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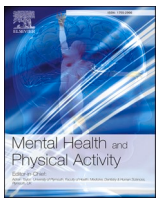

Feasibility and effects of high-intensity interval training for improving depressive symptoms in older adults: a systematic review and meta-analysis of randomized controlled studies

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ABSTRACT

Background: High-intensity interval training (HIIT) is an emerging and cost-effective exercise to reduce depressive symptoms. However, there is a lack of overview of HIIT for depressive symptoms among older adults. The objective of this study was to synthesise the feasibility and effects of HIIT on depressive symptoms among older adults.

Methods: This study followed the PRISMA guideline. Eight electronic databases (PubMed, EMBASE, Medline, PsycINFO, SPORTDiscus, Web of Science, Scopus, and Cochrane Central Register of Controlled Trials (CENTRAL)) were searched to screen eligible studies. Cochrane's risk of bias tool and GRADE approaches were used to evaluate the methodology and evidence quality. Random effects meta-analyses were performed for adverse events and depressive symptoms. Sub-group meta-analyses were performed on depressive symptoms based on characteristics of participants and the HIIT protocol.

Results: A total of 18 studies were identified in the systematic review. The retention and attendance rates of the HIIT group ranged from 59 % to 100 % and 74 % to 97 %, respectively. No significant differences were found in adverse events between HIIT and other exercises (RR = 1.34 [95 % CI 0.92, 1.95]; $p = 0.13$; $I^2 = 0$ %; n = 5). Depressive symptoms were significantly reduced immediately after HIIT (SMD = −0.19 [95 % CI -0.36, −0.02]; $p = 0.03$; $I^2 = 47$ %; n = 17). HIIT had a similar effect on depressive symptoms compared to other exercises (SMD = 0.06 [95 % CI -0.08, 0.20]; $p = 0.41$; $I^2 = 0$ %; n = 13) and non-exercise control groups (SMD = −0.08 [95 % CI -0.43, 0.27]; $p = 0.64$; $I^2 = 75$ %; n = 9).

Conclusion: HIIT demonstrated feasible attendance and retention, as well as a similar possibility of adverse events to conventional exercises among older adults. Depressive symptoms were reduced immediately after HIIT, while there was no superiority over other control groups among older adults. Future studies with high-quality evidence are needed to examine the effect of HIIT for improving depressive symptoms among older adults.

Prospero registration number: CRD42023443913.

1. Introduction

Ageing-related decline in health status and quality of life is significantly associated with depressive symptoms (Remm et al., 2023). The pooled global prevalence of depressive symptoms among older adults was 28.4 % in 2022 and may be undetected due to inadequate screening (Hu et al., 2022). Older adults with depressive symptoms are likely to be accompanied by chronic diseases such as diabetes (Luo et al., 2019), coronary heart disease (Gan et al., 2014), and cognitive impairment (Dotson et al., 2020). Furthermore, depressive symptoms are a risk factor for severe mental disorders, disability, and mortality in the elderly (Murphy et al., 2016). Therefore, effective interventions are essential for addressing depressive symptoms in older adults and should be investigated to inform relevant researchers and mental health specialists.

Exercise has been recommended as a cost-effective approach not only to reducing older adults' depressive symptoms (Bigarella et al.,

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2022; Miller et al., 2020), but also superior in enhancing physical health (e.g., aerobic capacity and muscular strength) and with fewer side effects than psychological and/or pharmaceutical interventions (Emmelkamp et al., 2014; Kelly et al., 2008). The health benefits can contribute to the remission of depressive symptoms. Conventional exercises, such as low to moderate-intensity aerobic exercise (Chen et al., 2022), multiple-component exercise (Schuch et al., 2016, and mind-body exercise (Dong et al., 2024), have been demonstrated to be effective for reducing depressive symptoms among older adults. However, older adults with depressive symptoms may not adhere to these exercises due to the long duration (Shaw et al., 2022). Short sessions and intensive exercise may positively impact mood and adherence (Chan et al., 2019; Heinrich et al., 2014; Schuch et al., 2016).

High-intensity interval training (HIIT) involves alternating periods of high-intensity exercise with recovery intervals of either low-intensity exercise or complete rest. Typically, high-intensity work intervals range from 10 s to 5 min, corresponding to 80 %–100 % of maximum heart rate or equivalent VO_2 max (Coates et al., 2023; Liguori & Medicine, 2020). HIIT has emerged as a time-efficient exercise modality for alleviating depressive symptoms by modulating brain-derived growth neurotrophins, dopamine, and the homeostasis of the HPA axis through enhanced cardiovascular and cerebrovascular function. This suggests a biological mechanism for HIIT interventions in the prevention and treatment of depression (Xu et al., 2024). In addition, HIIT can achieve comparable or better performance in cardiorespiratory function and physical fitness among older adults compared to low to moderate-intensity aerobic exercise and resistance training (Keating et al., 2020; Liang et al., 2024).

Although the number of HIIT interventions for older adults is increasing, existing reviews have focused solely on physical health outcomes in both healthy older adults and those with conditions such as cardiovascular disease, type-2 diabetes, Parkinson's, and Alzheimer's. A significant gap remains regarding the synthesis of evidence on the effects of HIIT in alleviating depressive symptoms in older adults (Keating et al., 2020; Liang et al., 2024; Marriott et al., 2021). As HIIT interventions are extended to older adults with depressive symptoms, a comprehensive evaluation of their feasibility—encompassing retention, attendance, adherence, and safety—is imperative. Feasibility in this context refers to the practicability of conducting a trial as designed, the suitability of the intervention for its intended users, and their willingness to engage with it. However, previous reviews provide a limited synthesis of these critical feasibility parameters in HIIT research for older adult populations (Keating et al., 2020; Liang et al., 2024; Marriott et al., 2021). Regarding the methodological limitations, existing HIIT reviews focusing on depressive symptoms only included comparators of non-exercise groups (Gaia et al., 2024), and blended non-exercise groups with exercise control groups (Tao et al., 2024). Such comparisons may blur our understanding of the merit of HIIT interventions. Moreover, depressive symptoms are characterised by recurrent episodes, and the immediate antidepressant effects may disappear when interventions are finished (de Zwart et al., 2019). Thus, the effects of exercise interventions on reducing depressive symptoms should be summarised for their long-term impact. However, previous reviews have not systematically examined long-term follow-up data to determine the sustainable benefits of HIIT on depressive symptoms. Therefore, this review aimed to add new knowledge by finding the gaps and implications of HIIT interventions applied to older adults for reducing depressive symptoms.

