise for clinical and non-clinical depression

The effectiveness of exercise interventions was examined across different population groups, distinguishing between those with clinically diagnosed depression and those without a formal clinical diagnosis. For populations with clinically diagnosed depression, eight reviews [26 105 109 114 118 126 129 138] (8 meta-analyses, 79 component reviews, 4,960 participants) reported a standardized

mean difference (SMD) of -0.73 (95% CI: -0.93 to -0.53). This effect size suggests a medium to large reduction in depressive symptoms among individuals with a clinical diagnosis. In populations explicitly identified as non-clinically diagnosed, two reviews [126 129] (2 meta-analyses, 24 component reviews, 1,617 participants) demonstrated a slightly larger effect, with an SMD of -0.81 (95% CI: -0.98 to -0.64). This indicates a substantial reduction in depressive symptoms, even among individuals without a formal clinical diagnosis of depression.

Anxiety

Anxiety-based population overall analysis

The analysis of exercise interventions for anxiety symptoms (Supplementary Table 4) revealed consistently positive outcomes across all examined subgroups, including various age categories, exercise modalities, and exercise parameters. The aggregate impact of exercise on anxiety symptoms, derived from nineteen reviews (20 meta-analyses, 214 component reviews, 15,737 participants). The overall standardised mean difference (SMD)[87] was -0.43 (95% CI: −0.55 to −0.32), indicating a small to medium reduction according to Cohen's d interpretations. [87 151]. The narrow 95% confidence interval (−0.55 to −0.32) suggests a high degree of precision in the estimate, further strengthening the reliability of the findings.

Anxiety-based population sub-group analyses

The efficacy of exercise interventions for anxiety symptoms was analysed across different age groups. For emerging adults, three reviews [123-125] (3 meta-analyses, 38 component reviews, 3,672 participants) demonstrated a medium reduction in anxiety symptoms, with a standardised mean difference (SMD) of −0.58 (95% CI: −0.64 to −0.52). In contrast, the adult population, examined in fifteen reviews [45 107 109 111 113 140-149] (16 meta-analyses, 167 component reviews, 11,550

participants), showed a slightly smaller effect size with an SMD of -0.40 (95% CI: −0.54 to −0.26).

Exercise modes for anxiety

The analysis of exercise interventions for anxiety revealed that all examined modalities demonstrated efficacy, albeit with varying degrees of impact. Aerobic exercise exhibited the most substantial effect on anxiety symptoms. Four reviews [45 125 140 142] (5 meta-analyses, 25 component reviews, 938 participants) reported a standardised mean difference (SMD) of −0.70 (95% CI: −0.94 to −0.45), indicating a medium to large reduction in anxiety. Resistance-based interventions also showed promise, with one study [125] (1 meta-analysis, 5 component reviews, 300 participants) yielding an SMD of -0.56 (95% CI: -0.84 to -0.28), suggesting a medium effect on anxiety reduction. Mind-body interventions demonstrated comparable efficacy. Eight reviews (9 meta-analyses, 74 component reviews, 5,175 participants) reported an SMD of -0.50 (95% CI: -0.67 to -0.32), indicating a medium effect size. Mixed exercise interventions, while still effective, showed a slightly lower impact. Nine reviews [107 111 113 124 125 145 148 150] (10 meta-analyses, 131 component reviews, 10,802 participants) reported an SMD of -0.35 (95% CI: -0.48 to -0.23), suggesting a small to medium effect on anxiety symptoms. Whilst the one group-based exercise study [142] (1 meta-analysis, 2 component reviews, 72 participants) showed a positive impact SMD of -0.60 (95% CI -0.94 to -0.26), no meta-analysis data was available for individual-based exercise on anxiety.

Exercise intensity for anxiety

For medium-intensity exercise interventions, one study [147] (1 meta-analysis, 8 component reviews, 1,250 participants) reported a standardised mean difference (SMD) of -0.06 (95% CI: -0.22 to 0.09). This effect size, being close to zero and with a confidence interval crossing the null

value, suggests that medium-intensity exercise may have a negligible or inconsistent effect on anxiety symptoms. In contrast, low-intensity exercise interventions demonstrated a more substantial impact. The same study [147] (1 meta-analysis, 4 component reviews, 460 participants) reported an SMD of -0.58 (95% CI: -1.39 to 0.24) for low-intensity exercise. While this effect size indicates a medium reduction in anxiety symptoms, the wide confidence interval, which crosses the null value, suggests considerable uncertainty in the estimate. No data was available for medium to vigorous exercise interventions for anxiety.

Exercise duration for anxiety

The impact of exercise intervention duration on anxiety symptoms was examined across different time frames, revealing an intriguing inverse relationship between intervention length and effect size. Long-term interventions, lasting over 24 weeks, demonstrated the least significant effect. One study [147] (1 meta-analysis, 7 component reviews, 1,013 participants) reported a standardised mean difference (SMD) of -0.03 (95% CI: -0.18 to 0.13). The confidence interval crossing zero suggests that these extended interventions may have a negligible or inconsistent effect on anxiety symptoms. Medium-term interventions, ranging from 9 to 24 weeks, showed a more substantial impact. Two reviews [125 147] (4 meta-analyses, 23 component reviews, 2,285 participants) yielded an SMD of -0.50 (95% CI: -0.64 to -0.37), indicating a medium reduction in anxiety symptoms. Interestingly, short-term interventions of up to 8 weeks demonstrated the largest effect. Two reviews [123 125] (2 meta-analyses, 12 component reviews, 267 participants) reported an SMD of -0.70 (95% CI: -0.92 to -0.47), suggesting a medium to large reduction in anxiety symptoms.

Exercise frequency for anxiety

The relationship between exercise frequency and anxiety reduction was examined, revealing an unexpected pattern in the efficacy of different exercise schedules. Two reviews [123 125]

investigated higher-frequency interventions involving exercise three or more days per week (4 meta-analyses, 18 component reviews, 1,573 participants). These interventions demonstrated a medium effect on anxiety reduction, with a standardized mean difference (SMD) of -0.50 (95% CI: -0.71 to -0.30). In contrast, lower-frequency interventions, consisting of exercise one or two days per week, were examined in one study [125] (1 meta-analysis, 6 component reviews, 293 participants). These less frequent interventions showed a more significant effect, with an SMD of -0.71 (95% CI: -0.95 to -0.47), indicating a medium to large reduction in anxiety symptoms.

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

The efficacy of exercise interventions for anxiety was examined in populations with clinically diagnosed anxiety disorders. Two reviews [45 146] (1 meta-analysis, 19 component reviews, 935 participants) on clinically diagnosed anxiety were analysed. These reviews reported a standardised mean difference (SMD) of -0.42 (95% CI: -0.61 to -0.22). This effect size indicates a small to medium reduction in anxiety symptoms among individuals with clinical anxiety diagnoses, whilst no data was available for the non-clinical anxiety population.

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, some signs of asymmetry is observed for the reviews that examined anxiety as indicated by an imbalance in the distribution of reviews, with more reviews on the left side (negative effects) compared to the right side (positive effects). (Figures 2a and 2b).

Discussion

This meta-meta-analysis of randomised controlled trials demonstrated that exercise has a medium-sized effect on depression symptoms and a small to medium effect on anxiety symptoms. Categorisation by age groups indicates that exercise for emerging adults with depression and anxiety shows a medium effect, with all other age groups reporting a small to medium effect. Exercise is shown to have a medium effect on depression symptoms for perinatal females, with a higher impact for post-natal populations. All exercise formats have shown a medium effect, with aerobic, group-based and supervised activities showing the most substantial implications for both depression and anxiety symptoms. Higher levels of intensity, duration, and frequency are all associated with the most positive effect on depression, whilst the reverse applies to interventions for anxiety populations, with shorter bouts of exercise showing evidence of the highest effect. Among the intervention formats examined, aerobic exercise demonstrated the strongest therapeutic efficacy in ameliorating both depression and anxiety symptoms, with resistance training, mixed-modality exercise, and mind-body interventions following in descending order of effectiveness. All intervention formats yielded medium effect sizes, with the sole exception of mixed-modality exercise for anxiety management, which produced effects within the small range.

These findings are generally consistent with prior systematic reviews examining the impact of various exercise modalities on depression and anxiety in adult populations. Moreover, the results suggest that exercise interventions may be more efficacious than pharmacological treatments [152-154], comparable to cognitive behavioural therapy and similar psychotherapeutic approaches [152 155]. Given these findings, it is advisable to consider exercise promotion as a cost-effective and widely accessible primary intervention for mitigating symptoms of depression and anxiety. Furthermore, clinicians should be encouraged to assess their patients' physical activity

levels regularly [156] and consider other lifestyle factors, such as diet and sleeping patterns, to provide a best-fit solution to mental health challenges [157].

Depression

Exercise demonstrates a positive effect on depressive symptoms across all examined subgroups. This consistency suggests that exercise may be universally beneficial for managing depressive symptoms, regardless of individual characteristics or exercise specifics.
Exercise interventions demonstrated significant efficacy in mitigating depressive symptoms among perinatal populations, with the most pronounced effects observed in postnatal cohorts. This finding is particularly salient given the high prevalence and potential severity of postpartum depression, which typically manifests within one month of childbirth and may persist for up to one year. The development of depressive disorders in new mothers carries substantial implications for both maternal and child health outcomes [158]. Consequently, the identification of factors that may mitigate the risk of depression during this critical period is of paramount importance. The marked effectiveness of exercise interventions in this population underscores the potential for non-pharmacological approaches in managing perinatal mental health, potentially offering a low-risk, high-benefit strategy for improving maternal mental health during this vulnerable period [159 160].

Our findings indicate that exercise interventions demonstrate greater efficacy in reducing depressive symptoms among populations with primary depression compared to prior reviews on those with comorbid physiological conditions [30 60]. This may reflect the impact of pre-existing severe medical conditions on motivation to exercise [161 162] and reiterate participation bias for physically healthier populations [163]. While the overall effect is positive, the review of subgroups suggests that there may be nuanced differences in the impact of exercise based on specific

population characteristics. Further analysis of these subgroups could provide more targeted insights for tailored interventions.

The depression-based results also show a more positive impact for longer exercise durations, higher frequency, and increased exercise intensity. It may be possible that longer-term exercise interventions have more influence on the longer-term nature of depression symptoms and diagnosis. This is consistent with research on other forms of depression interventions, such as pharmaceutical [154] and psychotherapeutic treatments [164], which show similar growth in positive outcomes the more prolonged the intervention is applied.

Several important observations can be drawn from the findings comparing group exercise with individual activity. The markedly higher effect size for group-based interventions compared to individual-based interventions suggests that the social component of exercise may play a crucial role in its antidepressant effects, whilst the non-overlapping confidence intervals between the two formats indicate that the difference in efficacy is likely statistically significant. The efficacy of group-based interventions highlights the potential importance of social interaction and support in enhancing the mood-elevating effects of exercise. Clinicians and health professionals might consider prioritising group-based exercise programs when recommending physical activity for depression management. Future research could explore the specific mechanisms by which group dynamics enhance the antidepressant effects of exercise, potentially informing more effective intervention designs.

The higher effect size for supervised interventions over unsupervised suggests that professional oversight or guidance may enhance the antidepressant effects of exercise. While the confidence intervals for the two intervention types overlap slightly, the difference in effect sizes is substantial enough to warrant consideration in clinical practice.

These outcomes align with research demonstrating exercise's social support benefits [165], suggesting that the psychological sense of belonging may contribute additional value [166] and confer advantages at biological and psychosocial levels [36 167]. Consequently, although group and supervised exercise activities necessitate additional temporal and financial resources, this investment can yield substantially more significant improvements. These findings underscore the potential value of incorporating supervised elements into exercise interventions for depression while also acknowledging the efficacy of self-directed exercise programs. Further research may be beneficial in identifying the specific factors within supervised programs that contribute to their enhanced effectiveness. 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 [30 168 169]. Further research may be warranted to identify and develop optimal evaluative frameworks for assessing the efficacy of group-based and supervised exercise interventions. Such frameworks could significantly inform evidence-based decision-making processes when designing and implementing future programs. Developing robust assessment methodologies may facilitate a more nuanced understanding of the factors contributing to successful outcomes in these intervention modalities, thereby enhancing their potential impact on mental health outcomes [170-172].

Exercise interventions appear to be effective in reducing depressive symptoms across both clinical and non-clinical populations, with large effect sizes in both groups. The efficacy of exercise in non-clinical populations highlights its potential as a preventive strategy or early intervention for individuals at risk of developing clinical depression. These findings underscore the robust antidepressant effects of exercise across both clinical and non-clinical populations.

Anxiety

The effect sizes reported for anxiety suggest that exercise interventions are associated with a meaningful decrease in anxiety symptoms compared to control conditions. The consistency of positive outcomes across diverse subgroups underscores the robustness of exercise as a potential therapeutic approach for managing anxiety. In contrast to depression, the anxiety-based overall findings of our study are consistent with similar studies for anxiety-based populations that include pre-existing conditions for adults only [60] and adults in a non-clinical setting [30]. Early-stage interventions for anxiety disorders have been shown to mitigate the onset of secondary mental health disorders [173] and shorter-term psychotherapy interventions have been shown to demonstrate immediacy of results [174]. Further meta-analyses that review how different exercise parameters impact anxiety may help confirm if shorter-term interventions are more appropriate for anxiety-based populations.

The more pronounced effect observed in emerging adults could be attributed to various factors, such as potentially higher baseline anxiety levels, greater neuroplasticity, or differences in lifestyle and environmental stressors compared to the adult population. 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.

The pattern of results for intervention parameters on anxiety indicates an inverse relationship, with lower intensity, shorter duration, and less frequent interventions appearing more efficacious in reducing anxiety symptoms. This unexpected relationship may reflect better adherence to less demanding schedules, reduced risk of overtraining, or more effective recovery

periods in lower-frequency interventions. These findings challenge the conventional assumption that more exercise leads to better anxiety management outcomes and suggest that less frequent exercise regimens may offer substantial benefits for individuals with anxiety. However, given the limitations in the available data, further research should aim to elucidate the mechanisms underlying this time-dependent relationship and explore strategies to maintain the effectiveness of exercise interventions for anxiety management over extended periods.

Whilst the scope of our study did not encompass an assessment of exercise motivations and explicitly excluded populations affected by physiological factors that might influence exercise engagement, it is imperative to acknowledge that contributing factors to motivation, including physical health and depression and anxiety characteristics, invariably play a crucial role in the adoption of exercise interventions [175]. When adequately understood and aligned, incorporating intrinsic motivational factors into exercise program design can significantly influence intervention adherence and participation rates [86 176 177]. Therefore, future research on intervention design and exercise prescription should prioritise the consideration of individual circumstances, motivations, and needs.

Strengths and Limitations

The primary objective of this review was to conduct an umbrella synthesis of data from meta-analyses of randomised controlled trials, aiming to present comprehensive conclusions applicable across diverse population groups. The substantial volume of meta-analyses available for depression-based studies engenders high confidence in the results across the analysed age groups, exercise types, and sub-categories.

Our research distinguishes itself through its comprehensive approach, 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 aims to mitigate the confounding effects of physiological illness-related motivations on exercise engagement and its subsequent psychological outcomes [85 178]. This study's robustness is underscored by its synthesis of data from 72 meta-analyses, incorporating 926 component studies and involving 66,707 participants. This study represents one of the initial comprehensive applications of the PRIOR framework's complete recommendations in assessing the impact of exercise on depression and anxiety [81]. This extensive evidence base provides substantial support for the study's findings and contributes significantly to the existing body of knowledge in this field. By applying the PRIOR framework to our findings, we can present these results with a high degree of confidence.

However, the inherent nature of synthesising a wide range of studies inevitably leads to nuanced variations, with some categories presenting challenges in obtaining pertinent meta-analytical data. It is important to note that a meta-meta-analysis is, by design, constrained by the quality and quantity of its constituent studies.

Conversely, notable gaps emerge in anxiety-based categories, with a particular absence of anxiety-based meta-analytical data for late adulthood, youth, and perinatal groups in our study. Youths experiencing anxiety demonstrate a reduced propensity to seek support [179], while anxiety symptoms persist at notable rates among older female populations [180]. Perinatal women exhibit elevated rates of anxiety [181], and this demographic continues to be identified as necessitating more comprehensive analyses of intervention strategies [182]. These findings highlight a significant opportunity for researchers to conduct meta-analyses on specific data for anxiety-symptomatic

population groups that may be understudied despite showing potential for positive outcomes from exercise interventions.

While the nature of exercise motivation was intentionally excluded from the original scope of this study, an examination of motivational theories may prove instrumental in informing the development of future exercise intervention policies. Although the beneficial impact of exercise on depression and anxiety is well-established, this knowledge alone may be insufficient to engender sustained exercise participation. Self-determination theory posits that all individuals possess three fundamental psychological needs - autonomy, competence, and relatedness - as integral to personal growth and development [176]. These three needs can be aligned with our study outcomes, illustrating the significance of autonomy (choice in exercise modality), competence (enhanced self-efficacy in exercise execution), and relatedness (social dimensions and integration of exercise within broader personal frameworks). Additionally, the placebo effect associated with exercise engagement may contribute to perceived improvements in depressive and anxious symptomatology [183]. Moreover, an inverse analysis of our research objectives, examining the impact of stress, depression, and anxiety on exercise motivation [184] [185]- could help identify additional motivational factors crucial for designing efficacious exercise interventions.

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 moderate-intensity exercise utilised disparate source definitions for intensity [186] [187], while exercise duration parameters showed wide variations within component studies. It is worth noting that inconsistencies in the definitions of intensity parameters across studies precluded the inclusion of additional research in this analysis. This limitation underscores the need for standardised intensity classifications in future investigations

to facilitate more comprehensive comparisons. Therefore, future research designs should carefully evaluate the most appropriate definitions of relevant exercise parameters.

Concurrently, age category definitions demonstrated substantial inconsistency, as exemplified by two studies that classified youth as individuals aged 12 to 25 [50 126] , which were subsequently excluded from our analysis of youth populations. Future studies should consider adopting widely recognised and standardised definitions of exercise parameters and age categories to enhance the validity of multiple replications [188]. In addition, our study examined the effects of exercise interventions on depression and anxiety over durations ranging from under 8 weeks to over 24 weeks. However, the cross-sectional nature of this research limits our understanding of long-term outcomes. Future longitudinal investigations should consider evaluating the impact of exercise on depression and anxiety over extended periods, which may elucidate whether the observed effects are sustained or diminish over time due to habituation. Moreover, advancements in technology, particularly the integration of smart devices capable of autonomously tracking physical activity, could enhance the precision of exercise parameter measurements in subsequent studies. This technological integration may yield more accurate and comprehensive data, thereby strengthening the validity of future research findings in this domain.

Analyses of depression-based data for perinatal and youth populations yielded high to very high Corrected Covered Area [95] (CCA) ratings, indicative of substantial duplication among component studies. This finding underscores the necessity for additional, diverse studies focusing on these specific demographic groups. Conversely, all other categories, encompassing both depression and anxiety domains, demonstrated CCA calculations interpreted as low or slight overlap. This latter finding suggests a high degree of uniqueness among component

studies, thereby enhancing the reliability of conclusions drawn from the meta-meta-analyses in these categories.

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 Standardised Mean Difference (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). Furthermore, generative artificial intelligence software may support synthesis for future meta-meta-analyses and mitigate the risk of component study duplication.

Despite most meta-analyses in our study being categorised as 'critically low' (n=43) or 'low' (n=23) quality according to AMSTAR-2, a tool for assessing systematic reviews, our findings suggest that these ratings may not significantly impact the overall results. Applying the AMSTAR-2 categorisation revealed only a few studies rated as 'high' quality (n=6) (Table 4). The low ratings were primarily due to the lack of pre-registered protocols and failure to explicitly list excluded component studies, two critical factors in the AMSTAR-2 assessment. To investigate the impact of these ratings, we conducted sensitivity analyses across the three quality domains. These analyses (Supplementary Figures 22, 23, 24, 34) showed little difference in results when compared, suggesting that while implementing the full range of AMSTAR-2

domains would have increased the studies' quality ratings, it is unlikely that this would have significantly altered the robustness of the overall findings.

