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SYSTEMATIC REVIEW

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Influence of aerobic exercise on depression in young people: a meta-analysis

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Abstract

Objective To investigate the influence of aerobic exercise on depression among the young people.

Data sources PubMed, Web of science, Embase, Cochrane, EBSCO were searched from inception to November 2023.

Study selection RCT studies, assessing the use of aerobic exercise in young people aged 6–35 years and then determining the development of depression in young people (aged 6–35 years), were selected, and mean ± SD values adjusted for the presence of baseline depression were extracted.

Data extraction and synthesis Study quality was assessed using the Review manager 5.4.1 and Cochrane 5.1 item on risk of bias and precision of observational studies. Two reviewers conducted all review stages independently. Selected data were pooled using random-effects meta-analysis.

Main outcomes and measures The included studies evaluated the relationship between aerobic exercise and depression at various time points among young individuals, and provided corresponding mean ± SD values. Depression diagnosis in the selected studies was conducted using the Depression Correlation Scale.

Results After screening 2296 articles, 163 articles were selected for full-text review, and 8 of those were further reviewed. Ultimately, 12 studies, involving 658 individuals, were included in the meta-analysis. The results of the meta-analysis indicated that aerobic exercise could effectively improve depression in young people (d = -1.33, 95%CI: -1.78 ~ -0.87, $P < 0.05$). Subgroup analysis demonstrated that aerobic exercise was beneficial for both depression (d = -2.68, 95%CI: -3.87 ~ -1.48, $P < 0.05$) and non-depression (d = -0.85, 95%CI: -1.20 ~ -0.51, $P < 0.05$) conditions, as well as for low intensity (d = -0.93, 95%CI: -1.29 ~ 0.58, $P < 0.05$) and moderate intensity (d = -2.08,95%CI:-2.88 ~ -1.27, $P < 0.05$) exercises. Additionally, aerobic exercise was found to significantly alleviate depression in young people when performed for 40 min or less (d = -2.00,95%CI: -2.96 ~ -1.04, $P < 0.05$), whereas durations exceeding 40 min showed a lesser effect (d = -0.85,95%CI:-1.47 ~ -0.24, $P < 0.05$). Furthermore, the duration-based analysis revealed that aerobic exercise improved depression levels in young people regardless of duration, whether it was for less than 6 weeks (d = -1.27,95%CI: 2.12 ~ 0.14, $P < 0.05$), 6 to 11 weeks (d = 1.55, 95% CI: 2.16 ~ 0.94, $P < 0.05$), or more than 12 weeks (d = 1.00, 95% CI: -1.76 ~ -0.24,$P < 0.05$). Overall, these findings suggest that aerobic exercise is a promising intervention for alleviating depression in young individuals.

Conclusions Both short (less than 40 min) and long (more than 40 min) periods of aerobic exercise were effective in improving depressive symptoms. However, the optimal duration of aerobic exercise may vary depending on the specific population and individual factors studied, such as age, health status, and exercise tolerance. Therefore, this study concluded that the most effective exercise regimen, 40 min of moderate-intensity aerobic exercise

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three times a week for 6 to 11 weeks, showed more significant improvement in depression indicators in individuals with depressive symptoms.

Keywords Aerobic Exercise, Young people, Depression

Introduction

Depression stands as the prevailing mental health disorder and a pronounced public concern in contemporary society. Distinguished from ordinary mood fluctuations, depressive symptoms manifest as recurrent episodes characterized by diminished concentration, pronounced feelings of guilt, profound despair regarding the future, and, in severe cases, tendencies toward self-harm or suicidal ideation. The severity of depressive symptoms is categorized into low, moderate, and high, with research indicating a lifetime prevalence of depression ranging from 17 to 30% [1]. The current trend indicates a noticeable increase in the prevalence of mental disorders among progressively younger individuals, accounting for approximately 13% of the global burden of disease within the age group of 10–19. Statistical data indicates that 1.1% of adolescents aged 10–14 and 2.8% of those aged 15–19 report experiencing symptoms of depression [2]. Hence, investigating the prevalence of depression in young individuals is of paramount importance. For the purposes of this study, we define "young people" as individuals who are no older than 35 years of age. This definition is consistent with various international organizations and studies, which recognize that the youth category can extend to 35 years in some cases. For example, the United Nations acknowledges that while youth is usually defined as individuals aged 15–24, it can be extended to 35 in different circumstances. For instance, the African Union's African Youth Charter defines youth as individuals aged 15–35 years [3].

While medical advancements have led to a growing diversity in the treatment of depression, the predominant methods still revolve around pharmacological and psychotherapeutic interventions. Pharmacological treatments, in particular, find frequent application in clinical settings. Pigott, H.E [4] has suggested that, through pharmacological intervention, only 50% of patients exhibit marked improvement in depressive symptoms, often accompanied by corresponding side effects. Therefore, there is a clinical imperative to actively seek novel approaches for treating depression. Many studies have shown that physical exercise is a non-pharmacological treatment for depression. It can be treated alone or as an adjunct to medication and psychotherapy [5]. Aerobic exercise, as the primary form of exercise therapy, offers several advantages, including high adherence, straightforward exercise planning, minimal adverse effects, and broad suitability for diverse populations. Numerous studies have confirmed the positive impact of aerobic exercise interventions on various physiological manifestations associated with different conditions. These benefits encompass aspects such as including emotional regulation, cognitive health, and overall quality of life [6–8].

Therefore, choosing aerobic exercise to improve depressive symptoms in young individuals may yield significant benefits. However, the quantitative relationship between aerobic exercise and depression indicators in adolescents remains unclear. Current research primarily focuses on investigating various exercise interventions such as resistance training, Tai Chi, and yoga, on depression indicators in young people, without strong specificity towards particular exercises. Current research often compares the efficacy of various exercise modalities, such as aerobic, resistance, and combined exercises, in managing depression. However, these studies frequently overlook the potential benefits of focusing exclusively on a single exercise modality. Therefore, our study aims to provide detailed insights into the optimal aerobic exercise period, frequency, duration, and intensity. This can help young patients better determine the best aerobic training regimen when choosing aerobic exercise. we aim to synthesize the effect sizes of different aerobic exercises and their impact on adolescent depression indicators. Through subgroup analysis, this study seeks to identify subtle relationships between various forms of aerobic exercise and depression indicators, thus providing a theoretical basis for developing personalized aerobic exercise prescriptions for young individuals.