The objectives of this study were to synthesise the feasibility and effects of HIIT interventions on depressive symptoms among older adults compared with both non-exercise control groups and other exercise modalities. This review also aimed to identify the potential moderating effects of measurement tools of depressive symptoms, characteristics of participants, and HIIT protocols on HIIT effects on depressive symptoms among older adults.

2. Methods

This systematic review was registered in PROSPERO (CRD42023443913). The protocol of this review adheres to PRISMA guidelines (Moher et al., 2009).

2.1. Eligibility criteria

The inclusion criteria were applied based on the PICOS (Chandler et al., 2019): (1) **P**articipants: older adults with a mean age ≥60 years old; (2) **I**ntervention: the study must involve HIIT intervention which is defined as an exercise with a high-intensity interval lasting for a duration separated by a period of recovery. The high-intensity intervals vary from 10 s to 5 min between 80 % and 100 % maximum heart rate or equivalent and the duration of recovery was not exceed triple of workout interval (Liguori & Medicine, 2020; Weston et al., 2014); (3) **C**omparators: non-exercise groups or any exercise intervention except HIIT; (4) **O**utcomes: the outcome included depressive symptoms and feasibility (e.g., attendance and adverse event); (5) **S**tudy design: randomized controlled trials (cluster or individual RCTs) or RCTs pilot study; participants are randomly assigned to one of two or more groups; (6) human studies and written in English. Studies were excluded if: (1) HIIT interventions or the comparators were combined with other interventions; (2) protocols and conference abstracts.

2.2. Information source and search strategy

Systematic electronic searching of eight sources, including PubMed, EMBASE, Medline, PsycINFO, SPORTDiscus, Web of Science, Scopus, and Cochrane Central Register of Controlled Trials (CENTRAL), was initially conducted from their respective inception dates to May 1, 2024. Grey literature was searched using Opengrey to uncover unpublished studies. The search strategies were designed considering the MeSH terms and the PICOS framework. The complete list of search terms is provided in the Appendix. The reference lists of identified articles and related published systematic reviews were manually searched.

2.3. Selection process

All search results were imported into EndNote, and duplicates were excluded. Two researchers (YPW and DP) independently performed the title and abstract screening of retrieved articles and full-text screening of each identified article. No automated or semi-automated approaches (e.g., machine learning-based) were used for automatically screening records. A reviewer discussion and consultation with a third independent reviewer (YD) were conducted when discrepancies arose during judgment determination.

2.4. Data collection and items

Data were extracted by a reviewer (YPW) and double-checked by the secondary reviewers (DP and YD). The data extraction sheet was established in accordance with the Cochrane Handbook for Systematic Reviews (Cumpston et al., 2019) and the CERT checklist to describe the exercise intervention protocol of each study (Slade et al., 2016). Depressive symptoms are described as mean and SD. If the data of mean and SD were not reported in the study, alternative statistics such as median and 95 % CI were used to convert to the mean and SD according to the Cochrane manual (Cumpston et al., 2019; Higgins et al., 2019). The detailed formulas for converting data were presented in the Appendices. Follow-up data were extracted if the study reported the results multiple times. The indicators of feasibility, including retention, attendance, exercise intensity compliance, and adverse events, are described as percentages or event numbers.

2.5. Study risk of bias and certainty assessment

The risk of bias in each study was independently evaluated by two reviewers (YPW and DP) using the Cochrane risk-of-bias tool (RoB2) (Higgins et al., 2011). The Grading of Recommendations Assessment, Development, and Evaluation (GRADE) approach (Group, 2004) was used to evaluate the certainty of evidence and findings in the meta-analysis. The GRADE quality of RCT studies was initially rated high. Points were downgraded to moderate, low, or very low based on the limitations identified in five dimensions: the risk of bias, inconsistency, publication bias, imprecision, and indirectness (Group, 2004). If $>$ 50 % of the studies had $>$1 risk item, the evidence was assessed as high risk of bias. Heterogeneity between studies was assessed by the I^2 and Tau^2 statistics test. $I^2>$ 50 % or Tau^2 $>$0.2 was regarded as the criterion for heterogeneous results across studies (Higgins et al., 2003). A sensitivity analysis was performed using the leave-one-out method (Higgins, 2008), excluding studies that had an impact on the heterogeneity to examine the robustness of the results. Indirectness results from indirect PICOS (e.g., aligned specific population and outcomes measures). Imprecision was indicated by a wide range of 95 % CI (e.g., across the line of a small effect size). Publication bias was detected by Egger's regression test, where $p < 0.05$ and assisted by a funnel plot, which was analysed via Stata 17 software (Lin & Chu, 2018). The more detailed criteria and index were introduced in the Appendix Supplement 4.

2.6. Synthesis methods

Review Manager 5.4 software (Cochrane, London, UK) was used to perform the meta-analyses. A random-effects model was used to calculate the standardised mean difference (SMD) effect size. The SMD was based on mean change, SD, and sample size in each group for each study (Chandler et al., 2019). Statistical significance was indicated by a p-value less than 0.05. Meta-analyses were conducted comparing HIIT with non-exercise and/or exercise groups on depressive symptoms and adverse events post-intervention. The risk ratio of adverse events that occurred in the HIIT and other exercise groups was analysed using a random effects model (Niemeijer et al., 2020). At follow-up, insufficient (two) retrieved RCTs compared HIIT with a non-exercise group (Ellingsen et al., 2017; Krawcyk et al., 2019) or an exercise group (Ellingsen et al., 2017; Terada et al., 2022); therefore, the sustained effects of HIIT were synthesised narratively. The retention, attendance, and exercise intensity compliance with the intervention were summarised using a narrative approach.

Subgroup analyses were performed to explore further the effects of HIIT on depressive symptoms by measurement tools of depressive symptoms (HADS, Hospital Anxiety and Depression Scale or others), the characteristics of participants (clinical or non-clinical), and HIIT protocol characteristics, which included program duration ($<$12 or $\geq$12 weeks), frequency ($\leq$2 or $>$2 times/week), high-intensity interval time ($\leq$1 or $>$1 min), a ratio of workout and recovery ($\leq$1 or $>$1), exercise