Conclusions and future directions

This meta-meta-analysis supports the hypothesis that all exercise modalities can effectively mitigate depression and anxiety symptoms across all age groups, demonstrating significant efficacy beyond pharmaceutical and psychotherapeutic interventions. While these findings are generalised within the context of a meta-meta-analysis, highlighting specific outcomes can assist medical professionals and individuals identify the most suitable forms of exercise based on individual preferences and circumstances [189]. Policymakers should consider promoting group and supervised exercise formats, which yield the most substantial outcomes and psychosocial benefits. Furthermore, additional research is warranted for specific population groups, such as youth and perinatal individuals, where the anxiety-reducing effects of exercise, although promising, are not as thoroughly understood. Our findings indicate that these demographic cohorts may derive significant benefits from exercise interventions targeting depression. Expanding research efforts to encompass these groups would address a critical gap in the existing literature and potentially inform more targeted and effective interventions across diverse life stages.

Whilst the volume of evidence supports exercise as an effective intervention, the consideration of exercise being recommended by clinical professionals remains low [190], with global variations observed in front-line recommendations [191]. Several factors have been identified as crucial for the successful implementation of exercise programs, including co-designed approaches and the identification of individually tailored exercise interventions [192 193]. Additionally, enhancing clinicians' knowledge base and capacity to develop pragmatic guidelines

has been recognised as essential [194]. Pragmatic approaches have been suggested that can help practitioners prescribe and monitor exercise [195], with clarity and simplicity of guidelines as key elements in fostering patient engagement [196]. Therefore, producing academic evidence translated into simple and widely understood guidelines emerges as a potential strategy to promote broader adoption of exercise interventions in clinical practice [193].

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Appendices

Appendisx 1 – Search terms

SCOPUS ((TITLE (depression OR anxiety OR "Mood disorder" OR "Behavioural symptoms" OR depress* OR mood OR compulsive OR ocd) OR ABS (depression OR anxiety OR "Mood disorder" OR "Behavioural symptoms" OR depress* OR mood OR compulsive OR ocd))) AND ((TITLE (exercise OR yoga OR sports OR running OR jogging OR "physical conditioning" OR "exercise therapy" OR "Physical activity") OR ABS (exercise OR yoga OR sports OR running OR jogging OR "physical conditioning" OR "exercise therapy" OR "Physical Activity"))) AND ((TITLE ("Meta-Analysis" OR "Meta Analysis" OR systematic OR umbrella) OR ABS ("Meta-Analysis" OR "Meta Analysis" OR systematic OR umbrella))) AND ((TITLE (rct OR random* OR "control trial") OR ABS (rct OR random* OR "control trial")))
PsychINFO (tiab(depression) OR tiab(anxiety) OR tiab(mood) OR tiab(behavioral issues) OR tiab(Mental Health) OR tiab(depressive)) AND (tiab(Exercise) OR tiab(Yoga) OR tiab(Running) OR tiab(jogging) OR tiab(Sport) OR tiab(Exercise Therapy) AND tiab(physical activity)) AND (tiab(Meta Analysis) OR tiab(meta-analysis) OR tiab(systematic review) OR tiab(umbrella)) AND (tiab(RCT) OR tiab(randomised control trial) OR tiab(randomized control trial) OR tiab(randomised control) OR tiab(randomized trial))
CINAHL TI (depression OR anxiety OR "Mood disorder" OR "Behavioural symptoms" OR depress* OR mood OR compulsive OR ocd OR "Mental Health") AND TI (exercise OR yoga OR sports OR running OR jogging OR "physical conditioning" OR "exercise therapy" OR "Physical activity") AND TI (rct OR random* OR "control trial" AND TI ("Meta-Analysis" or "Meta Analysis" or systematic or umbrella)
Ovid MEDLINE 1 - exp Depression/ or exp Anxiety/ or exp Mood Disorders/ or Depressive.mp. or exp Behavioral Symptoms/ [mp=title, book title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms, population supplementary concept word, anatomy supplementary concept word] 2 - exp Exercise/ or Yoga/ or exp Sports/ or exp Running/ or exp exercise therapy/ or physical conditioning.mp. [mp=title, book title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease

supplementary concept word, unique identifier, synonyms, population supplementary concept word, anatomy supplementary concept word] 3 - "Randomized Controlled Trials as Topic"/ or RCT.mp. or random*.mp. [mp=title, book title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms, population supplementary concept word, anatomy supplementary concept word] 4 – 1 and 2 and 3 5 - limit 4 to (meta analysis or "review" or "systematic review") 6 - limit 5 to (meta analysis or "review" or "systematic review")
SPORTDiscus (depression OR anxiety OR "Mood disorder" OR "Behavioural symptoms" OR depress* OR mood OR compulsive OR ocd OR "Mental Health") AND TI (exercise OR yoga OR sports OR running OR jogging OR "physical conditioning" OR "exercise therapy" OR "Physical activity") AND (rct OR random* OR "control trial" AND TI ("Meta-Analysis" or "Meta Analysis" or systematic or umbrella)

Supplementary Table 1 - Characteristics of individual studies

Meta-Analysis Study reference	Component studies (n=)	Population sample total (n=)	Population characteristics	Intervention categories	Outcome categories	AMSTAR Categorisation
Axelsdottir, 2021	4	159	Youth Under 18; Depression symptoms	Mixed exercise	Depression	High
Aylett 2018,	6	204	Adults aged 18 and over; Anxiety symptoms	Aerobic	Anxiety	High
Bailey, 2017	16	771	Youth and Adolescents aged 12 to 25; Depressive symptoms, clinical and non-clinical, and depression diagnosis	Mixed exercise, aerobic and combined aerobic and resistance sub-categories	Depression	Low
Bjorkman, 2021	10	605	Adults aged 18 and over; Post Traumatic Stress Disorder	Mixed exercise	Anxiety	Critically low
Bridie, 2012	9	519	Late Adulthood aged 60 and over; Depression symptoms	Mixed exercise	Depression	Low
Carter, 2016	8	384	Youth Under 18; Depressive symptoms	Mixed exercise	Depression	Critically low
Carter, 2019	17	1428	Postnatal females; Depression symptoms	Mixed exercise	Depression	Low
Carter, 2021	9	515	Youth & Adolescent aged under 25; Anxiety symptoms	Mixed exercise	Anxiety	Low
Chi, 2013	6	365	Late Adulthood aged 55 and over; Depression symptoms	Mind-body, duration up to 12 weeks and above 24 weeks.	Depression	Critically low
Conn, 2010 (a)	60	2679	Adults aged 18 and over; Depression symptoms	Mixed exercise, supervised and unsupervised sub-categories	Depression	Critically low
Conn, 2010 (b)	13	2786	Adults aged 18 and over; Anxiety symptoms	Mixed exercise	Anxiety	Critically low
Correia, 2024	13	1058	Adults aged 18 to 65; Depression diagnosis	Mixed exercise, frequency up to 150 minutes per week and over 150 minutes per week. Intensity light to moderate, moderate, and moderate to vigourous. Group and individual based activity.	Depression	Critically low
Cramer, 2013	7	281	Adults aged 18 and over; Depression and anxiety symptoms	Mind-body	Depression and anxiety	Low
Cramer, 2018	5	279	Adults aged 18 and over; Anxiety symptoms	Mind-body	Depression and anxiety	Low
Daley, 2009	5	221	Postnatal females; Postnatal depression	Mixed exercise	Depression	Critically low
Daley, 2014	6	348	Prenatal females; Depression symptoms	Mixed exercise	Depression	Critically low
Daley, 2018	8	528	Postnatal females; Mothers with depression <1 year postpartum	Mixed exercise, including group based sub-category	Depression	Critically low
Davis, 2021	6	215	Adults aged 18 to 65; Depression diagnosis	Aerobic	Depression	Critically low
Ensari, 2015	36	1233	Adults aged 18 and over; Depression symptoms	Mixed exercise	Anxiety	Critically low
Gallegos, 2017	4	174	Adults aged 18 and over; Post Traumatic Stress Disorder	Mind-body	Anxiety	Critically low

Meta-Analysis Study reference	Component studies (n=)	Population sample total (n=)	Population characteristics	Intervention categories	Outcome categories	AMSTAR Categorisation
Gong, 2015	6	375	Prenatal females; Depression symptoms	Mind-body	Depression	Critically low
Guo, 2020	10	573	College students, age not explicit; Depression symptoms	Mixed exercise	Depression	Critically low
Heissel, 2023	41	2658	Adults aged 18 to 65; Depression symptoms	Mixed exercise, aerobic, resistance, group-based, individual, supervised and unsupervised sub-categories. Intensity, low, moderate and vigourous.	Depression	Low
Huang, 2023	50	3366	Emerging adults aged 18 to 30; Depressive mood	Mixed exercise, duration 6 to 8 weeks, 10 to 12 weeks, 14 to 17 weeks, 18 to 24 weeks. Frequency, 2, 3, 4 and 5 days per week. Mind-body activities, qijong, wushushanda and yoga. Aerobic, basketball and resistance.	Depression	Critically low
Jazayeri, 2022	42	1558	Adults aged 18 and over; Depression symptoms	Aerobic, resisatance and combined sub-categories	Depression	Critically low
Ko, 2023	5	328	Late Adulthood aged 60 and over; Depression symptoms	Mind-body, yoga.	Depression	Critically low
Krogh, 2017	35	2498	Adults aged 18 and over; Major depression symptoms	Mixed exercise	Depression	Low
Lawlor, 2001	10	432	Adults aged 18 and over; Depression diagnosis	Mixed exercise	Depression	Low
Lee, 2021	22	1025	Adults aged 18 to 59, and aged 60 and over; Depression symptoms	Mixed exercise, aerobic, individual, group, supervised and unsupervised sub-categories.	Depression	Critically low
Li, 2023	35	5293	Youth Under 18; Depression symptoms	Mixed exercise, aerobic, resistance, group-based and mind-body sub-categories.	Depression	High
Lin, 2022	17	1910	Emerging adults aged 18 to 30; Depression and anxiety symptoms	Mind-body	Depression and anxiety	Low
Liu, 2022	20	2866	Perinatal females; Perinatal Depression symptoms	Mixed exercise, mind-body, aerobic, individual and group-based sub-categories. Bout duration 40 to 90 minutes and above 150 minutes. Duration 3 to 4 weeks, 6 to 9 weeks, and 12 weeks and above	Depression	Low
Liu, 2023	17	1463	Prenatal females; Depression diagnosis	Mixed exercise	Depression	Critically low
Luo, 2022	15	2003	Emerging adults aged 18 to 30; Depression and anxiety symptoms	Mixed exercise, frequency 3 days or less per week and 4 days a week or more. Duration 8 weeks or less and over 8 weeks	Depression and anxiety	Critically low

Meta-Analysis Study reference	Component studies (n=)	Population sample total (n=)	Population characteristics	Intervention categories	Outcome categories	AMSTAR Categorisation
Mahmoudi, 2022	26	1354	Late Adulthood aged 60 and over; Depression symptoms	Mixed exercise, aerobic and combined aerobic and resistance sub-categories. Female and male categorisation. Exercise duration 9 to 24 weeks, and above 24 weeks.	Depression	Low
Martínez-Domínguez, 2018	27	3662	Adults aged 40 and over; Anxiety symptoms	Mixed exercise, duration 12 to 18 weeks and 6 to 14 months, intensity low and medium	Anxiety	Critically low
Mead, 2010	23	907	Adults aged 18 and over; Depression symptoms	Mixed exercise, including aerobic, resistance and mixed exercise sub-categories	Depression	High
Morres, 2018	11	455	Adults aged 18 and over; Major depressive disorder	Mixed exercise	Depression	Low
Morres, 2022	16	2025	Perinatal females; Perinatal Depression symptoms	Mixed exercise	Depression	Low
Nebiker, 2018	29	1424	Adults aged 18 and over; Depression diagnosis	Aerobic and resistance.	Depression	Critically low
Park, 2014	24	3152	Late Adulthood aged 65 and over; Depression symptoms at 3 months, 6 months, and 12 months	Mixed exercise	Depression	Critically low
Ramos-Sanchez, 2021	13	731	Adults aged 18 and over; Diagnosed Anxiety	Mixed exercise	Anxiety	High
Robertson, 2012	8	295	Adults aged 18 and over; Depression symptoms	Aerobic, walking, including group walking sub-category	Anxiety	Critically low
Rosenbaum, 2014	20	1298	Adults aged 18 and over; Depressive symptoms with a mental illness	Mixed exercise	Depression	Critically low
Rosenbaum, 2015	7	383	Adults aged 18 and over; Post Traumatic Stress Disorder	Mixed exercise	Depression and anxiety	Critically low
Rossi, 2024	29	1980	Adults aged 18 to 65; Depression symptoms	Resistance, duration 11 weeks or less and 12 weeks or more. Frequency 1 to 2 times per week and 3 or more times per week.	Depression	Low
Sanchez-Polan, 2021	13	2531	Prenatal females; Depression symptoms	Mixed exercise	Depression	Low
Sani, 2023	4	243	Adults aged 18 and over; Depression symptoms	Mind-body	Depression	Low
Schuch, 2016	9	384	Adults aged 18 and over; Major depressive disorder	Mixed exercise	Depression	High
Stubbs, 2017	6	262	Adults aged 18 and over; Depression symptoms	Aerobic	Anxiety	Low
Volbehr, 2018	11	603	Adults aged 18 to 65; Depression and anxiety symptoms	Mind-body	Depression	Critically low
Wang 2014,	4	247	Adults aged 18 and over; Anxiety symptoms	Mind-body	Anxiety	Critically low
Wang, 2022	19	1205	Youth Under 18; Depression diagnosis and depression symptoms	Mixed exercise	Depression	Critically low
Wang, 2023	12	1260	Postnatal females; Postnatal depression	Mixed exercise, aerobic walking exercise, mind-body yoga activity.	Depression	Low
Zeng, 2023	12	731	Adults aged 45 and over; Depression symptoms	Mind-body activities, tai-chi. Duration 9 to 24 weeks and above 24 weeks.	Depression	Critically low
Zhang, 2023	13	433	Youth Under 18; Depression symptoms	Mixed exercise, aerobic, individual and group-based sub-categories. Duration 8 weeks or less, 8 to 12 weeks, over 12 weeks. Frequency 1 or 2 days per week, 3 days a week or more. Intensity low or moderate to vigourous.	Depression	Low
Zoogman, 2019	38	2295	Adults aged 18 and over; Anxiety symptoms	Mind-body, yoga	Anxiety	Critically low

Supplementary Table 2

AMSTAR-2 categorisation

	AMSTAR 2 -Critical domains							AMSTAR 2 - Non critical domains									Overall AMSTAR 2 rating
	2 Protocol registered	4 Literature search	7 List of excluded studies	9 Risk of bias from studies included	11 Appropriate meta-analytical methods	13 Consideration of bias in results	15 Assessment of publication bias	1 PICO criteria applied	3 Included study designs explained	5 Study selection in duplicate	6 Data extraction in duplicate	8 Included studies described	10 Funding sources stated	12 Impact of risk of bias on results	14 Heterogeneity explained	16 Conflicts of interest reported	
Axelsdottir, 2021	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	**High**
Aylett, 2018	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	**High**
Bailey, 2017	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	**Low**
Bjorkman, 2021	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	**Critically low**
Bridle, 2012	No	Yes	Partial	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	**Low**
Carter, 2016	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	**Critically low**
Carter, 2019	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	**Low**
Carter, 2021	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	**Low**
Chi, 2013	No	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	**Critically low**
Conn, 2010 (a)	No	Yes	No	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No	**Critically low**
Conn, 2010 (b)	No	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	**Critically low**
Correia, 2024	Yes	Yes	No	Yes	Yes	No	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	**Critically low**
Cramer, 2013	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	**Low**
Cramer, 2018	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No	**Low**
Daley, 2009	No	Yes	No	Partial	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	**Critically low**
Daley, 2014	No	Yes	No	No	Yes	No	No	Yes	Yes	Yes	Yes	No	Yes	No	Yes	Yes	**Critically low**
Daley, 2018	Yes	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	**Critically low**
Davis, 2021	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No	**Critically low**
Ensari, 2015	No	Yes	No	No	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	**Critically low**
Gallegos, 2017	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	**Critically low**
Gong, 2015	No	Yes	Yes	No	Yes	No	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	**Critically low**
Guo, 2020	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	**Critically low**
Heissel, 2023	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	**Low**
Huang, 2023	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No	Yes	Yes	**Critically low**
Jazayeri, 2022	No	Yes	No	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	**Critically low**
Ko, 2023	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	**Critically low**
Krogh, 2017	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	**Low**
Lawlor, 2001	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	**Low**
Lee, 2021	Yes	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	**Critically low**
Li, 2023	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	**High**
Lin, 2022	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	**Low**
Liu, 2022	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	**Low**
Liu, 2023	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	**Critically low**
Luo, 2022	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	**Critically low**
Mahmoudi, 2022	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	**Low**
Martínez-Domínguez, 2018	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	**Critically low**
Mead, 2010	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Partial	Yes	Yes	Yes	Yes	**High**
Morres, 2018	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No	**Low**
Morres, 2022	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	**Low**
Nebiker, 2018	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	**Critically low**
Park, 2014	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No	**Critically low**
Ramos-Sanchez, 2021	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	**High**
Robertson, 2012	No	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No	No	No	No	**Critically low**
Rosenbaum, 2014	Yes	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	**Critically low**
Rosenbaum, 2015	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	**Critically low**
Rossi, 2024	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	**Low**
Sanchez-Polan, 2021	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	**Low**
Sani, 2023	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	**Low**
Schuch, 2016	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	**High**
Stubbs, 2017	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	**Low**
Volbehr, 2018	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	**Critically low**
Wang, 2014	No	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	**Critically low**
Wang, 2022	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	**Critically low**
Wang, 2023	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	**Low**
Zeng, 2023	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	**Critically low**
Zhang, 2023	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	**Low**
Zoogman, 2019	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	No	Yes	Yes	No	**Critically low**

Supplementary Table 3

Depression synthesis results

Population sub category	Outcome	Overall papers (n=)	Individual meta-analysis effects (n=)	Component studies (n=)	Participant population (n=)	CCA Score	Standardised mean difference estimate	Standard error	P value	Confidence Interval upper boundary	Confidence Interval lower boundary	Heterogeneity (i2)
Late adulthood (over 55)	Depression	6	8	72	5,860	0.88%	-0.41	0.05	<0.0001	-0.51	-0.30	0.00
Adults (18+)	Depression	20	20	382	20,235	2.47%	-0.67	0.07	<0.0001	-0.81	-0.53	92.61
Emerging adults (college students)	Depression	4	4	54	4,180	1.42%	-0.81	0.12	<0.0001	-1.06	-0.57	60.14
Youth (under 18)	Depression	6	6	79	7,474	10.53%	-0.44	0.08	<0.0001	-0.66	-0.33	49.54
Female prenatal	Depression	4	4	42	4,717	18.67%	-0.46	0.07	<0.0001	-0.59	-0.32	0.03
Female postnatal	Depression	4	4	42	3,437	26.92%	-0.70	0.11	<0.0001	-0.92	-0.48	0.00
Female perinatal	Depression	9	10	120	13,045	13.78%	-0.49	0.07	<0.0001	-0.63	-0.35	62.14
Clinical depression diagnosis	Depression	7	8	79	4,960	1.70%	-0.73	0.10	<0.0001	-0.93	-0.53	52.08
Non-clinical depression diagnosis	Depression	2	2	24	1,617	14.81%	-0.81	0.09	<0.0001	-0.98	-0.64	0.00