Methods

Study design

This systematic review and meta-analysis was registered with PROSPERO (registration number:CRD42023494476). Inclusion criteria, defined by Population, Intervention, Comparator, Outcome, and Study design (PICOS) [9] were:

> Participants: We included young adults (aged 6–35) diagnosed with depressive symptoms.
> Intervention: Aerobic exercise interventions were the focus, including activities such as running, cycling, or swimming.

Comparison: The comparison group consisted of individuals receiving no exercise or usual care for depression management.
Outcome: The primary outcome measured was improvement in depressive symptoms, assessed using standardized depression scales such as the BDI,CGI,BDI- ii, CMAS-R, das -21, BRUMS, SCL-90.
Study Design: RCTs.

Search strategy

This systematic review and meta-analysis adheres to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines [10]. Through systematic exploration of the PubMed, Web of Science, Embase, Cochrane, and EBSCO databases, the search period spans from the inception of database records to November 2023. Employing a comprehensive search strategy, the approach integrates subject terms and free-text terms into three distinct groups. The first group centers on outcome measures, utilizing "Depression" as the subject term and encompassing associated free-text terms such as (Depressive Symptoms, Depressive Symptom, Symptom, Depressive, Emotional Depression, Depression, Emotional). The second group addresses the study population, employing "Adolescent" as the free-text term and incorporating related terms like (Teenagers, Youths, Adolescence). The third group pertains to intervention methods, utilizing "Exercise" as the subject term and incorporating pertinent free-text terms such as (Aerobic exercise, Exercise Training, Physical Activity). Terms within each group are logically connected using the logical operator OR, while the distinct groups are interconnected with the logical operator AND. Upon completion of the literature retrieval process, a dual-blind methodology will be implemented by two independent reviewers for the purposes of inclusion and exclusion. The retrieved literature will be consolidated within the EndnoteX9 reference management software, which will subsequently facilitate an initial duplicate check through its inherent system. Further scrutiny will ensue through a detailed examination of titles and author years. Subsequent to this, a preliminary screening of identified articles will be executed based on a meticulous review of titles and abstracts. The selected articles following this preliminary screening will be downloaded, and in instances where disparities arise between the two reviewers, a third reviewer will be engaged to deliberate on the inclusion status of the divergent articles. The search Strategy is shown in Table 1 below.

Study selection

Inclusion criteria

Two reviewers (D,JX and W.T) independently assessed all titles and abstracts along with full texts of potentially relevant articles. Studies were included if they met the following criteria: (1) Include literature that involves study subjects aged 6–35 years [11]; (2) Incorporate literature specifically focused on aerobic exercise as the modality of physical activity; (3) Include literature with outcome measures based on relevant depression assessment scales; (4) Include literature exclusively derived from randomized controlled trials.

Exclusion criteria

Two reviewers (D,JX and W,T) independently assessed all titles and abstracts along with full texts of potentially relevant articles. Studies were excluded if they did not meet the following criteria: (1) Exclude non-English literature; (2) Exclude conference papers.(3) Exclude review articles and meta-analyses; (4) Exclude animal experiments; (5) Exclude literature involving participants aged 35 years and above; (6) Exclude literature for which the full text cannot be obtained; (7) Exclude literature where outcome measures are not expressed as mean ± standard deviation; (8) Exclude literature wherein the exercise intervention does not encompass aerobic exercise.

Table 1 Search terms

Search term classification	Term
Intervention method	Exercise[Mesh]; Exercises; Physical Activity; Activities, Physical; Activity, Physical; Physical Activities; Exercise, Physical; Exercises, Physical; Physical Exercise; Physical Exercises; Acute Exercise; Acute Exercises; Exercise, Acute; Exercises, Acute; Exercise, Isometric; Exercises, Isometric; Isometric Exercises; Isometric Exercise; Exercise, Aerobic; Aerobic Exercise; Aerobic Exercises; Exercises, Aerobic; Exercise Training; Exercise Trainings; Training, Exercise; Trainings, Exercise
Study subjects	Adolescent [Mesh]; Adolescents; Adolescence; Teens; Teenagers; Teenager; Youth; Youths; Adolescents, Female; Adolescent, Female; Female Adolescent; Female Adolescents; Adolescents, Male; Adolescent, Male; Male Adolescent; Male Adolescents
Outcome indicator	Depression[Mesh]; Depressive Symptoms; Depressive Symptom; Symptom, Depressive; Emotional Depression; Depression, Emotional

Data extraction

A structured form in Excel 2019 was used to extract the following data. Relevant information was extracted independently by two authors(D,JX and W,T) and imported into EndnoteX9 software:(1) Extract fundamental bibliographic details from the literature, encompassing authorship and publication year; (2) Retrieve demographic information concerning study subjects, comprising age, gender distribution, and sample sizes for both experimental and control groups; (3) Collect details pertaining to the exercise intervention, including the modality of intervention, duration, intensity, frequency, and the overall duration of the exercise regimen; (4) Capture information related to outcome measures, specifically focusing on pertinent depression assessment scales.

Quality assessment

The quality assessment of the included literature follows the standards outlined in the Cochrane 5.1 Handbook. This comprehensive approach includes evaluating randomization methods, allocation concealment, blinding procedures, completeness of outcome data, selective reporting of study results, and identification of potential biases. Additionally, the data extraction process and quality assessment adhere to the Cochrane Risk of Bias Assessment version 2 (August 2019 version). Literature that meets specific criteria and demonstrates low risk is categorized accordingly. High risk is assigned to studies that fail to meet these criteria, while instances where criteria are not explicitly addressed are categorized as unclear risk, with specific reasons provided.

The assessment of literature quality is independently conducted by two reviewers (D, JX and W, T), with any discrepancies resolved through consultation with a third party (L, YF).