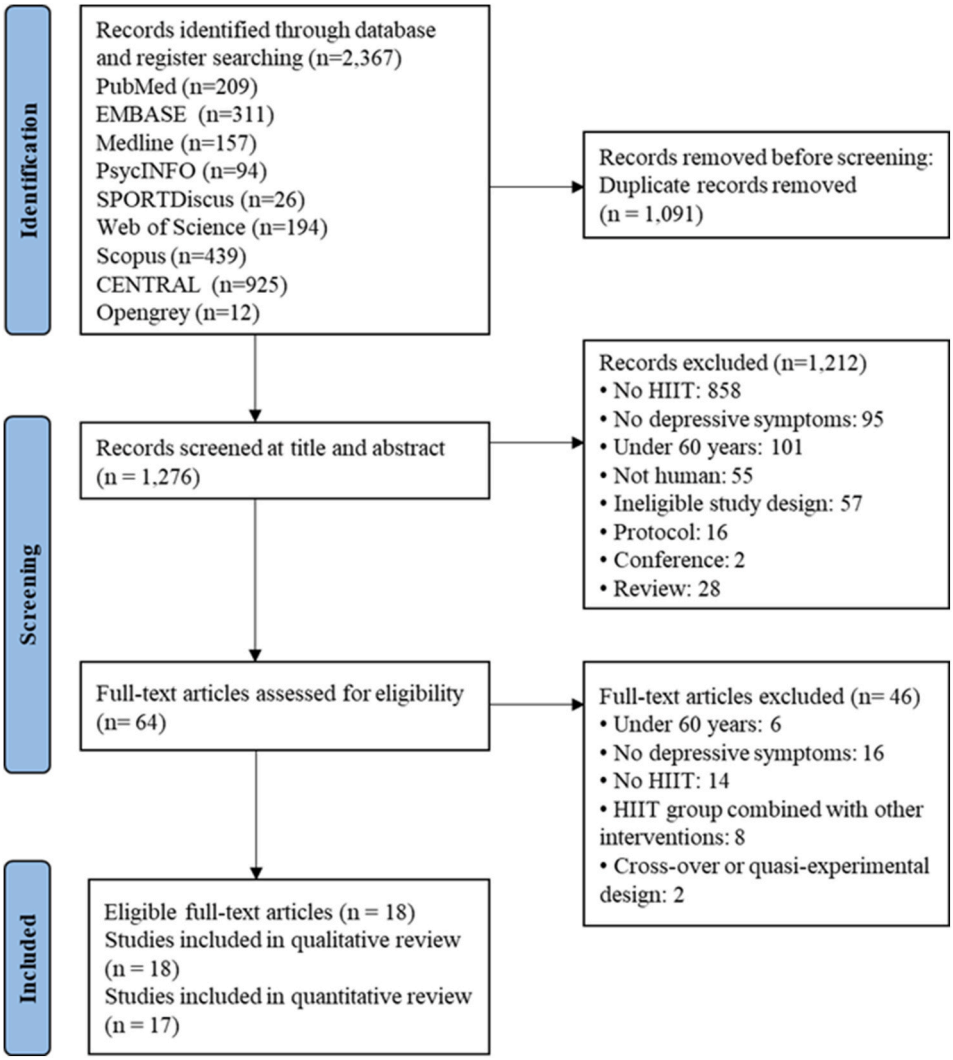

Fig. 1. PRISMA flowchart for study identification, screening, and inclusion.

type (cycling or running, combined exercise), and progression (yes or no, whether the training was prescribed progressively by increasing workload), and male ratio (≤0.5 or >0.5).

3. Results

3.1. Study selection

The initial systematic search generated 2367 records. After removing duplicates, 1276 records were screened via title and abstract (Fig. 1). Full texts of sixty-four potential articles were screened. Eighteen studies (1375 participants) met the inclusion criteria of the review.

3.2. Study characteristics

The detailed and comprehensive characteristics of eligible studies, including participant characteristics, outcome assessment, comparators, and HIIT protocol, are presented in Table 1. In the eighteen RCTs, the mean age of participants ranged from 60 to 73 years old, where 72 % being male. The sample size of included RCTs ranged from 18 to 215. Included studies applied HIIT among patients with cardiovascular disease (Chrysohoou et al., 2014; Ellingsen et al., 2017; Krawcyk et al., 2019, 2023; Lee et al., 2019; Pedersen et al., 2015; Reed et al., 2022; Schönfelder et al., 2021; Smart & Steele, 2012; Sosner et al., 2019; Terada et al., 2022), chronic obstructive pulmonary disease (Arnardóttir et al., 2006; Puhan et al., 2006), cancer (Piraux et al., 2021, 2022), Parkinson's (Uc et al., 2014), and non-clinical participants (Gujral et al., 2024; Sokołowski et al., 2021). 61 % (11/18) of studies were conducted in Europe. The duration of the HIIT program ranged from 2 weeks to 5 years, and HIIT interventions were commonly conducted for 12 weeks (Chrysohoou et al., 2014; Ellingsen et al., 2017; Pedersen et al., 2015; Reed et al., 2022; Terada et al., 2022). HIIT was conducted 2–5 times per week. The exercise section of HIIT lasted for 15–28 min. The workout intervals and recovery ratio was 1:1 in 8 studies (Arnardóttir et al., 2006; Chrysohoou et al., 2014; Pedersen et al., 2015; Piraux et al., 2021, 2022; Smart & Steele, 2012; Sosner et al., 2019; Uc et al., 2014), followed by 4:3 in 6 studies (Ellingsen et al., 2017; Lee et al., 2019; Reed et al., 2022; Schönfelder et al., 2021; Sokołowski et al., 2021; Terada et al., 2022), and one study applied 3:2 (Krawcyk et al., 2019). The combination of interval time and repetition ranged from 15s*20 to 4 min*4. Intensity of exercise protocols was defined as 77 %–95 % Hrmax (Ellingsen et al., 2017; Krawcyk et al., 2019; Lee et al., 2019; Pedersen et al., 2015; Piraux et al., 2021, 2022; Reed et al., 2022; Schönfelder et al., 2021; Sokołowski et al., 2021; Terada et al., 2022; Uc et al., 2014), or ≥70 % VO_2 max (Smart & Steele, 2012), or 80 %–100 % Watt peak (Arnardóttir et al., 2006; Puhan et al., 2006; Sosner et al., 2019). 63 % (10/16) of studies adopted stationary cycling as an exercise type, and 31 % (5/16) of studies adopted combined exercise. Additionally, 56 % (9/16) of studies gradually progressed the HIIT protocol, with progression varying in intensity, interval time, and the number of intervals.

3.3. Results of syntheses

3.3.1. Feasibility

The retention rate reported in the HIIT group ranged from 59 % to 100 %, and most studies (16/18) reported high retention (≥74 %). The attendance rate ranged from 74 % to 97 %, and participants in the included studies attended an average of 87 % of HIIT sessions. Five studies (Arnardóttir et al., 2006; Lee et al., 2019; Piraux et al., 2022; Puhan et al., 2006; Sokołowski et al., 2021) indicated that the target exercise intensity was reached during HIIT sessions. Three studies (Ellingsen et al., 2017; Reed et al., 2022; Uc et al., 2014) indicated a lower intensity than required. No significant difference was observed between HIIT and other exercise control groups regarding adverse events (RR = 1.34 [95 % CI 0.92, 1.95]; $p = 0.13$; $I^2 = 0$ %; n = 5) (Ellingsen et al., 2017; Krawcyk et al., 2019; Lee et al., 2019; Reed et al., 2022; Uc et al., 2014) (Fig. 2A). Those studies reporting adverse events were conducted in older adults with chronic heart failure (Ellingsen et al., 2017), coronary artery disease (Lee et al., 2019; Reed et al., 2022), minor stroke (Krawcyk et al., 2019), and mild to moderate Parkinson's disease (Uc et al., 2014).