Exercise sub category	Outcome	Overall papers (n=)	Individual meta-analysis effects (n=)	Component studies (n=)	Participant population (n=)	CCA Score	Standardised mean difference estimate	Standard error	P value	Confidence Interval upper boundary	Confidence Interval lower boundary	Heterogeneity (i2)
Aerobic	Depression	13	14	154	8,352	2.49%	-0.75	0.12	0.00	-0.98	-0.53	91.04
Resistance	Depression	8	8	93	4,770	3.96%	-0.62	-0.16	<0.0001	-0.93	-0.31	90.45
Mind body (Yoga, Tai Chi, Qigong, Pilates & Wushusanda)	Depression	11	16	90	7,257	0.96%	-0.53	0.07	<0.0001	-0.66	-0.39	64.22
Mixed exercise (not defined in other categories)	Depression	32	36	559	42,669	1.82%	-0.59	0.04	<0.0001	-0.67	-0.51	80.02
Group exercise	Depression	7	7	70	4,858	2.42%	-0.71	0.12	<0.0001	-0.93	-0.47	55.49
Individual	Depression	5	5	41	2,263	2.72%	-0.38	0.14	0.01	-0.65	-0.11	82.71
Intensity low	Depression	2	2	7	327	0.00%	-0.30	0.14	0.03	-0.57	-0.02	0.00
Intensity moderate	Depression	2	2	28	1,759	4.08%	-0.74	0.40	0.06	-1.51	-0.04	90.39
Intensity moderate to vigourous	Depression	2	2	11	591	0.00%	-0.78	0.24	0.00	-1.26	-0.31	20.87
Duration - Short term up to 8 weeks	Depression	4	4	21	958	0.00%	-0.76	0.16	<0.0001	-1.07	-0.45	17.90
Duration - Medium term 9 to 24 weeks	Depression	4	7	45	2,874	0.00%	-0.44	0.07	<0.0001	-0.57	-0.31	46.83
Duration - Long term over 24 weeks	Depression	2	2	20	987	0.00%	-1.11	0.46	0.02	-2.01	-0.21	85.82
Frequency - 1 to 2 days a week	Depression	3	3	30	1,820	0.00%	-0.43	0.15	0.01	-0.73	-0.13	73.75
Frequency - 3 or more days a week	Depression	4	6	39	2,270	0.00%	-0.52	0.12	<0.0001	-0.75	-0.29	58.90
Supervised	Depression	3	3	93	4,624	2.78%	-0.69	0.20	0.00	-1.08	-0.30	90.58
Unsupervised	Depression	3	3	35	1,698	2.78%	-0.46	0.10	<0.0001	-0.66	-0.26	0.00

Overall AMSTAR-2 category	Outcome	Overall papers (n=)	Individual meta-analysis effects (n=)	Component studies (n=)	Participant population (n=)	CCA Score	Standardised mean difference estimate	Standard error	P value	Confidence Interval upper boundary	Confidence Interval lower boundary	Heterogeneity (i2)
AMSTAR-2 High	Depression	4	4	71	6,743	3.08%	-0.64	0.19	0.00	-1.01	-0.27	82.19
AMSTAR-2 Low	Depression	18	18	289	22,875	3.47%	-0.63	0.06	<0.0001	-0.75	-0.51	80.88
AMSTAR-2 Critically Low	Depression	23	30	352	21,442	1.65%	-0.58	0.06	<0.0001	-0.69	-0.47	86.95

Overall category	Outcome	Overall papers (n=)	Individual meta-analysis effects (n=)	Component studies (n=)	Participant population (n=)	CCA Score	Standardised mean difference estimate	Standard error	P value	Confidence Interval upper boundary	Confidence Interval lower boundary	Heterogeneity (i2)
Depression OVERALL	Depression	45	52	712	50,970	1.30%	-0.60	-0.04	<0.0001	-0.68	-0.52	87.31

Supplementary Table 4

Anxiety synthesis results

Population sub category	Outcome	Overall papers (n=)	Individual meta-analysis effects (n=)	Component studies (n=)	Participant population (n=)	CCA Score	Standardised mean difference estimate	Standard error	P value	Confidence Interval upper boundary	Confidence Interval lower boundary	Heterogeneity (i2)
Adults (18+)	Anxiety	15	16	167	11,550	1.02%	-0.40	0.07	<0.0001	-0.54	-0.26	77.82
Emerging adults (college students)	Anxiety	3	3	38	3,672	1.22%	-0.58	0.03	<0.0001	-0.64	-0.52	0.00
Clinical anxiety diagnosis	Anxiety	2	2	19	935	6.25%	-0.42	0.10	<0.0001	-0.61	-0.22	0.00

Exercise sub category	Outcome	Overall papers (n=)	Individual meta-analysis effects (n=)	Component studies (n=)	Participant population (n=)	CCA Score	Standardised mean difference estimate	Standard error	P value	Confidence Interval upper boundary	Confidence Interval lower boundary	Heterogeneity (i2)
Aerobic	Anxiety	4	6	27	1,010	0.00%	-0.67	0.10	<0.0001	-0.87	-0.47	36.28
Resistance	Anxiety	1	1	5	300	0.00%	-0.56	0.14	<0.0001	-0.84	-0.28	0.00
Mind body (Yoga, Tai Chi, QiJong, Pilates & Wushusanda)	Anxiety	7	9	74	5,175	1.11%	-0.50	0.09	<0.0001	-0.67	-0.32	58.69
Mixed exercise (not defined in other categories)	Anxiety	9	10	131	10,802	0.85%	-0.35	0.07	<0.0001	-0.48	-0.23	84.11
Group exercise	Anxiety	1	1	2	72	0.00%	-0.60	0.18	0.00	-0.94	-0.26	0.00
Intensity low	Anxiety	1	1	4	460	0.00%	-0.58	0.42	0.16	-1.39	0.24	93.00
Intensity moderate	Anxiety	1	1	8	1,250	0.00%	-0.06	0.08	0.74	-0.22	0.09	29.00
Duration - Short term up to 8 weeks	Anxiety	2	2	12	267	0.00%	-0.70	0.12	<0.0001	-0.92	-0.47	0.00
Duration - Medium term 9 to 24 weeks	Anxiety	2	4	23	2,285	0.00%	-0.50	0.07	<0.0001	-0.64	-0.37	0.00
Duration - Long term over 24 weeks	Anxiety	1	1	7	1,013	0.00%	-0.03	0.10	0.76	-0.18	0.13	0.00
Frequency - 1 to 2 days a week	Anxiety	1	1	6	293	0.00%	-0.71	0.12	<0.0001	-0.95	-0.47	0.00
Frequency - 3 or more days a week	Anxiety	2	5	24	2,327	0.00%	-0.50	0.09	<0.0001	-0.67	-0.33	9.44

Overall category	Outcome	Overall papers (n=)	Individual meta-analysis effects (n=)	Component studies (n=)	Participant population (n=)	CCA Score	Standardised mean difference estimate	Standard error	P value	Confidence Interval upper boundary	Confidence Interval lower boundary	Heterogeneity (i2)
AMSTAR-2 High	Anxiety	2	2	19	935	6.25%	-0.42	0.10	<0.0001	-0.61	-0.22	0.00
AMSTAR-2 Low	Anxiety	5	5	27	1,915	0.00%	-0.45	0.11	<0.0001	-0.65	-0.24	25.11
AMSTAR-2 Critically Low	Anxiety	12	13	168	12,887	0.57%	-0.44	0.08	<0.0001	-0.59	-0.28	89.58

Overall category	Outcome	Overall papers (n=)	Individual meta-analysis effects (n=)	Component studies (n=)	Participant population (n=)	CCA Score	Standardised mean difference estimate	Standard error	P value	Confidence Interval upper boundary	Confidence Interval lower boundary	Heterogeneity (i2)
Anxiety OVERALL	Anxiety	19	20	214	15,737	0.82%	-0.43	0.06	<0.0001	-0.55	-0.32	82.07