Statistical analysis

The synthesis of effect sizes, assessment of publication bias, sensitivity analyses, and subgroup analyses are performed using Review Manager 5.4.1. Given that the outcome measures in this study are continuous variables, mean ± standard deviation is employed as the effect scale. Heterogeneity across studies is quantified through I^2 and Q tests; when $I^2 < 50\%$ and $P > 0.1$, denoting negligible heterogeneity, a fixed-effect model is applied, while in cases of significant heterogeneity, a random-effects model is employed. Publication bias is scrutinized using a funnel plot, and the robustness of results is ascertained through sensitivity analysis.

Standardization of depression scales

In this meta-analysis, we included studies that used various scales to measure depressive symptoms, including the Beck Depression Inventory (BDI), Clinical Global Impression (CGI), Beck Depression Inventory-II (BDI-II), Children's Manifest Anxiety Scale-Revised (CMAS-R), Depression Anxiety Stress Scales-21 (DASS-21), Brunel Mood Scale (BRUMS), and Symptom Checklist-90 (SCL-90). To standardize the results across these different tools, we calculated the standardized mean difference (SMD) for each study.

The SMD is calculated by subtracting the mean score of the control group from the mean score of the intervention group and dividing the result by the pooled standard deviation of both groups. This approach allows us to combine and compare the effect sizes from different studies, despite the use of different scales. Additionally, we used a random-effects model to account for the variability among studies.

Results

Search result

A total of 2296 articles were identified, with 281 from the Web of Science database, 138 from PubMed, 325 from Embase, 495 from Cochrane, and 1057 from EBSCO. After importing these articles into the Endnote software and eliminating duplicates, 1780 unique articles remained. During the title review, 270 articles related to reviews, animal experiments, and conferences were excluded, resulting in 1510 remaining articles. Subsequent abstract screening led to the exclusion of 1347 articles that did not meet criteria related to outcome indicators, intervention measures, and study subjects, leaving a total of 107 articles. Full-text reading further narrowed down the selection by excluding articles with inconsistent data indicators, non-English articles, and those without full text, resulting in a final selection of 8 articles for the Meta-analysis. The detailed screening process is depicted in Fig. 1.

Basic features of included studies

This study systematically incorporated a total of 8 articles, encompassing 12 randomized controlled trials (RCTs). Each study adhered to an RCT design, with sample sizes ranging from 26 to 55 participants, contributing to a cumulative total of 658 subjects. Among these, the experimental group comprised 329 individuals, mirroring the control group. The included articles comprehensively reported participant health status, exercise modalities, intensity, duration, frequency, and depression assessment scales. 1 study focused on individuals with existing depressive conditions, while 11 targeted non-depressed participants. Common exercise modalities included cycling, treadmill walking, with varying exercise intensities from low to high. Exercise durations spanned from 27.5 to 60 min, cycles ranged from 3 to 22 weeks,

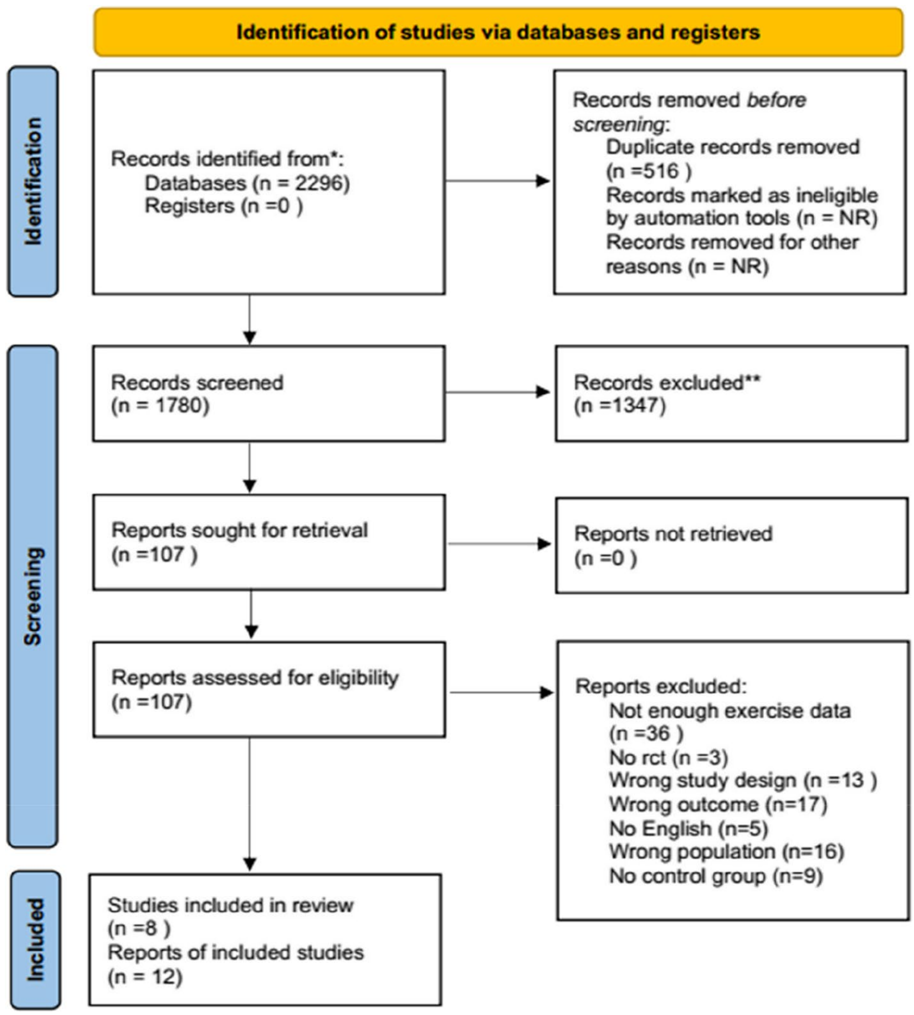

Fig. 1 PRISMA flow diagram of the study selection process

and frequency generally ranged from 2 to 4 sessions per week. Table 2 provides a succinct summary of the fundamental characteristics of the incorporated literature.

