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REVIEW

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Effects of high-intensity interval training on depressive and anxiety symptoms in healthy individuals: A systematic review and meta-analysis of randomized clinical trials

Jhonatan Wélington Pereira Gaia[1,2] | **Felipe Barreto Schuch**[3,4,5] | **Rodrigo Weyll Ferreira**[1] | **Edielen de Lima Souza**[1] | **Verônica Moreira Souto Ferreira**[1] | **Daniel Alvarez Pires**[1]

[1]Graduate Program in Human Movement Sciences, Federal University of Pará, Castanhal, Pará, Brazil

[2]Graduate Program in Physical Education, Federal University of Santa Catarina, Santa Catarina, Brazil

[3]Department of Sports Methods and Techniques, Federal University of Santa Maria, Santa Maria, Brazil

[4]Institute of Psychiatry, Federal University of Rio de Janeiro, Rio de Janeiro, Brazil

[5]Faculty of Health Sciences, Universidad Autónoma de Chile, Providência, Chile

Correspondence
Jhonatan Wélington Pereira Gaia, Graduate Program in Human Movement Sciences, Federal University of Pará, Pará, Brazil.
Email: jhonatan.gaia@castanhal.ufpa.br

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Abstract

Although evidence regarding the effects of high-intensity interval training (HIIT) on mental health has increased in recent years, there is still no consensus regarding the effects of HIIT on the symptoms of depression and anxiety in a healthy population. Therefore, this systematic review aimed to investigate the effects of HIIT on depressive and/or anxiety symptoms in healthy individuals. The following four databases were searched: PubMed, Scopus, Embase, and PsycINFO. Only randomized clinical trials (RCTs) were included. We performed a random-effects meta-analysis based on standardized mean difference (SMD). The risk of bias was assessed using the RoB 2.0 tool, and the certainty of the evidence was evaluated based on recommendations GRADE. Eight RCTs evaluating 471 participants (81% female) were considered eligible for inclusion. The results of the meta-analysis showed that HIIT-based interventions had no significant effect on reducing anxiety (SMD = −0.17; 95% CI: −0.53, 0.19; $p = 0.27$) and depressive symptoms (SMD = −0.38; 95% CI: −1.06, 0.30; $p = 0.17$) compared with the passive control group. In conclusion, HIIT does not improve symptoms of depression and anxiety in healthy individuals. This finding is based on evidence of very low certainty. Therefore, the evidence is still not consistent enough to support HIIT as a viable strategy to reduce both outcomes because of the limited number of included studies and the overall quality of evidence.

KEYWORDS

depression, exercise, mental disorders, mental health, physical activity

1 | INTRODUCTION

Depression and anxiety have been described as the main problems related to mental health.[1] Even without reaching a clinical limit for diagnosis, depressive and/or anxiety symptoms can be debilitating and interfere with daily activities, quality of life, and psychological health.[2,3] In addition to being risk factors for the development of mental disorders,[4] depressive and/or anxiety symptoms need to have accessible prevention strategies because of the negative impact of these symptoms on health.[4–6]

Regular physical exercise has been described as an approach that can be used to promote mental health in different age groups.[6–8] Meta-analyses have shown that interventions based on physical activity have a moderate effect of reducing depressive symptoms,[7,9] in addition to providing a protective effect against the development of depression, reducing the risk by approximately 22% in the general population.[10] Similarly, higher levels of physical activity are associated with decreased anxiety symptoms and a lower probability of developing anxiety disorders.[11] The positive effects of physical exercise on the reduction of depressive and anxiety symptoms have been observed both in clinical populations and in healthy individuals[9–11] and may be an important part of intervention strategies aimed at the prevention and early treatment of mental health disorders.[5,6]

However, the nature of the exercise likely influences the association between physical exercise and mental health.[12] For example, the effects of exercise on anxiety and depression symptoms in individuals with mental disorders can be moderated by the exercise intensity.[13,14] Exercise interventions based on moderate-to-vigorous intensity are likely to have greater effects in reducing these symptoms in patients with anxiety[13] and major depressive disorders.[14] Furthermore, the type of exercise seems to influence the magnitude of the effect of exercise on depressive and anxiety symptoms in both healthy individuals and patients with mental disorders,[9] in which aerobic exercises tend to have greater anxiolytic and antidepressant effects[9–11] than resistance training.[15,16] Participation in vigorous physical activities, such as high-intensity interval training (HIIT), could provide benefits to cognition and mental health in healthy individuals (e.g., executive function and psychological well-being) similar to or greater than those derived from low- and moderate-intensity exercises.[17–19]

HIIT is characterized by alternating series of high-intensity and short-duration exercises (usually ≥80% of maximum heart rate [HRmax]), followed by brief periods of passive or active recovery.[20,21] The lower training volume entailed in HIIT provides an efficient alternative in terms of time management to favor mental health benefits.[18] However, although short exercise sessions may have a positive impact on emotional health,[12] higher exercise intensity is commonly associated with lower adherence.[22] potentially hindering sustained physical exercise participation. Evidence indicates that HIIT does not have an advantage over moderate-intensity training in long-term exercise adherence.[22] Lower adherence to HIIT, particularly in unsupervised settings, may stem from difficulties in maintaining the prescribed intensity.[22] This could lead to discontinuation of participation in the intervention or engagement in exercise at lower intensities.[22]

The evidence summarized in a meta-review of 33 systematic reviews suggests that HIIT is a safe intervention that can provide benefits on different indicators of physical and mental health.[23] In general, studies that have investigated the efficacy and viability of HIIT in training programs aimed at young people have shown positive results in improving physical and mental health.[17,24,25] Randomized clinical trials lasting 8 weeks have shown that HIIT is effective in improving cardiorespiratory fitness and executive function in adolescent students[17,24] and young university students.[25] Although some results indicate that HIIT provides a sense of satisfaction and pleasure,[25] as well as a small improvement in psychological well-being,[17] these studies did not observe significant reductions in negative psychological aspects such as stress or anxiety,[25] psychological distress,[17] affect, or sleep quality of healthy individuals or individuals with physical diseases,[26] HIIT seems to promote reductions in depressive symptoms in patients with mental disorders,[23,27] but we found no study that has summarized the effects of HIIT on anxiety and depression symptoms in the overall healthy population.