Figure 1

PRISMA flowchart of study selection process

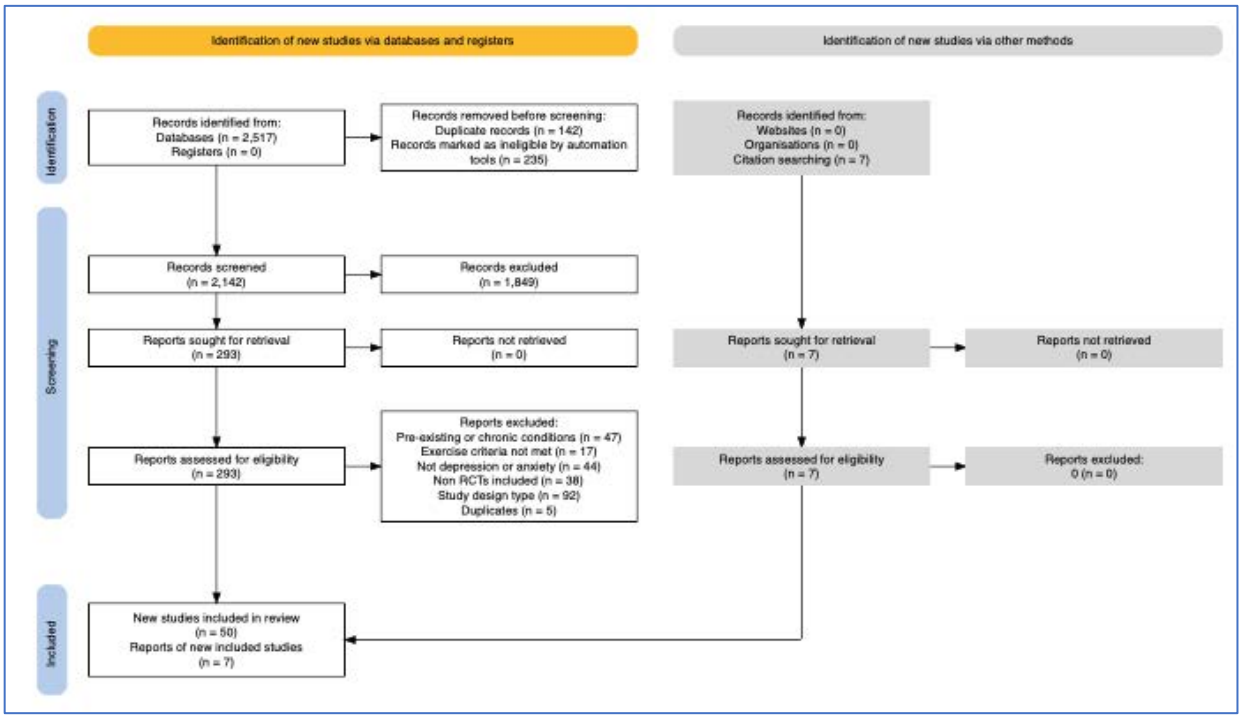


Figure 2a

Funnel plot analysis of publication bias for Depression

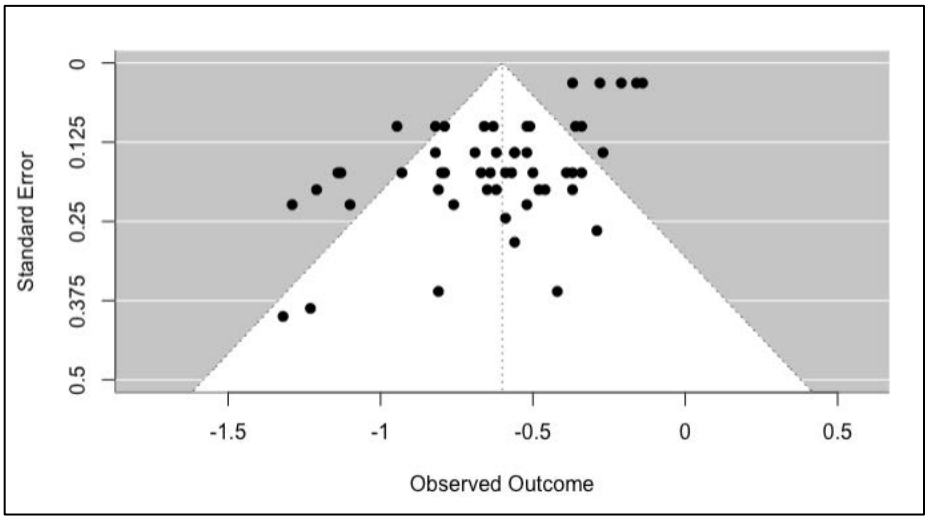


Figure 2b

Funnel plot analysis of publication bias for Anxiety

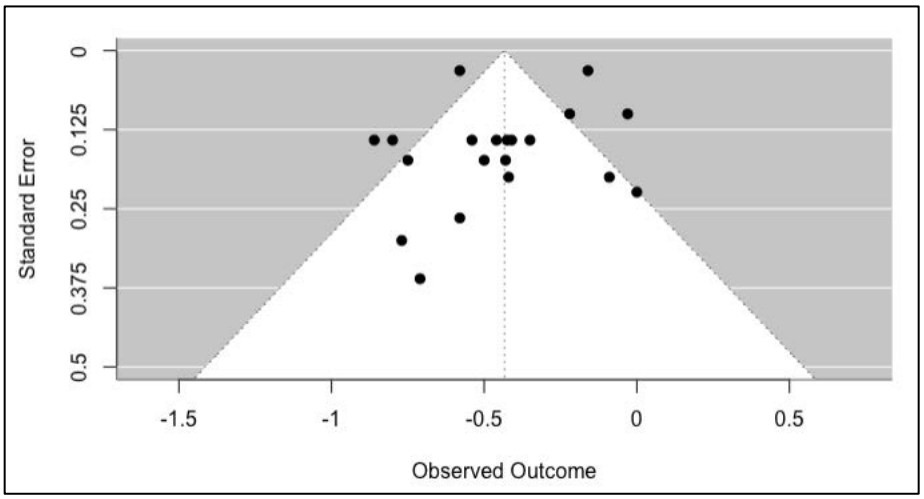


Figure 3

Forest plot for depression outcomes on all studies

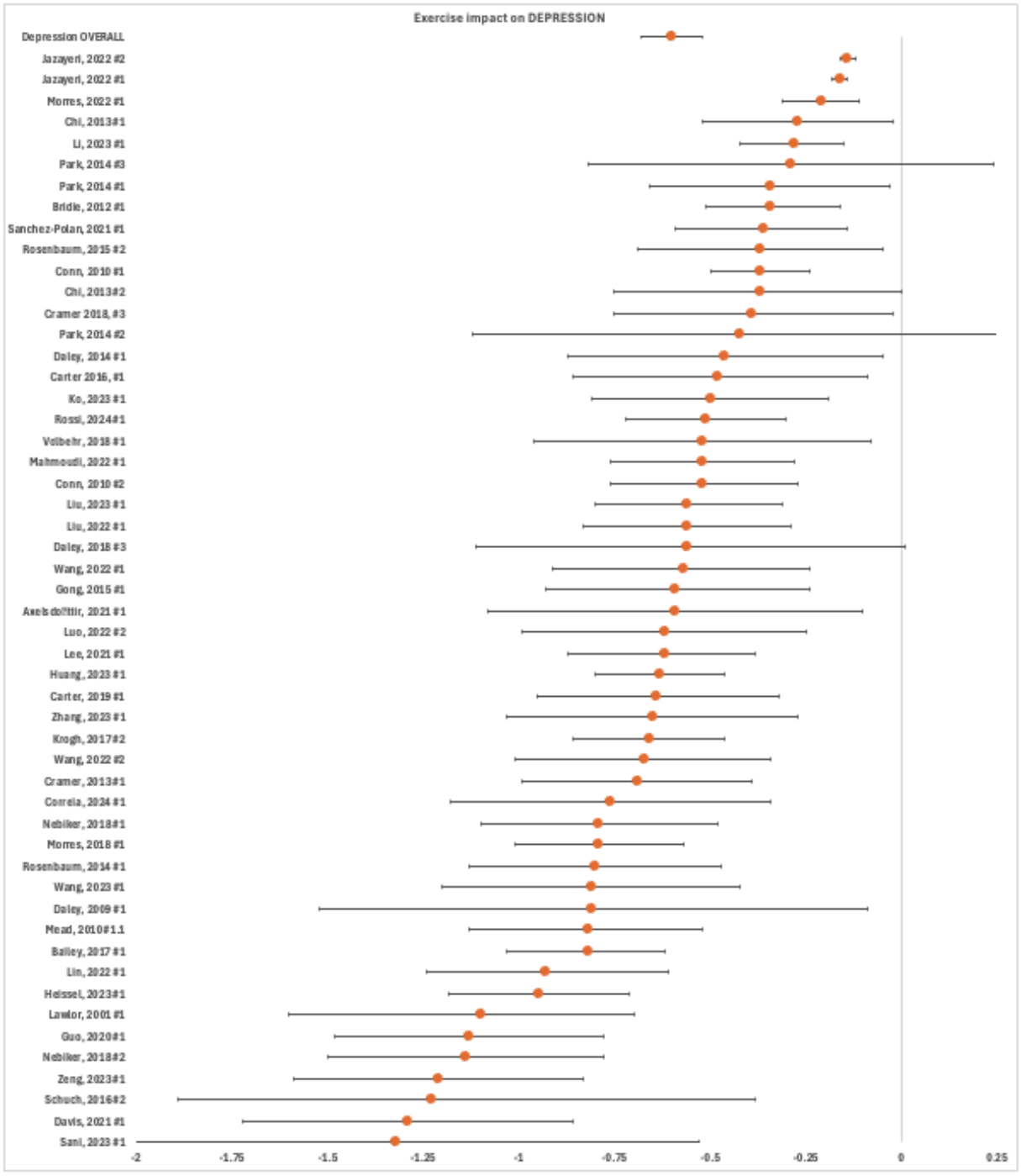


Figure 3a

Forest plot for depression outcomes by category

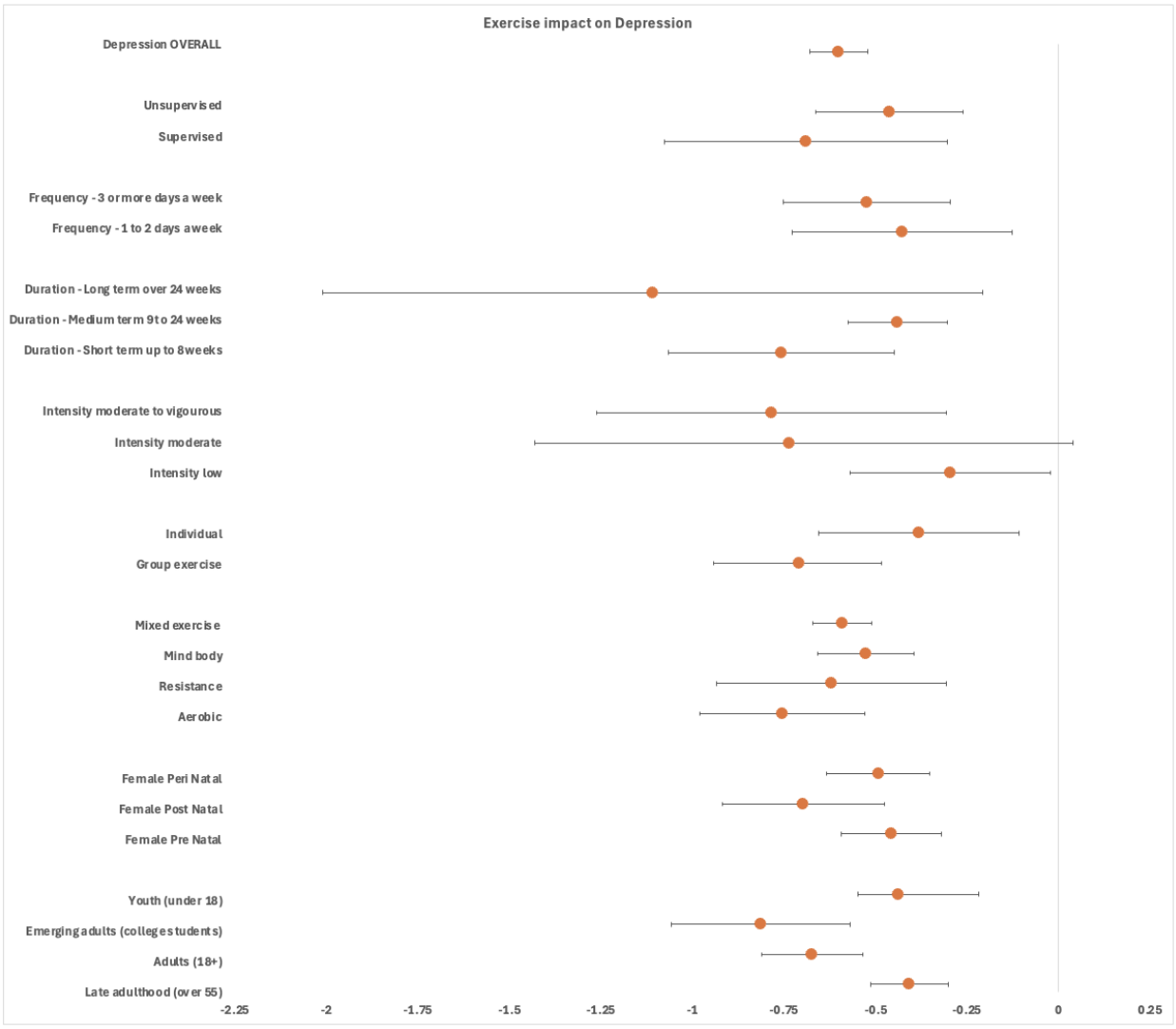


Figure 4

Forest plot for depression – Late adulthood

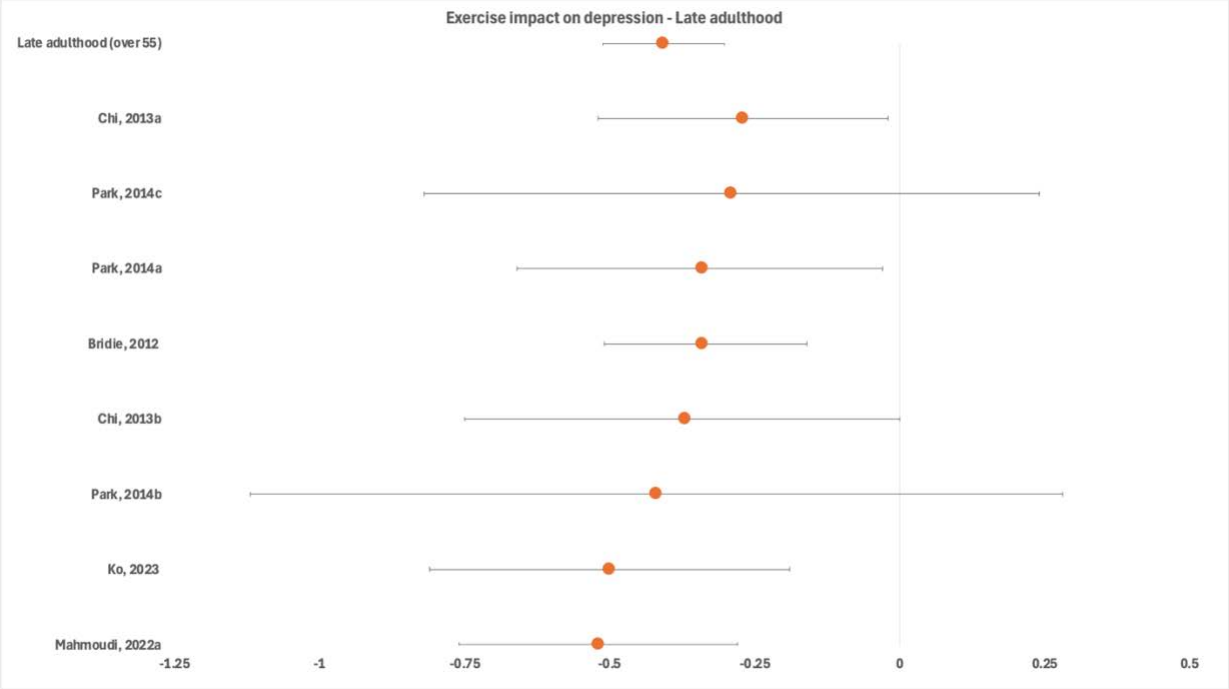


Figure 5

Forest plot for depression – Adults

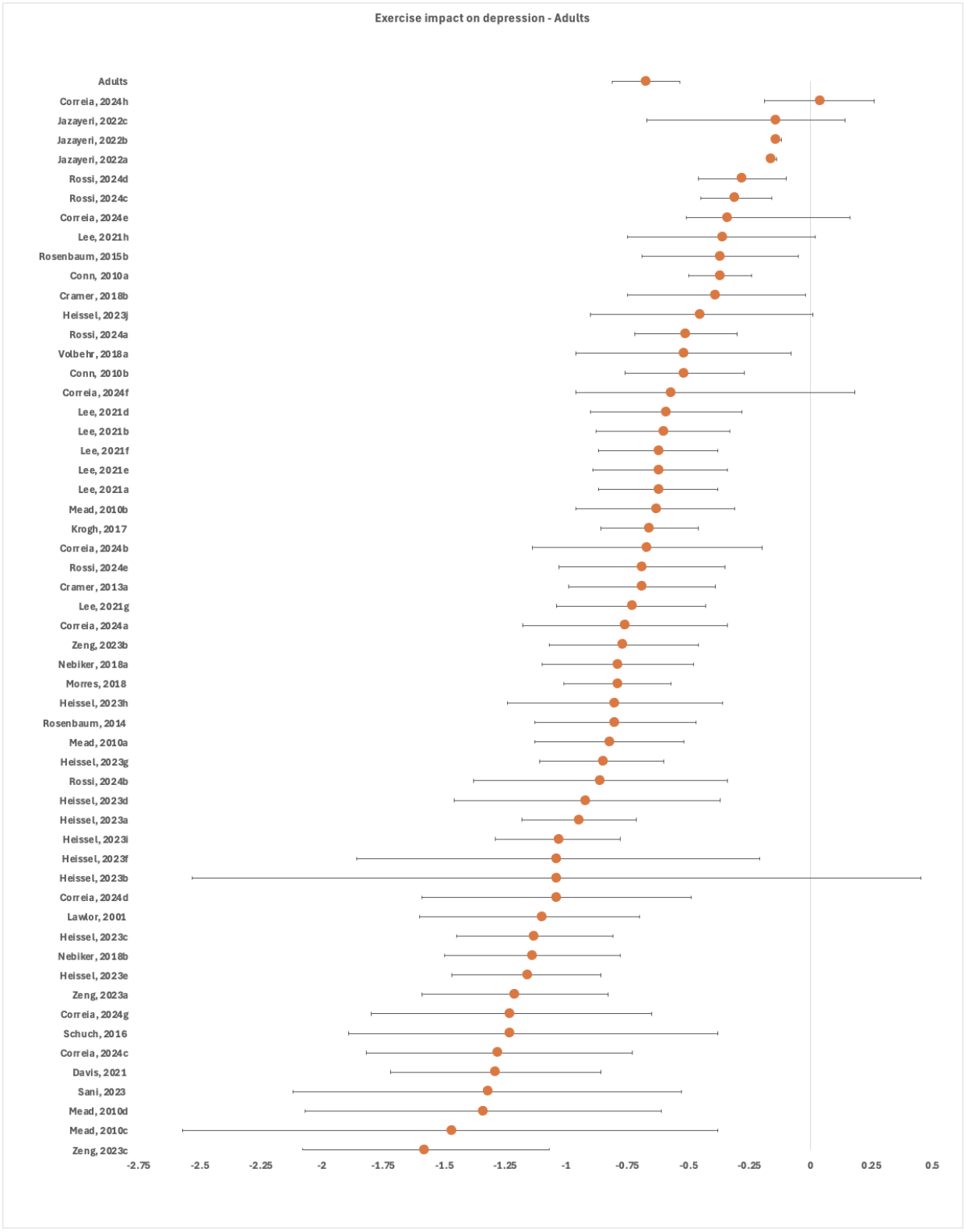


Figure 6