Literature quality assessment

All incorporated articles meticulously delineated the methods employed for group allocation, yet failed to specify whether the execution of the allocation strategy was conducted covertly. Given that participants were required to endorse informed consent documents before engaging in the experiment and that the implementation of the motor intervention necessitated relevant medical personnel to furnish protective measures or oversight, the implementation of blinding for both participants and researchers proved to be relatively challenging, thereby categorizing all 12 studies as high-risk endeavors. Despite this, each study exhibited minimal or negligible participant attrition during the intervention phase, signifying a low-risk profile concerning data stability. Notably, there was an absence of selective reporting or other biases across all scrutinized literature, as depicted in the quality assessment results outlined in the accompanying Fig. 2.

Bias assessment

The outcome indicators from the included studies demonstrate a symmetrical distribution of data points on either side of the funnel plot, indicating the absence of publication bias, as illustrated in Fig. 3 below.

Sensitivity analysis

Performing a sensitivity analysis on the included studies, systematically excluding each literature one by one, revealed no significant changes in the outcome indicators. This indicates that the results of this meta-analysis are stable and reliable.

Table 2 List of basic features of included literatures

First author, year	Sex	Age	Country	Depressive disorder people	Sample size	Experimental group interventions				Outcome indicator	Results
					T/C	Period/Week	Intensity/MHR	Frequency/ times/week	Duration time		
B. Wipfli 2011 [12]	M/F	20.66 ± 2.1	USA	N	30/35	7	70%	3	30 min	BDI	Significant decrease in BDI scores (4.83–2.57)
Carroll W. Hughes 2013 (1) [13]	M/F	15 ± 2	USA	Y	14/12	3	81%	3	30-40 min	CGI	Compared with control group (3.2–4.1), significant, decrease in depression severity(3.0–3.8)
Carroll W. Hughes 2013 (2) [13]	M/F	15 ± 2	USA	Y	14/12	6	81%	3	30-40 min	CGI	Compared with control group (2.7–3.3), significant decrease in depression severity (2.3–2.9)
Carroll W. Hughes 2013 (3) [13]	M/F	15 ± 2	USA	Y	14/12	9	81%	3	30-40 min	CGI	Compared with control group (2.4–3.1), significant decrease in depression severity (1.6–2.3)
Carroll W. Hughes 2013 (4) [13]	M/F	15 ± 2	USA	Y	14/12	12	81%	3	30-40 min	CGI	Compared with control group (1.6–2.5), significant decrease in depression severity (1.0–1.9)
Emily M. Paolucci 2018 (1) [14]	M/F	21 ± 2	Canada	N	18/18	6	88–90%	3	40 min	BDI-II	Significant decrease in BDI- II scores (13.2–12.2)
Emily M. Paolucci 2018 (2) [14]	M/F	21 ± 2	Canada	N	19/18	6	74–77%	3	27.5 min	BDI-II	Significant decrease in BDI- II scores (11.4–9.4)
Ena Monserrat 2020 [15]	M/F	10.02 ± 0.79	México	N	14/12	20	70–85%	2	50 min	CMAS-R	Significant decrease in CMAS-R Interquartile range. (36.5–31.75)
G. Tharani 2018 [16]	F	20 ± 2	India	N	15/15	8	60–80%	3	45 min	DASS-21	Significant decrease in DASS in pre- and post-test $P \leq 0.001$ ***
Gary S. Goldfield 2015 [17]	M/F	15.5 ± 1.4	Canada	N	14/12	22	60–85%	4	20-45 min	BRUMS	No Significant change in BRUMS
James 1988 [18]	M	16.4 ± 1.1	USA	N	32/37	12	86%	3	40 min	BDI	the aerobic group decrease in BDI scores of 4.78 (±6.9)
Sedigheh 2012 [19]	F	17.43 ± 2.09	Iran	N	32/32	6	50–70%	3	60 min	SCL-90	Significant decrease in SCL-90, $p < 0.0001$

M male, F female, *T* test group, *C* control group, *MHR* Max Heart Rate, *N* No, *Y* yes, *BDI* Beck Depression Inventory, *CGI* Clinical Global Impression, *BDI-II* Beck Depression Inventory-II, *CMAS-R* Children's Manifest Anxiety Scale-Revised, *DASS-21* Depression Anxiety Stress Scales-21, *BRUMS* Brunel Mood Scale, *SCL-90* Symptom Checklist-90