3.3.2. Intervention effects

The meta-analyses were based on seventeen studies, including 568 older adults. The results revealed that depressive symptoms were significantly improved immediately following HIIT intervention (SMD = −0.19 [95 % CI -0.36, −0.02]; p = 0.03; $I^2 = 47$ %; n = 17), as shown in Fig. 2B. However, no significant decrease in depressive symptoms score was identified in HIIT compared with non-exercise control groups with high heterogeneity (SMD = −0.08 [95 % CI -0.43,0.27]; $p = 0.64$; $I^2 = 75$ %; n = 9) (Fig. 2C). Moreover, the difference between depressive symptoms in HIIT and exercise control groups was not statistically significant (SMD = 0.06 [95 % CI -0.08,0.20]; $p = 0.41$; $I^2 = 0$ %; n = 13) (Fig. 2D), with 0 % heterogeneity.

Studies did not detect a significant improvement in depressive symptoms between the HIIT and control groups following 6, 10, and 12-month follow-ups (Ellingsen et al., 2017; Krawcyk et al., 2019). In contrast, Tereda et al. (2022) observed significant improvements after 14 weeks of follow-up compared to control groups (Terada et al., 2022).

3.4. Subgroup analyses

Subgroup analysis indicated that the effects of HIIT compared to non-exercise control groups were not moderated by the measurement tools, the health status and gender of participants and HIIT protocol, including program duration, frequency, workout time, ratio, exercise type, and progression (see Table 2). However, the results exhibited high heterogeneity in other measures, clinical older adults, and HIIT prescribing ≥12 weeks, >2 times/week, ≤1 min high-intensity interval, interval ratio ≤1, cycling or running, with progression. Comparable effects of HIIT to other exercises on reducing depressive symptoms among older adults were found independent of measurement tools, health status, gender, and HIIT protocol characteristics.

3.5. Risk of bias and GRADE assessment

The risk of bias analysis (Fig. 3) revealed some concerns regarding the overall methodological quality among the eighteen studies. Five studies were assessed as having a low risk of bias. Evidence of low certainty indicated that HIIT did not affect the reduction of depressive symptoms compared with non-exercise control groups (Table 3). The evidence was downgraded due to inconsistency and imprecision. The sensitivity analysis where one study accounting for high heterogeneity was removed, and the results did not change (SMD = 0.11 [95 % CI -0.07, 0.28]; $p = 0.23$; $I^2 = 0$ %; n = 8). The evidence of moderate certainty indicated that HIIT had similar effects to exercise groups in improving depressive symptoms. The evidence was downgraded due to publication bias, and the corresponding funnel plots are presented in the Appendix.

4. Discussion

This systematic review and meta-analysis evaluated the feasibility and effects of HIIT on depressive symptoms in older adults with or without comorbidities. The review identified that HIIT was considered feasible for older adults with comorbidities such as cardiovascular disease, chronic obstructive pulmonary disease, cancer, and Parkinson's under supervision. The evidence indicated that depressive symptoms in older adults were significantly improved after HIIT intervention compared to pre-training measures. However, HIIT did not show significance in improving depressive symptoms compared to the non-exercise control group, with low evidence quality. HIIT showed

Table 1
Characteristics of the included studies, participants and HIIT protocols.

Study			Participants			Measurement tool of Depressive symptoms	Comparators
Author, year	Country	Group sample size (n)	Mean age	Male %	Health status		
Chrysohoou et al. (2014)	Greece	HIIT (50); non-exercise group (50)	63 ± 9	79	Chronic heart failure (CHF) patients	Zung Depression Rating Scale (ZDRS)	Usual care
Sokołowski et al. (2021)	Norway	HIIT (29); MICT (21); non-exercise control (37)	72.7 ± 2.2	51	Healthy older adults	Hospital Anxiety and Depression Scale (HADS)	30mins/day MPA guidelines; MICT in 70 % HR peak for 50 min
Piraux et al. (2021)	Belgium	HIIT (27); RES (25); non-exercise control (26)	67.4 ± 8.9	100	Prostate cancer patients undergoing radiotherapy	Centre for Epidemiologic Studies Depression Scale (CES-D)	Usual care: resistance training for 5–8 weeks
Piraux et al. (2022)	Belgium	HIIT (6); RES (6); non-exercise group (6)	61 (54; 65)	72	Localised rectal cancer, neoadjuvant chemoradiotherapy (NACRT) followed by surgery.	Centre for Epidemiologic Studies Depression Scale (CES-D)	Usual care: resistance training for 5 weeks
Pedersen et al. (2015)	Denmark	HIIT (35); diet group (35)	62.3 ± 5.7	78	CAD has been diagnosed for more than 6 months	Hospital Anxiety and Depression Scale (HADS)	Low-energy diet
Puhan et al. (2006)	Switzerland	HIIT (49); HICT (51)	69.0 ± 9.2	66	Chronic obstructive pulmonary disease (COPD)	Hospital Anxiety and Depression Scale (HADS)	High-intensity continuous training for 3 weeks
Schönfelder et al. (2021)	Austria	HIIT (22); MICT (18); pyramid training (19)	61.3 ± 11.6	74	Outpatient cardiac rehabilitation CAD	Hospital Anxiety and Depression Scale (HADS)	MICT at 65–85 % peak HR; pyramid training from 65 to 95–65 % peak heart rate
Ellingsen et al. (2017)	Norway	HIIT (77); MICT (65); non-exercise control (73)	65 (58–68)	19	Chronic heart failure	Hospital Anxiety and Depression Scale (HADS)	Recommendation of regular exercise at home; MICT for 12 weeks
Arnardóttir et al., 2006	Sweden	HIIT (28); MICT (32)	65 ± 7	15	Patients with moderate or severe COPD	Hospital Anxiety and Depression Scale (HADS)	MICT for 16 weeks
Krawcyk et al. (2019)	Denmark	HIIT (31); non-exercise group (32)	63.7 ± 9.2	78	Within 1–21 days of stroke onset	The Major Depression Inventory (MDI)	Usual care
Terada et al. (2022)	Canadian	HIIT (43); MICT (44); Nordic walking (43)	61 ± 7	85	Coronary artery disease (CAD)	Beck Depression Inventory-II (BDI-II)	MICT for 12 weeks; Nordic walking for 12 weeks
Reed et al. (2022)	Canadian	HIIT (43); MICT (44); Nordic walking (43)	61 ± 7	85	Coronary artery disease (CAD)	Beck Depression Inventory-II (BDI-II)	MICT for 12 weeks; Nordic walking for 12 weeks
Lee et al. (2019)	Canada	HIIT (17); MICT (14)	69.3 ± 9.9	0	Women with coronary artery disease (CAD)	Centre for Epidemiological Studies Depression Scale (CES-D)	MICT is either walking or jogging on the track or treadmill
Sosner et al. (2019)	Canada	HIIT (28); MICT (14)	65 ± 7	52	Hypertension participants	Profile of Mood States (POMS) test	MICT for 2 weeks
Smart and Steele (2012)	America	HIIT (10); MICT (13)	59.1 ± 11	90	Chronic Heart Failure Patients	The Hare-Davis Cardiac Depression Scale	MICT for 16 weeks
Uc et al., 2014	America	HIIT (22); MICT (21)	65.5 ± 6.4	68	Mild to moderate Parkinson's disease	Geriatric Depression Scale (GDS)	MICT for 6 months
Gujral et al. (2024)	Australia	HIIT (31); MICT (31); non-exercise group (30)	69.1 ± 5.2	46	Community cognitively normal older adults	Depression, Anxiety and Stress (DASS)	Moderate intensity cycling; one-time educational session
Krawcyk et al. (2023)	Denmark	HIIT (35); usual care (34)	64.4 ± 8.5	81	The elderly with a lacunar stroke	The Major Depression Inventory (MDI)	Usual care