In general, it has been suggested that HIIT can be an effective strategy to improve aspects of mental health, such as well-being and severity of depression, in populations with mental illness or physical diseases.[26,28] Although one meta-analysis indicated that HIIT can promote a moderate reduction in the severity of depression when compared with no exercise intervention,[26] the existing meta-analyses included people with mental disorders or physical diseases who tend to have a greater severity of depression and anxiety symptoms than the general population.[26–28] Therefore, the effects of HIIT on the symptoms of depression and anxiety in the general population remain unknown.[29] The present study aimed to systematically summarize randomized clinical trials evaluating the effects of HIIT on depressive and anxiety symptoms in individuals without diagnosed clinical conditions, compared to a passive control group (e.g., no intervention/on the waiting list). Additionally, we sought to evaluate potential moderating factors such as modality, frequency, and duration of HIIT. Investigating this gap can contribute to the design of exercise-based interventions and the optimization of mental health recommendations.

2 | METHODS

This systematic review with meta-analysis followed the recommendations of the Cochrane Handbook for Systematic Reviews of Interventions[30] and was reported according to the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA).[31,32] The study protocol was registered in the International Prospective Register of Systematic Reviews (PROSPERO) under the registration code CRD42021265608.

2.1 | Eligibility criteria

The elaboration of the research question, steps of searching for evidence, and defining the eligibility criteria were based on the components of the PICOT strategy (Table 1). Thus, the studies had to meet the following criteria for inclusion in this systematic review:

a. Randomized controlled clinical trial investigating HIIT, based on a high-intensity interval protocol (e.g., >80% HR_{max}/HR_{peak}/$HR_{recovery}$ or >90% of the maximum oxygen consumption (VO_2max) or >80% of the power/maximum speed), with a duration of at least 4 weeks and at least two sessions per week. Any form of physical exercise (running, cycling, etc.) was considered to be eligible.
b. Study sample composed of healthy individuals of any age, without a diagnosis of physical disease or mental disorder. Studies with participants diagnosed with physical diseases (including a variety of conditions such as acute and chronic illnesses, cardiovascular disorders, metabolic disorders, and skeletal disorders) or psychological disorders, elite athletes, or animal experiments were excluded from this review. RCTs involving participants with high scores for symptoms of depression and anxiety but who did not meet the diagnostic criteria (e.g., clinical diagnosis ruled out by the standardized psychiatric interview or scores below the cut-off point for severe depression/anxiety based on a validated instrument) were included.
c. Study identifying the method used to evaluate exercise intensity (e.g., heart rate, effort rate, or other validated methods), as well as identifying the characteristics of the intervention (e.g., intensity, number of sessions, duration of each session, duration of recovery between sessions, exercise mode, and work-recovery relationship).
d. Passive control group without physical exercise (e.g. no intervention/on the waiting list).
e. Evaluation of depressive and/or anxiety symptoms as primary or secondary outcome based on validated instruments.

Only original studies published in peer-reviewed scientific journals were considered. Unpublished manuscripts, study protocols, and abstracts of conferences/congresses were considered to be ineligible.

TABLE 1 Description of the PICOT strategy.

Acronym	Definition	Description
P	Population	Healthy population
I	Intervention	Physical exercise based on a high-intensity interval protocol
C	Comparator	Passive control group (without exercise)
O	Outcomes	Depressive and/or anxiety symptoms
T	Type of study	Randomized controlled clinical trial

2.2 | Sources of information and search strategy

Author JW performed a systematic search on April 12, 2021, in the following databases: MEDLINE/PubMed, Scopus, Embase, and PsycINFO. The search strategy was designed to cover terms related to the main outcomes of interest. The terms had to be present in the title, abstract, or keywords. The last update of the search strategy was carried out on December 10th, 2023. Full details of this search strategy can be found in Data S1.

The search terms used were ("high-intensity interval training" OR "hiit" OR "intermittent exercise" OR "interval exercise" OR "sprint interval training" OR "sprint interval exercise") AND (depression OR "depressive symptoms" OR anxiety OR "anxiety symptoms" OR anxious). The systematic search considered all the studies published until December 10, 2023. No language restrictions were imposed. The gray literature was not considered in this study.

2.3 | Study selection process

The screening and selection stages of the studies were conducted independently by two researchers (JW and VF). After removing duplicates, the titles and abstracts were examined to identify potentially relevant studies according to the eligibility criteria. The studies that made it through this screening were read in full to evaluate their eligibility and were excluded if they did not meet all the criteria. Any divergence in the screening and selection stages was resolved by a third researcher (DA). The reference lists of the articles selected in the second stage were

reviewed to identify other eligible studies. Figure 1 provides an overview of the article selection process.

2.4 | Data extraction process and synthesis method

Data extraction was performed by the JW using a standardized form and reviewed by a second evaluator (EL). The information extracted from the studies included details of the publication, names of the authors, study design, sample characteristics, details about the interventions used, measurement instruments, and the main results. Additionally, all available quantitative data regarding the outcomes of anxiety and depression (e.g., mean and standard deviation) and their respective statistical values (e.g., *p*-values and *t*-statistics) were collected. In the absence of relevant data for the meta-analysis, we contacted the corresponding authors via e-mail to request additional information.

2.5 | Assessment of risk of bias

The risk of bias in the included studies was evaluated using the revised Cochrane Risk of Bias Tool for Randomized Clinical Trials (RoB 2.0).[33] RoB 2.0 addresses five specific domains: (1) bias due to the randomization process; (2) bias due to deviations from intended interventions; (3) bias due to missing outcome data; (4) bias in the measurement of the outcomes; and (5) bias in the selection of the reported result. Two researchers (JW and RF) independently applied the tool to each included study and recorded any supporting information, classifying each result as having a "high", a "low", or "some concerns" about the risk of bias. Any discrepancies in the assessment of the risk of bias were resolved in a consensus meeting between the researchers, with a third researcher (DA) acting independently for a final judgment if necessary. Following the guidelines provided for RoB 2.0, we wrote a general summary of the risk of bias judgment (low, some concerns, and high) for each specific domain, and the overall risk of bias for each study was the highest level of risk in the domains that were evaluated.[33]

2.6 | Measures of effect and data analysis

Owing to the expected heterogeneity between studies, a random-effects model was chosen to calculate the

