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Effect of different physical activity interventions on perinatal depression: a systematic review and network meta-analysis

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Abstract

Background Perinatal depression can have profound impacts on both families and society. Exercise therapy is gradually becoming a widely used adjunct treatment for perinatal depression. Some studies have already focused on the relationship between physical activity and perinatal depression (PND). However, there is currently a lack of systematic and comprehensive evidence to address the crucial question of making optimal choices among different forms of physical activity. This study aims to compare and rank different physical activity intervention strategies and identify the most effective one for perinatal depression.

Methods Four databases, namely PubMed, Cochrane Library, Embase, and Web of Science, were searched for randomized controlled trials assessing the impact of physical activity interventions on perinatal depression. The search covered the period from the inception of the databases until May 2024. Two researchers independently conducted literature screening, data extraction, and quality assessment. Network meta-analysis was performed using Stata 15.1.

Results A total of 48 studies were included in the analysis. The results indicate that relaxation therapy has the most effective outcome in reducing perinatal depression (SUCRA = 99.4%). Following that is mind-body exercise (SUCRA = 80.6%). Traditional aerobics and aquatic sports were also effective interventions (SUCRA = 70.9% and 67.1%, respectively).

Conclusion Our study suggests that integrated mental and physical (MAP) training such as relaxation therapy and mind-body exercise show better performance in reducing perinatal depression. Additionally, while exercise has proven to be effective, the challenge lies in finding ways to encourage people to maintain a consistent exercise routine.

Trial registration This study has been registered on PROSPERO (CRD 42,023,469,537).

Keywords Physical activity, Women, Perinatal depression, Network meta-analysis

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Introduction

Perinatal Depression (PND), defined as depression occurring during pregnancy (prenatal depression) or after childbirth (postpartum depression), is a common mental disorder with a prevalence exceeding 10% [1, 2]. Risk factors for PND may include a history of depression, lower socioeconomic status, poor physical health, anxiety about pregnancy, and reduced social support, while better living conditions and higher levels of education are possible protective factors [3, 4]. Research suggests that the prevalence of perinatal depression is higher among women in low and middle-income countries compared to women in high-income countries [5], and first-time mothers may have a higher risk of postpartum depression compared to multiparous women [6]. Perinatal depression may negatively affect a mother's quality of life, intimate relationships, birth outcomes, and the likelihood of breastfeeding. Additionally, it may have long-term impacts on a child's social, emotional, cognitive, language, motor, and adaptive behavior development [7, 8].

Both pharmacological and non-pharmacological treatments may help alleviate symptoms of perinatal depression in women [9]. However, due to concerns about potential adverse effects of medications on the health of the fetus and infant, some women tend to prefer non-pharmacological treatments [10]. Non-pharmacological treatments primarily include psychological interventions, physical therapies, exercise therapy, music therapy, acupuncture, and more [11]. Psychological intervention may be a first-line treatment for mild to moderate perinatal depression, with their therapeutic effects possibly lasting 6–12 months [12]. Among these, Cognitive Behavioral therapy (CBT) and Interpersonal Therapy (IPT) are both potentially effective psychological interventions for treating perinatal depression [13].

It's worth noting that exercise therapy, due to its low cost and ease of implementation, has gradually become a widely used adjunctive treatment for postpartum depression [14]. Exercise during pregnancy and postpartum may benefit the health of both the mother and the fetus. It can potentially reduce the risk of conditions such as preeclampsia, gestational hypertension, gestational diabetes, excessive weight gain during pregnancy, and complications during delivery. It may also improve the psychological health of pregnant and postpartum women, reducing the incidence and severity of perinatal depression [15–18]. The American College of Obstetricians and Gynecologists (ACOG) considers exercise to be generally safe for perinatal women and recommends that women engage in moderate-intensity exercise for 20–30 min most days of the week, as it may play a significant role in preventing postpartum depression [19].

Previous studies have indicated that aerobic exercise may be positively correlated with the alleviation of perinatal depression symptoms. Group exercise, participant-choice exercise, and combined interventions involving exercise have all shown potential efficacy as intervention measures [14, 20]. Prenatal yoga has been demonstrated to possibly improve current mood and reduce symptoms of both prenatal and postpartum depression [21–23]. Compared to sedentary women, those who engage in moderate physical activity in an aquatic environments may have a lower risk of postpartum depression [24]. A randomized controlled trial indicated that progressive muscle relaxation exercise (PMRE) may reduce the risk of postpartum depression and increase maternal attachment [25].

Previous meta-analyses have often focused on the relationship between physical activity and perinatal depression [26–28]. However, there is a lack of high-quality evidence to support decisions regarding the optimal choice among various physical activity interventions. To address this gap and provide more precise and safe treatment options for women with perinatal depression, this study conducted a network meta-analysis and systematic review based on high-quality randomized controlled trials (RCTs). The aim was to compare and rank different physical activity interventions and determine the best physical activity intervention for perinatal depression. This research seeks to offer more accurate guidance for the treatment of perinatal depression in women.

Methods

Protocol and registration

We followed the requirements of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines for literature inclusion, data organization, statistical analysis, and results reporting. This study has also been registered on PROSPERO (CRD 42,023,469,537).

Data sources and search strategy

We conducted a comprehensive search for relevant literature on the association between physical activity and perinatal depression in four electronic databases: PubMed, Cochrane Library, Embase, and Web of Science. The initial search covered the period from the inception of each database up to June 20, 2023. Considering the timeliness of the research, we also conducted a secondary search covering the period from June 20, 2023, to May 19, 2024. Following the PICOS (Population, Intervention, Comparison, Outcome, Study Design) principles, the search terms included "Exercise" or "Exercises" or "Physical Activity" or "Physical Activities" or "Motor Activity" or "Sport" or "Aerobics" or "Training" or "Trainings" or "Jogging" or "Walking" or "Ambulation" or "Yoga" or "Swimming" or "Dancing" or "Cycling" or "Resistance" or "Pilates" or "Stretching" and "Postpartum Depression" or "Postnatal Depression" or "Postnatal Dysphoria" or "Postpartum Dysphoria" or "Puerperal depression" or "Antepartum depression" or "Antenatal depression" or "Perinatal depression" or "Prenatal depression" or "Depression during pregnancy" or "Postpartum psychosis." For specific search strategies, please refer to Appendix B1 and Appendix B2.

Study selection

After conducting the literature search using the aforementioned search strategy, two authors (YS and DL) independently conducted the literature screening process. Initial screening was performed by reviewing the titles and abstracts of the retrieved articles to identify potentially relevant studies. Subsequently, the articles with higher relevance were selected for full-text retrieval and examination. Ultimately, the literature meeting the criteria was included in the statistical analysis. In cases of disagreement, group discussions were held among team members to reach a consensus.

Inclusion and exclusion criteria

This systematic review, based on the PICOS framework, established criteria for the selection, inclusion, and exclusion of literature.

Inclusion criteria for literature were as follows:

(1) Study subjects were perinatal women, including those during pregnancy and within one year postpartum [29].
(2) Interventions involved various types of exercise or physical activity.
(3) Studies reported data on depression indicators in perinatal women before and after the intervention.
(4) Experimental study designs were limited to randomized controlled trials (RCTs).
(5) Original data were provided.
(6) The studies were written in English.

Exclusion criteria for literature were as follows:

(1) Study participants were not perinatal women.
(2) The intervention did not include physical activity.
(3) There was no reporting on depression-related outcomes.
(4) The study types included qualitative research, reviews, theses, conference papers.
(5) Non-interventional study designs, including cross-sectional studies, case-control studies, and cohort studies.
(6) Original data were not provided.
(7) The studies were written in a language other than English.