Study	HIIT protocol										
Author, year	Program duration	Days/ week	Workout intensity	Exercise type	Recovery mode	Interval ratio	Workout time	Workout intervals	Session time	Progression	Setting, supervision
Chrysohoou et al. (2014)	12 weeks	3	80 %–100 % peak work rate	Cycle ergometer	Passive	1:1	30s	Not reported	45 min	Intensity	Rehabilitation centre; supervised
Sokołowski et al. (2021)	5 years	2	85–95 % HR peak; Borg 16-20	Cycling, walking, running, skiing	Active	4:3	4 min	4	35–45 min	no	Setting not reported; supervised
Piraux et al. (2021)	5–8 weeks	3	≥85 % HR max	Cycle ergometer	Active	1:1	1 min	8–15	26–40 min	Intervals number	Rehabilitation centre: individually supervised
Piraux et al. (2022)	5 weeks	3	≥85 % HR max	Cycle ergometer	Active	1:1	1 min	8–15	26–40 min	Intervals number	Rehabilitation centre: individually supervised

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Table 1 (*continued*)

Study	HIIT protocol										
Author, year	Program duration	Days/ week	Workout intensity	Exercise type	Recovery mode	Interval ratio	Workout time	Workout intervals	Session time	Progression	Setting, supervision
Pedersen et al. (2015)	12 weeks	3	85–90 % HR peak; Borg 17-18	Cycle ergometer	Active	1:1–4:3	1–4 min	4	38–48 min	Interval time	Rehabilitation centre; supervised
Puhan et al. (2006)	3 weeks	4–5	90–100 % maximum exercise capacity	Cycle ergometer	Active	1:2	20s	20	24 min	Intensity	Rehabilitation in hospital; individually supervised
Schönfelder et al. (2021)	6 weeks	3	85–95 % HR peak	Cycle ergometer	Active	4:3	4 min	4	35 min	No	Rehabilitation in a hospital, supervised
Ellingsen et al. (2017)	12 weeks	3	90–95 % HR max	Treadmill running	Active	4:3	4 min	4	38 min	No	Rehabilitation centre; supervised
Arnardóttir et al., 2006	16 weeks	2	≥80 % peak exercise capacity	Cycle ergometer	Active	1:1	3 min	5	39 min	No	Rehabilitation centre; group supervised
Krawcyk et al. (2019)	12 weeks	5	77–93 % HR max; 14–16 Borg	Self-chosen or cycling	Active	3:2	3 min	3	≥15 min	No	Home-based
Terada et al. (2022)	12 weeks	2	85–95 % HR peak	Treadmill, cycle ergometer, elliptical, or dancing	Active	4:3	4 min	4	45 min	Session time	Rehabilitation centre; group supervised
Reed et al. (2022)	12 weeks	2	85–95 % HR peak	Treadmill, cycle ergometer, elliptical, or dancing	Active	4:3	4 min	4	45 min	Session time	Rehabilitation centre; group supervised
Lee et al. (2019)	24 weeks	5	90 %–95 % HR peak; RPE 17	Walking or jogging	Active	4:3	4 min	4	25–30 min	No	Rehabilitation centre; supervised
Sosner et al. (2019)	2 weeks	3	100 % of peak power output (Watt)	Cycle ergometer	Passive	1:1	15s	20	34 min	No	Rehabilitation centre; supervised
Smart and Steele (2012)	16 weeks	3	≥70 % VO2 max; RPE 3-5	Cycle ergometer	Passive	1:1	1 min	Not reported	60 min	Intensity 2–5 W/ week	Rehabilitation centre; supervised
Uc et al., 2014	6 months	3	80–90 % HR max	Track walking	Active	1:1	3 min	3	18–45 min	Session time	Rehabilitation centre
Gujral et al. (2024)	6 months	2	>80 % aerobic capacity; 18 RPE	Cycle ergometer	Active	1:2	1 min	11	50 min	No	Research centre; supervised
Krawcyk et al. (2023)	12 weeks	5	77–93 % HRmax; 14–16 Borg	Cycle ergometer	Active	3:2	3 min	3	15 min	No	Home-based

HIIT: high-intensity interval training; MICT: moderate-intensity continuous training; RES: resistance training; HICT: high-intensity continuous training.
HIIT: high-intensity interval training; HR: heart rate; RPE: rating of perceived exertion.

comparable effects on depressive symptoms in contrast to other exercises, with a moderate certainty of evidence.