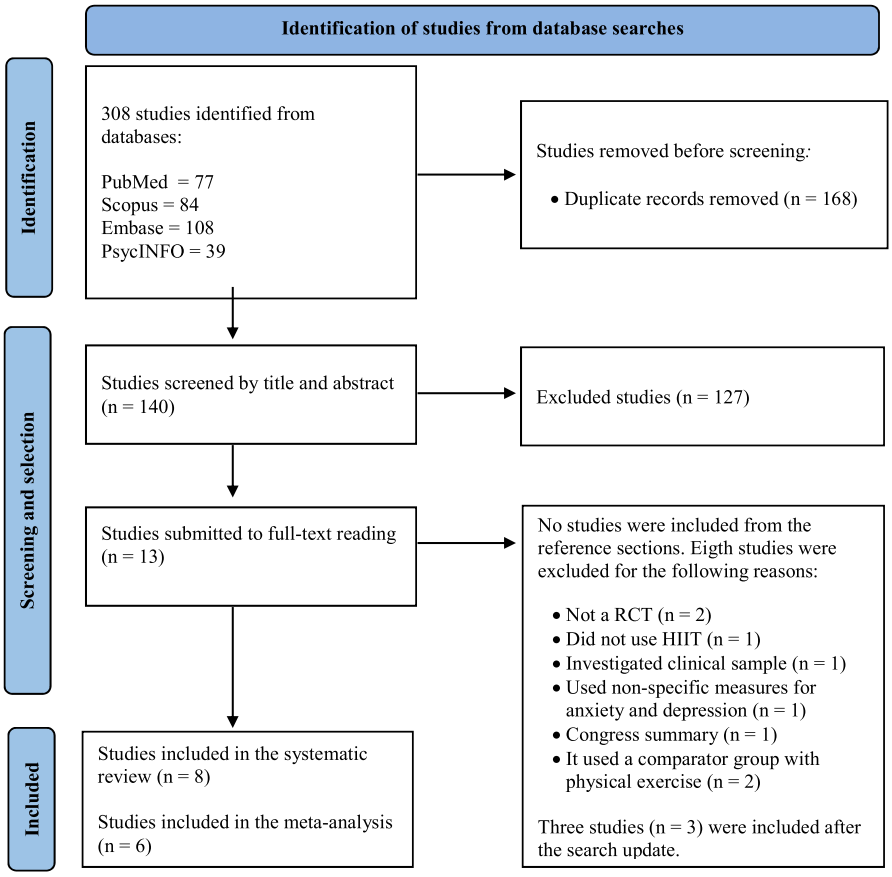

FIGURE 1 Flow diagram of the studies identified following the PRISMA guidelines.

average distribution of the effects of the intervention on depressive and anxiety symptoms. Thus, we performed a meta-analysis based on the standardized mean difference (SMD) effect sizes and their respective 95% confidence intervals (CIs) using the Hartung-Knapp-Sidik-Jonkman (HKSJ) method,[34,35] which adjusts the confidence interval to reflect the uncertainty in the heterogeneity estimate among the studies.[30,35] This method has been described as more appropriate for meta-analyses and demonstrates superior technical properties compared to the moment-based DerSimonian and Laird approach.[30,35,36] The SMD was calculated for each group based on the mean difference (mean change), standard deviation (SD), and sample size for each study condition to compare the interventions. In cases where the RCT used more than two arms, we considered the control group without exercise compared to the HIIT group. If the relevant data were not provided, we calculated the effect size from alternative statistics (e.g., t-test, standard error) using the methods described in the Cochrane manual.[30] One study[37] had imputed data (SD). The effect size was classified as no effect (<0.20), small (between 0.20 and 0.49), moderate (between 0.50 and 0.79), and large (>0.80) based on the criteria proposed by Cohen.[38]

The magnitude and impact of heterogeneity between the studies were determined by calculating the Chi^2 and I^2 statistics. The values of heterogeneity were categorized as considerable (>75%), substantial (between 50% and 90%), moderate (between 30% and 60%), or not important (<40%).[30] Owing to the diversity of the intervention protocols used, subgroup analyses were performed to verify the influence of HIIT characteristics (modality, frequency, and duration of the session) based on a previous meta-analysis.[26] Differences from protocol: Considering that the methodological diversity among the comparators could generate confusion in the interpretation of the results, we decided to restrict the analysis to "studies with a passive control group (no exercise)" instead of "control group with or without exercise" established in the protocol. Nevertheless, we provided complementary analyses of the comparison between HIIT and moderate-intensity training (MIT) (Data S2) based on studies excluded from the main analyses because they did not use a passive control group. Publication bias, as well as other sensitivity, subgroup, and meta-regression analyses previously planned in the protocol, were not performed because of the small number of included studies and the absence of heterogeneity. All analyses were conducted using R (R Foundation for Statistical Computing, version 4.3.0) and R Studio (R Studio Team, 2023), using the "meta" package.[39] Statistical significance was set at $p < 0.05$.

2.7 | Assessment of evidence certainty

We evaluated the certainty of the evidence based on the Grading of Recommendations Assessment Development and Evaluation (GRADE).[40] Two researchers (EL and JW) independently addressed the five GRADE domains (risk of bias, inconsistency, imprecision, indirect effects, and publication bias) to assess the certainty of the body of evidence in the included RCTs. The certainty of the evidence was classified as high, moderate, low, or very low. Any divergence in the evaluations was resolved through a consensus meeting between the researchers. We justify all decisions to decrease the certainty rating of any study using footnotes and provide comments to help readers understand the results when necessary.

3 | RESULTS

3.1 | Selection of studies

Initially, 308 studies were identified from the databases. After removing duplicates, 140 studies were judged based on their titles and abstracts, resulting in 13 studies selected for full-text reading. Of these, eight studies were excluded, and the main reasons for this decision are described in Data S3 (Table S1). Three studies[41–43] were included after updating the search. Finally, eight studies[25,37,41–46] were considered eligible for inclusion. Two studies were excluded from the meta-analysis due to insufficient data in their report.[41,44] The details of the selection process are shown in Figure 1.

3.2 | Characteristics of the studies

Table 2 shows the characteristics of the eight studies included in the present review.[25,37,41–46] The studies were published between January 2018 and June 2022 and involved 471 participants (81% female). The mean age of the participants in each study ranged from 19 to 41 years old. Six samples were composed of young adults[25,37,42,44–46] and two studies investigated adults.[41,43] Seven studies evaluated participants of both sexes[25,37,41–45] whereas one study investigated only female participants.[46] The duration of intervention in these studies was 4 weeks,[42,44] 6 weeks,[41,43,45,46] 8 weeks,[25] and 9 weeks.[37]

Regarding the HIIT protocol, 25% ($n = 2$) of the studies used a running-based protocol,[37,45] 50% ($n = 4$) of the studies used a home intervention protocol based on circuit training,[41–43,46] 12.5% ($n = 1$) used a protocol involving various combinations of aerobic and resistance exercises[25] and 12.5% ($n = 1$) used a protocol involving cycling.[44]

TABLE 2 Characteristics of the included studies.