Data extraction

The data from the included trials were independently extracted by two authors (YS and DL). Any discrepancies that arose during this process were resolved through group discussions. The following information was extracted from each study:

(1) Descriptive information, such as author(s), year, and country.
(2) Participant characteristics, including age range, gender, and sample size.
(3) Intervention details, including time, frequency, and duration.
(4) Outcome measurements, specifically related to perinatal depression.

When interventions or outcomes were unclear but presented graphically, the Engauge Digitizer software was used to extract data. For studies with multiple follow-up assessments, data were only extracted immediately after the intervention. In cases where standard deviations were not provided, they were calculated from the confidence intervals (95%) of the mean within the intervention or control group.

Quality assessment

We utilized the Cochrane Risk of Bias assessment tool (RoB2) to evaluate the quality of the studies based on five criteria: (1) Randomization process; (2) Deviation from intended interventions; (3) Missing outcome data; (4) Outcome measurement; (5) Selection of the reported result. Based on this, we assessed the overall bias of each study, categorizing them as having low risk, high risk, or some concerns.

Statistical analysis

We calculated the Standardized Mean Difference (SMD) with a 95% confidence interval (CI) for continuous outcomes. We assessed the statistical heterogeneity using the P-value from the chi-square test and the I^2 statistic. Considering that the included studies utilized various depression scales, we employed a random-effects model to ensure consistency and comparability in calculating the average difference. Following the recommendations of PRISMA NMA, we used a Bayesian framework and the Markov chain Monte Carlo simulation in Stata 15.1 software to aggregate and analyze NMA data [30, 31]. Node-splitting analysis was used to quantify and explain the consistency between indirect and direct comparisons. If the p-value was greater than 0.05, it was considered consistent through the consistency test.

We conducted a network meta-analysis using a Bayesian model. Data preprocessing was performed using the network package, and evidence network plots were generated. In the evidence network plot, each point represents an intervention, and the size of the point corresponds to the sample size included in the respective intervention study. Lines connecting two points represent direct comparisons between two interventions, and the thickness of the line segment indicates the number of studies included in the comparison, with thicker lines indicating more included studies. To rank the effects of different types of exercise, we calculated the Surface Under the Cumulative Ranking Curve (SUCRA) and presented the probability ranking in a table. SUCRA is expressed as a percentage, where a higher proportion indicates a better effect of the intervention. To assess publication bias, we generated a funnel plot and conducted both Begg's test and Egger's test. Additionally, we applied the trim-and-fill method using a random-effects model for further analysis.

Results

Trial selection

To ensure the accuracy of the literature retrieval and screening process, two researchers (YS and DL) with expertise in the fields of perinatal depression and exercise science independently screened titles, abstracts, and full-text articles after the literature search was completed. The inter-rater reliability (Cohen's kappa) between these two screening stages was calculated, including the screening stages for titles and abstracts, as well as the full-text screening stage. The consistency levels were categorized as follows: fair consistency (0.40–0.59), good consistency (0.60–0.74), and excellent consistency (>0.75) [32].

In our initial search, we conducted a comprehensive search of four electronic databases from their inception to June 20, 2023, identifying a total of 7,912 articles. Following the removal of duplicate studies (n=1,494), 6,418 relevant articles remained. Subsequently, through title and abstract screening, 6,295 articles were excluded, leaving 102 articles eligible for full-text review. During this stage, the inter-rater reliability between the two assessors was classified as "good" (Cohen's kappa=0.73). After a full-text review, 57 articles were further excluded. Among these, 11 were not randomized controlled trials, 17 did not involve exercise interventions, 26 had unavailable data, and 3 lacked full-text access. Consequently, the initial search screened out 45 studies. To ensure the research was up-to-date, we also conducted a secondary search, comprehensively reviewing the literature from June 20, 2023, to May 19, 2024, in the four electronic databases, identifying 896 articles. After these two searches and careful screening, a total of 48 studies were included in the quantitative synthesis (Fig. 1). During this stage, the inter-rater reliability between the two assessors was classified as "excellent" (Cohen's kappa=0.84).

Trial characteristics

Table 1 presents the characteristics of the 48 included studies. All studies were published between 2003 and 2024. The United States had the highest number of publications, with a total of 11 papers. The sample size in the intervention groups ranged from 8 to 396 individuals, totaling 2,930 perinatal women. The control group sample sizes ranged from 7 to 382 individuals, totaling 2,907 perinatal women. The average age of women included in the experimental and control groups was less than 40 years.

To investigate whether different types of physical activity have varying effects on perinatal women's depression, we classified them into seven types based on common features of physical activity and previous related research [27, 33]. This classification was determined through team discussions and expert consultations. The seven types include aquatic sport (2 studies) [24, 34], combination exercise (10 studies) [35–44], mind-body exercise (14 studies) [22, 23, 45–56], relaxation therapy (3 studies) [25, 57, 58], strength training (2 studies) [59, 60], traditional aerobics (12 studies) [20, 61–71], and walking (5 studies) [72–76].

Non-physical activity interventions included no intervention, health education, social support, and usual care. Measurement tools commonly used for perinatal depression included the Edinburgh Postnatal Depression Scale (EPDS), Center for Epidemiological Studies Depression Scale (CES-D), Beck Depression Inventory (BDI), Hospital Anxiety and Depression Scale (HADS), Psychological General Well-Being Index (PGWBI), Depression Anxiety Stress Scales (DASS), Profile of Mood States (POMS), Hamilton Depression Rating Scale (HDRS), and Physical health questionnaire-9 (PHQ-9), among others.

Risk of bias

Of the 48 studies, 35 were considered to have a low risk of bias in the randomization process, while 13 studies did not specify their randomization process. All studies were deemed to have a low risk of bias in terms of deviations from intended interventions and missing outcome data. For outcome measurement bias, 39 studies were considered to have a low risk, while 9 studies were considered to have a high risk. Regarding selective reporting bias, 47 studies were judged to have a low risk, with only 1 study having a high risk of selective reporting bias. Based on these five criteria, we categorized the overall risk of the 48 studies: 38 studies were considered to have a low overall risk of bias, and 10 studies were considered to have a high overall risk of bias. Detailed bias assessment results of the included studies can be found in Fig. 2 and Appendix C.