4.1. Intervention characteristics

HIIT interventions included in this review were conducted in Western countries, and 16 out of 18 RCT_S were applied in clinical older adults. Thus, this calls for more HIIT research in Eastern countries and non-clinical older adults in the future. The typical protocol duration was ≥12 weeks with 2–3 sessions per week, and prescribed 15–30 min HIIT section in one session, which is similar to previous reviews conducted among adults (Nicole Korman et al., 2020a, 2020b; Martland et al., 2022; Wu et al., 2020). The target outcomes and participants may be the underlying reasons for the variation in interval time and repetition of the HIIT protocol. In future studies, the suitable protocol for improving depressive symptoms in older adults still needs to be investigated to optimise the benefits and effect size of the intervention. Additionally, almost all HIIT interventions were conducted in a rehabilitation centre or research lab using equipment such as a cycle ergometer, commonly found in previous reviews (Keating et al., 2020; Marriott et al., 2021; Stern et al., 2023). To some extent, this implies the challenge of applying HIIT in real-world settings, such as residential communities, which warrants future study.

4.2. Feasibility of HIIT intervention

This review found that HIIT intervention has high retention and attendance among older adults in supervised settings, supporting previous reviews (Marriott et al., 2021; Stern et al., 2023). The healthy older adults presented more active engagement (Stern et al., 2023). Nevertheless, eliminating barriers to attending HIIT remains essential in future interventions, as older adults may face physical and psychological obstacles to participating in long-term exercise programs. HIIT session with no more than 40 min is associated with more attendance in the intervention (Arnardóttir et al., 2006; Ellingsen et al., 2017; Krawcyk et al., 2019; Lee et al., 2019; Piraux et al., 2021, 2022; Puhan et al.,

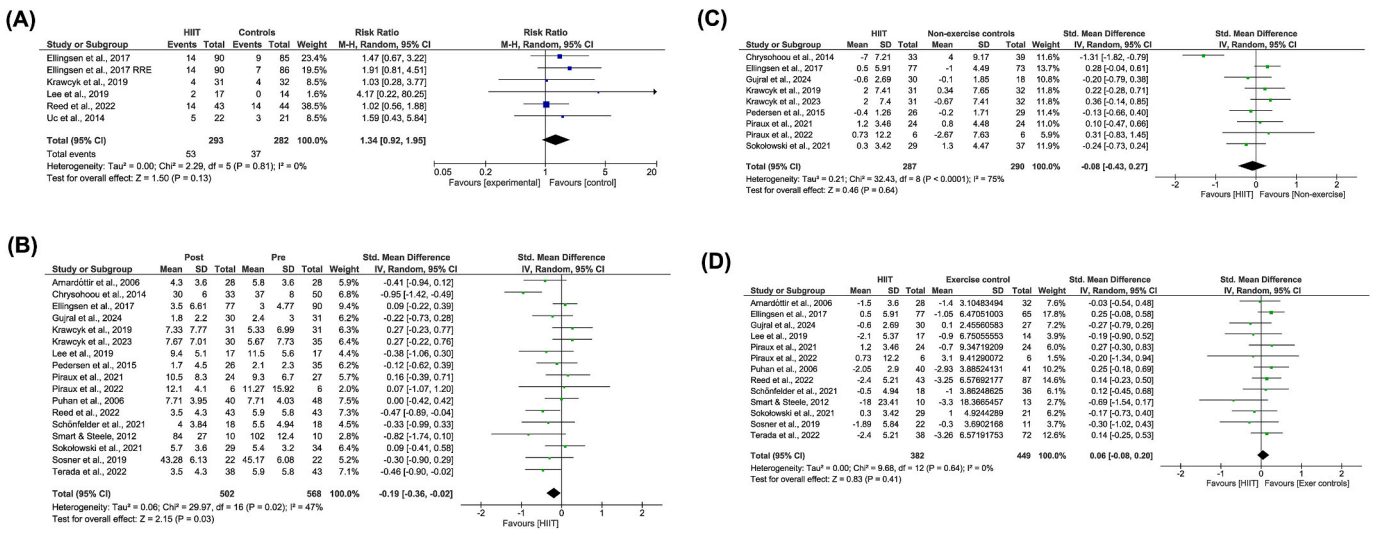

Fig. 2. Meta-analysis of (A) adverse events of HIIT vs. exercise control, (B) pre-vs. post-intervention in HIIT, (C) mean change from baseline to post-intervention of HIIT vs. non-exercise control, (D) mean change from baseline to post-intervention of HIIT vs. exercise control. SMD indicates the mean difference. The plotted points represent the SMDs, and the horizontal error bars indicate the 95 % CIs.

2006), which could be used in future interventions. The other influential components, such as pain or chronic disease, should be investigated through future HIIT research in older adults. Although the rate of adverse events did not significantly differ from that reported in exercise control groups, some adverse events were reported to occur in older adults with pre-existing diseases, including chronic heart failure (Ellingsen et al., 2017), coronary artery disease (Lee et al., 2019; Reed et al., 2022), minor stroke (Krawcyk et al., 2019), and mild to moderate Parkinson's disease (Uc et al., 2014). It implies that pre-exercise physical health and fitness screening should be warranted to minimise the risk of adverse events among older adults.

4.3. *Effects of HIIT intervention*

This study is consistent with previous reviews reporting no superior effects of HIIT than non-exercise on depressive symptoms among healthy adults (Gaia et al., 2024), while inconsistent in general adults (Tao et al., 2024), adults with severe mental illness (N. Korman et al., 2020a, 2020b), or physical illness (Martland et al., 2022; Wu et al., 2020). This highlights the population gap and underscores the need for this study. However, this review suggests that the immediate effect of HIIT intervention, compared to baseline, in reducing depressive symptoms is supported by previous meta-analyses in adults (Wu et al., 2020). It is possible that depressive symptoms can be alleviated through enhanced self-efficacy and resilience following challenging exercise (Conradsson et al., 2010; Eather et al., 2020; Jung et al., 2014). HIIT can also modulate depression-related biomarkers, such as brain-derived neurotrophins, dopamine, and hypothalamic-pituitary-adrenal axis homeostasis, after HIIT (Xu et al., 2024). The insignificant improvement of HIIT on depressive symptoms compared to non-exercise conditions may arise from the fact that depressive symptoms were not the primary outcome. Some of the included studies conducted a priori sample size calculations based on their primary outcomes, while a few were pilot trials with small sample sizes and no prior estimation. Consequently, improvements in depressive symptoms may not have been detected due to insufficient statistical power in the individual studies included in this meta-analysis. Furthermore, there was low certainty of evidence due to the inconsistency and imprecision of study results. Thus, more research is warranted to identify the effects of HIIT intervention on the primary outcome of depressive symptoms. The findings also demonstrated that HIIT had a similar impact to other exercises (e.g., moderate-intensity continuous training and resistance training) on depressive symptoms in older adults. However, the comparator of exercise modality was very limited, as found in a scoping review (Marriott et al., 2021). This suggests that future research can focus on comparing the effect of HIIT with other exercise modalities on depressive symptoms, such as commonly recommended mind-body exercises recommended for older adults. Further, the insignificant effects can be attributed to performing a lower intensity than the required HIIT prescription. Three studies reported a lower intensity than required HIIT protocol, which prescribed 3–4 min continuous high-intensity intervals for patients with heart diseases or Parkinson's disease (Ellingsen et al., 2017; Reed et al., 2022; Uc et al., 2014). This indicates that high-volume HIIT with long intervals may not be tolerated and feasible for older adults with comorbidities to achieve the health benefits. Low-volume HIIT with short intervals (e.g., $\leq$1 min) warrants further study and application to older adults in future HIIT interventions. Only three studies have investigated the follow-up of HIIT, suggesting that the antidepressant effect disappeared after the HIIT intervention terminated for 6, 10, and 12 months (Ellingsen et al., 2017; Krawcyk et al., 2023; Terada et al., 2022). It constrains sufficient empirical evidence on relapses or recurrence of depressive symptoms following HIIT. Future studies should emphasise the long-term impact of HIIT intervention on depressive symptoms, as well as exploring how to extend the residual effects.