Forest plot for depression – Emerging adults

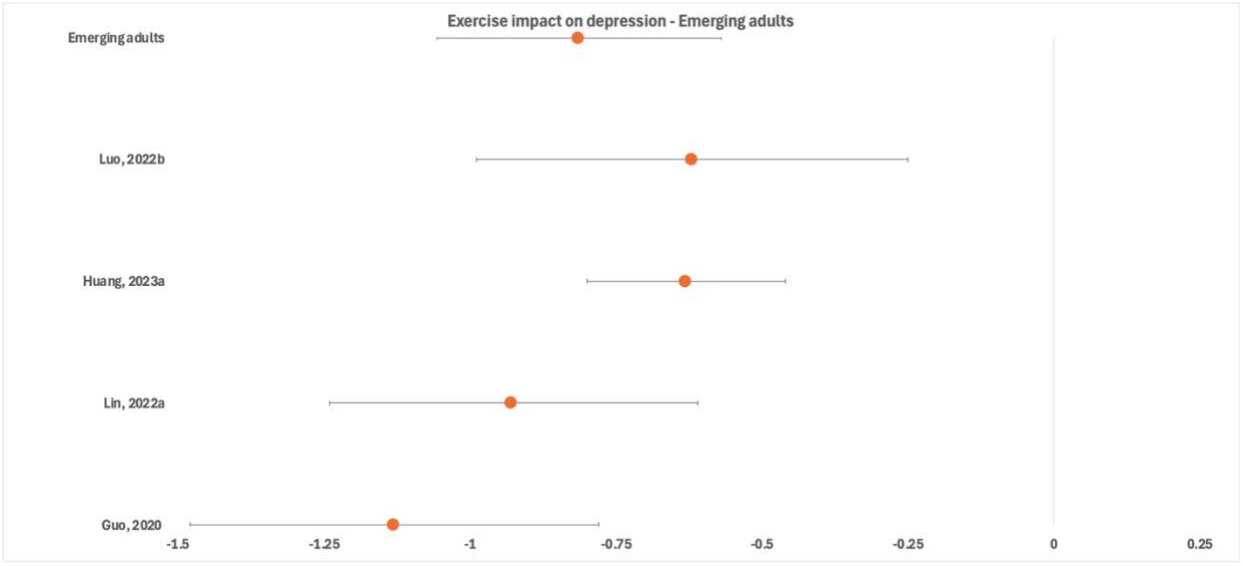


Figure 7

Forest plot for depression – Youth

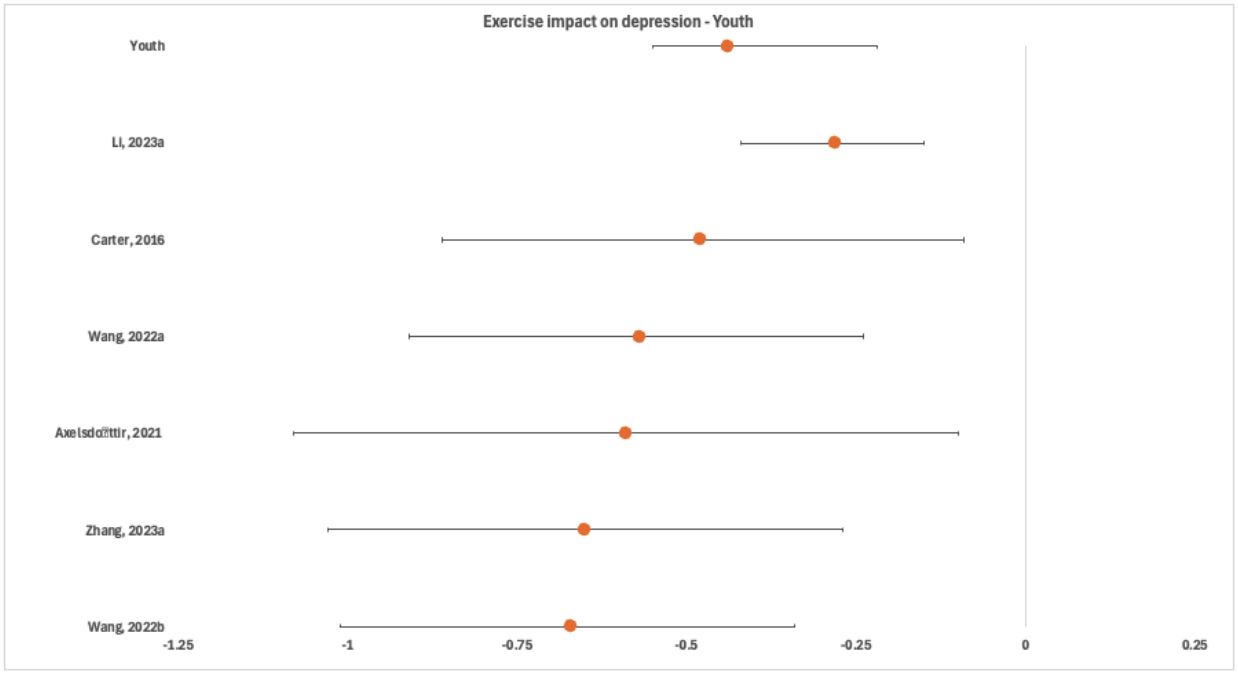


Figure 8

Forest plot for depression – Prenatal

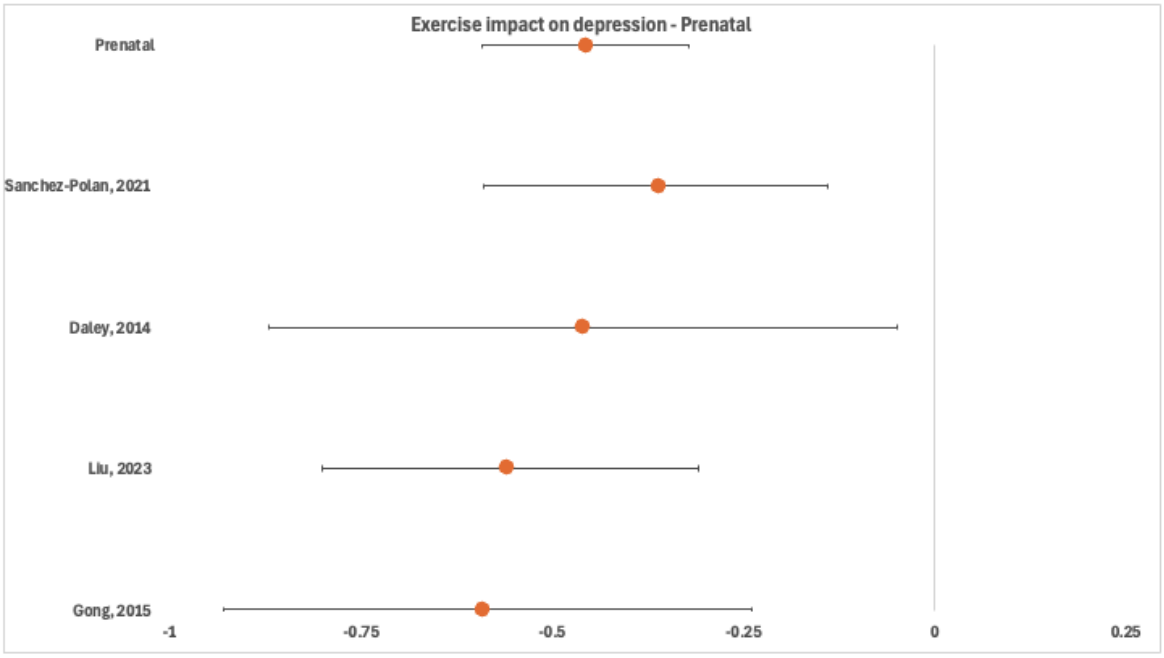


Figure 9

Forest plot for depression – Postnatal

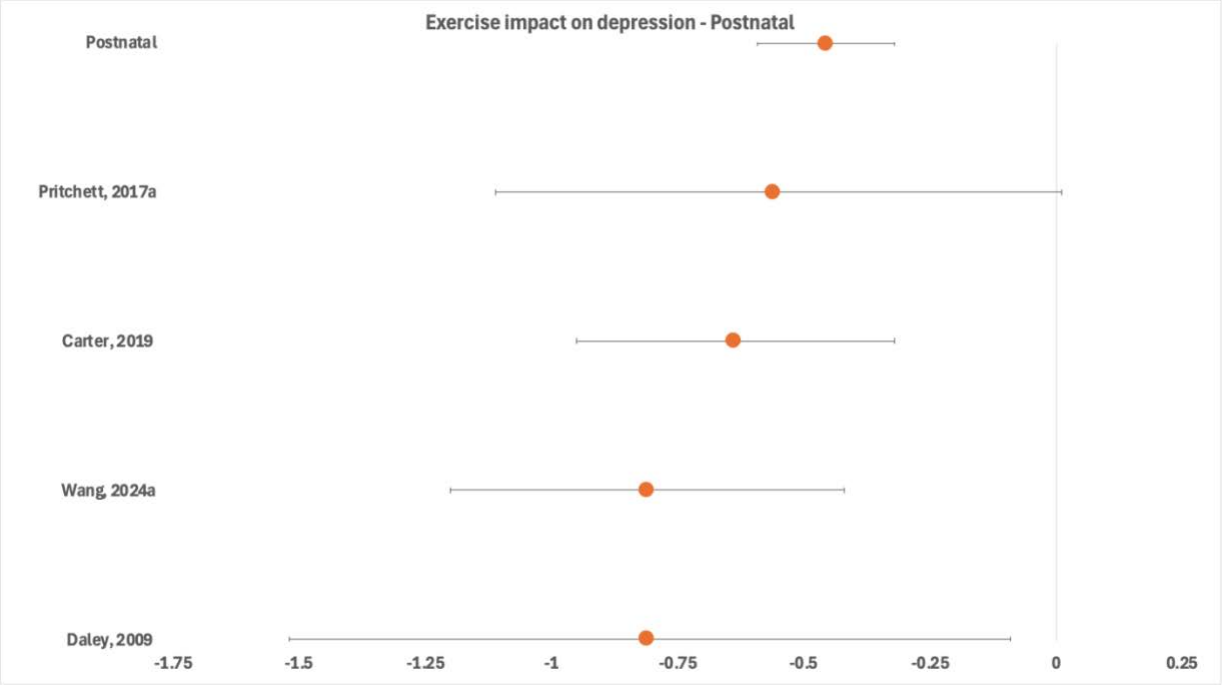


Figure 10

Forest plot for depression – Perinatal

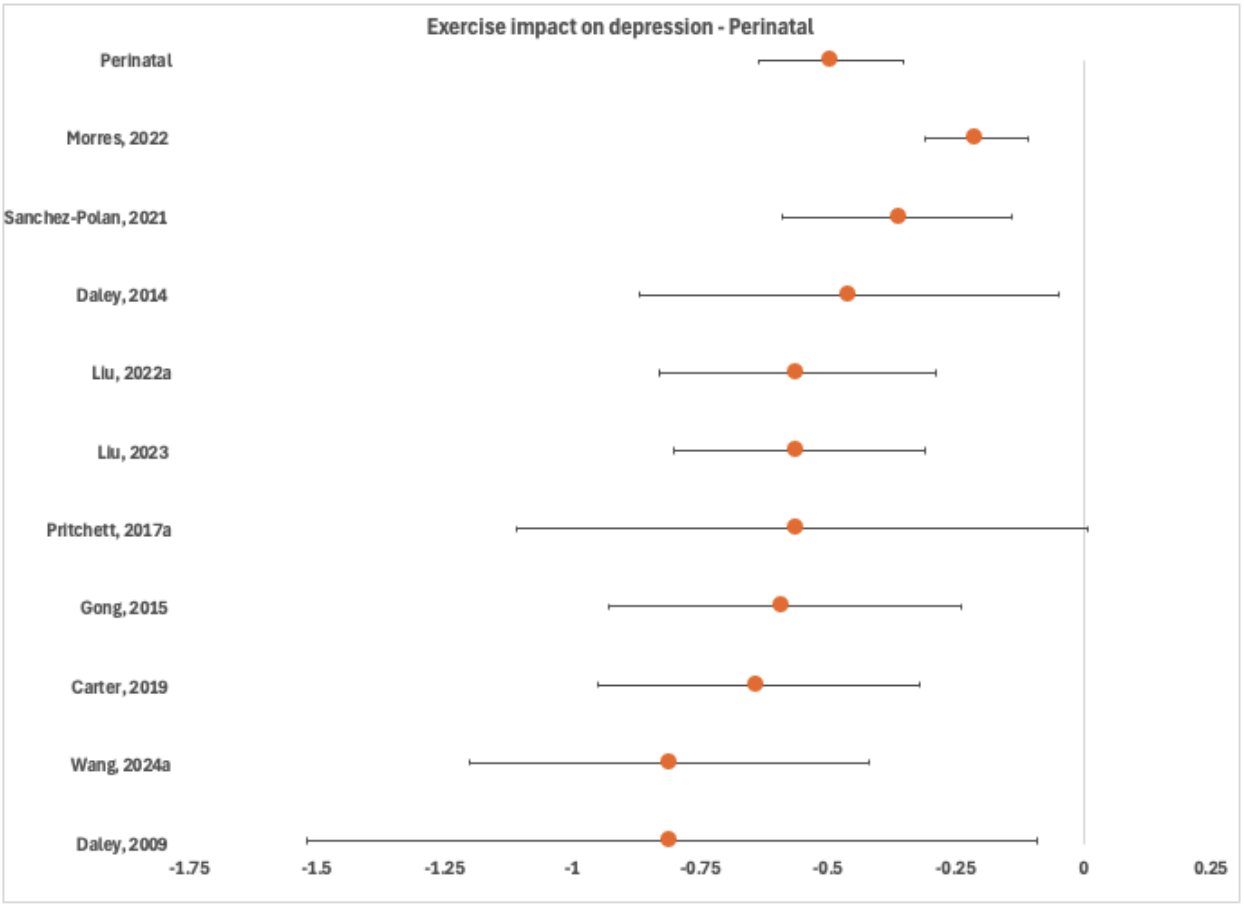


Figure 11

Forest plot for depression – Aerobic

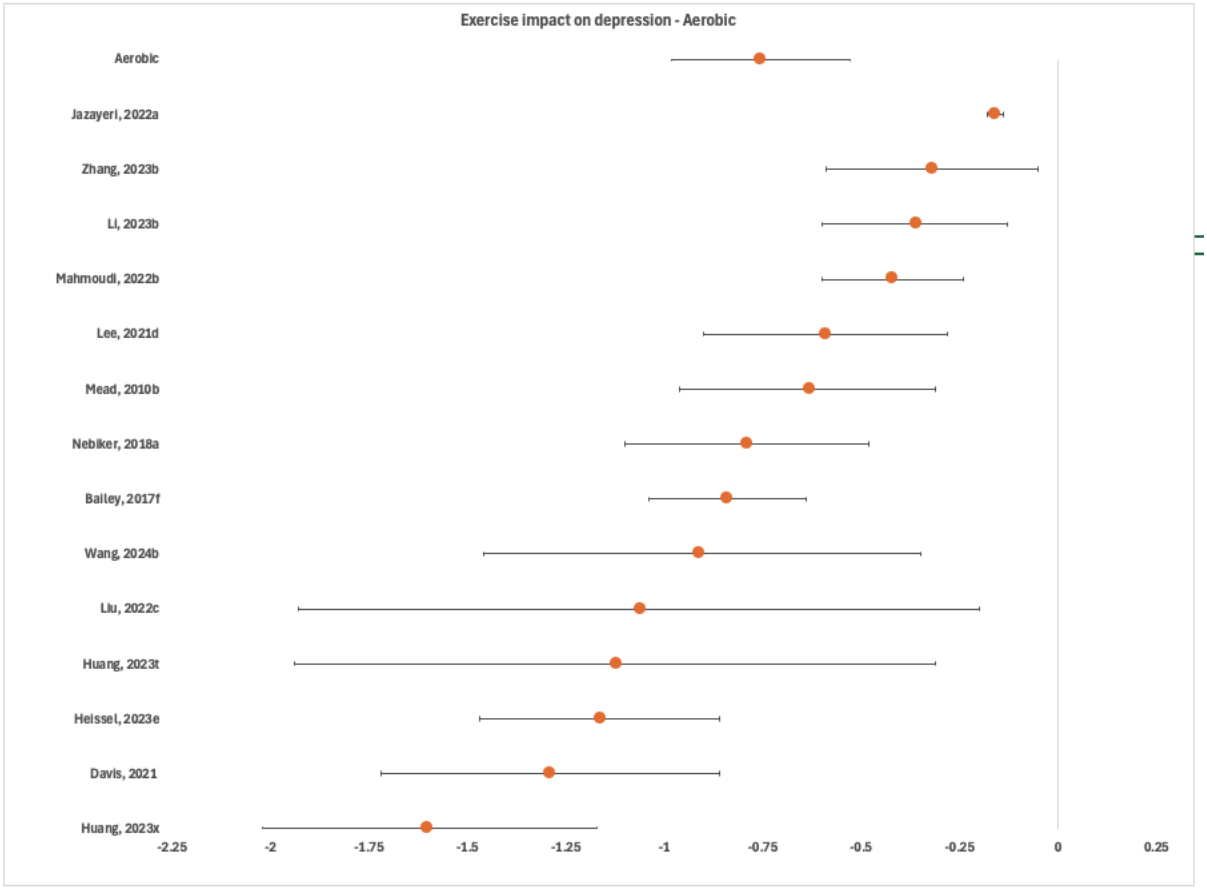


Figure 12

Forest plot for depression – Resistance

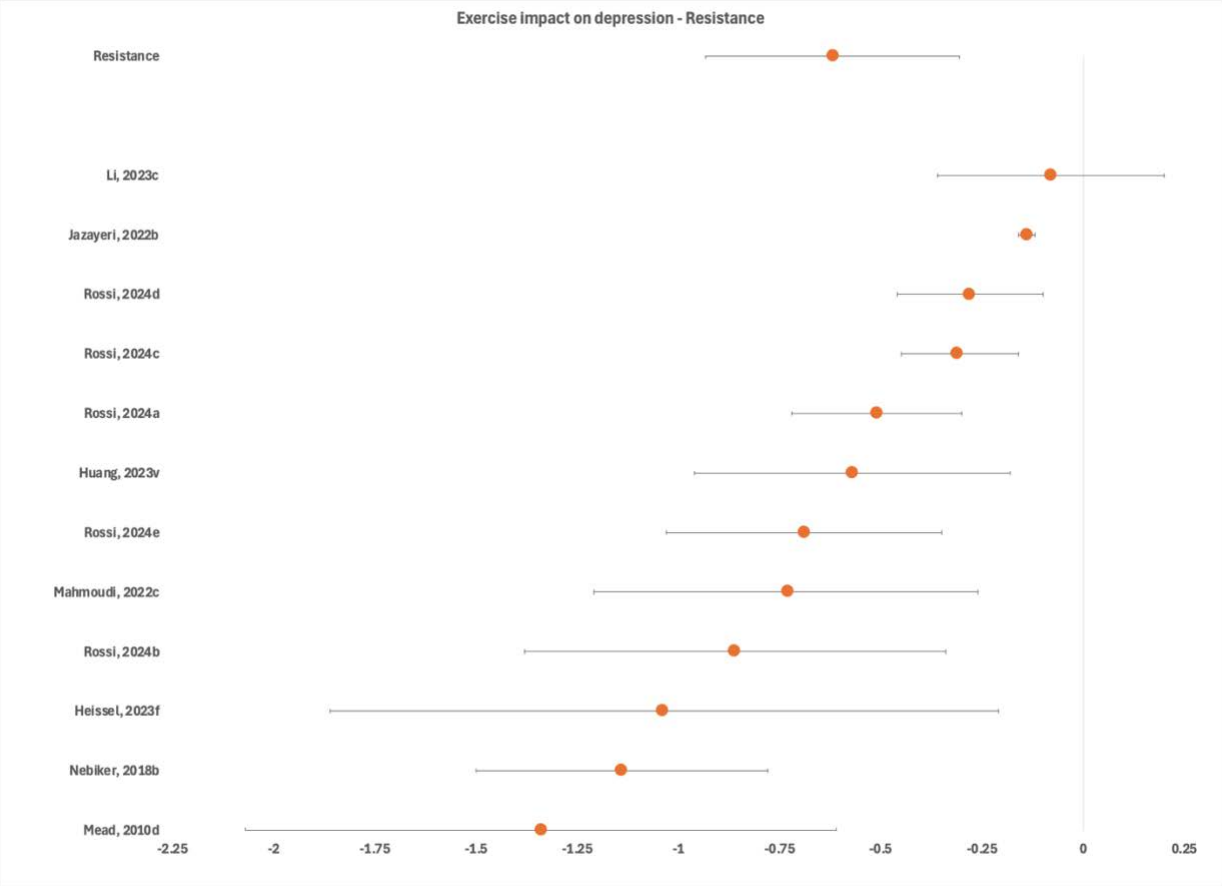


Figure 13

Forest plot for depression – Mindbody

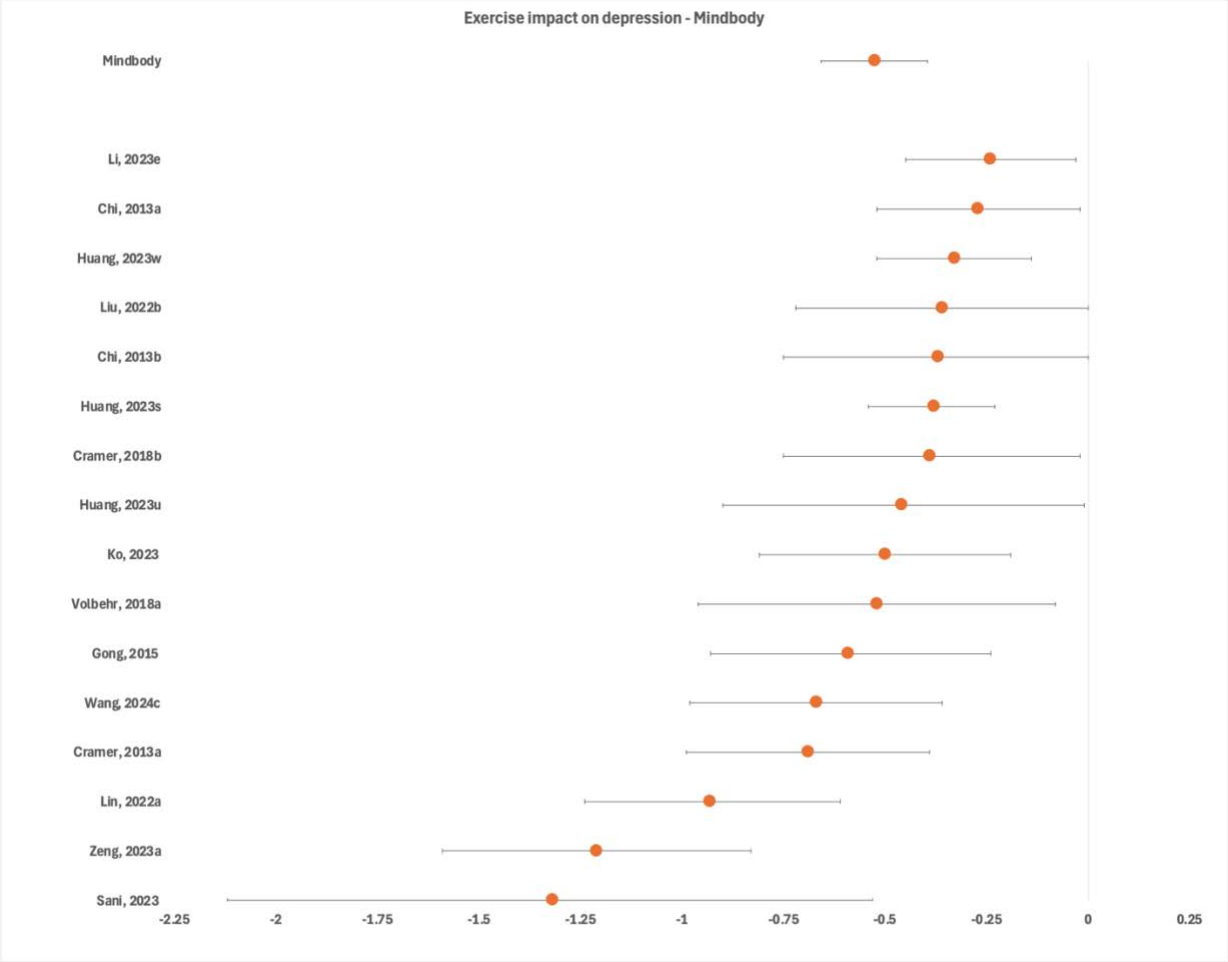