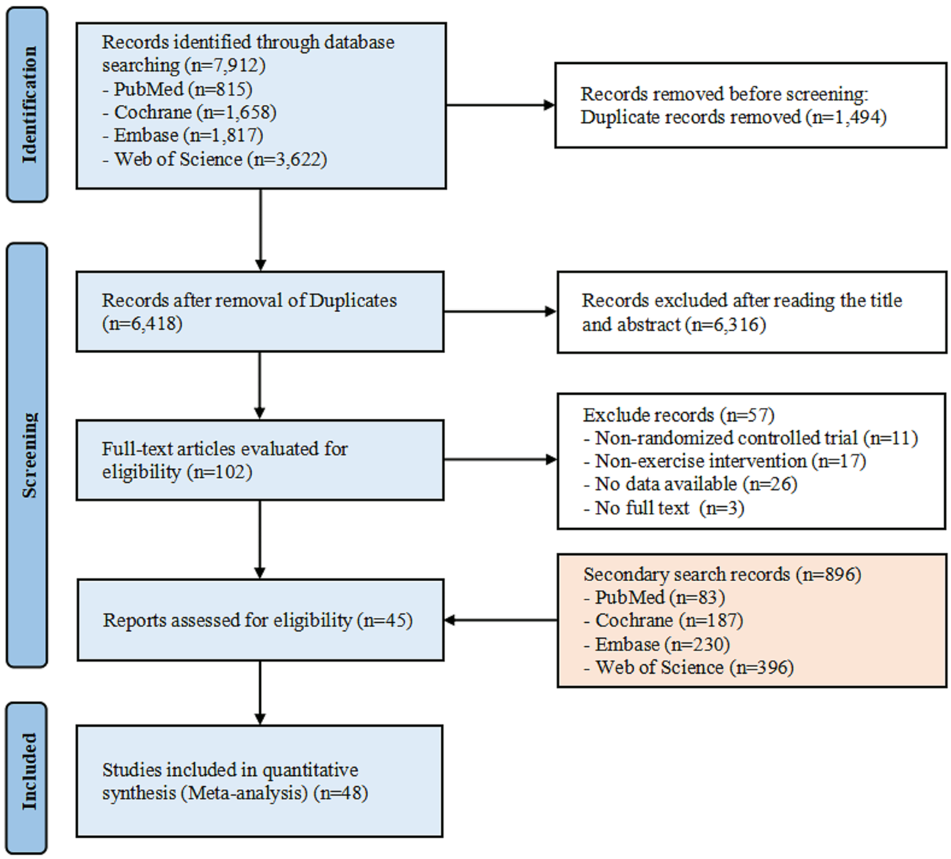

Fig. 1 A summary of the evidence searches and selection process

Certainty of evidence

Assessment was conducted according to the GRADE method, and the specific results can be found in Appendix E1.

Network meta-analysis

Figure 3 represents the Network Meta-Analysis diagram. It is evident that the three interventions with the largest sample sizes in the experimental group are traditional aerobics, mind-body exercise, and combination exercise. In the control group, the three interventions with the largest sample sizes are usual care, health education, and no intervention. The most frequently studied comparisons involve traditional aerobics versus usual care, combination exercise versus usual care, and mind-body exercise versus usual care.

As shown in Table 2, the statistically significant results of the network meta-analysis are as follows: Relaxation therapy [MD=-3.13, 95% CI=(-6.02, -0.23)] demonstrated greater efficacy compared to mind-body exercise. When compared to traditional aerobics, relaxation therapy [MD=-3.69, 95% CI=(-6.58, -0.80)] showed superior effectiveness. Relaxation therapy [MD=-4.10, 95% CI=(-7.61, -0.58)] exhibited higher efficacy than walking. In comparison to combination exercise, relaxation therapy [MD=-4.90, 95% CI=(-7.92, -1.87)] was more effective. Both relaxation therapy [MD=-5.21, 95% CI=(-8.28, -2.14)] and mind-body exercise [MD=-2.08, 95% CI=(-3.98, -0.19)] demonstrated greater efficacy than health education. When contrasted with strength training, relaxation therapy [MD=-5.69, 95% CI=(-9.84, -1.53)] exhibited higher effectiveness.

Relaxation therapy [MD=-5.91, 95% CI=(-8.60, -3.21)], mind-body exercise [MD=-2.78, 95% CI=(-4.16, -1.40)], and traditional aerobics [MD=-2.21, 95% CI=(-3.50, -0.93)] were all more effective than usual care. When compared to no intervention, relaxation therapy [MD=-6.45, 95% CI=(-9.35, -3.55)], mind-body exercise [MD=-3.32, 95% CI=(-5.14, -1.50)], and traditional aerobics [MD=-2.76, 95% CI=(-4.68, -0.83)] showed greater effectiveness. Furthermore, relaxation therapy [MD=-7.75, 95% CI=(-12.42, -3.08)], mind-body exercise [MD=-4.62, 95% CI=(-8.40, -0.84)], and traditional aerobics [MD=-4.06, 95% CI=(-8.06, -0.06)] were found to be more effective than social support.

In terms of the probability of different interventions affecting depression as indicated by SUCRA, relaxation therapy ranked first (SUCRA = 99.4%), followed by mind-body exercise (SUCRA = 80.6%). Subsequently, traditional aerobics and aquatic sport ranked next (SUCRA = 70.9%

Table 1 Summary table of included reviews

Study	Country	*N* (IG; CG)	Age (IG; CG)	Intervention (IG)			Intervention (CG)			Perinatal period	Out-comes
				Intervention content	Intervention time, frequency, period	Type	Intervention content	Interven-tion time, frequency, period	Type		
Aguilar-Cordero et al. [24]	Spain	65; 64	34.52 ± 4.50; 33.67 ± 5.37	Exercise in an aquatic environment	60 min, 3 weekly, 18 weeks	Aquatic sport	Recommen-dations and consultations	NR	Usual care	Prenatal	EPDS
Armstrong et al. [72]	Australia	10; 10	NR; NR	Pram-walk-ing + social support	30–40 min, 3 weekly, 12 weeks	Walking	NI	NI	NI	Postpartum	EPDS
Armstrong et al. [73]	Australia	9; 10	≤ 29 7, ≥30 12	Pram-walking	40 min, 2 weekly, 12 weeks	Walking	Non-structured sessions	90 min, 1 weekly, 12 weeks	Social support	Postpartum	EPDS
Bose. [67]	India	26; 28	NR; NR	Exercise (heating and cycling)	40–60 min, 4 weekly, 4 weeks	Tradi-tional aerobics	Patient handout	NR	Health education	Prenatal	PHQ-9
Buttner et al. [23]	USA	27; 29	29.81 ± 5.17; 32.45 ± 4.78	Yoga	150 min, 1 weekly, 8 weeks	Mind-body exercise	NI	NR	NI	Postpartum	HDRS
Coll et al. [40]	Brazil	187; 382	27.2 ± 5.5; 27.3 ± 5.5	Exercise (aero-bic activities, strength train-ing, etc.)	60 min, 3 weekly, 16 weeks	Combi-nation exercise	Usual care	NR	Usual care	Prenatal	EPDS
Daley et al. [62]	UK	16; 15	21–30 20, 31–40 17, >40 1	Exercise (pram-walking, etc.) + exercise consultations	30 min, 5 weekly, 12 weeks	Tradi-tional aerobics	Usual care	NR	Usual care	Postpartum	EPDS
Daley et al. [33]	UK	43; 42	31.7 ± 5.3; 29.3 ± 5.7	Exercise (walk-ing, jogging, etc.) + exercise consultations	30 min 3-5 weekly, 6 months	Tradi-tional aerobics	Usual care	NR	Usual care	Postpartum	EPDS
Daley et al. [76]	UK	189; 194	27.7 ± 6.2	Walking + exer-cise consulta-tions + behav-ioural support	30 min, 6–7 weekly, 8 weeks	Walking	Behavioural support	20 min, 6 weekly, 4 weeks	Usual care	Prenatal	EPDS
Davis et al. [22]	USA	20; 19	29.74 ± 5.40; 30.57 ± 4.46	Yoga	75 min, 1 weekly, 8 weeks	Mind-body exercise	Usual care	NR	Usual care	Prenatal	EPDS
Duchette et al. [52]	USA	10; 9	27.1 ± 2.88; 30.1 ± 4.10	Yoga	75 min, 1 weekly, 10 weeks	Mind-body exercise	Do not participate in yoga	NR	NI	Prenatal	EPDS

Table 1 (continued)