Authors Country	Design Groups	Participants	Interventions	Measures	Results
Alonso-Fernández et al.[41] Spain	RCT HIIT vs. Control	HIIT: $n = 11$ Age = 34 ± 5 Years % of women: 55% Control: $n = 10$ Age = 36 ± 6 Years % of women: 60%	6 weeks 2–3 sessions/week M: home intervention based on the "Tabata" method (e.g., burpees, squat jump). I: ≥80% HR_{max} S: 16–32 W/R: 20s/10s	Depressive symptoms: CES-D	HIIT significantly reduced depressive symptoms compared to the control intervention.
Eather et al.[25] Australia	RCT HIIT vs. Control	HIIT $n = 27$ Age = 20 ± 1 years % of women: 64% Control $n = 26$ Age = 20 ± 2 years % of women: 68%	8 weeks 3 sessions/week M: Intervention based on a combination of aerobic (e.g., jumping, jumping) and resistance (e.g., push-ups, squats, sit-ups) exercises using body weight or basic equipment (e.g., sports balls or 2 kg medicine balls). I: ≥85% HR_{max} W/R: 30 s/30s	Symptoms of anxiety: STAI	HIIT did not promote significant improvements in the perception of anxiety.
Lucibello et al.[37] Canada	RCT HIIT vs. Control	% of women: 63% HIIT $n = 25$ Age = 20 ± 3 years Control $n = 21$ Age = 19 ± 2 years	9 weeks 3 sessions/week M: Running (sprints) on the treadmill. I: 90–95% HR_{max} S: 10 W/R: 60 s/60s	Depressive symptoms: BDI-II Symptoms of anxiety: BAI	Depressive and anxiety symptoms decreased throughout the intervention in both the HIIT and control groups. HIIT was not more effective than control in reducing indicators of anxiety or depression.
May et al.[44] USA	RCT HIIT vs. HRVBT vs. Control	% of women: 82% Age = 19 ± 1 years HIIT $n = 30$ HRVBT $n = 30$ Control $n = 30$	4 weeks 3 sessions/week M = Cycling on the stationary bicycle. I = 90% HR_{max} S = 10 W/R = 60 s/60s	Depressive symptoms: CES-D Symptoms of anxiety: STAI	HIIT did not promote significant improvements in the perception of depressive symptoms or anxiety compared to control.
Paolucci et al.[45] Canada	RCT HIIT vs. MIT vs. Control	Age = 21 ± 2 years HIT $n = 18$% of women: 71% MIT $n = 19$% of women: 68% Control $n = 18$% of women: 72%	6 weeks 3 sessions/week M = Running (sprint) on the treadmill. I: 80% of maximum power S: 10 W/R: 60s/60s	Depressive symptoms: BDI-II Symptoms of anxiety: BAI	HIIT significantly reduced depressive symptoms compared to the control intervention. HIT did not promote significant improvements in the perception of anxiety.

TABLE 2 (Continued)

Authors Country	Design Groups	Participants	Interventions	Measures	Results
Philippot et al.[42] Belgium	RCT HIIT vs. Control	HIIT $n = 13$ Age = 20 ± 1 years % of women: 85% Control $n = 15$ Age = 20 ± 1 years % of women: 93%	4 weeks 3 sessions/week M = home intervention based on circuit training. HIIT = I: ≥80% HR_{max} S: 10 W/R: 30s/30s	Depressive and anxiety symptoms DASS-21	HIIT reduced depressive symptoms compared to control but did not promote significant improvements in the perception of anxiety.
Puterman et al.[43] Canada	RCT HIIT vs. Yoga vs. HIIT+yoga vs. Control	% of women: 87% HIIT $n = 82$ Age = 41 ± 12 years Yoga $n = 86$ Age = 37 ± 12 years HIIT+yoga $n = 83$ Age = 41 ± 12 years Control: $n = 83$, Age = 41 ± 12 years	6 weeks Four sessions/week M = home intervention based on circuit training. HIIT = I: ≥80% HR_{max} S: Not informed W/R: Not informed	Depressive symptoms: CES-D	HIIT did not significantly reduce depressive symptoms after 6 weeks compared to control.
Zhang et al.[46] China	RCT HIIT vs. Control	% of women: 100% HIIT N = 33 Age = 23 ± 2 years Control N = 29 Age = 23 ± 2 years	6 weeks 2 sessions/week M = home intervention based on circuit training (for example, jumping jacks, burpees): first 15-minute session +5-minute rest + second 15-minute session; I = 80% HR_{peak} S: 15 each session W/R: 30 s/30s	Symptoms of anxiety: STAI	Only HIIT significantly reduced anxiety, but the changes after HIIT and control were not significantly different from each other.

Abbreviations: Age, mean age of the participants; BAI, Beck Anxiety Inventory; BDI-II, Beck-II Depression Inventory; BDI-13, Beck Depression Inventory, Spanish version; CES-D, Studies Depression Scale; DASS-21, The Depression, Anxiety, and Stress scales−21 Items; HIIT, high-intensity interval training; HRVBT, training based on heart rate variability; I, HIIT intensity; M, HIIT modality; MIT, moderate-intensity training; N, number of participants; RCT, randomized controlled trial; S, number of series; STAI, Trait and State Anxiety Inventory; STAI-E, Trait and State Anxiety Inventory, Spanish version; W/R, work/recovery ratio.

3.3 | Effects of HIIT on anxiety symptoms

Based on five studies[25,37,42,45,46] including a total of 225 participants, interventions using HIIT did not result in a significant reduction in anxiety symptoms compared to the control interventions (SMD = −0.17; 95% CI: −0.53, 0.19; $p = 0.27$), as shown in Figure 2. The heterogeneity of these results was considered not important ($I^2 = 0\%$; 95% CI: 0%, 79%; $p = 0.27$).

3.4 | Effects of HIIT on depressive symptoms

The results of the meta-analysis based on four studies,[37,42,43,45] including 275 participants, revealed that HIIT interventions were not significantly associated with a reduction in depressive symptoms compared to the control group (SMD = −0.38; 95% CI: −1.06, 0.30; $p = 0.17$), as shown in Figure 3. The heterogeneity of these findings was considered moderate ($I^2 = 47\%$; 95% CI: 0%, 82%; $p = 0.13$).

3.5 | Subgroup analyses

3.5.1 | HIIT and anxiety symptoms

The results of subgroup analyses of anxiety symptoms are shown in Table 3. HIIT had no effect on anxiety symptoms compared with the control group, regardless of HIIT characteristics (modality, duration, or frequency of the HIIT protocol used). Forest plots of the subgroup analyses are available in Data S2 (Figures S3–S5).