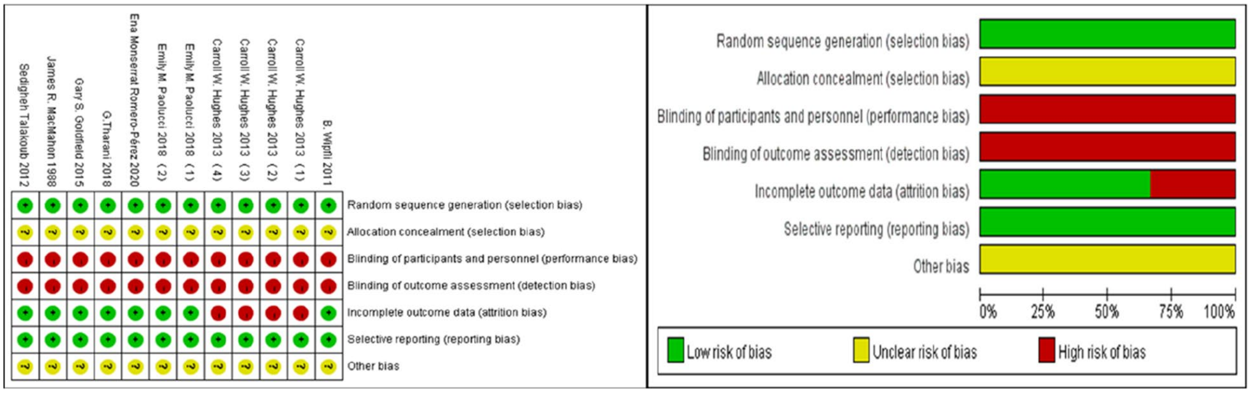

Fig. 2 Cochrane risk of bias assessment chart

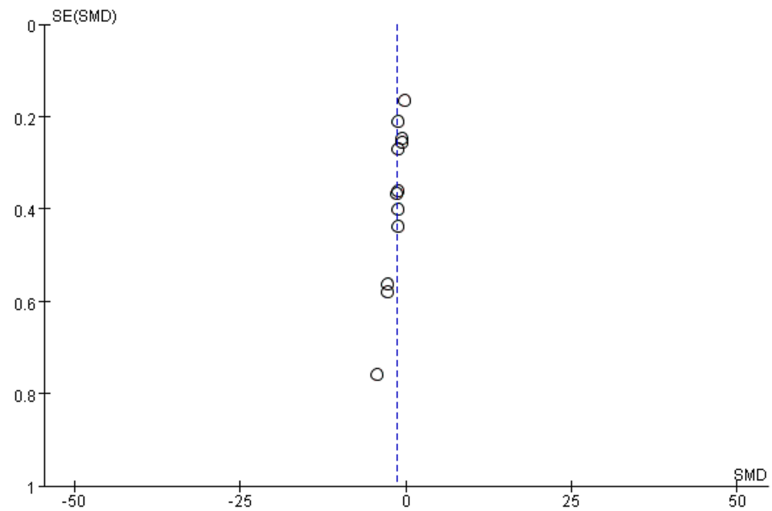

Fig. 3 Publication bias funnel plot

Effect size test

The included articles underwent a heterogeneity test, and given that the I^2 value exceeded 50% in this study, a random-effects model was employed to merge the effect sizes. Furthermore, due to variations in the assessment tools for depression across studies, the Standardized Mean Difference (SMD) was adopted as the effect size metric. Among the 12 studies, a collective data set from 659 participants was analyzed for depression indicators. The results indicate that aerobic exercise has a significant positive impact on reducing depression levels in young individuals (d = -1.33, 95% CI: -1.78 to -0.87, $P < 0.05$), as illustrated in Fig. 4.

Subgroup analysis

Study participants

Due to substantial heterogeneity indicated by $I^2 > 50\%$, a subgroup analysis was conducted to pinpoint the source of this heterogeneity. Initially, the study participants underwent a subgroup analysis, being divided into non-depressed and depressed groups. The non-depressed group comprised 554 individuals providing depression level data, while the depressed group involved 104 individuals. The findings revealed that aerobic exercise demonstrated a significant positive impact on improving depression levels in both the depressed group (d = -2.68, 95% CI: -3.87 to -1.48, $P < 0.05$) and the non-depressed group (d = -0.85, 95% CI: -1.20 to -0.51, $P < 0.05$). Detailed results are presented in Fig. 5 below.

Exercise intensity

Employing exercise intensity as a subgroup for analysis, it was segmented into low, moderate, and high intensity. A dataset of 159 individuals contributed to the low-intensity group, 246 individuals to the moderate-intensity group, and 253 individuals to the high-intensity group. The findings revealed that both low-intensity (d = -0.93, 95% CI: -1.29 to 0.58, $P < 0.05$) aerobic exercise and moderate-intensity (d = -2.08, 95% CI: -2.88 to -1.27,