Subgroup analysis did not find differential effects of HIIT on depressive symptoms by measurement tool, health status, gender, and protocol characteristics. Existing reviews among adults also did not find the moderating effects of health conditions and HIIT protocol (e.g., program duration, exercise type, and frequency) on depressive symptoms (Gaia et al., 2024; Martland et al., 2022; Tao et al., 2024; Wu et al., 2020). Although health status and gender did not impact the effects, most participants were male, and with comorbidity, it indicated that future HIIT can explore more among healthy older adults and females. As the pre-specification of subgroups and statistical power can affect the reliability of the results (Pigott, 2020), more research should be conducted to identify the differential intervention effects of HIIT across subgroups. Understanding how interventions work in different subgroups can contribute to a customised protocol for specific groups that benefit the most.

4.4. *Limitations and strengths*

Several limitations warrant consideration in this review. Firstly, depressive symptoms were not clinically diagnosed as major depressive

Table 2
HIIT effects on depressive symptoms by subgroups.

Subgroup	RCTs (Participants)	Meta-analysis			Subgroup difference	
		SMD [95 % CI]	*p*-value	I^2	*p*-value	I^2
HIIT vs non-exercise controls						
Health status						
Clinical	7 (463)	−0.04 [-0.49, 0.41]	0.86	81 %	0.53	0 %
Non-clinical	2 (114)	−0.23 [-0.60, 0.15]	0.23	0 %		
Measurement tool of depressive symptoms						
HADS	3 (271)	0.02 [-0.33, 0.37]	0.93	48 %	0.7	0 %
Other measurement	6 (306)	−0.11 [-0.67, 0.44]	0.69	81 %		
Program duration						
<12 weeks	2 (60)	0.14 [-0.37, 0.65]	0.59	0 %	0.41	0 %
≥12 weeks	7 (517)	−0.14 [-0.55, 0.28]	0.52	81 %		
Frequency						
≤2 times/week	2 (114)	−0.23 [-0.60, 0.15]	0.23	0 %	0.53	0 %
>2 times/week	7 (463)	−0.04 [-0.49, 0.41]	0.86	81 %		
Workout time						
≤1 min	4 (180)	−0.33 [-1.10, 0.43]	0.39	82 %	0.25	22.90 %
>1 min	5 (397)	0.13 [-0.10, 0.35]	0.26	19 %		
Workout: recovery ratio						
≤1	4 (180)	−0.33 [-1.10, 0.43]	0.93	82 %	0.25	22.90 %
>1	5 (397)	0.13 [-0.10, 0.35]	0.26	19 %		
Exercise type						
Cycling or running	6 (385)	−0.18 [-0.71, 0.34]	0.49	82 %	0.37	0 %
Combined exercise	3 (192)	0.11 [-0.25, 0.46]	0.56	36 %		
Progression						
Yes	4 (187)	−0.31 [-1.07, 0.44]	0.42	83 %	0.28	13.10 %
No	5 (390)	0.12 [-0.11, 0.36]	0.31	24 %		
Male Ratio						
≤0.5	2 (198)	0.10 [-0.36,0.56]	0.66	51 %	0.48	0 %
>0.5	7 (379)	−0.13 [-0.58, 0.32]	0.58	78 %		
HIIT vs. other exercises						
Health status						
Clinical	11 (724)	0.10 [-0.05, 0.25]	0.18	0 %	0.12	58 %
Non-clinical	2 (107)	−0.22 [-0.60, 0.16]	0.26	0 %		
Measurement tool of depressive symptoms						
HADS	5 (387)	0.14 [-0.07, 0.34]	0.19	0 %		
Other measurement	8 (444)	−0.01 [-0.20, 0.18]	0.92	0 %	0.31	4.3 %
Program duration						
<12 weeks	5 (228)	0.13 [-0.14, 0.39]	0.35	0 %	0.55	0 %
≥12 weeks	8 (603)	0.03 [-0.14, 0.20]	0.72	2 %		
Frequency						
≤2 times/week	5 (407)	0.01 [-0.19, 0.21]	0.91	0 %	0.52	0 %
>2 times/week	8 (424)	0.10 [-0.09, 0.30]	0.3	0 %		
Workout time						
≤1 min	6 (254)	−0.06 [-0.35, 0.23]	0.7	21 %	0.36	0 %
>1 min	7 (577)	0.10 [-0.07, 0.27]	0.24	0 %		
Workout: recovery ratio						
≤1	7 (314)	−0.04 [-0.27, 0.20]	0.77	5 %	0.31	2.90 %
>1	6 (517)	0.12 [-0.06, 0.30]	0.2	0 %		
Exercise type						
Cycling or running	10 (541)	0.05 [-0.12, 0.22]	0.58	0 %	0.83	0 %
Combined exercise	3 (290)	0.08 [-0.16, 0.32]	0.51	0 %		
Progression						
Yes	6 (404)	0.12 [-0.08, 0.32]	0.24	0 %	0.48	0 %
No	7 (403)	0.02 [-0.18, 0.22]	0.85	0 %		
Male Ratio						
≤0.5	4 (290)	0.03 [-0.22, 0.28]	0.83	11 %	0.79	0 %
>0.5	9 (541)	0.07 [-0.11, 0.24]	0.44	0 %		

HIIT: high-intensity interval training; RCT: randomized controlled trial; HADS: Hospital Anxiety and Depression Scale; Other measurements: Zung Depression Rating Scale (ZDRS), Centre for Epidemiologic Studies Depression Scale (CES-D), The Major Depression Inventory (MDI), Beck Depression Inventory-II (BDI-II), Depression subscale of Profile Of Mood States Scales (POMS), The Hare-Davis Cardiac Depression Scale (HDCD), Geriatric Depression Scale (GDS), Depression subscale of Depression, Anxiety and Stress Scales (DASS).