Study	Country	N (IG; CG)	Age (IG; CG)	Intervention (IG)			Intervention (CG)			Perinatal period	Out-comes
				Intervention content	Intervention time, frequency, period	Type	Intervention content	Interven-tion time, frequency, period	Type		
El-Rafie et al. [20]	Egypt	50; 50	26.7 ± 2.3; 28.4 ± 2.6	Aerobic exer-cise (step aero-bics, bicycling, or walking)	60 min, 3 weekly, 12 weeks	Tradi-tional aerobics	Usual care	NR	Usual care	Prenatal	CES-D
Field et al. [47](1)	USA	37; 38	24.4 ± 4.7; 26.0 ± 5.6	Tai chi/yoga	20 min, 1 weekly, 12 weeks	Mind-body exercise	NI	NR	NI	Prenatal	CES-D
Field et al. [48](2)	USA	40; 39	24.4 ± 4.7; 24.5 ± 5.02	Yoga	20 min, 1 weekly, 12 weeks	Mind-body exercise	Leader-less group sessions	Consistent with IG	Social support	Prenatal	EPDS
Forsyth et al. [75]	UK	11; 11	25.0 ± 5.1; 27.0 ± 5.5	Pram-walk-ing + exercise consultations	150 min, 1 weekly, 12 weeks	Walking	Usual care	NR	Usual care	Postpartum	EPDS
Gallagher et al. [51]	USA	48; 31	30.44 ± 6.17; 27.65 ± 7.46	Yoga	30 min, 2 weekly, average of 7.46 (3–16) instructor-led sessions	Mind-body exercise	Usual care	NR	Usual care	Prenatal	HADS
Garnæs et al. [41]	Norway	38; 36	31.3 ± 3.8; 31.4 ± 4.7	Treadmill walk-ing + resistance training	50–60 min, 4 weekly, from gestational weeks 12–18 to delivery	Combi-nation exercise	Usual care	NR	Usual care	Prenatal	PGWBI
Gustafsson et al. [39]	Norway	396; 365	30.5 ± 4.4; 30.4 ± 4.3	Aerobic and strength training	45–60 min, 3 weekly, 12 weeks	Combi-nation exercise	Usual care	NR	Usual care	Prenatal	PGWBI
Haruna et al. [65]	Japan	48; 47	33.8 ± 3.6; 33.7 ± 4.0	Aerobic exer-cise (bounce on an exercise ball)	90 min, 4 weekly, 4 weeks	Tradi-tional aerobics	NR	NR	NI	Postpartum	EPDS
Heh et al. [61]	China	33; 30	NR; NR	Stretching exercise	60 min, 3 weekly, 3 months	Tradi-tional aerobics	Usual care	NR	Usual care	Postpartum	EPDS
Huang et al. [63]	China	61; 64 64; 64	32.13 ± 4.50, 30.67 ± 3.70; 31.91 ± 4.85	Individualised dietary and physical activ-ity education plan	30–40 min, 1 bimonthly, from gestational weeks 16 to six months postpartum (IG 1), from 24–48 h after birth to six months postpartum (IG 2)	Tradi-tional aerobics	Obstetric educational programme	1 trimonthly	Health education	Postpartum	BDI
Keller et al. [74]	USA	39; 54	28.3 ± 5.59; 28.3 ± 5.59	Group walk-ing + 4 differ-ent types of support	1 weekly, 12 weeks	Walking	Health information	1 monthly	Health education	Postpartum	EPDS

Table 1 (continued)

Study	Country	N (IG; CG)	Age (IG; CG)	Intervention (IG)			Intervention (CG)			Perinatal period	Outcomes
				Intervention content	Intervention time, frequency, period	Type	Intervention content	Intervention time, frequency, period	Type		
Kim et al. [59]	Korea	23; 22	32.22 ± 2.58; 31.50 ± 4.48	Structured bed exercise (isometric exercise)	30 min, 1 daily, 4 days	Strength training	NR	NR	NI	Prenatal	EPDS
Kim et al. [54]	Korea	8; 8	39.71 ± 2.01; 38.14 ± 1.39	Pilates	50 min, 2 weekly, 8 weeks	Mind-body exercise	Do not participate in any exercise	NR	NI	Prenatal	EPDS
Kiyak et al. [58]	Turkey	71; 70	30.70 ± 6.44; 30.70 ± 6.37	Progressive muscle relaxation exercises + laughter therapy	40 min, 3–4 times, from the first day of ovarian stimulation protocol to the day of oocyte retrieval	Relaxation therapy	Usual care	NR	Usual care	Prenatal	BDI
Lewis et al. [37]	USA	61; 63	31.69 ± 5.27; 31.39 ± 4.63	Exercise (walk, bike, weights, etc.) + exercise consultations	30 min, 5 weekly, 6 months	Combination exercise	Wellness/support contact	NR	Health education	Postpartum	EPDS
Mitchell et al. [45]	USA	12; 12	26.6(18–37)	Yoga	20 min, 2 weekly, 12 weeks	Mind-body exercise	Parenting education	Consistent with IG	Health education	Prenatal	CES-D
Mohammadi et al. [66]	Iran	38; 36 36; 36	25.2 ± 4.7, 25.5 ± 4.6; 25.3 ± 5.2	Stretching and breathing practices + exercise education	20–30 min, 3 weekly, from gestational weeks 26–32 to delivery (IG 1), from gestational weeks 26–32 to 2 months postpartum (IG 2)	Traditional aerobics	Antenatal and postnatal ordinary education	40 min	Health education	Postpartum	EPDS
Nadholta et al. [55]	India	34; 43	29.31 ± 3.42; 29.71 ± 3.00	Yoga	40–60 min, 5 weekly, 16 weeks	Mind-body exercise	Usual care	NR	Usual care	Prenatal	DASS
Nasiri et al. [57]	Iran	26; 28	24.82 ± 4.15; 25.75 ± 4.72	Progressive muscle relaxation exercises + guided imagery	7 weekly, 6 weeks	Relaxation therapy	Usual care	1 weekly, 6 weeks	Usual care	Postpartum	BDI
Navas et al. [34]	Spain	139; 132	31.1 ± 4.1; 31.5 ± 4.2	Aerobic water exercise	45 min, 3 weekly, 5 months	Aquatic sport	Usual care	NR	Usual care	Postpartum	EPDS
Newham et al. [49]	UK	29; 22	31 ± 5; 31 ± 7	Yoga	8 weeks	Mind-body exercise	Usual care	NR	Usual care	Prenatal	EPDS

Table 1 (continued)

Study	Country	*N* (IG; CG)	Age (IG; CG)	Intervention (IG)			Intervention (CG)			Perinatal period	Out-comes
				Intervention content	Intervention time, frequency, period	Type	Intervention content	Interven-tion time, frequency, period	Type		
Norman et al. [35]	Australia	62; 73	29.3 ± 4.0; 30.1 ± 5.3	Group exercise (involving cardiovascular and strength compo-nents) + health education	60 min, 1 weekly, 8 weeks	Combi-nation exercise	Written educational material	1 weekly, 8 weeks	Health education	Postpartum	EPDS
O'Connor et al. [60]	USA	44; 45	28 ± 5; 29 ± 4	Resistance exercise	17 min, 2 weekly, 12 weeks	Strength training	NI	NR	NI	Prenatal	POMS
Özkan et al. [70]	Turkey	34; 31	28.90 ± 4.83	Exercise	30 min, 5 weekly, 4 weeks	Tradi-tional aerobics	Usual care	NR	Usual care	Postpartum	EPDS
Perales et al. [38]	Spain	90; 77	31.08 ± 3.39; 31.66 ± 3.86	Exercise (walk-ing, aerobic dance, muscle exercises, etc.)	55–60 min, 3 weekly, from gestational weeks 9–12 to 39–40	Combi-nation exercise	Usual care	NR	Usual care	Prenatal	CES-D
Robledo-Colonia et al. [64]	Colombia	37; 37	21 ± 3	Aerobic exercise	60 min, 3 weekly, 3 months	Tradi-tional aerobics	Usual care	1 weekly, 12 weeks	Usual care	Prenatal	CES-D
Rong et al. [53]	China	32; 32	29.00 ± 2.81; 28.16 ± 2.78	Yoga	60 min, 3 weekly, 12 weeks	Mind-body exercise	Usual care	Consistent with IG	Usual care	Prenatal	EPDS
Satyapriya et al. [46]	India	51; 45	26.41 ± 3.01; 24.96 ± 2.58	Integrated yoga	60–120 min, 3–7 weekly, 16 weeks	Mind-body exercise	Stretching exercises	Consistent with IG	Traditional aerobics	Prenatal	HADS
SONGØY-GARD et al. [36]	Norway	379; 340	30.59 ± 4.3; 30.57 ± 4.2	Aerobic and strengthening exercises	45–60 min, 3 weekly, 12 weeks	Combi-nation exercise	Usual care	NR	Usual care	Postpartum	EPDS
Teychenne et al. [71]	Australia	32; 30	33.6 ± 3.7; 33.0 ± 3.7	Treadmill walking or cycling + social support	12 weeks	Tradi-tional aerobics	NI	NR	NI	Postpartum	EPDS
Uçakcı Asalıoğlu et al. [25]	Turkey	25; 27	29.48 ± 3.65; 26.22 ± 3.78	Progres-sive muscle relaxation	2 weekly, from gestational weeks 36–37 to 6 weeks postpartum	Relax-ation therapy	Routine follow-up	NR	NI	Postpartum	EPDS
Uebelacker et al. [50]	USA	11; 7	28.0 ± 5.9; 28.9 ± 6.0	Yoga	75 min, 1 weekly, 9 weeks	Mind-body exercise	Perinatal health education	Consistent with IG	Health education	Prenatal	EPDS