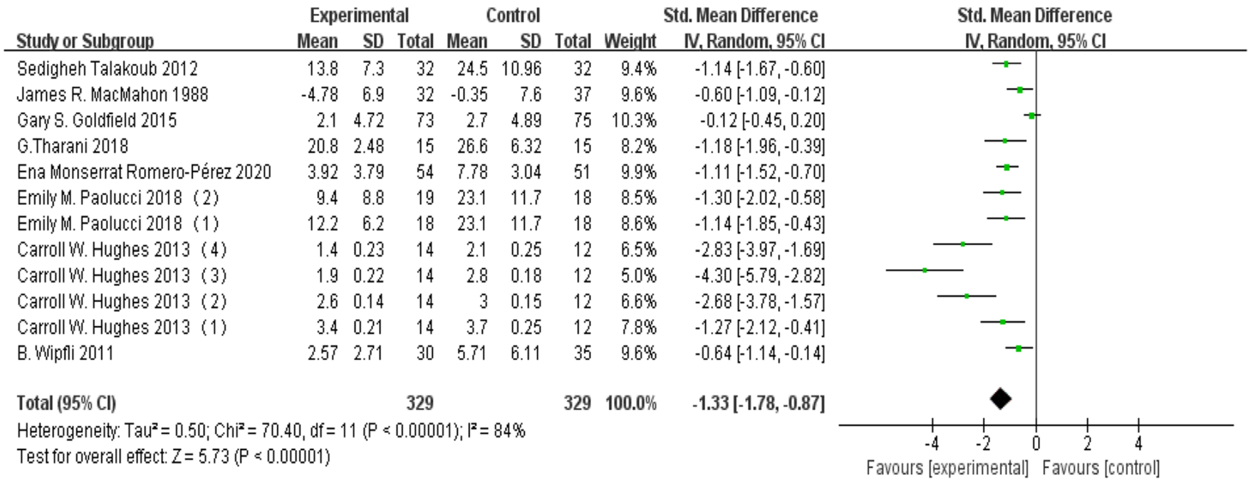

Fig. 4 Forest plot for heterogeneity test

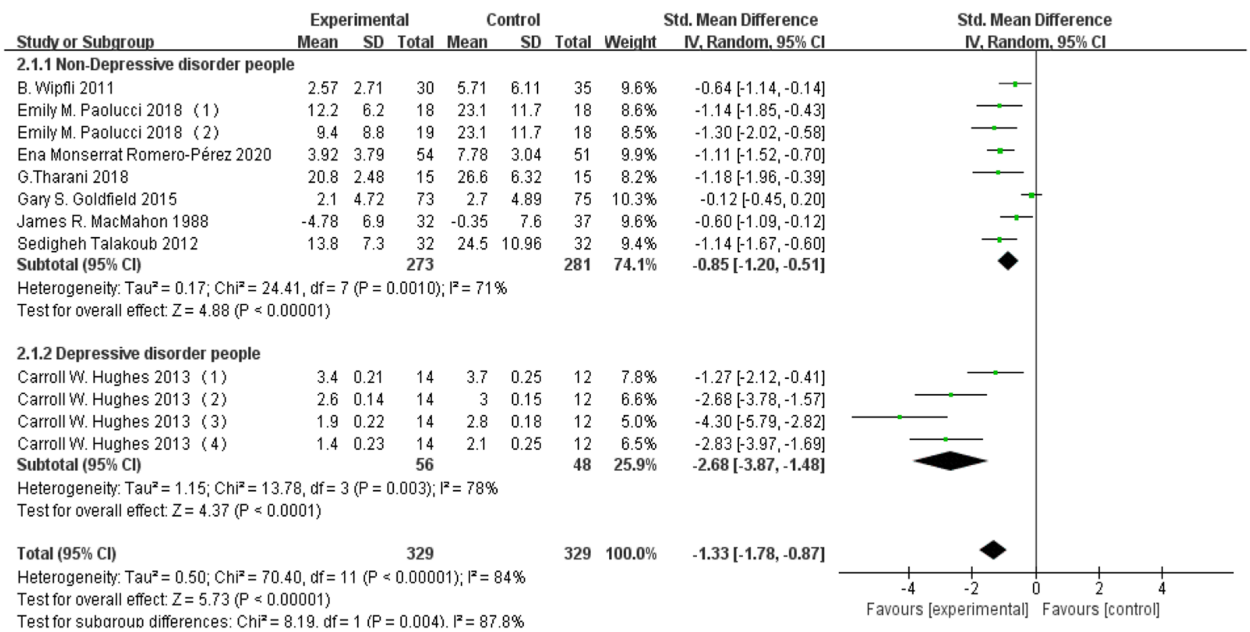

Fig. 5 Forest plot for subgroup analysis of study participants

$P<0.05$) aerobic exercise exhibited efficacy in ameliorating depression levels in the depressed group (d = -2.68, 95% CI: -3.87 to -1.48, $P<0.05$). However, high-intensity aerobic exercise did not yield a statistically significant improvement in depression levels among young individuals ($P>0.05$). Detailed results are depicted in Fig. 6 below.

Exercise duration

Segmenting exercise duration into two categories—40 min or less and over 40 min—subgroup analysis was conducted. A dataset of 209 individuals contributed to the 40 min or less group, while 347 individuals provided data for the over 40 min group. The results revealed that both aerobic exercises lasting 40 min or less (d = -2.00, 95% CI: -2.96 to -1.04, $P<0.05$) and those exceeding 40 min (d = -0.85, 95% CI: -1.47 to -0.24, $P<0.05$) were effective in ameliorating depression levels in young individuals. Detailed results are depicted in Fig. 7 below.

Exercise period

Subdividing exercise period into three categories—less than 6 weeks, 6–11 weeks, and 12 weeks or more