3.5.2 | HIIT and depressive symptoms

The results of the subgroup analysis of depressive symptoms based on the characteristics of the HIIT protocol are presented in Table 4. The modality and frequency of the HIIT protocol had no significant effects on depressive symptoms compared with the control group. However, the duration of the HIIT interventions had a significant effect on depressive symptoms. Interventions lasting less than 6 weeks (SMD = −0.78; 95% CI: −1.40, −0.15) exhibited

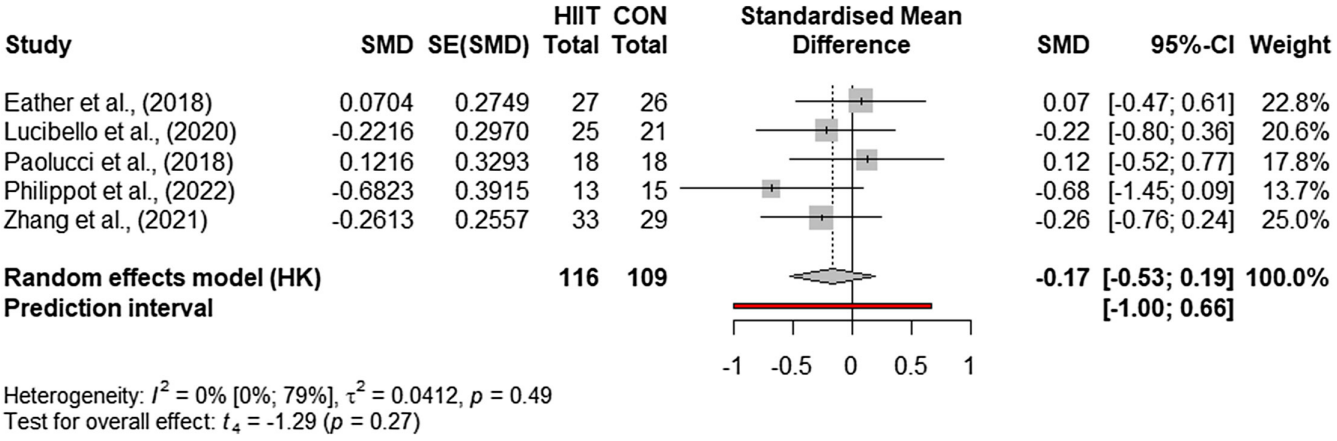

FIGURE 2 Meta-analysis of the effects of HIIT compared to the control group on anxiety symptoms.

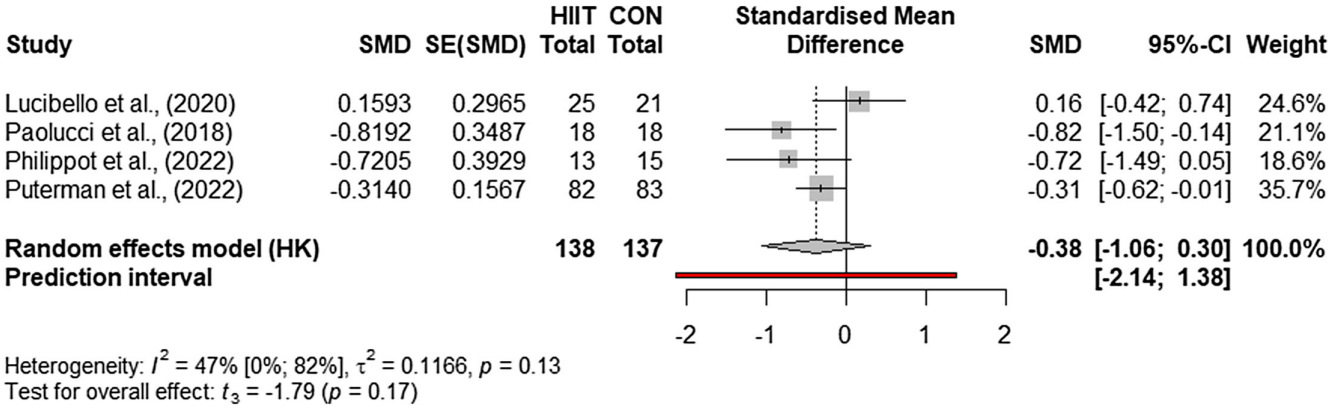

FIGURE 3 Meta-analysis of the effects of HIIT compared to the control group on depressive symptoms.

TABLE 3 Subgroup analyses of HIIT effects on anxiety symptoms compared to the control group.

		Meta-analysis			Subgroup difference	
Analysis	***k***	**SMD**	**95% CI**	I^2	***p* value**	I^2
Main Effect						
Anxiety symptoms	5	−0.17	(−0.53, 0.09)	0%	NA	NA
HIIT Characteristics						
Modality						
Running	2	−0.07	(−2.24, 2.11)	21%	0.51	0%
Circuit training	3	−0.24	(−1.11, 0.63)	0%		
Duration						
≤6 weeks	3	−0.25	(−1.17, 0.68)	20%	0.49	0%
>6 weeks	2	−0.07	(−1.92, 1.79)	0%		
Frequency						
≤3 sessions/week	5	−0.17	(−0.53, 0.09)	0%	NA	NA
>3 sessions/week	0	NA	NA	NA		

Abbreviations: CI, confidence interval; k, number of RCTs; NA, not applicable; SMD, standard mean difference.

a greater reduction in depressive symptoms compared to those lasting more than 6 weeks (SMD = −0.14; 95% CI: −3.03, 2.74). Forest plots of the subgroup analyses are available in Data S2 (Figures S6–S8).

3.6 | Risk of study bias

A summary of the assessment of the risk of bias of individual studies in each of the six domains is shown in Figure 4. In terms of overall risk, there were concerns about the risk of bias in most studies due to the lack of sufficient detail in their reports. Seven studies had "some concerns" of bias,[25,37,41,42,44–46] and only one study[43] was evaluated with a "low risk of bias." The justification for these evaluations is presented in Data S4. Bias due to deviations from the intended interventions and bias in the selection of reported results were the main domains considered problematic. A general summary of the judgment of risk of bias is shown in Figure 5.

3.7 | Certainty of evidence

Evidence of very low certainty indicated that HIIT had no effect on reducing anxiety symptoms. The evidence was downgraded in the indirect evidence domain, imprecision, inconsistency, and risk of bias. Regarding depressive symptoms, the evidence of very low certainty indicates that HIIT had no effect on reducing these symptoms. Again, evidence was downgraded in the indirect evidence domain, imprecision, inconsistency, and risk of bias. Table 5 presents a summary of the results, with footnotes explaining downgrade judgments (decreased the certainty of the evidence).

4 | DISCUSSION

This systematic review aimed to investigate the effects of HIIT on depressive and anxiety symptoms in healthy individuals. Overall, the results of the meta-analysis indicated that HIIT-based interventions had no significant effect on reducing anxiety and depressive symptoms in healthy individuals compared to the control group without physical exercise. In summary, the included studies provided very low certainty evidence that HIIT does not improve the symptoms of depression and anxiety in healthy individuals.