Figure 14

Forest plot for depression – Mixed Exercise

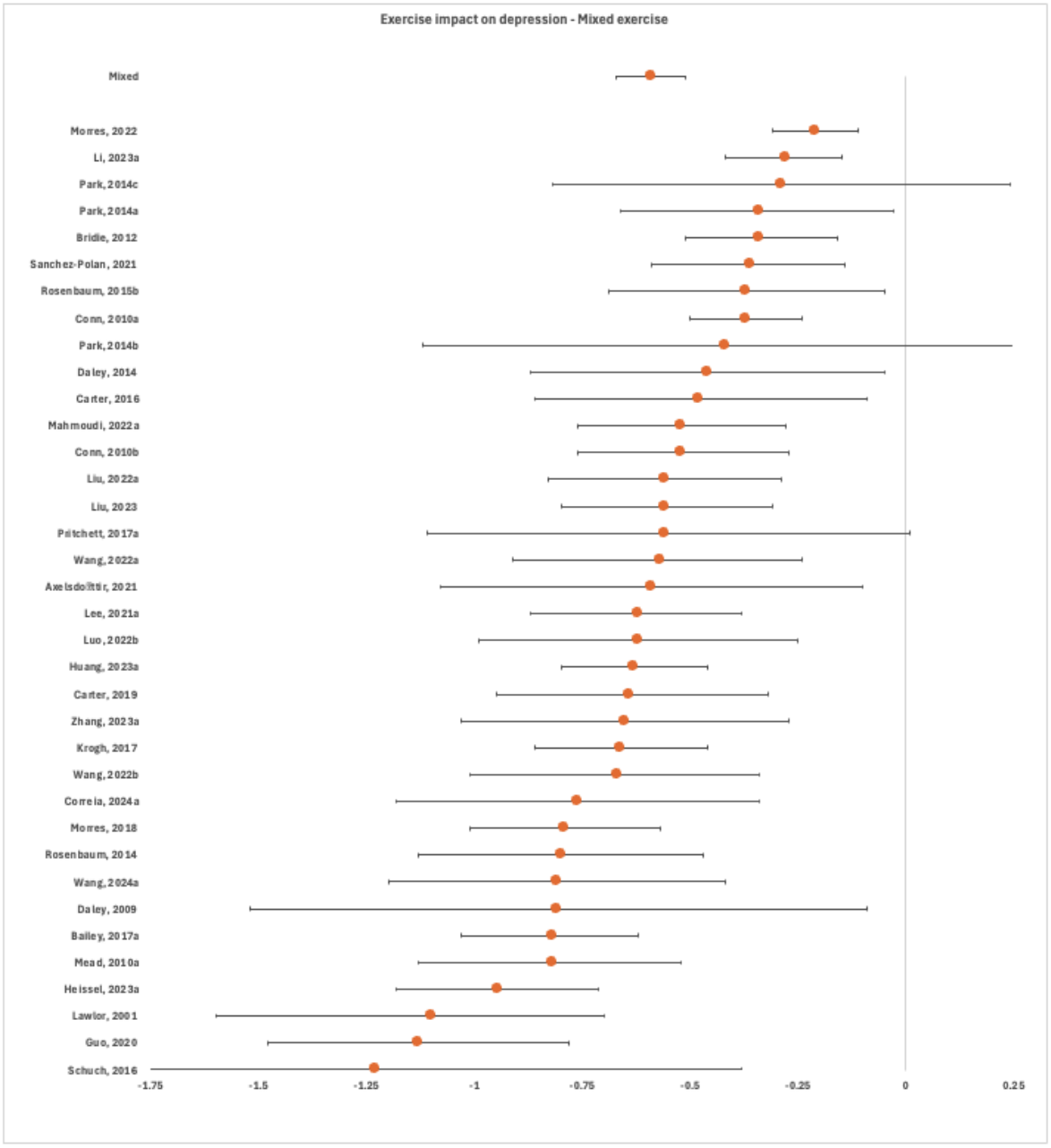


Figure 15

Forest plot for depression – Group exercise

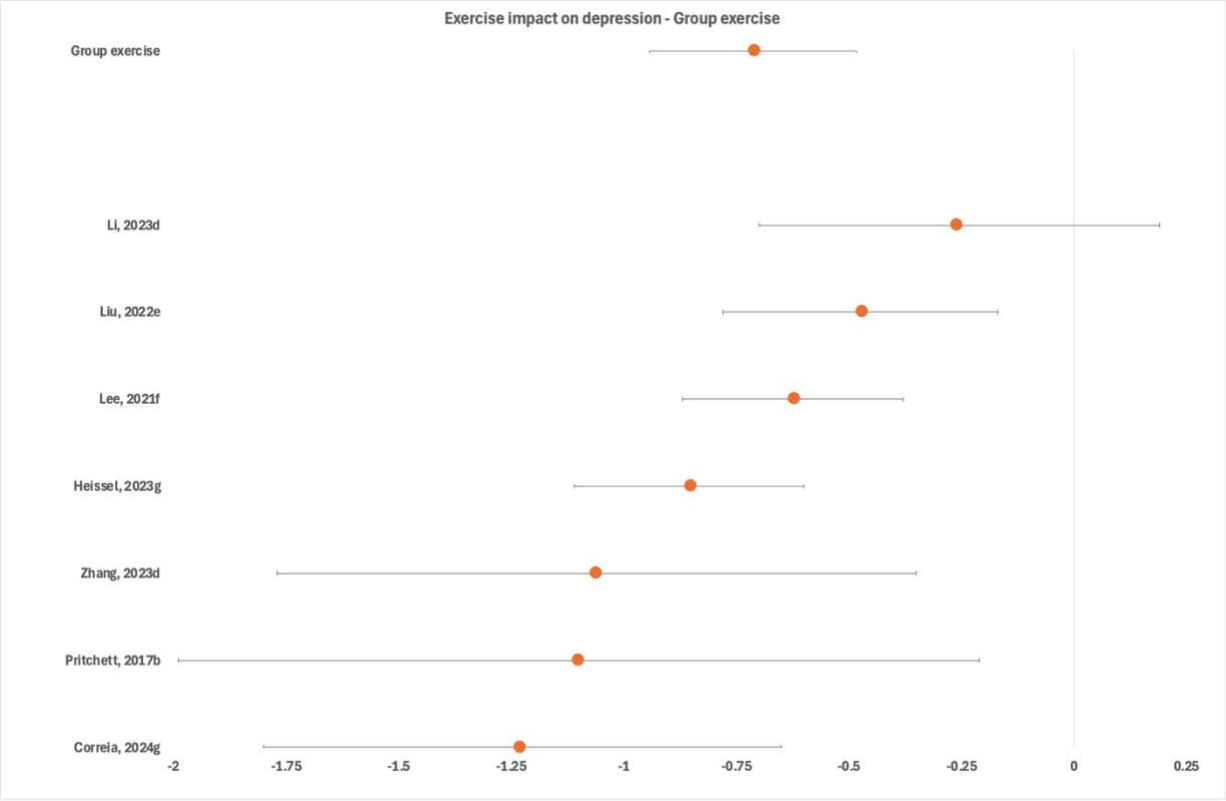


Figure 16

Forest plot for depression – Individual exercise

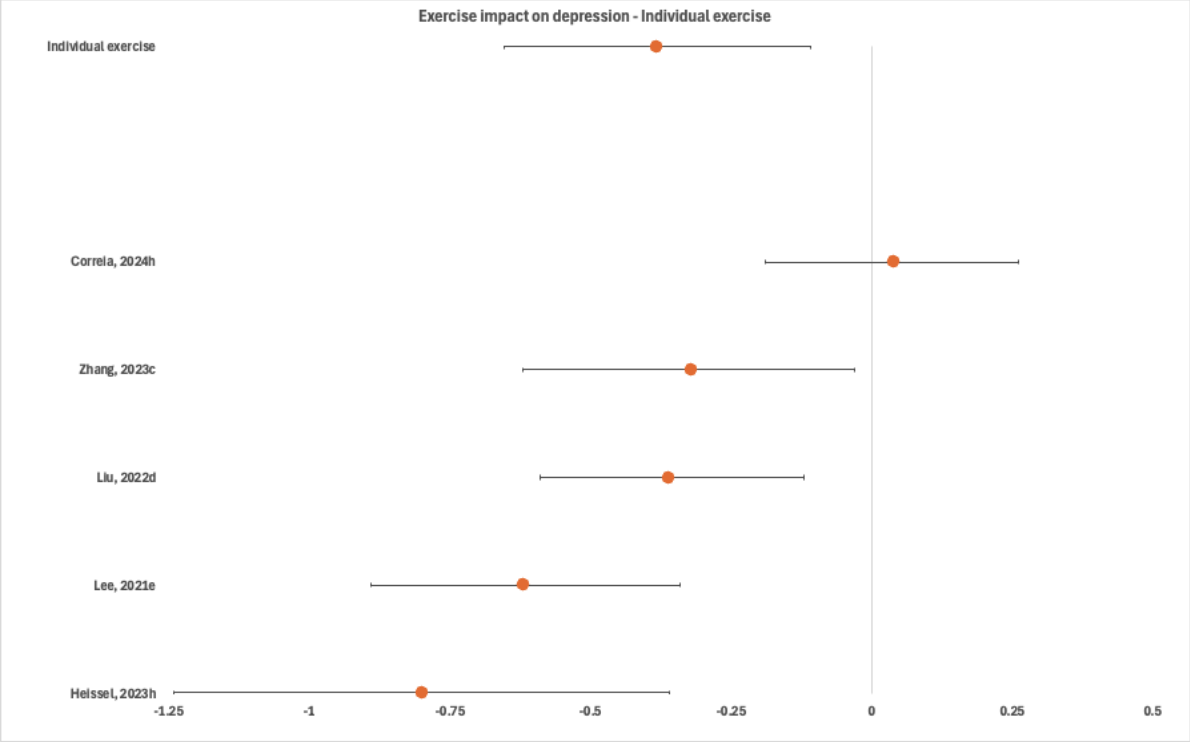


Figure 17

Forest plot for depression – Exercise intensity

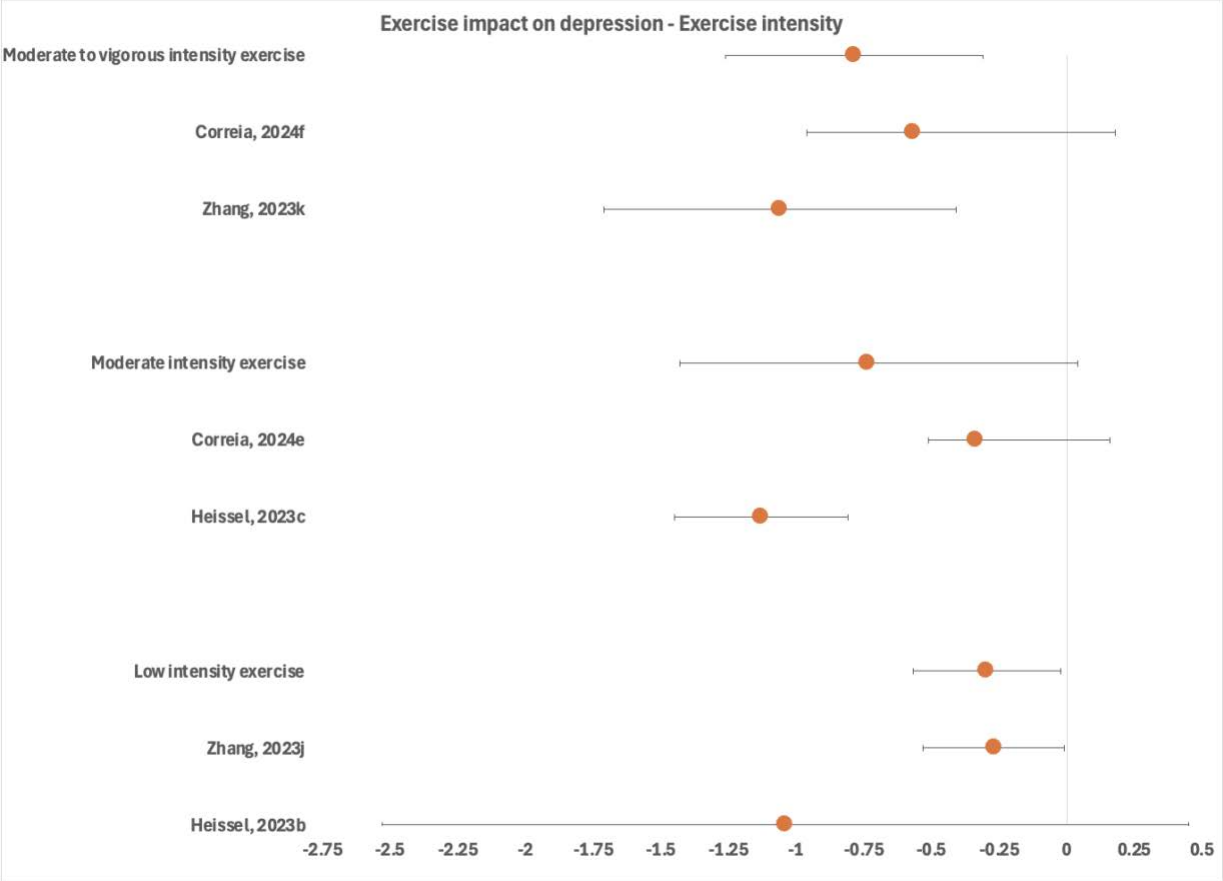


Figure 18

Forest plot for depression – Exercise duration

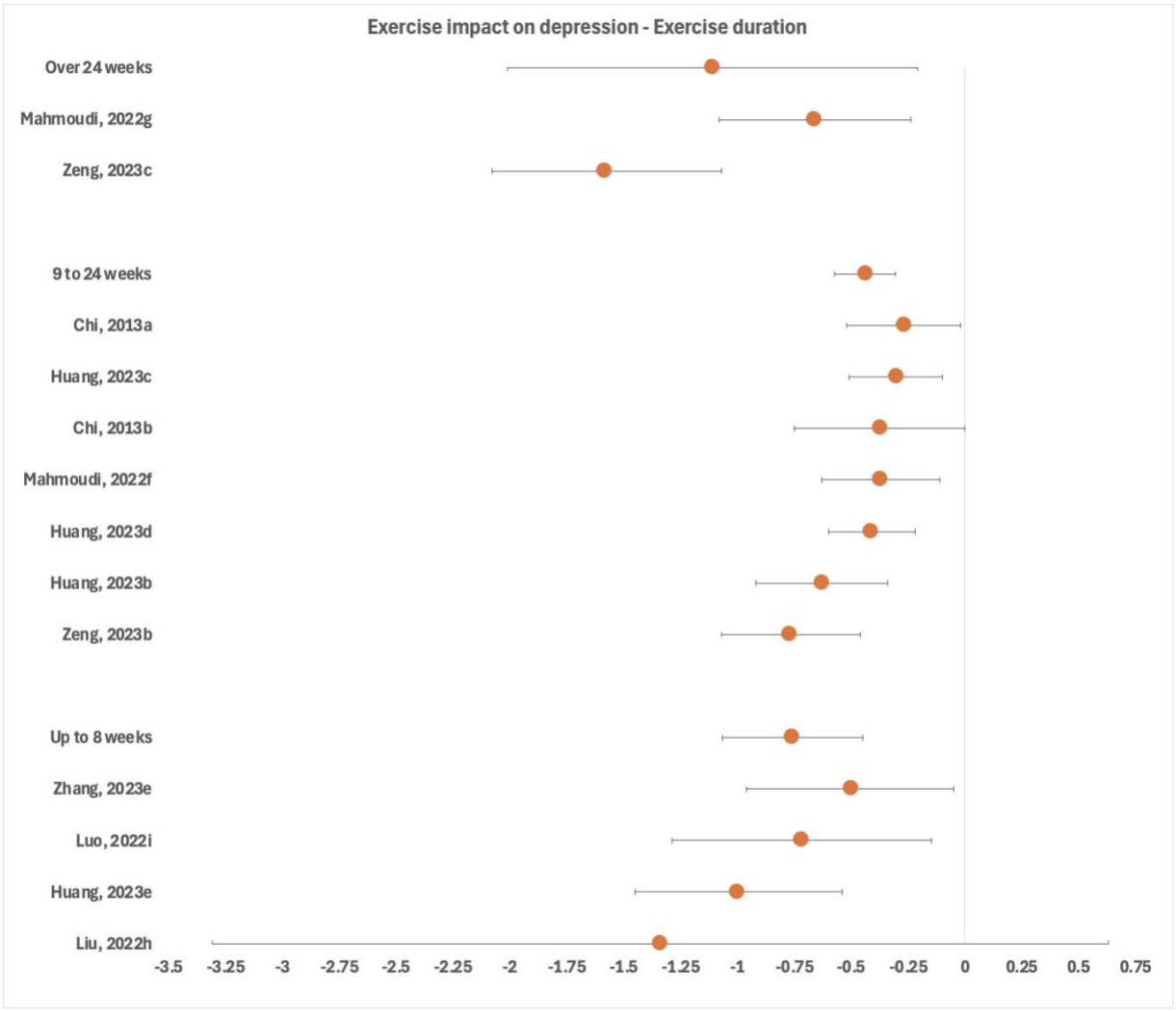


Figure 19

Forest plot for depression – Exercise frequency

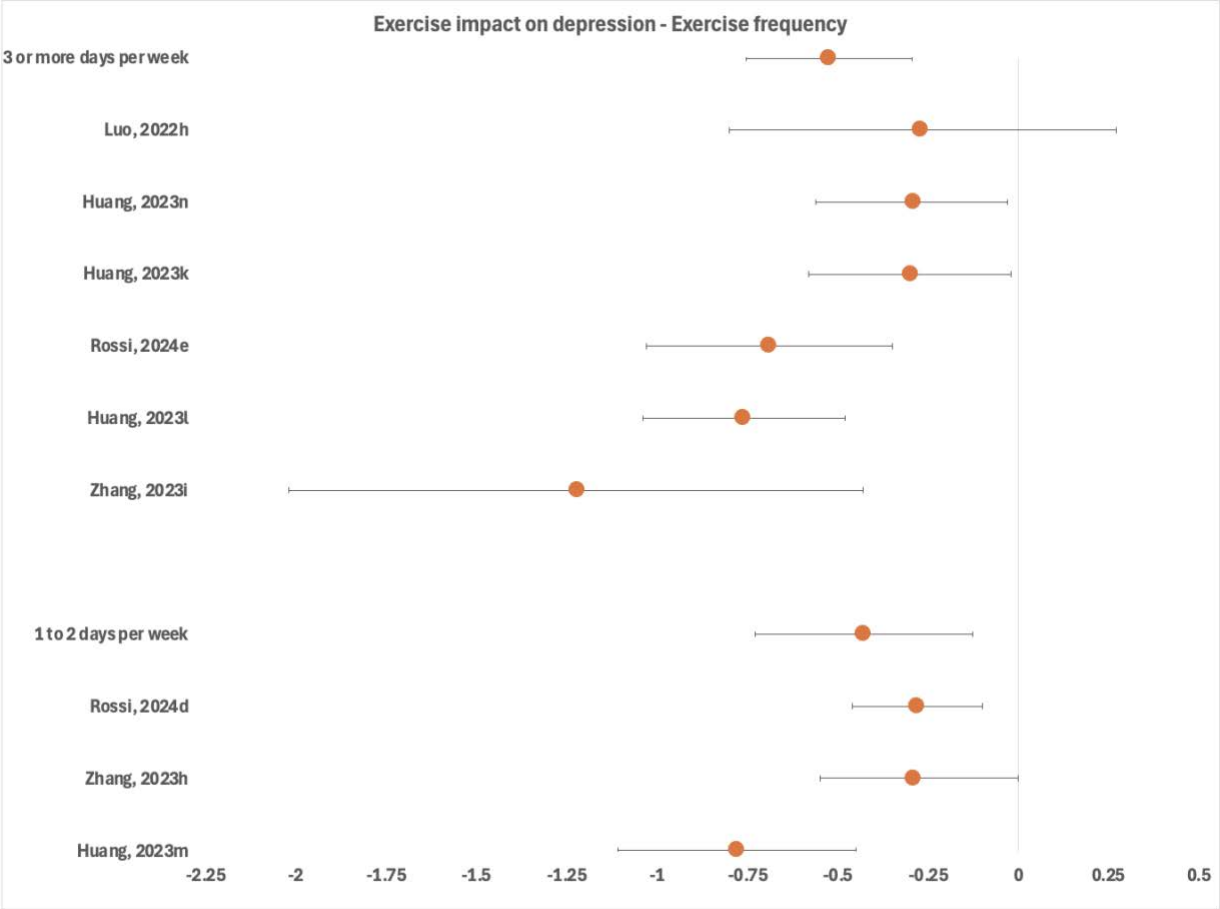


Figure 20

Forest plot for depression – Exercise supervision

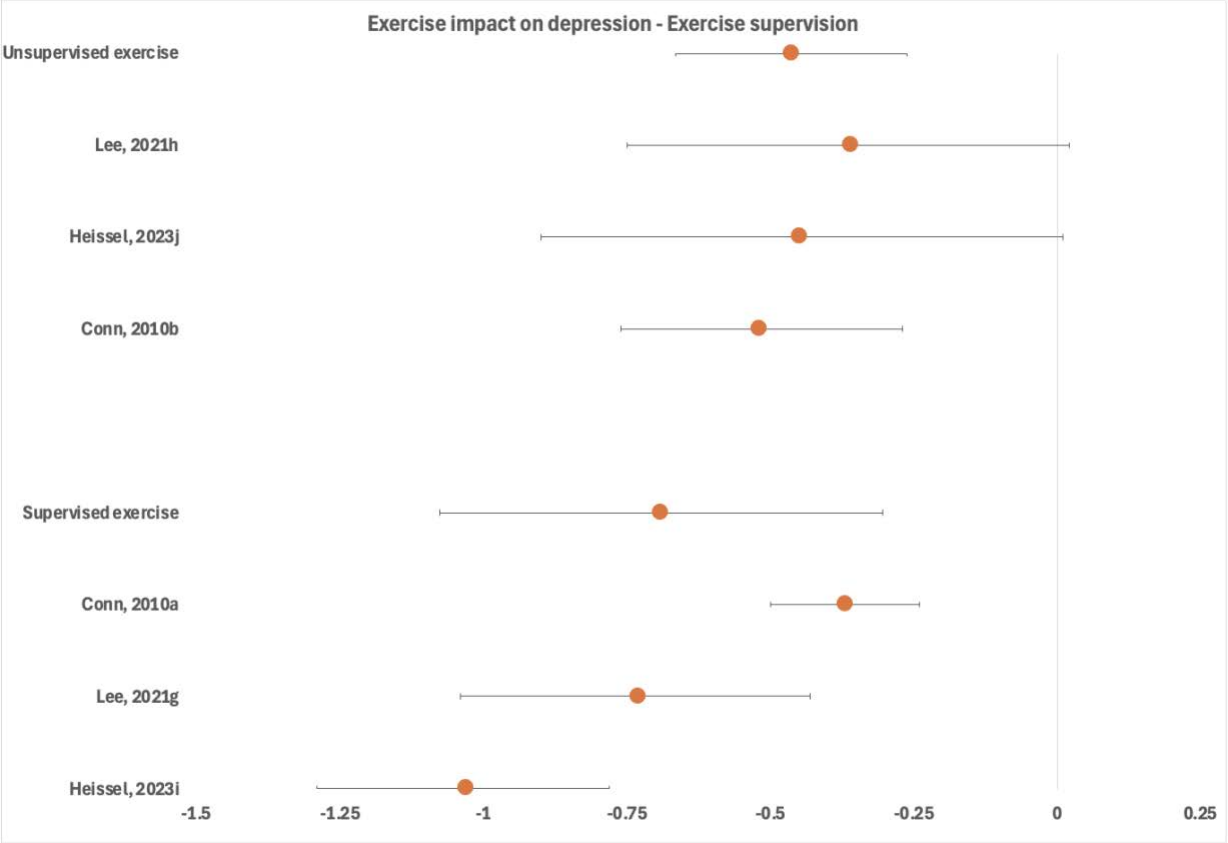