disorder, reducing the ability to detect changes in depressive symptoms. Some identified RCTs were pilot studies without a priori sample size calculations, which featured relatively small sample sizes, potentially constraining the precision of the effect estimate. As a result, the findings cannot differentiate between small study bias and publication bias. Secondly, all included studies originated in developed Western countries, which implies the population representativeness and generalizability of the findings regarding HIIT interventions on depressive symptoms. Moreover, the risk of bias assessment reveals "some concern" regarding result reporting in certain included studies, raising the possibility of methodological bias that could undermine the validity of the results.There is a clear need for additional high-quality studies and improved reporting of interventions to enhance the robustness of future research findings. Additionally, this review did not include prediction intervals, which would have presented a more comprehensive picture of the evidence. The high heterogeneity of the studies, due to cohorts with

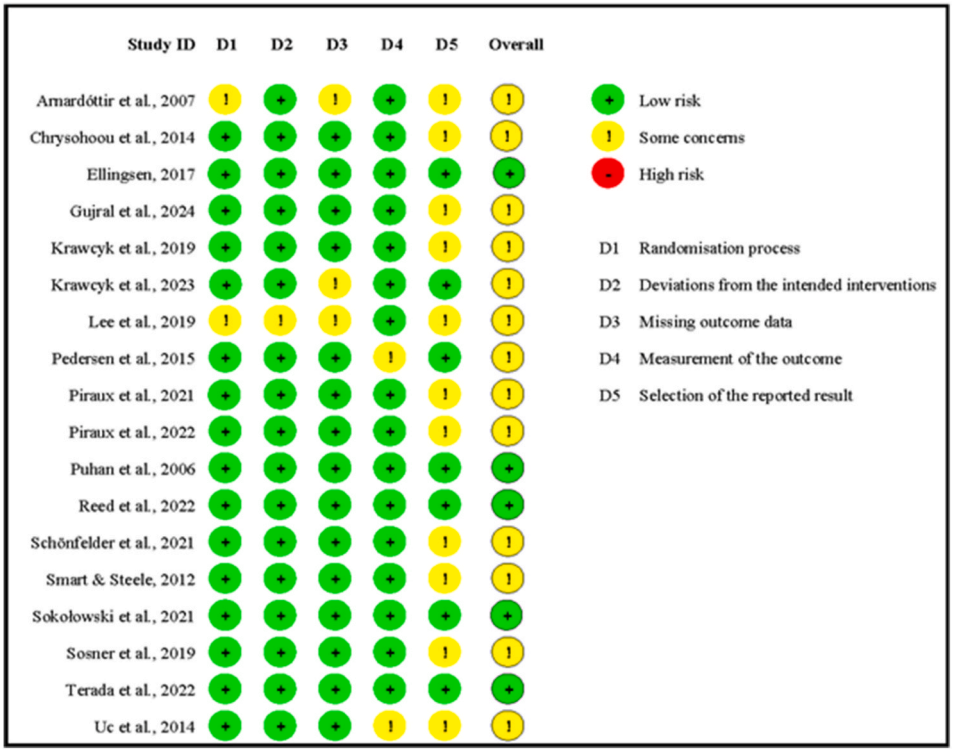

Fig. 3. Risk of bias assessment (ROB).

Table 3
Summary of meta-analysis findings and quality of evidence.

Analysis	Number of RCTs (participants)	Meta-analysis		Heterogeneity		Egger's test	Quality of evidence (GRADE)					
Depressive symptoms		Estimate of effect size [95 % CI]	*P*	I^2	Tau^2	*P*	Risk of bias	Inconsistency	Imprecision	Indirectness	Publication bias	Evidence quality
HIIT vs non-exercise control group	9 (577)	−0.08 [-0.43, 0.27]	0.64	75 %	0.21	0.85	None	−1	−1	None	None	Low
HIIT vs. exercise control group	13 (831)	0.06 [-0.08, 0.20]	0.41	0 %	0.00	0.02	None	None	None	None	−1	Moderate

HIIT: high-intensity interval training; RCT: randomized controlled trial.

various morbidities, may limit the precision and generalizability of intervention effects. Finally, the low quality of evidence limited the certainty of the HIIT effects on depressive symptoms, owing to the conflicting results across the included studies and the imprecision reflected in the wide confidence intervals. Further research is warranted on this topic, contributing additional evidence to enhance our understanding of the antidepressant effects of HIIT.

Notwithstanding these limitations, this study provides synthesised evidence on the effects of HIIT on depressive symptoms among older adults. The findings offer more focused insights into this topic in the ageing population subset by narrowing the range of participant characteristics, such as age and health condition. This review provides new evidence for clinical practice and academic research to develop HIIT interventions for depressive symptoms in older adults.

5. Conclusions

This review provides evidence indicating that HIIT can be an option for older adults with depressive symptoms, with high attendance, retention, and compliance rates. HIIT also presents a similar risk of adverse events compared to traditional exercise. This review suggests that HIIT is comparably effective to other exercise interventions for improving depressive symptoms among older adults. Existing research on this topic has applied diverse HIIT protocols but has not suggested superior characteristics for achieving greater improvement in depressive symptoms. The findings indicate a research gap in investigating dose-response relationships and optimal HIIT protocols that can yield larger effect sizes on older adults' depressive symptoms. More rigorous research is necessary to provide solid evidence and determine the optimal protocol for HIIT. Future studies should encompass high-quality evidence from a larger sample size to examine both the immediate and long-term effects of HIIT on depressive symptoms.

CRediT authorship contribution statement

Yanping Wang: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Formal analysis, Data curation, Conceptualization. **Yanping Duan:** Writing – review & editing, Supervision, Project administration, Methodology, Funding acquisition, Conceptualization. **Dehiwala Liyanage Ishanka Harshani Kusum Peiris:** Writing – review & editing, Validation, Software, Data curation. **Wei Liang:** Writing – review & editing, Validation, Supervision, Conceptualization.

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Declaration of competing interest

On behalf of the authors, the authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Abbreviations

HIIT	High-intensity interval training
RCT	Randomized controlled trials
RoB	Risk of Bias
GRADE	The Grading of Recommendations Assessment, Development, and Evaluation
RR	Risk ratio
SMD	Standardised mean difference
SD	Standard deviation
CI	95 % Confidence interval
HR	Heart rate
VO_2 max	Maximal oxygen consumption
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
CERT	Consensus on Exercise Reporting Template

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.mhpa.2025.100731.

Data availability

Data will be made available on request.

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