According to our results, HIIT had no positive effect on the reduction of depressive and anxiety symptoms in the healthy population compared with the control group. Although some studies have indicated a positive effect of HIIT in reducing anxiety,[37,46] these effects were not greater than those found in the control group. Similarly, although the included studies observed a positive effect of HIIT on the reduction of depressive symptoms,[37,41–45] HIIT was not more effective than the control group in reducing these symptoms in three studies.[37,43,44] Other studies have not found a positive effect of HIIT on depressive[37] and anxiety symptoms.[25,42,44,45] Therefore, we did not find convincing evidence for a positive effect of HIIT on depressive and anxiety symptoms in healthy individuals. This is contrary to the findings of a meta-analysis that investigated the

TABLE 4 Subgroup analyses of HIIT effects on depressive symptoms compared to the control group.

		Meta-analysis			Subgroup difference	
Analysis	***k***	**SMD**	**95% CI**	I^2	***p* value**	I^2
Main Effect						
Depressive symptoms	4	−0.38	(−1.06, 0.30)	47%	NA	NA
HIIT Characteristics						
Modality						
Running	2	−0.31	(−6.52, 5.90)	78%	0.86	47%
Circuit training	2	−0.40	(−2.54, 1.73)	0%		
Duration						
≤6 weeks	2	−0.78	(−1.40, −0.15)	0%	<0.01	47%
>6 weeks	2	−0.14	(−3.03, 2.74)	50%		
Frequency						
≤3 sessions/week	4	−0.38	(−1.06, 0.30)	47%	NA	NA
>3 sessions/week	0	NA	NA	NA		

Abbreviations: CI, interval confidence; k, number of RCTs; NA, not applicable; SMD, standard mean difference.

effects of HIIT on the mental health of healthy or physically ill individuals,[26] which indicated that HIIT improved depressive symptoms.

A possible explanation for the lack of an effect may be related to the fact that HIIT exacerbates a physiological response similar to psychological stressors, decreasing the body's ability to regulate its physiological response to other stressful events, and generating an increase in the perception of stress and anxiety.[37,45] Considering that in addition to not improving depressive symptoms,[37] two other studies showed that HIIT did not promote a reduction in the perception of stress[25] and anxiety,[42] this hypothesis may be plausible. However, it is possible that the results were influenced by the duration of the HIIT program, as a longer HIIT program (over 7 weeks) may be more effective in promoting mental health benefits.[26,28] Additionally, the absence of changes in anxiety symptoms may be due to a "ground effect."[47] This means that the severity of depressive and anxiety symptoms is higher in clinical populations, which creates more room for reduction than in healthy populations.[9] Therefore, despite the popularity of HIIT, this exercise modality may not be the most effective way to reduce anxiety[26,37] and depressive symptoms in healthy individuals.

Despite this, studies have suggested the potential of HIIT to improve physical and mental health.[17,48] Some findings from the studies included in this review partially corroborate these reports. Eight-week HIIT interventions promoted an increase in cardiorespiratory fitness[25] and had a moderate effect on upper-body muscle fitness.[25] Additionally, changes in cardiorespiratory fitness are associated with improvements in cognitive function.[25] Although they are not related to the reduction of depressive or anxiety symptoms,[25] these results may be important given the evidence of an inverse linear association between increased cardiorespiratory fitness and the incidence of common mental disorders.[49,50] Furthermore, HIIT may have a positive influence on other aspects of mental health in addition to symptoms of anxiety and depression. Evidence from systematic reviews indicates that HIIT has a small chronic effect on improving well-being and reducing malaise[18] as well as a positive effect on executive function in healthy individuals,[18,51] in addition to improving the well-being, and severity of depression[26] in populations with physical illness.

Furthermore, we performed subgroup analyses to evaluate the potential moderators of the effects of HIIT on depressive and anxiety symptoms, including modality, weekly frequency, and duration of intervention. Unexpectedly, our results showed that interventions lasting less than 6 weeks exhibited a greater reduction in depressive symptoms than those lasting more than 6 weeks. However, certain studies included in the subgroup analyses have presented a lack of proportionality with exceptionally large effect sizes compared to a non-exercise control group.[41,45] For instance, the study conducted by Paolucci et al.[45] reported virtually identical average scores on the BDI-II scale before and after the intervention for the HIIT group, indicating no significant change in depressive symptoms (13.2 ± 9.5 vs. 12.2 ± 6.2; MD = -1.41 ± 9.02), both below the threshold of "14" points associated with mild depressive symptoms. Curiously, the randomly assigned control group, initially categorized as only "mildly" depressed (16.7 ± 9.5), experienced a moderate increase in depressive symptoms within 6 weeks (23.1 ± 11.7), despite no apparent reason being provided. This effect (MD = 5.82 ± 8.22) exceeded the magnitude typically deemed clinically significant