Figure 21

Forest plot for depression – Clinical v non-clinical

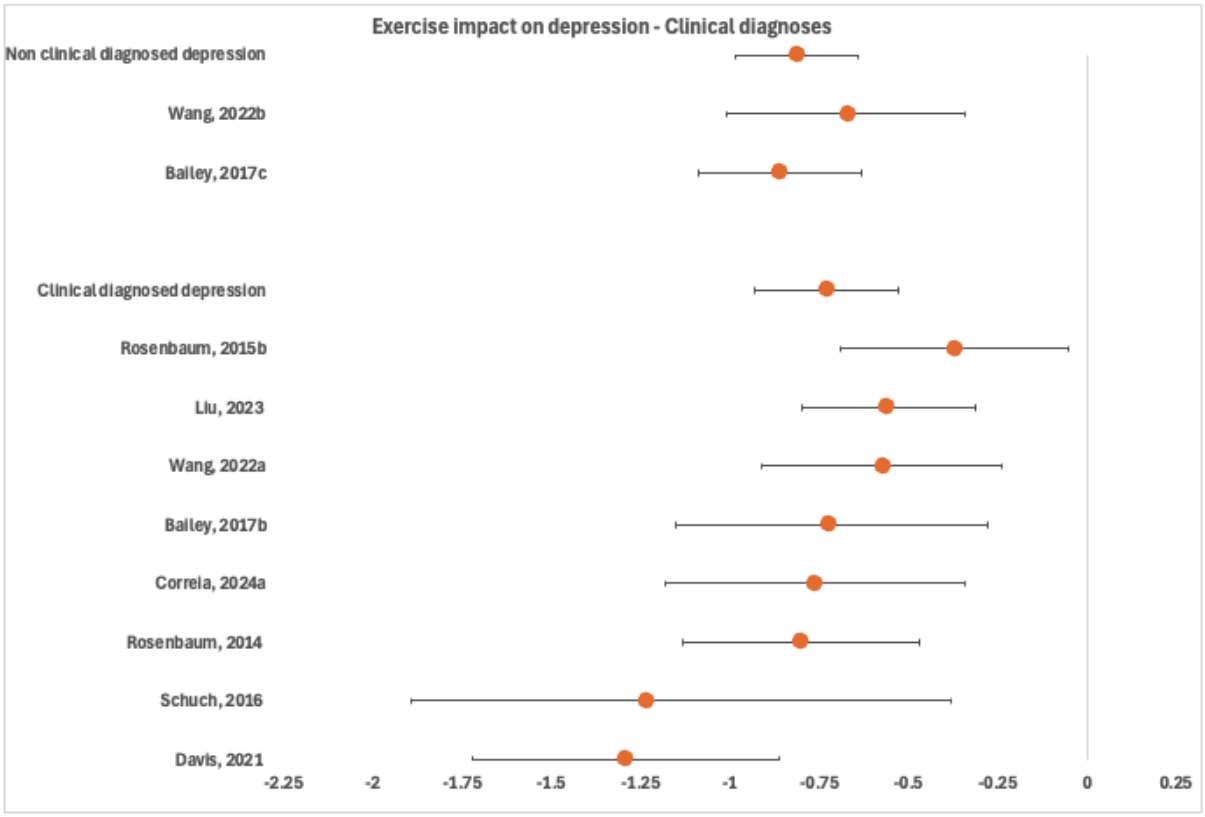


Figure 22

Forest plot for depression – AMSTAR High

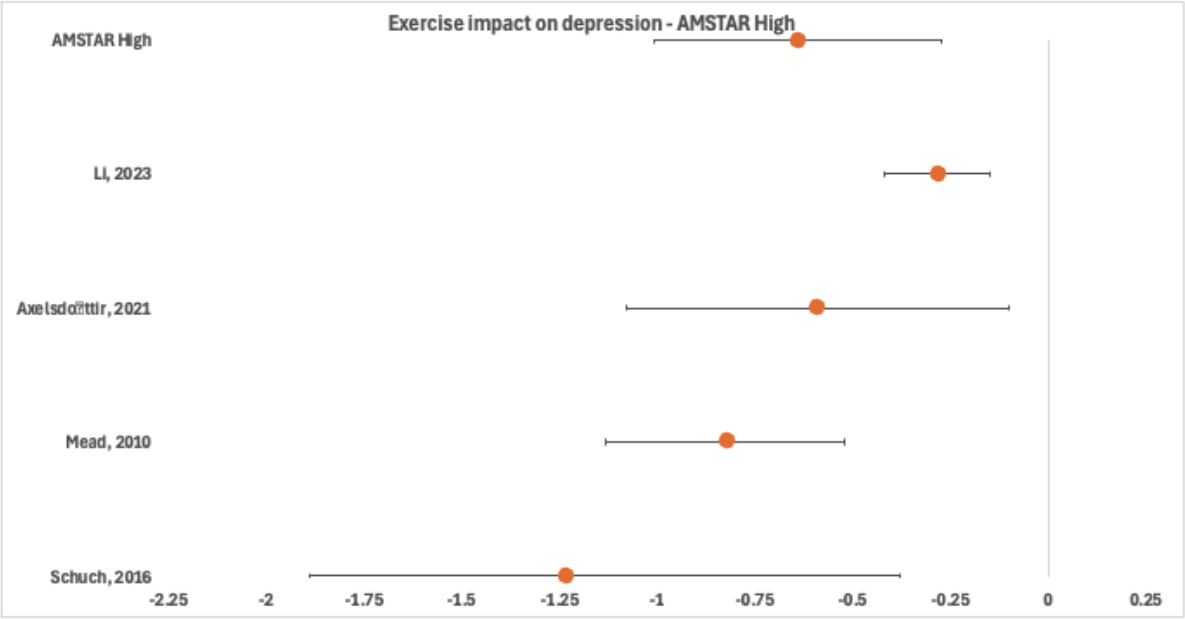


Figure 23

Forest plot for depression – AMSTAR Low

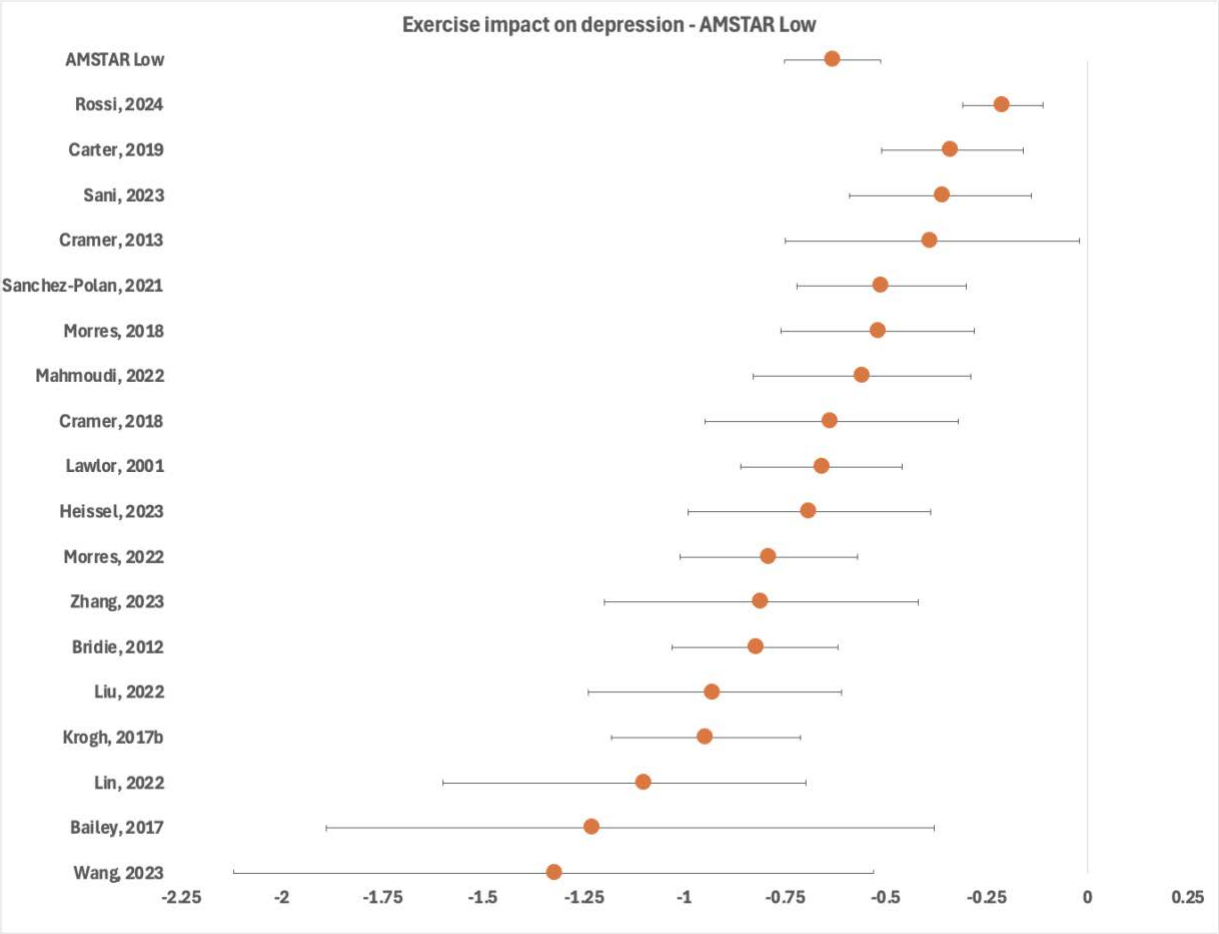


Figure 24

Forest plot for depression – AMSTAR Critically low

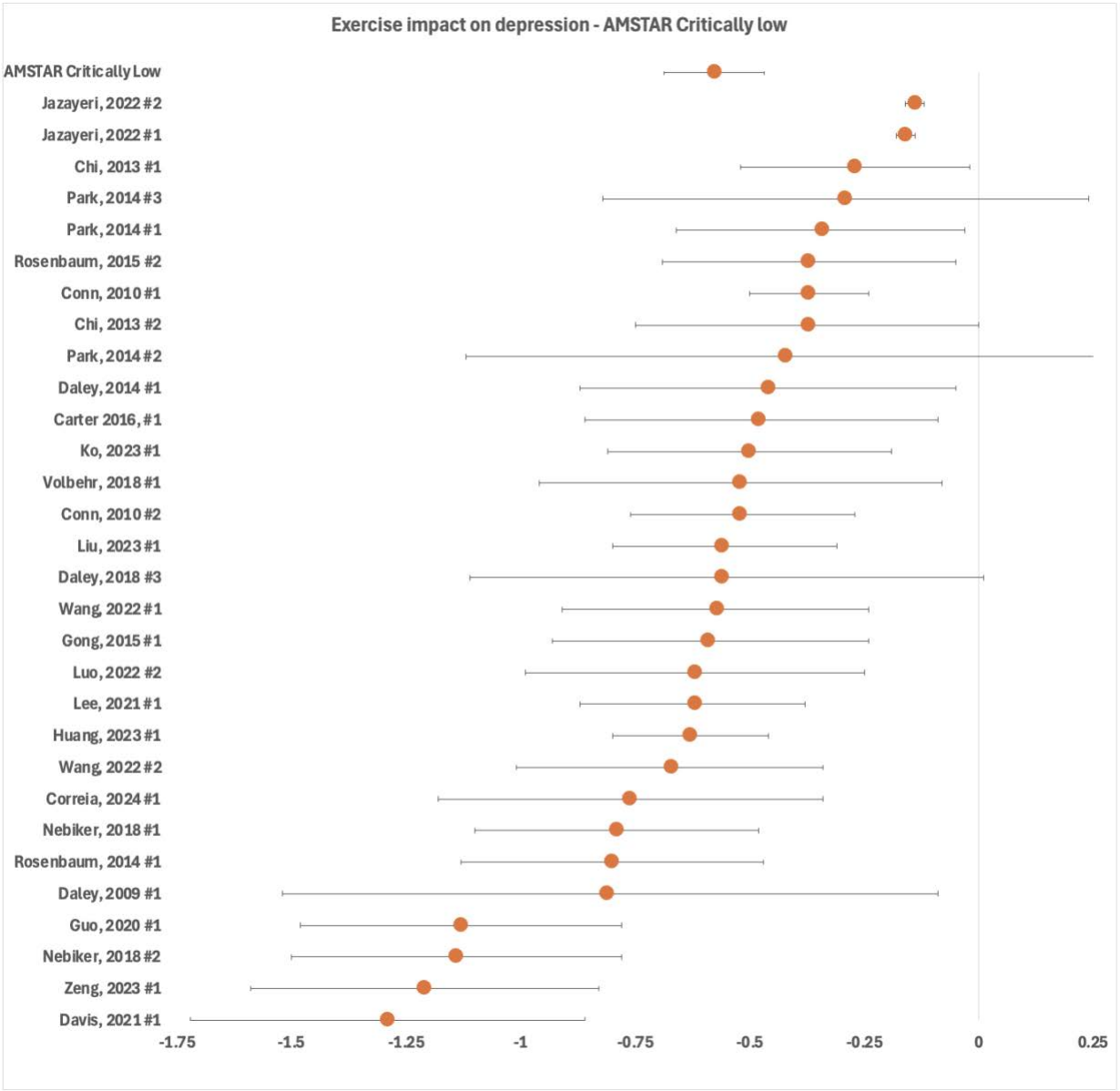


Figure 25

Forest plot for anxiety outcomes on all studies

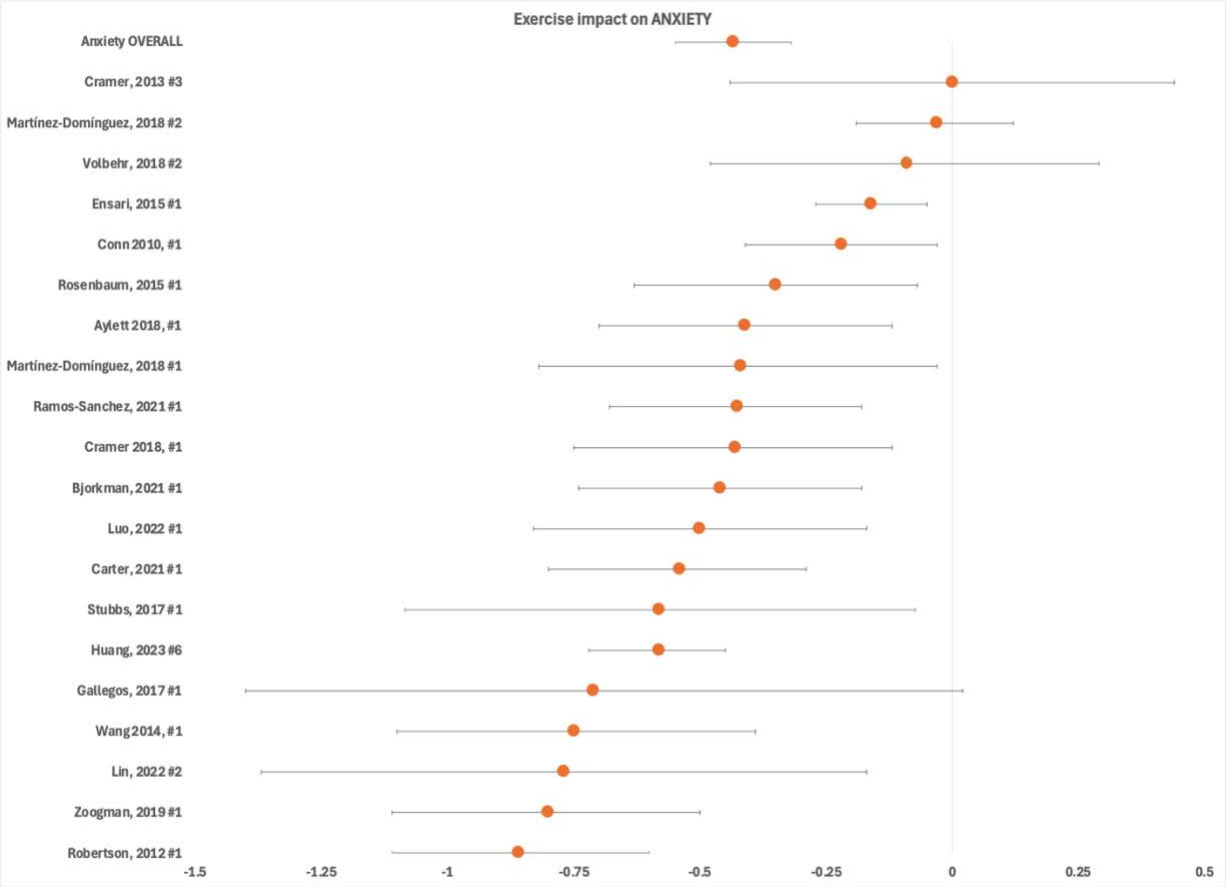


Figure 25a

Forest plot for anxiety outcomes by category

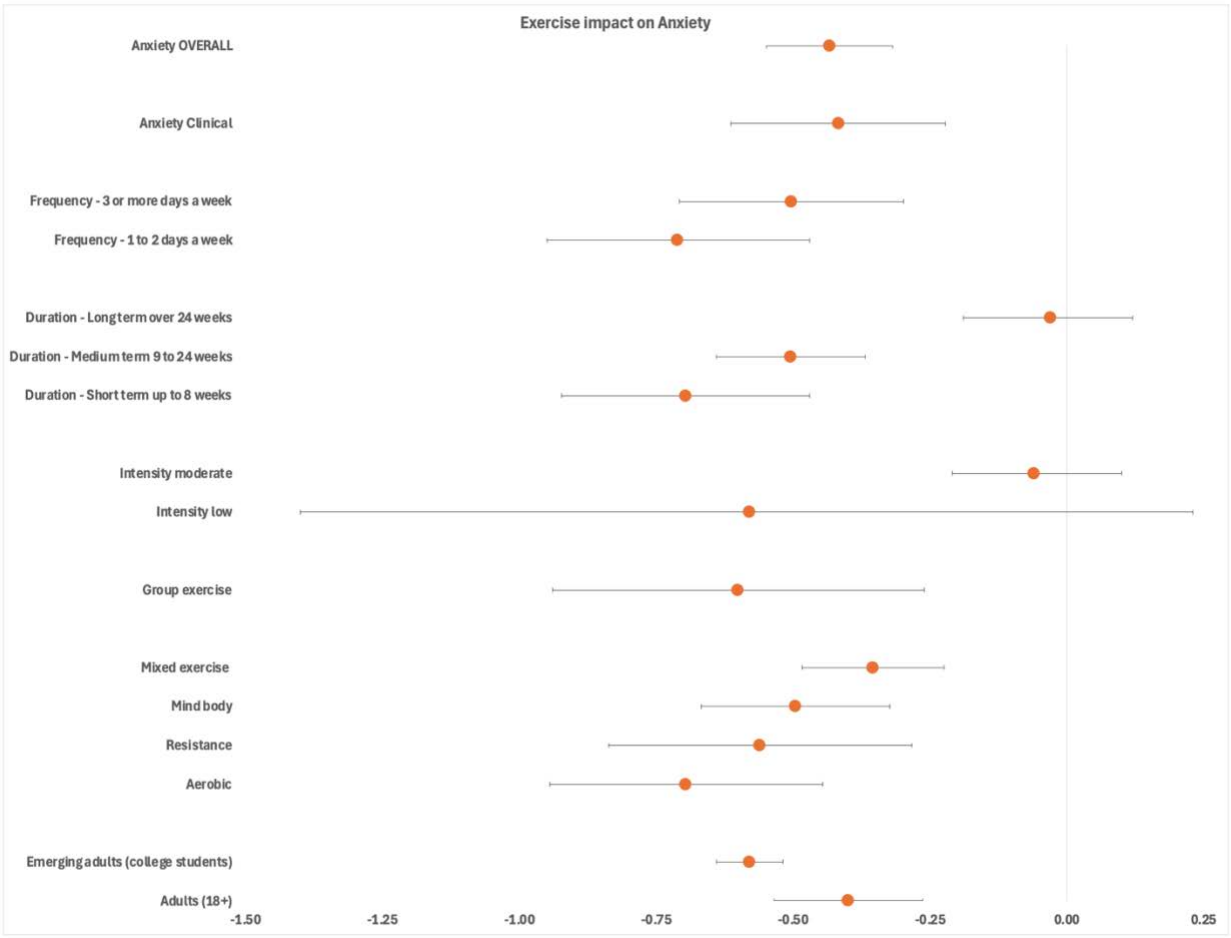


Figure 26

Forest plot for anxiety – Adults

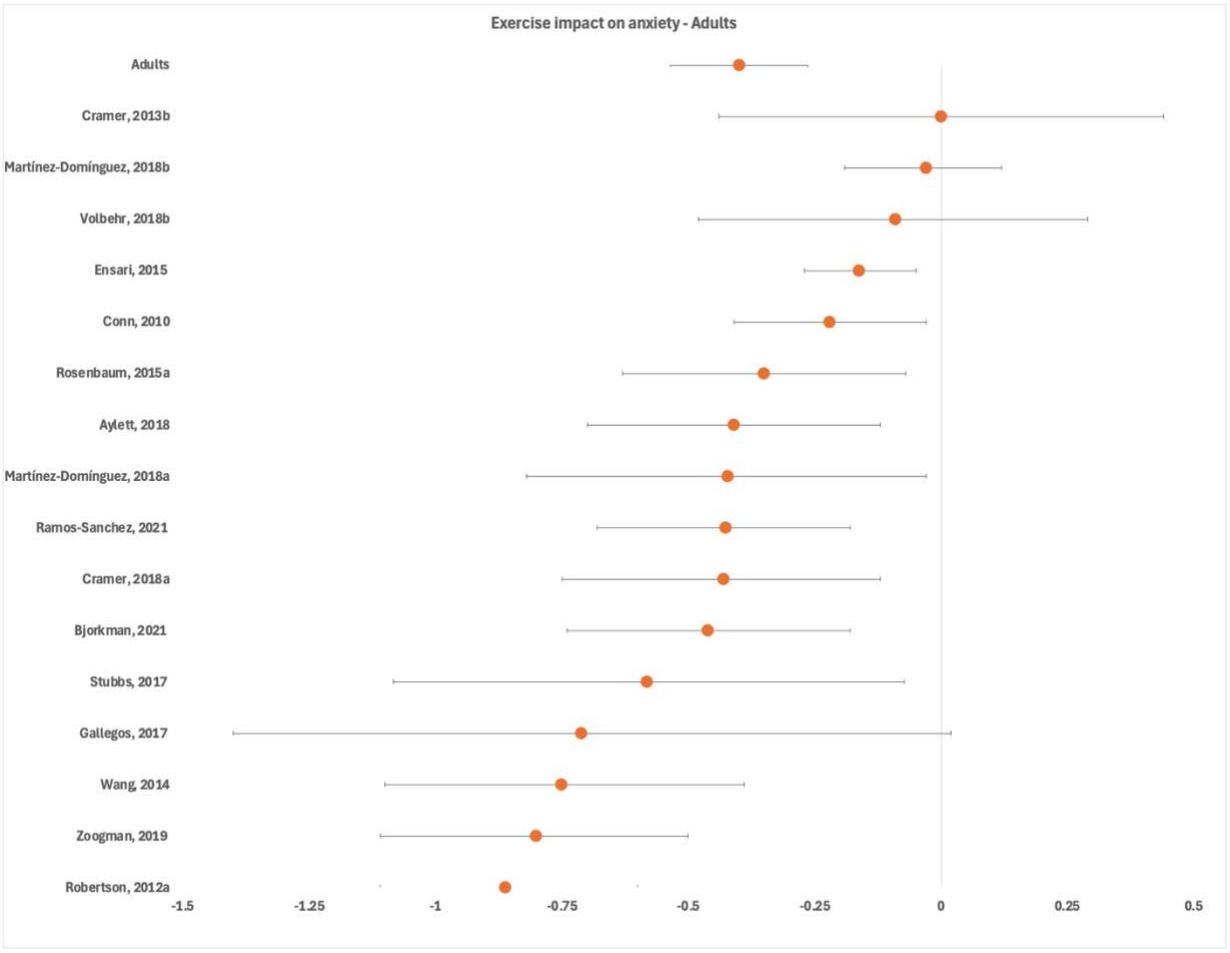


Figure 27