Table 1 (continued)

Study	Country	*N* (IG; CG)	Age (IG; CG)	Intervention (IG)			Intervention (CG)			Perinatal period	Outcomes
				Intervention content	Intervention time, frequency, period	Type	Intervention content	Intervention time, frequency, period	Type		
Vargas-Terrones et al. [42]	Spain	36; 25	32.5 ± 3.3; 32.6 ± 4.7	Exercise (aerobic activities, muscle strengthening exercises, etc.)	60 min, 3 weekly, from gestational weeks 12–16 to 38–40	Combination exercise	Usual care	NR	Usual care	Prenatal	CES-D
Wilczyńska et al. [43]	Poland	34; 20	31 ± 4; 32 ± 4	HIIT	60 min, 3 weekly, 8 weeks	Combination exercise	Health education	150 min, 1 weekly, 8 weeks	Health education	Prenatal	BDI
Wilczyńska et al. [44]	Poland	22; 16	30.18 ± 4.21; 32.38 ± 3.52	HIIT	60 min, 3 weekly, 8 weeks	Combination exercise	Health education	60 min, 1 weekly, 8 weeks	Health education	Prenatal	BDI
Yang et al. [69]	China	60; 62	31.89 ± 4.03; 32.45 ± 4.12	Aerobic gymnastic exercise	15 min, 3 weekly, 3 months	Traditional aerobics	Usual care	NR	Usual care	Postpartum	EPDS
Yıldırım et al. [56]	Turkey	17; 17	30.8 ± 7.0; 28.8 ± 5.6	Pilates	60 min, 2 weekly, 12 weeks	Mind-body exercise	Usual care	NR	Usual care	Prenatal	HADS

IG, intervention group; CG, control group; NR, no report; NI, no intervention; EPDS, Edinburgh Postnatal Depression Scale; CES-D, Center for Epidemiological Studies Depression Scale; BDI, Beck Depression Inventory; HADS, Hospital Anxiety and Depression Scale; PGWBI, Psychological General Well-Being Index; DASS, Depression Anxiety Stress Scales; POMS, Profile of Mood States; HDRS, Hamilton Depression Rating Scale; PHQ-9, Physical health questionnaire-9; HIIT, High-intensity interval training

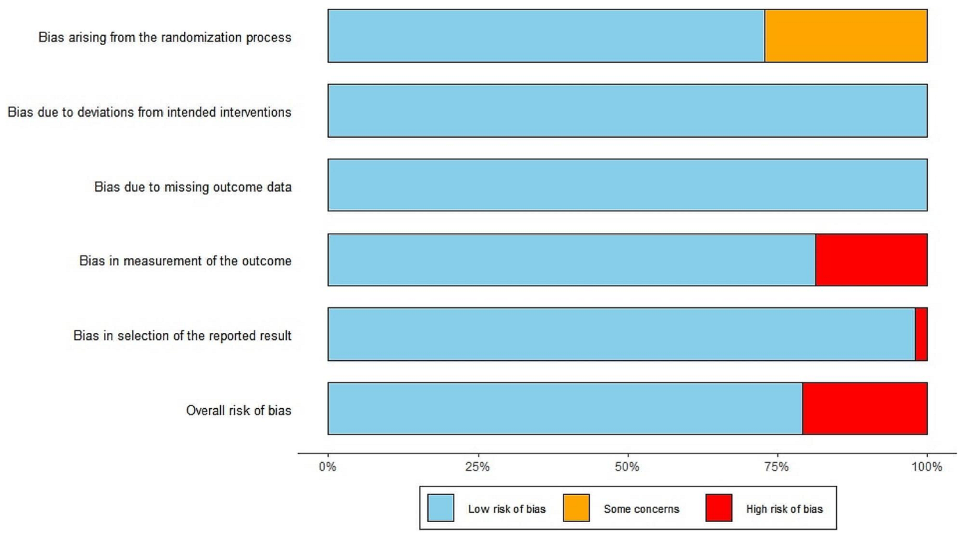

Fig. 2 Risk of bias of included studies

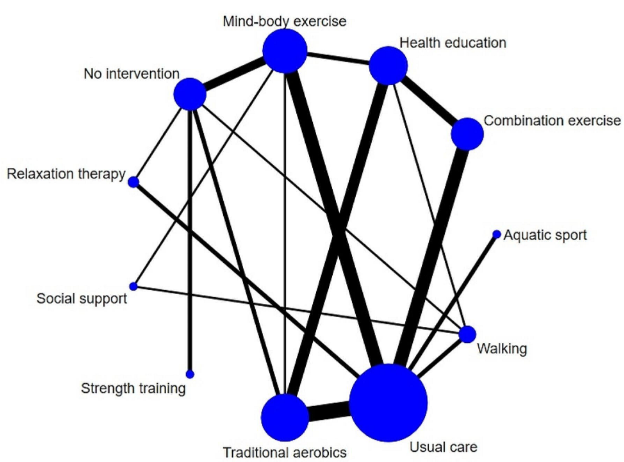

Fig. 3 Network diagram

and 67.1%, respectively). The specific results are presented in Fig. 4.

Publication bias

As shown in Fig. 5, we first used a funnel plot to assess publication bias. The distribution of studies in the funnel plot appeared roughly symmetrical, with no obvious signs of publication bias upon visual inspection. Subsequently, we conducted Begg's test and Egger's test, yielding the following results: Begg's test indicated significant bias ($p \leq 0.000$), while Egger's test showed no significant bias ($p = 0.075$), as detailed in Appendix D1 and Appendix D2. We conducted further evaluation of publication bias using trim-and-fill analysis with a random-effects model. The results indicated that after adjustment through trim-and-fill, there was a slight decrease in the estimated effect size, but the change was minimal. This suggests that there may be some publication bias present in the original data, but its impact is not substantial. Overall, the estimated effect size remained significant, indicating a certain robustness of the study findings (see Appendix D3 and Appendix D4). Additionally, sensitivity analysis conducted by iteratively excluding individual studies revealed no significant impact on the overall results (see Appendix D5 and Appendix D6).

Discussion

This study aimed to compare the effects of different physical activity interventions on perinatal depression in women. The research indicates that the top four intervention measures for reducing perinatal depression, in order, are relaxation therapy, mind-body exercise, traditional aerobics, and aquatic sports. Detailed results can be found in Table 3.