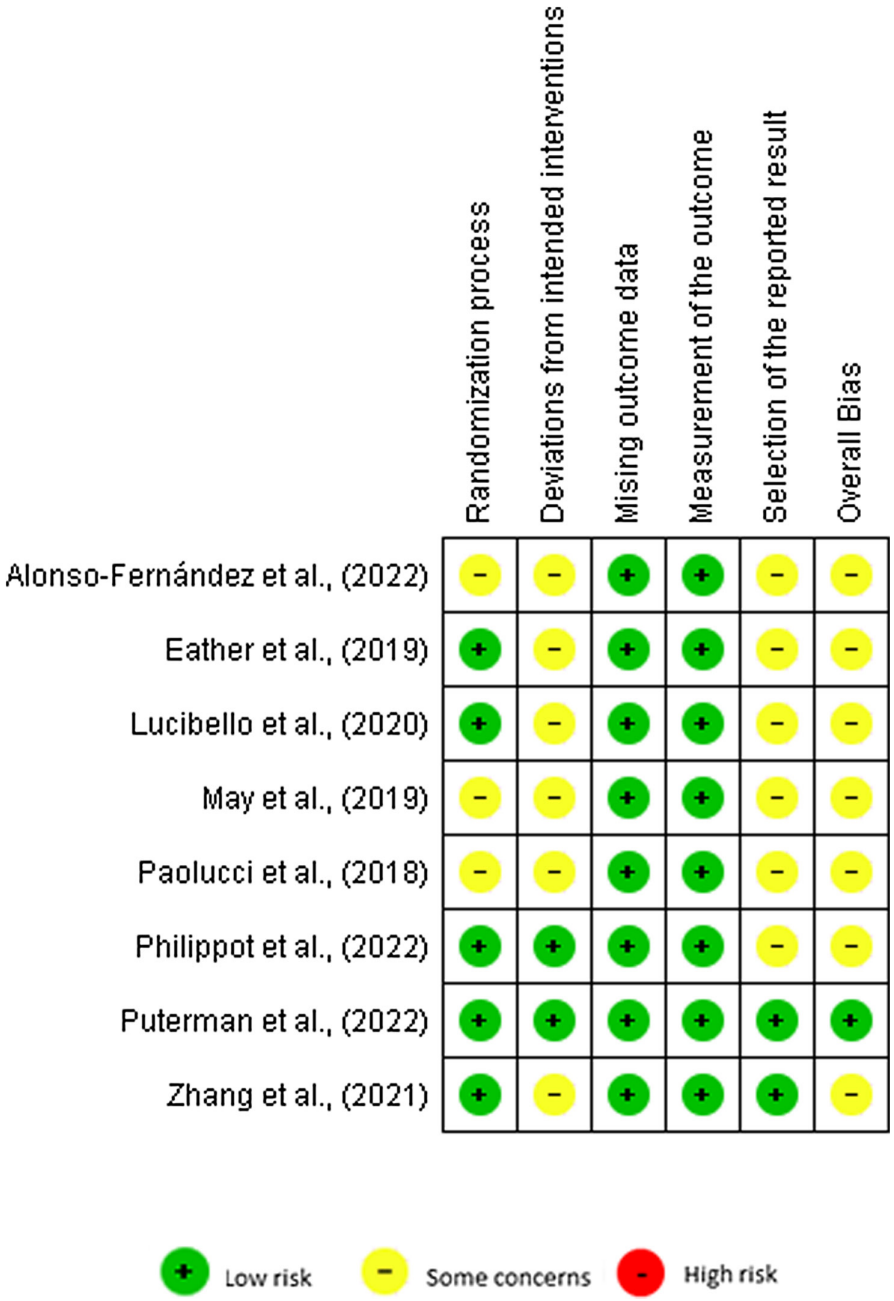

FIGURE 4 Judgment of the authors about each risk of bias item for each included study.

(e.g., a 3-point change on the BDI-II, approximately +1 point per week) and notably occurred without a corresponding observable change in anxiety or stress levels.[45] Consequently, a mechanistic explanation that adequately accounts for the magnitude of this effect size remains elusive, raising concerns about the plausibility of this result and emphasizing the need for cautious interpretation.

Additionally, our analyses did not indicate significant effects of the frequency and modality of HIIT interventions on depressive and anxiety symptoms. Although the included studies used different HIIT modalities (running, a combination of aerobic and resistance exercises, and circuit training), meta-analytical evidence suggests that the type of HIIT modality has no effect on mental health outcomes,[26] which is similar to the results of our meta-analysis. However, there is considerable inconsistency in the assessment of the training intensity during HIIT sessions. The lack of adequate monitoring of exercise intensity may lead to an overestimation of the actual intensity achieved by participants during periods of high-intensity exercise. This failure to implement HIIT can obscure the phenomenon wherein participants fail to adhere to the prescribed high-intensity protocol, resulting in exercise at an intensity lower than the intended level.[52] Therefore, it is important to ensure that exercise intensity monitoring is accurately and comprehensively reported in studies

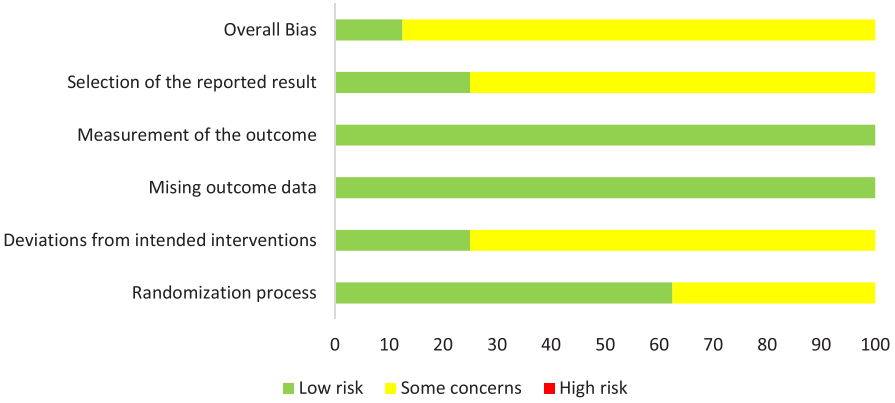

FIGURE 5 Summary of the judgments of the authors on each domain of risk of bias presented as percentages based in included studies.

that involve HIIT protocols.[52] In addition, it is important to investigate which characteristics of HIIT can be manipulated to promote mental health, and to assess the possible mechanisms underlying the effects of physical exercise on symptoms of anxiety and depression.

One of the main advantages of HIIT is related to the relatively short duration of training sessions, in some cases performed between 8 and 12 minutes,[25] resulting in physiological adaptations comparable to those obtained in longer training sessions, as is the case of continuous training of moderate intensity.[25,53] However, the preliminary results of our complementary analyses did not demonstrate the superiority of HIIT over MIT in reducing depressive and anxiety symptoms. Therefore, it seems necessary to consider holistic approaches that not only focus on the questionable time-efficiency benefits of HIIT, but also consider other motivational, psychological, and contextual factors that affect engagement in physical activities.[54] Understanding the complexity of these factors and developing personalized motivational and behavioral change strategies can be crucial in promoting an active and healthy lifestyle. Claims suggesting the absolute superiority of HIIT over continuous moderate-intensity exercise may be premature, especially in the absence of strong evidence to support them.[54] Further research, including large randomized studies with long-term follow-up, is needed to fully understand the effectiveness and benefits of HIIT on mental health.

In addition, findings from the existing literature on HIIT suggest that when participants transition to unsupervised settings, exercise intensity tends to be reduced, or they switch to alternative exercise modalities or discontinue exercising altogether.[22] This behavioral pattern has been observed in several randomized controlled trials in which adherence and dropout were the primary outcome measures.[55–57] These outcomes are consistent with investigations that have shown a negative association between higher exercise intensity and a decline in adherence and/or increase in dropout rates.[22] The lack of full and partial adherence highlights the challenge of maintaining consistency in this type of exercise program, particularly in the absence of ongoing support.[22,55] Therefore, when evaluating the effectiveness of HIIT in the context of public health, it is crucial to consider not only short-term physiological adaptations but also long-term behavioral change.[22] Particularly, attention should also be directed towards assessing its effectiveness in improving mental health indicators, such as depressive and anxiety symptoms. Additionally, further examination of individual differences in tolerance and acceptance of HIIT is necessary to develop personalized approaches that consider participants' preferences and limitations. Conducting rigorous and long-term research is essential to adequately assess the benefits and barriers related to HIIT and inform evidence-based public policies and exercise guidelines.[58]

4.1 | Limitations and implications for research and practice

This review has some limitations. First, few RCTs have evaluated the effects of HIIT on depressive and anxiety symptoms. The small number of high-quality studies is one of the main limitations of the field of physical activity and mental health research.[59] In addition, the small number of RCTs made it impossible to perform complementary analyses that our protocol had planned (e.g., publication bias analysis and meta-regression). Subgroup analyses considering participant characteristics (e.g., sex, age, and symptom severity) were also not performed. HIIT is a broad term with significant heterogeneity among protocols, which can create “noise” and negatively influence findings, especially with few RCTs in the analysis. We also do not consider the gray literature, which can favor publication bias and a less balanced view of the evidence. Thus, caution is needed when interpreting the strength of the evidence summarized in this review. The risk of bias found in the included RCTs limited our confidence in the potential effects of HIIT on depression and anxiety symptoms.