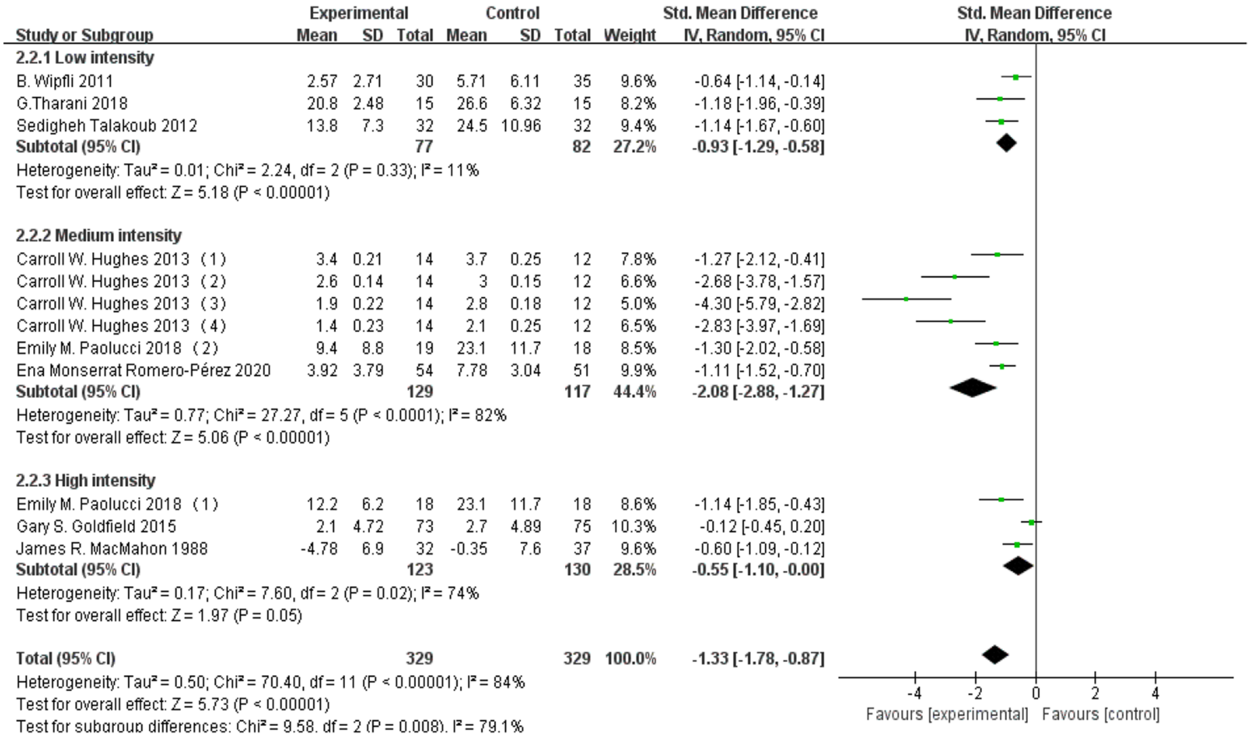

Fig. 6 Subgroup analysis based on exercise intensity

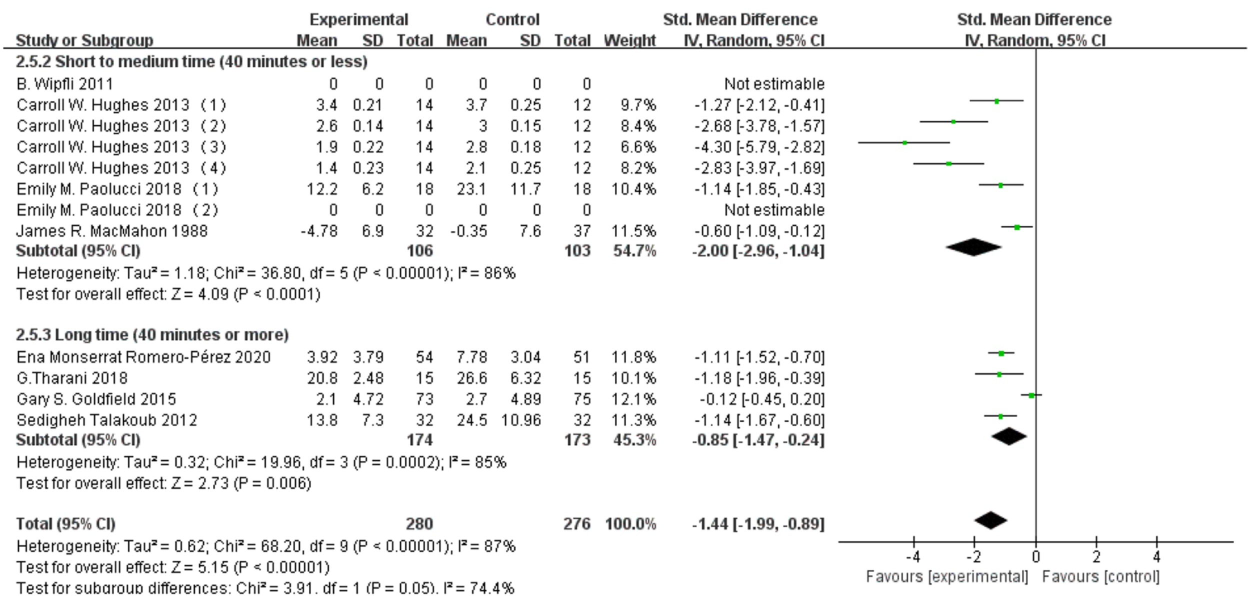

Fig. 7 Subgroup analysis based on exercise duration

conducted a subgroup analysis. A dataset of 105 individuals contributed to the less than 6 weeks group, 405 individuals to the 6–11 weeks group, and 348 individuals to the 12 weeks or more group. The results indicated that aerobic exercises lasting less than 6 weeks (d = -1.27, 95% CI: -2.12 to -0.14, $P < 0.05$), 6–11 weeks (d = -1.55, 95% CI: -2.16 to -0.94, $P < 0.05$), and 12 weeks or more (d = -1.00, 95% CI: -1.76 to -0.24, $P < 0.05$) were all effective in improving depression levels in young individuals. Detailed results are depicted in Fig. 8 below.

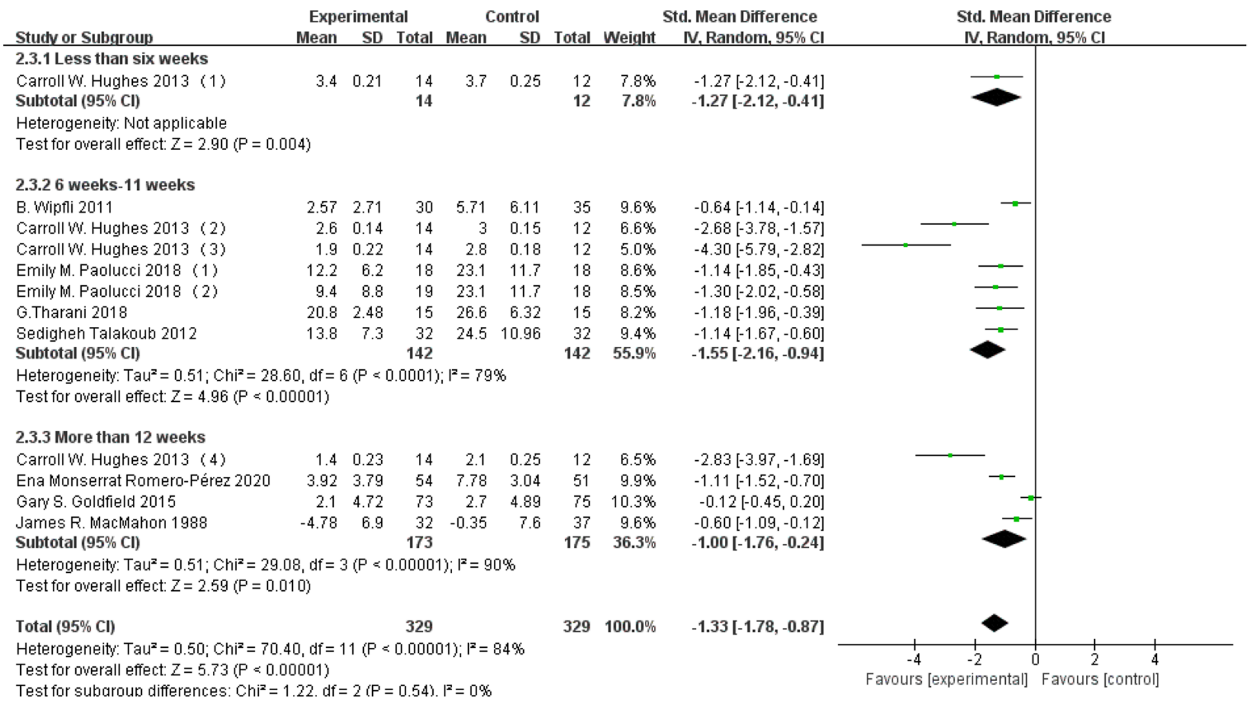

Fig. 8 Forest plot for subgroup analysis based on exercise period

Exercise frequency

Due to the consistent exercise frequency of approximately three times per week, no subgroup analysis was conducted.