Characteristics of depression include an increased preoccupation with negative information, difficulty in disengaging from negative information, and cognitive control deficits when processing negative information [77]. A recent study has shown that both physical activity and mental engagement can help maintain brain health, slowing down disease progression, and that intellectual engagement may be the most effective remedy for individuals with cognitive issues [78]. Mental and physical (MAP) training is an innovative clinical intervention that combines mental training through meditation with physical training through aerobic exercise [79]. The relaxation therapy and mind-body exercise in this study both fall under the integrated MAP training category. The results of this study suggest that, compared to traditional aerobics, integrated MAP training may offer more effective treatment for perinatal depression. On one hand, physical training can enhance muscle strength and flexibility, alleviate physiological discomfort such as back pain and

Table 2 League table on interventions

Relaxation therapy	Mind-body exercise	Traditional aerobics	Aquatic sport	Walking	Combination exercise	Health education	Strength training	Usual care	No intervention	Social support
Relaxation therapy	3.13 (0.23,6.02)	3.69 (0.80,6.58)	3.73 (-0.04,7.50)	4.10 (0.58,7.61)	4.90 (1.87,7.92)	5.21 (2.14,8.28)	5.69 (1.53,9.84)	5.91 (3.21,8.60)	6.45 (3.55,9.35)	7.75 (3.08,12.42)
-3.13 (-6.02,-0.23)	Mind-body exercise	0.56 (-1.06,2.19)	0.60 (-2.37,3.58)	0.97 (-1.63,3.57)	1.77 (-0.14,3.68)	2.08 (0.19,3.98)	2.56 (-0.93,6.05)	2.78 (1.40,4.16)	3.32 (1.50,5.14)	4.62 (0.84,8.40)
-3.69 (-6.58,-0.80)	-0.56 (-2.19,1.06)	Traditional aerobics	0.04 (-2.89,2.97)	0.41 (-2.12,2.94)	1.21 (-0.51,2.93)	1.52 (-0.01,3.05)	2.00 (-1.55,5.55)	2.21 (0.93,3.50)	2.76 (0.83,4.68)	4.06 (0.06,8.06)
-3.73 (-7.50,0.04)	-0.60 (-3.58,2.37)	-0.04 (-2.97,2.89)	Aquatic sport	0.37 (-3.17,3.91)	1.17 (-1.83,4.17)	1.48 (-1.60,4.56)	1.96 (-2.46,6.38)	2.18 (-0.46,4.81)	2.72 (-0.54,5.98)	4.02 (-0.69,8.73)
-4.10 (-7.61,-0.58)	-0.97 (-3.57,1.63)	-0.41 (-2.94,2.12)	-0.37 (-3.91,3.17)	Walking	0.80 (-1.82,3.42)	1.11 (-1.41,3.64)	1.59 (-2.51,5.69)	1.81 (-0.55,4.17)	2.35 (-0.47,5.17)	3.65 (-0.46,7.76)
-4.90 (-7.92,-1.87)	-1.77 (-3.68,0.14)	-1.21 (-2.93,0.51)	-1.17 (-4.17,1.83)	-0.80 (-3.42,1.82)	Combination exercise	0.31 (-1.28,1.90)	0.79 (-2.98,4.56)	1.01 (-0.43,2.44)	1.55 (-0.76,3.86)	2.85 (-1.26,6.96)
-5.21 (-8.28,-2.14)	**-2.08 (-3.98,-0.19)**	-1.52 (-3.05,0.01)	-1.48 (-4.56,1.60)	-1.11 (-3.64,1.41)	-0.31 (-1.90,1.28)	Health education	0.48 (-3.26,4.21)	0.70 (-0.91,2.30)	1.24 (-1.02,3.49)	2.54 (-1.55,6.63)
-5.69 (-9.84,-1.53)	-2.56 (-6.05,0.93)	-2.00 (-5.55,1.55)	-1.96 (-6.38,2.46)	-1.59 (-5.69,2.51)	-0.79 (-4.56,2.98)	-0.48 (-4.21,3.26)	Strength training	0.22 (-3.33,3.77)	0.76 (-2.22,3.74)	2.06 (-3.02,7.14)
-5.91 (-8.60,-3.21)	**-2.78 (-4.16,-1.40)**	**-2.21 (-3.50,-0.93)**	-2.18 (-4.81,0.46)	-1.81 (-4.17,0.55)	-1.01 (-2.44,0.43)	-0.70 (-2.30,0.91)	-0.22 (-3.77,3.33)	Usual care	0.54 (-1.38,2.46)	1.84 (-2.06,5.75)
-6.45 (-9.35,-3.55)	**-3.32 (-5.14,-1.50)**	**-2.76 (-4.68,-0.83)**	-2.72 (-5.98,0.54)	-2.35 (-5.17,0.47)	-1.55 (-3.86,0.76)	-1.24 (-3.49,1.02)	-0.76 (-3.74,2.22)	-0.54 (-2.46,1.38)	No intervention	1.30 (-2.81,5.41)
-7.75 (-12.42,-3.08)	**-4.62 (-8.40,-0.84)**	**-4.06 (-8.06,-0.06)**	-4.02 (-8.73,0.69)	-3.65 (-7.76,0.46)	-2.85 (-6.96,1.26)	-2.54 (-6.63,1.55)	-2.06 (-7.14,3.02)	-1.84 (-5.75,2.06)	-1.30 (-5.41,2.81)	Social support

The bold values represent the signify statistical significance

fatigue [80]. On the other hand, mental training can also promote hormone secretion in the endocrine and nervous systems, alleviate stress and negative emotions, and improve self-efficacy [53].

Some studies also provide supporting evidence: the combination of aerobic exercise and meditation can promote neurogenesis in the hippocampus and maintain the vitality of neurons, reduce rumination, improve defects in cognitive control processes, and reduce depressive symptoms [79]. Buddhist walking meditation can improve functional health and vascular reactivity, reduce depression, and appear to offer greater overall improvement compared to traditional walking exercise [81]. Combining mindfulness with physical activity seems to have a more beneficial impact on sleep quality and emotional regulation in individuals with severe depression compared to mindfulness or physical activity alone, making it a valuable treatment strategy [82].

Perinatal women typically need to consider various factors such as physiology, psychology, safety, and personal energy when selecting exercises, as these factors interact to potentially lead to different optimal forms of exercise compared to women with general depression. Specifically, physiological changes are significant during the perinatal period, including hormonal fluctuations, weight gain, and changes in body center of gravity, which may affect tolerance and effectiveness of different types of exercise. For instance, high-intensity exercise may be effective for women with general depression but may not be suitable or sustainable for pregnant women who may worry about miscarriage or harming the baby due to excessive exertion [83]. Secondly, the perinatal period is characterized by significant emotional fluctuations, with women experiencing higher levels of anxiety and emotional swings, which may affect their response to exercise. For example, gentle exercises such as yoga may be more suitable for perinatal women as they not only alleviate depression but also help reduce anxiety and stress [55]. Furthermore, perinatal women need to consider the safety and comfort of exercise. For example, low-impact, low-intensity exercises such as swimming or walking may be more suitable as they impose less stress on joints and muscles, reducing the risk of exercise-related injuries [84]. Lastly, perinatal women may have limited time and energy due to physical fatigue and the responsibility of caring for a newborn. Therefore, short, efficient, and home-based exercises may be more popular and effective.