Forest plot for anxiety – Emerging adults

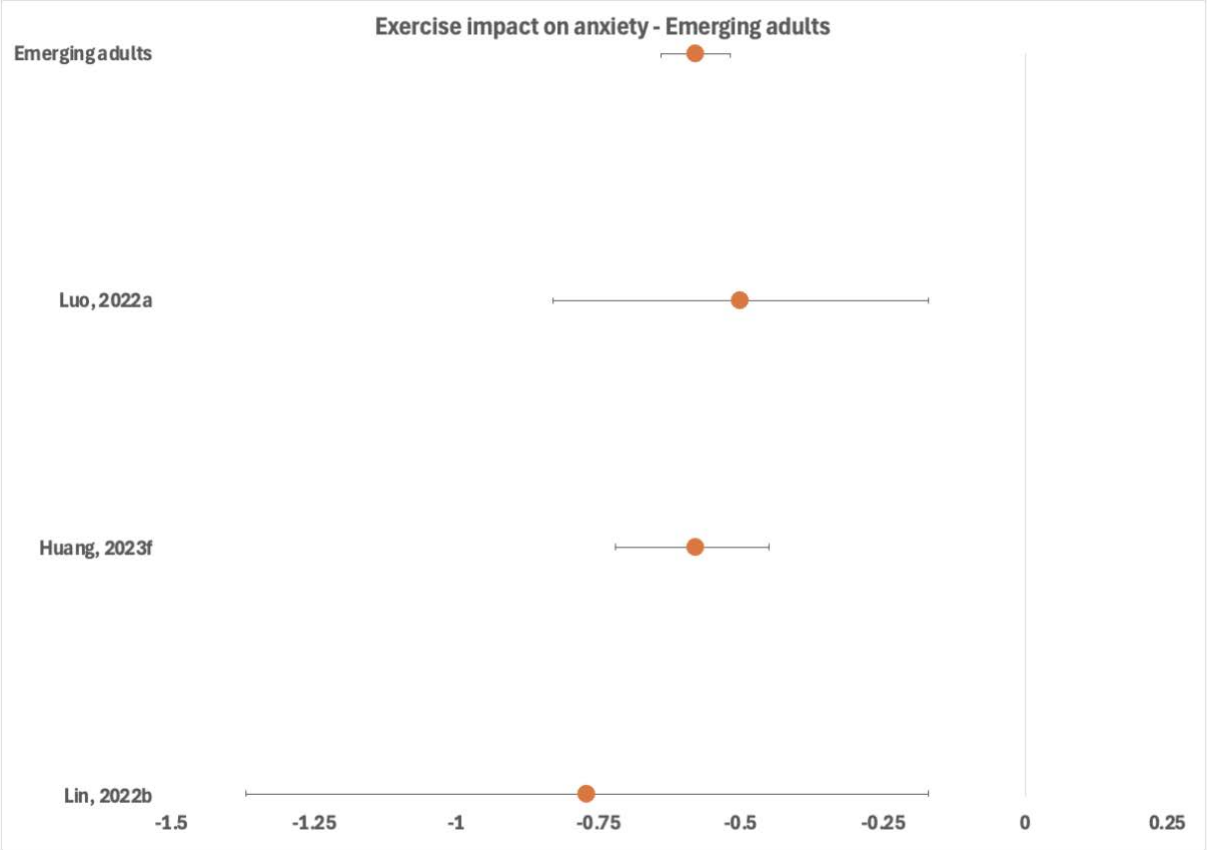


Figure 28

Forest plot for anxiety – Exercise type

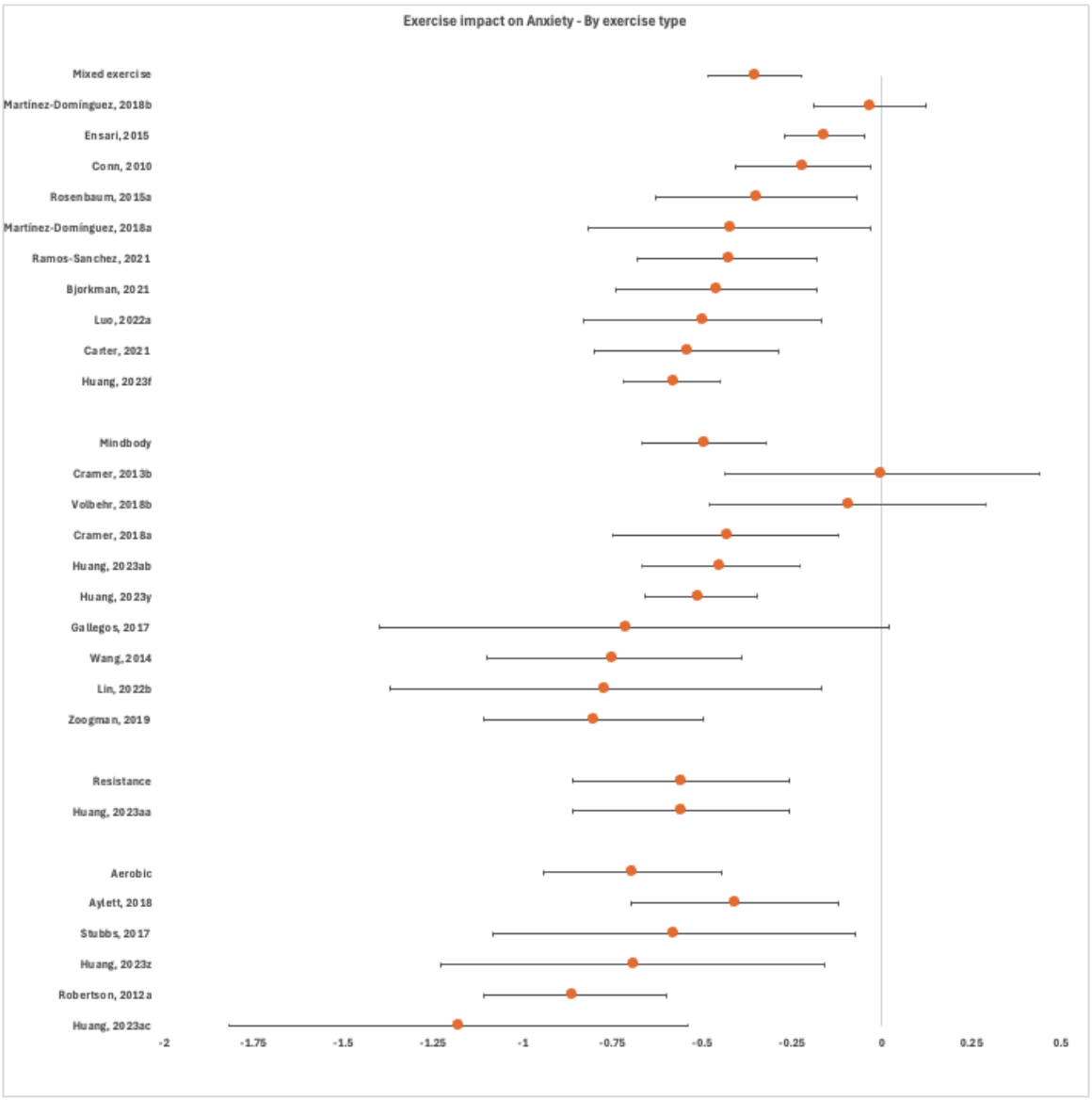


Figure 29

Forest plot for anxiety – Group exercise

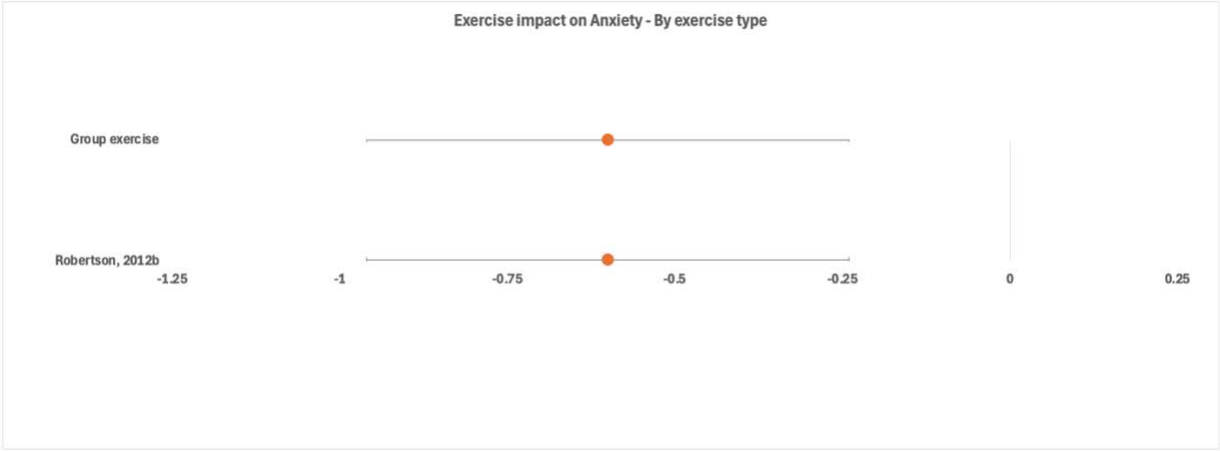


Figure 30

Forest plot for anxiety – Exercise intensity

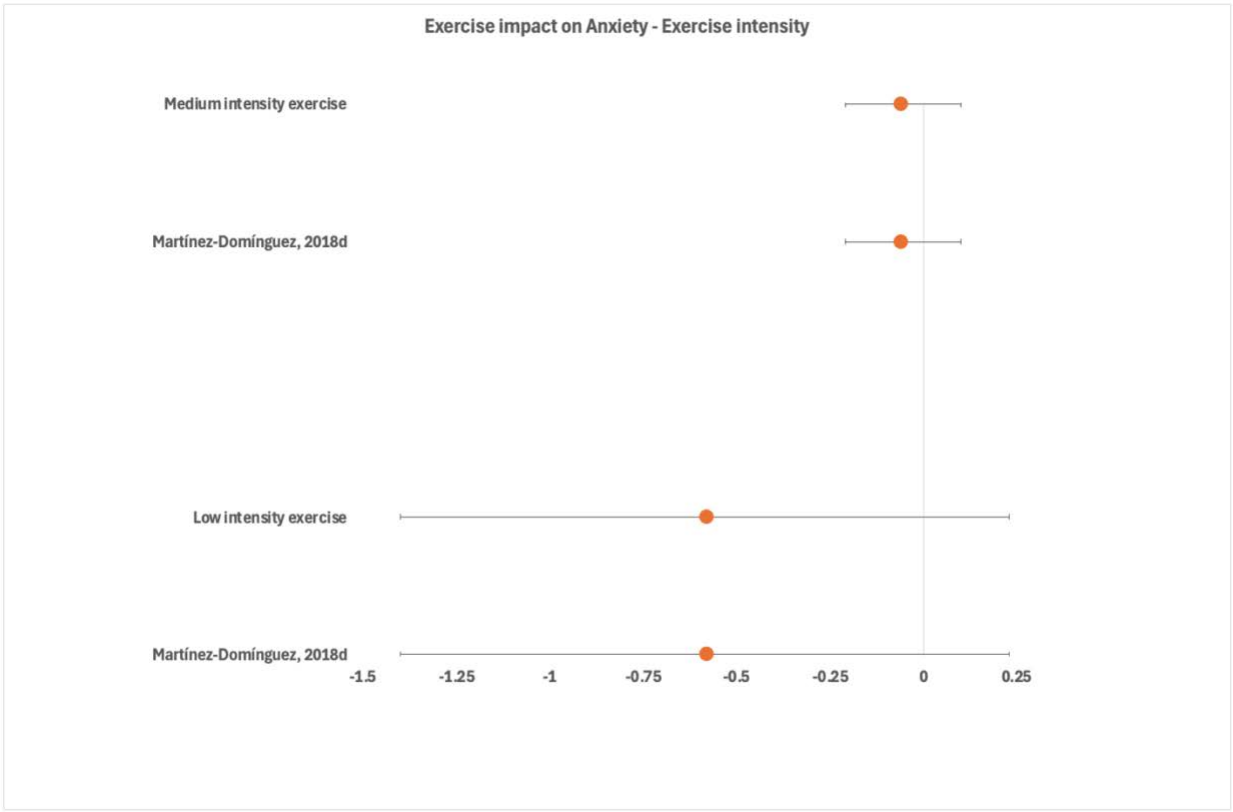


Figure 31

Forest plot for anxiety – Exercise duration

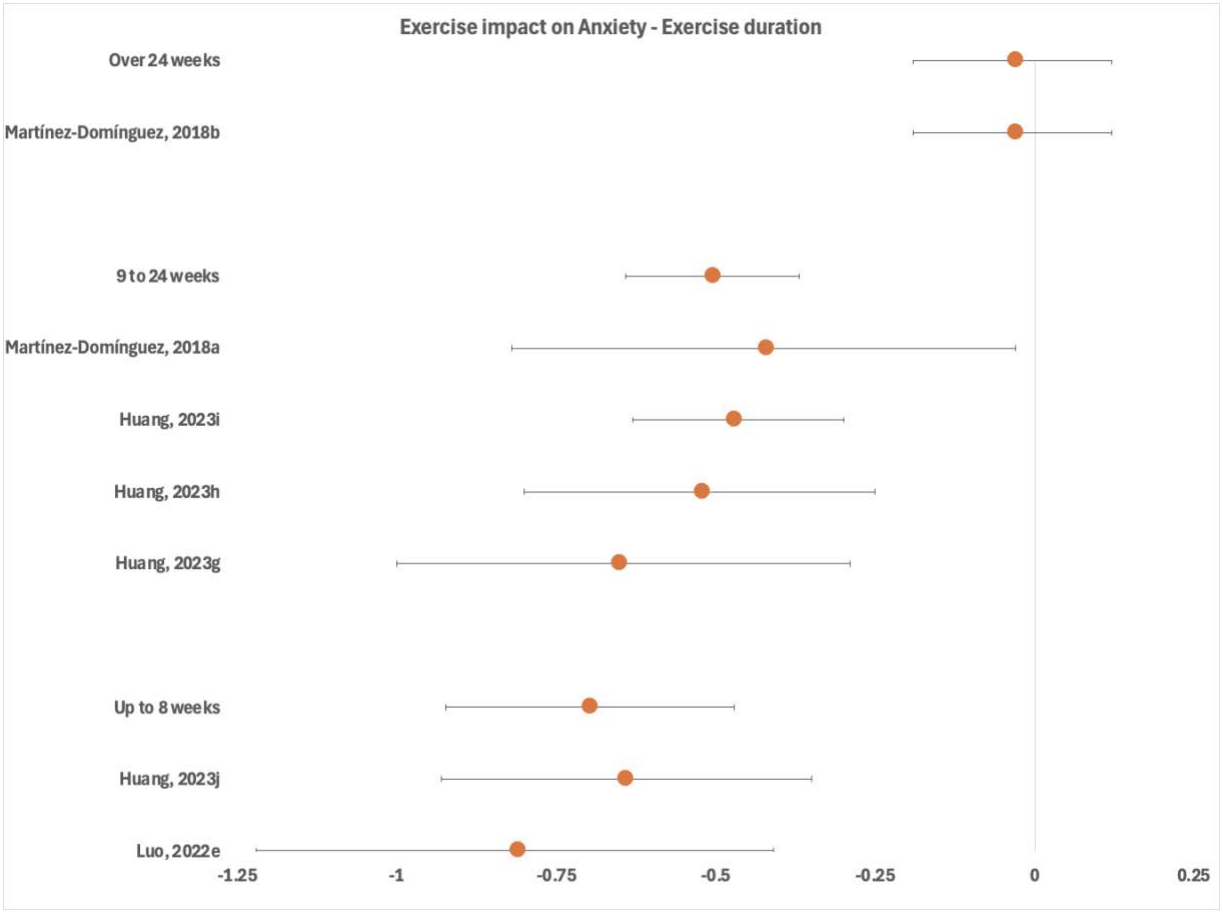


Figure 32

Forest plot for anxiety – Exercise frequency

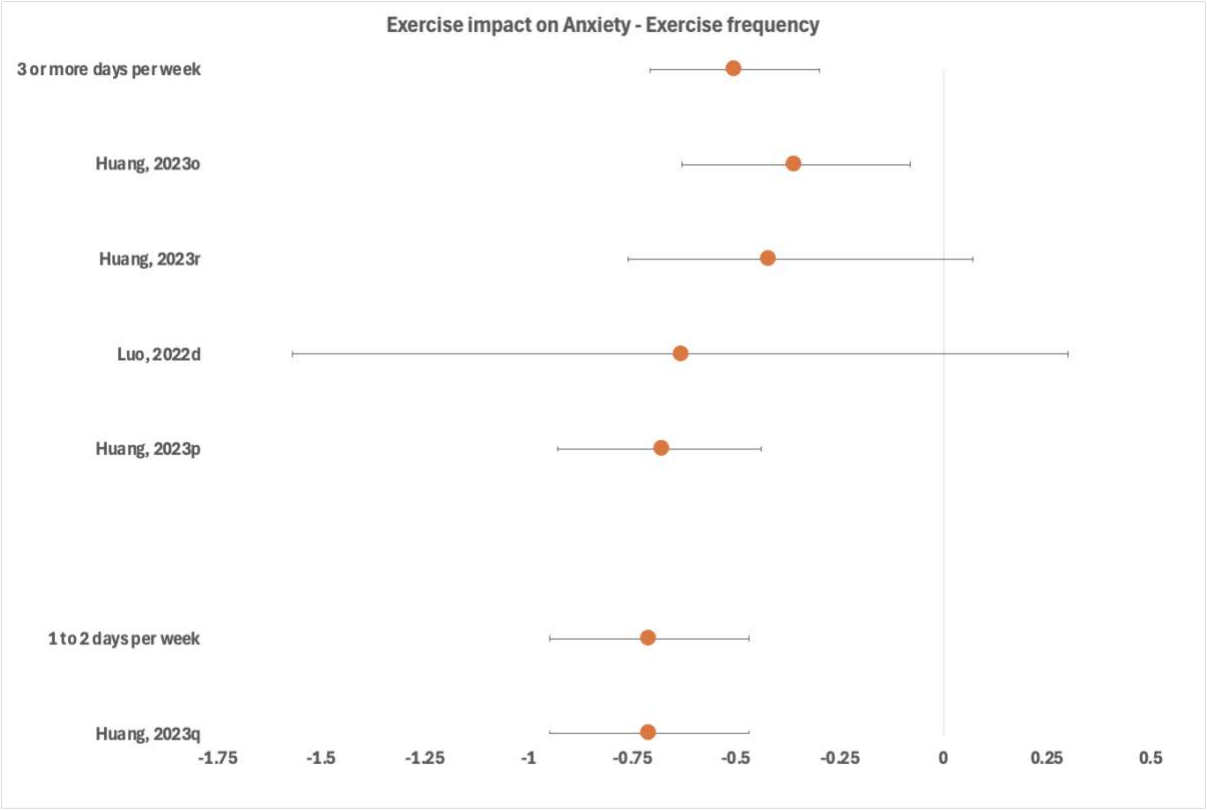


Figure 33

Forest plot for anxiety – Clinical diagnoses

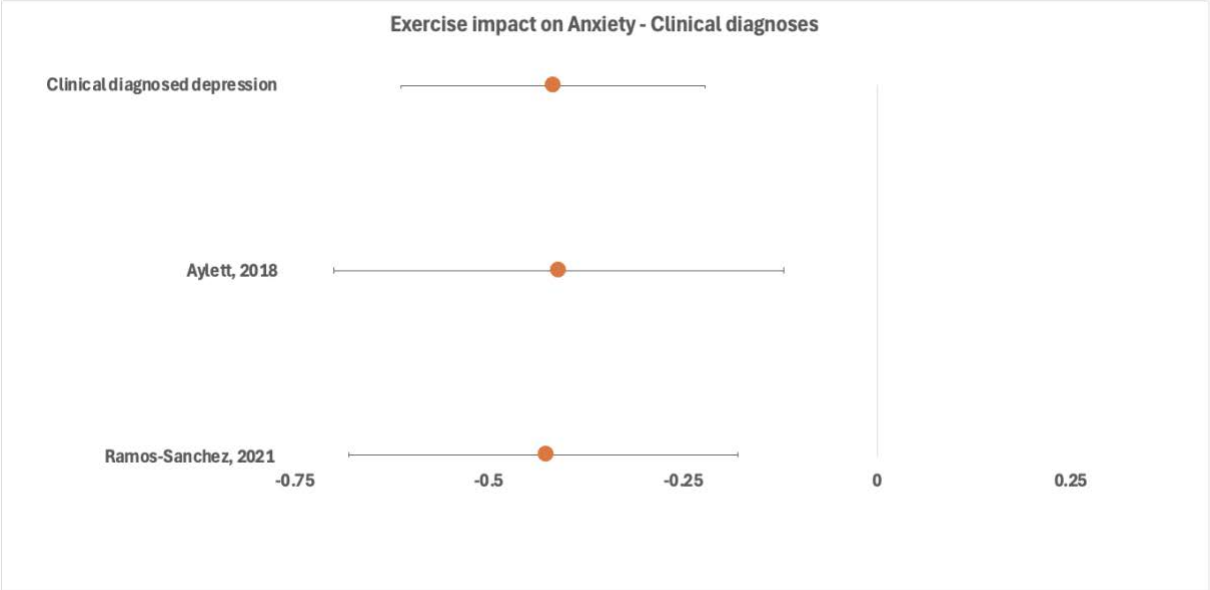


Figure 34

Forest plot for anxiety – AMSTAR categorization