TABLE 5 Summary of results and evaluation of the certainty of evidence (GRADE).

Outcome	Assessment of the certainty of evidence							No. of participants		Estimation of effect		Certainty of evidence
	No. of studies	Study design	Risk of bias	Inconsistency	Indirectness	Imprecision	Publication bias	HIIT	Control	SMD	95% CI	
Symptoms of anxiety	5	RCT	Serious[a]	Serious[b]	Serious[c]	Serious[d]	NA	116	109	−0.17	−0.53, 0.19	⊕◯◯◯ VERY LOW
Depressive symptoms	4	RCT	Serious[a]	Serious[b]	Serious[c]	Serious[d]	NA	138	137	−0.38	−1.06, 0.30	⊕◯◯◯ VERY LOW

Note: Comments and reasons for the downgrade.

Abbreviations: CI, confidence interval; HIIT, high-intensity interval training; NA, not assessable; RCT, randomized clinical trial; SMD, standardized mean difference.

[a]Downgrade one level due to the overall judgment that most studies had "some concerns" of bias.

[b]Downgrade one level due to a wide 95% CI for the I^2.

[c]Downgrade one level due to variability of the HIIT protocols used.

[d]Downgrade one level due to a wide 95% CI for the main estimative.

Most studies were rated as having "some concerns" about bias due to inadequate reporting. Insufficient details regarding the methods and results, unclear statements regarding primary and secondary outcome variables, and the absence of a protocol with prior information on study conduct were among the identified concerns. When a published protocol was available, most studies failed to provide specific information regarding statistical planning. The lack of pre-specification and the selective reporting of results fall under the category of "researcher degrees of freedom",[60] which refers to the various choices made by researchers during the design, execution, and analysis of an experiment that can influence the study outcomes and cause bias.[61] These practices may be considered questionable statistical practices that researchers may employ to obtain the desired outcomes.[62]

When interpreting the findings of studies on affective and psychological responses to HIIT, it is important to consider methodological aspects and evaluate the plausibility of the presented conclusions.[52] Most studies on the impact of HIIT on depressive and anxiety symptoms have used small samples with relatively short intervention periods. Given that low statistical power can compromise the validity of the results and lead to erroneous conclusions,[63] generalizing the findings of small RCTs can be problematic. Therefore, attention to methodological details and a more rigorous critical analysis of the studies are needed to ensure the reliability of the results and reproducibility of research on HIIT.[52]

We suggest that future RCTs should consider using standardized guidelines for conducting and reporting exercise interventions, such as the Consolidated Standards of Reporting Trials (CONSORT)[64] and Consensus on Exercise Reporting Template (CERT).[65] Adherence to the CONSORT and CERT recommendations can enhance the reliability and validity of RCT results, in addition to providing more consistent information for use in systematic reviews or replication in clinical practice.[64,65] We emphasize the ongoing need to adhere to rigorous scientific writing standards. The studies examining HIIT could provide valuable insights if researchers embrace more rigorous and transparent approaches to minimize bias and maximize the validity of the results. In addition, a methodology checklist was developed[52] that can help researchers understand and evaluate HIIT studies. The biases identified in the studies included in this review should be minimized in future research to improve methodological quality and provide more consistent evidence. Despite these limitations, the results summarized in this systematic review and meta-analysis extend the current knowledge on the effects of HIIT on mental health and present some strengths to be considered.

5 | CONCLUSION

This review provides evidence that HIIT has no significant effect on reducing depressive and anxiety symptoms in healthy individuals compared with a passive control group. Our results show that HIIT did not significantly alleviate these symptoms. Therefore, the evidence is still not consistent enough to provide support for HIIT to reduce both outcomes owing to the limited number of studies included and the overall quality of evidence.

6 | PERSPECTIVE

Although the literature on HIIT suggests that this modality is a potent stimulus for various health benefits, it is important to consider the limitations and challenges associated with its implementation in public health settings and ensure that the evidence is consistent with the "extraordinary nature of the claims."[62] We did not find consistent enough evidence to suggest HIIT as a viable public health strategy targeting the symptoms of anxiety and depression in healthy populations. The main issues that limit our confidence in HIIT involve the three points discussed earlier by Biddle & Batterham:[66] (i) studies with small samples and "some concerns" about the risk of bias; (ii) insufficient follow-up time to determine long-term effects on depressive and anxiety symptoms; and (iii) problems related to adherence. The lack of long-term data on adherence and dropout rates may compromise the effectiveness of HIIT as a sustainable physical activity promotion strategy.[22,66] Therefore, we provide preliminary evidence that advances the understanding of the impact of HIIT on mental health, indicating that this modality may not be the most effective way to reduce depressive and anxiety symptoms in healthy individuals.

AUTHOR CONTRIBUTIONS

All the authors contributed substantially to this study. Gaia J.W.P designed the systematic review, participated in the screening of studies, assessed the risk of bias and the certainty of the evidence, performed data extraction and statistical analysis, and wrote the manuscript; Ferreira V.M.S was one of the independent reviewers for the title, abstract, and full-text screening. Ferreira R.W was one of the independent reviewers in assessing the risk of bias. Sousa E.L was an independent reviewer in assessing the certainty of evidence and performed the data extraction. Schuch F.B. revised the manuscript and provided critical evaluations. Pires D.A. supervised all steps, participated in the study design, revised the manuscript, and provided critical evaluations. All authors have contributed to, read, and approved the final manuscript.

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CONFLICT OF INTEREST STATEMENT

All authors declare that there are no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

ORCID

Jhonatan Wélington Pereira Gaia https://orcid.org/0000-0003-0918-5542
Felipe Barreto Schuch https://orcid.org/0000-0002-5190-4515
Rodrigo Weyll Ferreira https://orcid.org/0000-0002-5317-1781
Edielen de Lima Souza https://orcid.org/0000-0002-5578-6659
Verônica Moreira Souto Ferreira https://orcid.org/0000-0002-1560-5120
Daniel Alvarez Pires https://orcid.org/0000-0003-2163-5606

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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