Relaxation therapy may be the most effective intervention for perinatal depression. Previous research has demonstrated that relaxation training, such as progressive

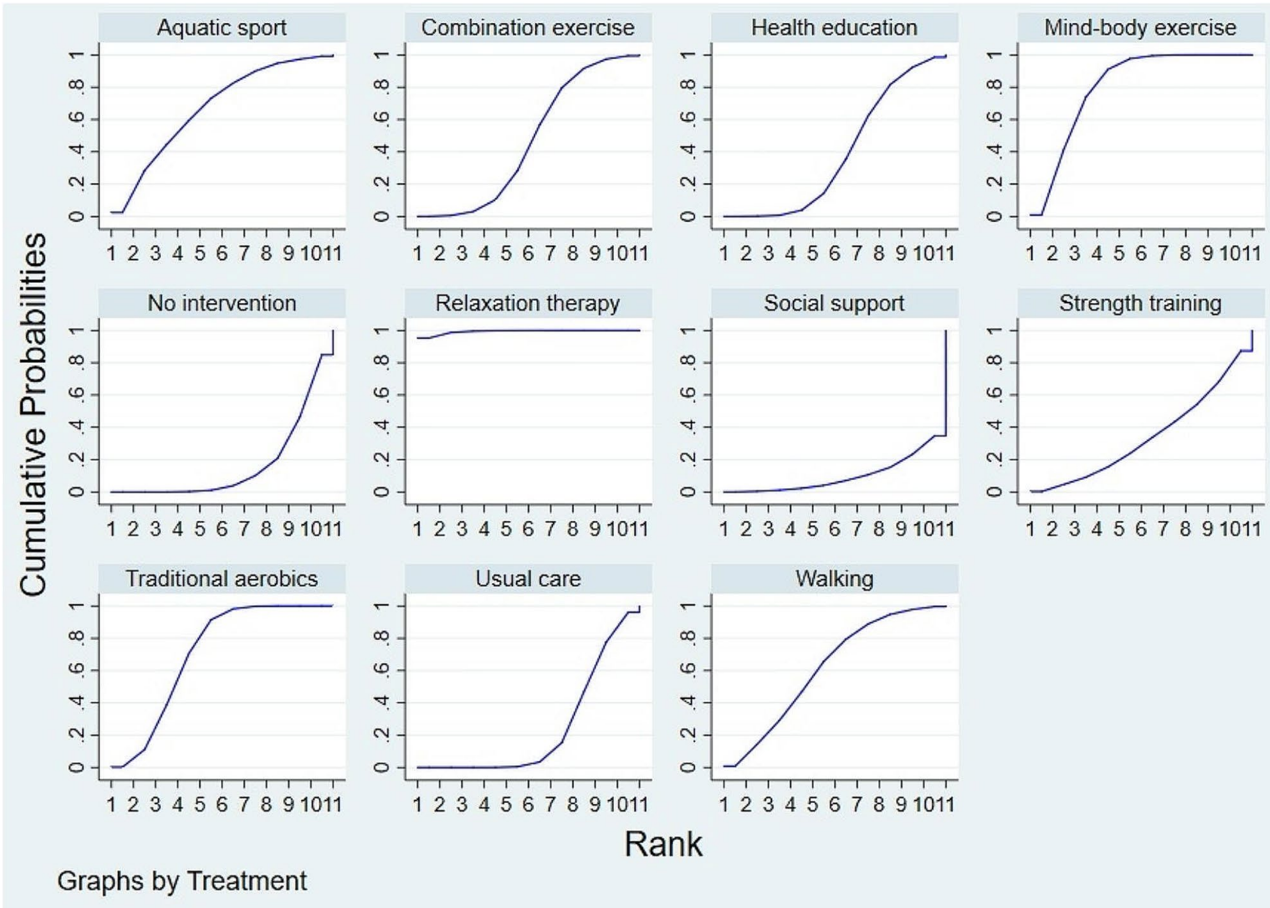

Fig. 4 SUCRA plot

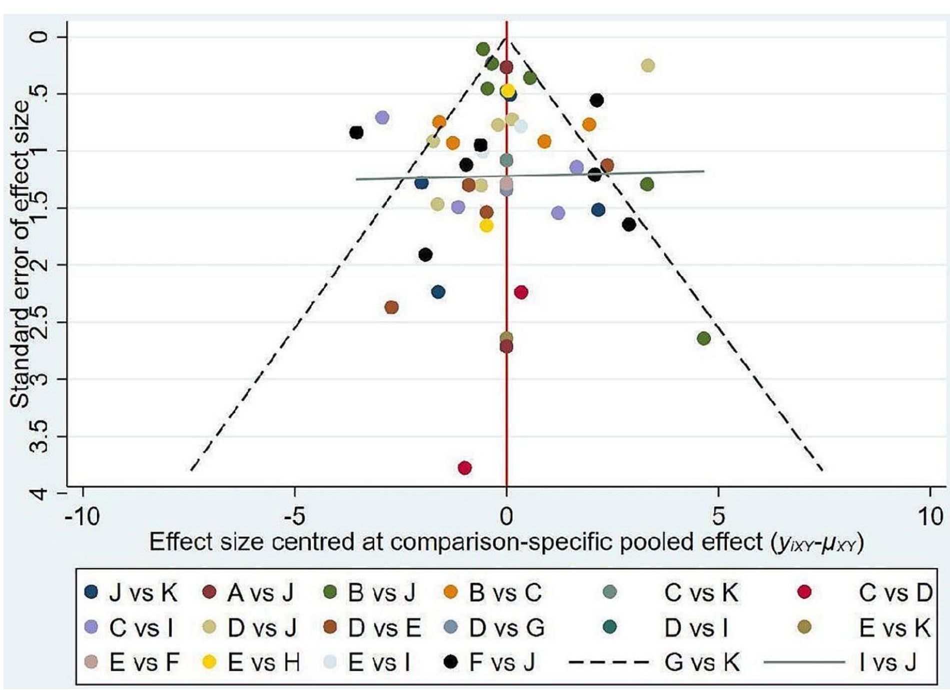

Fig. 5 Funnel plot on publication bias

Table 3 Ranking of SUCRA probabilities

Intervention	Sucra	Rank
Relaxation therapy	99.4	1
Mind-body exercise	80.6	2
Traditional aerobics	70.9	3
Aquatic sport	67.1	4
Walking	62.0	5
Combination exercise	46.5	6
Health education	38.7	7
Strength training	34.4	8
Usual care	23.9	9
No intervention	16.6	10
Social support	9.8	11

muscle relaxation, can help individuals reduce stress, enhance psychological and physiological relaxation, thereby improving overall health [85]. Progressive muscle relaxation is a deep muscle relaxation technique based on the principle that muscle tension is a physiological response to stimulating thoughts [86]. It can inhibit the activity of the sympathetic nervous system, promote relaxation of the body and mind, improve sleep quality, and reduce post-Cesarean section pain intensity [87, 88]. Additionally, muscle relaxation training helps stimulate the secretion of endorphins, enhancing immune function and happiness, potentially reducing depression and anxiety in pregnant women [89–91].

Several scholars have investigated the efficacy of relaxation therapy as an intervention for depression. Li et al. (2020) conducted a meta-analysis, revealing that relaxation techniques offer an economical, safe, and low-risk approach to alleviating depression symptoms in adult patients. Their findings underscored the ease of teaching and implementation [92]. Similarly, Jorm et al. (2015) reported in their meta-analysis that relaxation techniques outperformed no or minimal treatment in reducing self-reported depression symptoms, though they were not as effective as psychotherapy [93]. Conversely, Jia et al. (2020) found no significant difference in the efficacy of relaxation therapy and psychotherapy in reducing self-reported depression symptoms, suggesting that relaxation therapy may offer comparable benefits to psychotherapy [94]. Additionally, Klainin-Yobas et al. (2015) conducted a systematic review of 15 empirical studies focusing on relaxation interventions for anxiety and depression in the elderly. Their analysis indicated that elderly individuals receiving relaxation interventions generally experienced greater reductions in depression and anxiety compared to control groups, with progressive muscle relaxation training demonstrating the most pronounced effect [95].

Relaxation therapy offers several advantages over aerobic exercise and resistance training for perinatal women. First, dual benefits for physical and mental health. Relaxation therapy promotes blood circulation and relieves muscle tension, effectively reducing common perinatal discomforts such as back pain, edema, and insomnia. It emphasizes mind-body integration; by regulating breathing, focusing attention, and relaxing muscles, it alleviates anxiety and stress, thereby improving depressive symptoms. Chen et al. (2021) found that body-mind relaxation meditation is associated with changes in thalamocortical functional connectivity in patients with major depressive disorder, which may enhance positive emotions, emotional stability, and attention [96]. Tragea et al. (2014) showed that relaxation (breathing and progressive muscle relaxation) reduces anxiety and perceived stress in pregnant women and enhances their sense of internal control [97]. Second, high safety. Perinatal women, especially in late pregnancy, often feel fatigued or physically exhausted. Aerobic exercise and resistance training may put excessive strain on the body, while relaxation techniques like deep breathing, meditation, and body relaxation are mild physical activities with low demands and lower injury risks. This makes relaxation therapy more suitable for perinatal women. Third, easy to perform and sustainable. Relaxation therapy is simple and can be performed at home or any quiet environment without specific venues or equipment, making it convenient for long-term practice. It does not require prolonged sessions and can be flexibly scheduled, fitting well with the routines and daily arrangements of perinatal women.

Mind-body exercise may be the intervention that ranks second only to relaxation therapy. It is a gentle and slow form of exercise represented by practices like Tai Chi, Qigong, and yoga, emphasizing the coordination of meditation, physical exercise, and breathing [98, 99]. Mind-body therapies are often used in the treatment of depression to help alleviate its severity [100]. Yoga is one of the most commonly used mind-body interventions, which may alleviate physical and psychological discomfort, potentially reducing the risk of perinatal depression by increasing Brain-Derived Neurotrophic Factor (BDNF) and lowering serum cortisol levels [101–104]. Yoga can also improve psychological and physical health by promoting social connections and enhancing self-efficacy [23]. A Chinese Chan-based mind-body intervention has also been shown to potentially reduce the intake of antidepressant medication and improve depressive symptoms, including attention difficulties, gastrointestinal health issues, and overall sleep quality [105].

Traditional aerobics and aquatic sports may also be relatively effective physical activity interventions. Aerobic exercise may reduce depressive symptoms through biological mechanisms such as promoting the secretion of endorphins, serotonin, and norepinephrine [38]. Aquatic aerobic exercise is a low-impact activity with advantages such as a lower risk of miscarriage, reduced swelling, increased diuresis, decreased arterial pressure, and less back pain compared to weight-bearing exercise on land [106]. Water-based exercise programs can reduce fatigue and improve various aspects of emotional states, including tension, depression, anger, and mental fatigue, as well as enhance leg and abdominal muscle endurance [107].

In 2020, the WHO guidelines on physical activity and sedentary behavior recommended that all pregnant women and postpartum women without contraindications engage in at least 150 min of moderate-intensity aerobic exercise per week, along with muscle strength training and gentle stretching activities during pregnancy and postpartum, while reducing sedentary behavior [17]. A study suggested that exercise not only serves as a treatment for depression but also plays a positive role in preventing its onset. This study found a dose-response relationship between physical activity and the incidence of depression, indicating that even activity levels below the recommended guidelines can yield significant mental health benefits [108]. However, a recent study comparing the effects of antidepressant medication and running exercise on anxiety, depression, and overall health indicated that both therapies offer similar mental health benefits, but running exercise performs better in improving physical health. Although exercise therapy is a good option and might even be a better one, the challenge lies in increasing exercise adherence and motivating individuals to consistently engage in physical activity [109].

In summary, different physical activity interventions have varying degrees of impact on perinatal depression in women. The clinical significance of this study lies in providing clear intervention selection criteria for the treatment of perinatal depression. The results indicate that relaxation therapy and mind-body exercises such as yoga and tai chi significantly alleviate symptoms of perinatal depression. This provides empirical support for clinicians in formulating treatment plans, suggesting the inclusion of these forms of physical activity in the routine treatment protocols for perinatal women. Additionally, the study emphasizes the importance of encouraging and assisting perinatal women in maintaining long-term exercise habits. It highlights the need for healthcare providers to design sustainable intervention measures and support systems to enhance compliance and treatment effectiveness in perinatal women.

Strengths and limitations

This study has several strengths. Firstly, it is the first network meta-analysis on the impact of physical activity on perinatal depression, providing a scientific reference for the selection of appropriate physical activity interventions for perinatal women. Secondly, the inclusion of a substantial number of studies enhances the accuracy of the research findings. Thirdly, our study only included randomized controlled trials and excluded observational and cross-sectional studies, which increases the reliability of the results. However, there are also some limitations to our network meta-analysis. For instance, individual differences among perinatal women with depression may lead to heterogeneous effects of physical activity interventions, and different dosages of physical activity may influence the effectiveness of these interventions.

Future research could consider the following aspects. First, personalized physical activity interventions based on the individual characteristics of perinatal women with depression could be explored. For example, factors such as whether they are advanced maternal age (35 years or older), have a history of previous depression, experience depression during pregnancy or postpartum, or the severity of their depression (mild, moderate, or severe) could be taken into account when selecting targeted physical activity interventions. Tailoring interventions to the age, history of depression, timing of depression, and severity of depression among perinatal women can enhance the effectiveness of physical activity interventions. Second, investigating the optimal dosage of physical activity interventions for perinatal depression, including intervention frequency, duration, and intensity, would contribute to improving the precision of physical activity interventions.

Conclusion

This study explored the impact of different types of physical activities on perinatal depression. Based on the findings, we recommend women consider participating in integrated mental and physical (MAP) training, such as relaxation therapy and mind-body exercises, to potentially prevent or treat perinatal depression more effectively. Additionally, before implementing physical activity interventions, it is necessary to conduct comprehensive individual characteristic assessments of women with perinatal depression to ensure the selection of the optimal type of physical activity and intervention dosage. Furthermore, community and hospital staff can maintain regular communication with pregnant and postpartum women, supervise and encourage them to maintain consistent exercise habits, and provide support to alleviate adverse emotional experiences during the perinatal period. Future research could explore personalized physical activity interventions based on individual characteristics of women with perinatal depression. It could also investigate the optimal dosage of physical activity interventions for treating perinatal depression to enhance the effectiveness and accuracy of physical activity interventions.

Abbreviations

PND	Perinatal depression
MAP	Mental and physical training

CBT	Cognitive-behavioral therapy
IPT	Interpersonal therapy
ACOG	American College of Obstetricians and Gynecologists
RCTs	Randomized controlled trials
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
NMA	Network meta-analysis
PICOS	Population, Intervention, Comparison, Outcome, Study Design principles
SMD	Standardized Mean Difference
CI	Confidence interval
SUCRA	Surface Under the Cumulative Ranking Curve
EPDS	Edinburgh Postnatal Depression Scale
CES-D	Center for Epidemiological Studies Depression Scale
BDI	Beck Depression Inventory
HADS	Hospital Anxiety and Depression Scale
PGWBI	Psychological General Well-Being Index
POMS	Profile of Mood States
HDRS	Hamilton Depression Rating Scale
PHQ-9	Physical health questionnaire-9
WHO	World Health Organization
IG	Intervention group
CG	Control group
NR	No report
NI	No intervention
HIIT	High-intensity interval training

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12889-024-19564-w.

Supplementary Material 1

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Author contributions
All authors contributed to the study conception and design. YS and DL conceived and designed the study. YS, DL, CML and JLW collected the data. YS, JLW and DL analysed and interpreted the data. YS, DL and JLW drafted the manuscript. YS, CML and DL revised the manuscript. All authors have read and agreed to the published version of the manuscript.

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Declarations

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