Discussion

Impact analysis of aerobic exercise on depression indicators among young people

This study concludes that aerobic exercise can improve depression in young adults. The research highlights the crucial role of the hippocampus in depression studies, as it is a key brain structure related to emotions. Individuals with depression often exhibit a smaller hippocampal volume [20]. Hence, emphasizing the significance of investigating the relationship between hippocampal volume and depression. X, Y. M [21] conducted an aerobic exercise intervention study targeting individuals with severe depression. The research findings indicate that continuous aerobic exercise over six weeks led to improvements in participants' depressive conditions. Furthermore, engaging in moderate-intensity aerobic exercise for 12 months (3 times per week) resulted in an approximate 2% increase in hippocampal volume among patients. The proposed mechanism involves aerobic exercise promoting blood circulation, facilitating the delivery of sufficient oxygen and nutrients to brain regions. This, in turn, contributes to the augmentation of neurogenesis and synaptic connectivity. Through the formation of new neural cells, neural connections, and the reinforcement of synapses, aerobic exercise maintains or increases hippocampal volume, thereby ameliorating the depressive conditions in individuals with severe depression.

Other studies have suggested a strong correlation between depression and brain-derived neurotrophic factor (BDNF), with a marked reduction in BDNF levels observed in the brains of individuals with depression [22]. Luo, Lu [23]contends that post-aerobic exercise, there is an elevation in BDNF levels in individuals with severe depression, thereby ameliorating depressive conditions among participants. Exercise induces muscle contractions, energy metabolism, and an elevation in body temperature, activating the production and release of BDNF. The released BDNF stimulates neurogenesis, enhances synaptic formation and stability, ultimately resulting in an augmentation of hippocampal volume and an improvement in depressive conditions among participants. Moreover, the enduring emotional stress and pressure associated with depression have deleterious effects on brain structure. Bender, T [24] suggests that aerobic exercise can elevate β-endorphin levels, thereby improving depressive conditions among participants. β-endorphin is a hormone and neurotransmitter associated with regulating depression [25]. Aerobic exercise triggers a physiological stress response by activating the hypothalamic–pituitary–adrenal axis (HPA axis). Subsequently, this activation prompts the release of adrenaline and cortisol. The release of cortisol, in turn, stimulates hypothalamic neurons to produce β-endorphin, ultimately contributing to the improvement of depressive conditions among participants.

Impact analysis of aerobic exercise on depression indicators in both depressed and non-depressed populations

This study found that aerobic exercise improves depressive symptoms in both depressed and non-depressed individuals, with greater benefits observed in those diagnosed with major depressive disorder (MDD). Hughes, C. W [13] 和Goldfield, Gary S [26] conducted separate aerobic exercise interventions with young individuals to assess the impact on depression indicators. However, their conclusions appear contradictory. Hughes observed improvements in depression indicators among young individuals engaging in aerobic exercise, while Goldfield found no such improvement in the same population. Upon comparison, it was noted that Hughes focused on participants diagnosed with major depressive disorder, whereas Goldfield, targeted individuals with obesity. It is suggested that individuals with major depressive disorder may derive more significant benefits from aerobic exercise in alleviating depressive conditions.

Clinical studies indicate that individuals with severe depression typically exhibit dysfunction in the HPA axis. This dysfunction is characterized by abnormal secretion and release of glucocorticoids (GC), corticotropin-releasing hormone (CRH), and adrenocorticotropin hormone(ACTH). These irregularities lead to a weakening of hippocampal neurons, disrupting the hippocampus's normal regulatory role over the HPA axis. Consequently, there is an excessive activation of the HPA axis, giving rise to depressive emotions [27]. Pietrelli, Adriana [28] suggests that aerobic exercise can regulate the functioning of the HPA axis, improving depressive symptoms in individuals with severe depression. Aerobic exercise induces a physiological stress response, activating the HPA axis and leading to the release of CRH. This prompts the pituitary gland to release ACTH, triggering the synthesis and release of cortisol. Elevated cortisol levels then initiate a negative feedback loop on the hypothalamus and pituitary, inhibiting further release of CRH and ACTH, thus maintaining hormonal balance. This process contributes to the alleviation of depressive symptoms in individuals with severe depression.

Impact analysis of aerobic exercises on depression indicators in varying intensities among young people

This study found that both low and moderate-intensity aerobic exercise effectively alleviate depression symptoms in young individuals. However, high-intensity aerobic exercise did not show significant improvement. Low-intensity aerobic exercise, exceeding the minimum threshold, induces a stress response, while moderate-intensity exercise produces a more pronounced effect. Conversely, high-intensity aerobic exercise, surpassing the body's critical threshold, leads to adverse reactions such as fatigue. Helgadóttir, Björg [29] contends that mild to moderate depression patients can reduce depressive symptoms through a 12-week intervention of low-intensity aerobic exercise. The relaxed and enjoyable nature of low-intensity aerobic exercise can alleviate both physical and mental stress, reducing psychological tension and positively impacting the alleviation of depressive symptoms. Balchin, R [30] contends that intervention involving moderate-intensity aerobic exercise holds the potential to ameliorate depressive symptoms in the targeted demographic. By actively participating in moderate-intensity aerobic activities, individuals may experience notable improvements in cardiovascular health, heightened metabolic efficiency, an increased sense of pleasure, thereby fostering a positive impact on the overall depressive condition. Contrastingly, Legrand [31] contends that high-intensity aerobic exercise holds the potential to improve depressive symptoms among individuals in fitness or sports environments. Engaging in vigorous aerobic activities leads to an elevation in maximal oxygen consumption, enhanced cardiovascular function, and the cultivation of increased self-confidence, thereby contributing to the amelioration of depressive conditions.

Physiologically, Helgadóttir, B [29] contends that low-intensity aerobic exercise improves depressive symptoms in the studied population by promoting the release of the BDNF. This, as mentioned earlier, enhances neuronal survival and connectivity, subsequently leading to an increased hippocampal volume and an improvement in depressive conditions. Song, Dan [32] contends that moderate-intensity aerobic exercise can alleviate depressive symptoms in elderly individuals with mild cognitive impairment. This is achieved by inducing the release of dopamine hormones during exercise, enhancing feelings of pleasure and subsequently improving depressive conditions. Aerobic exercise stimulates neurons, leading to dopamine production, which is released into the synaptic cleft. Binding to receptors, it initiates intracellular signal transduction, ultimately influencing emotion-related brain regions and contributing to the amelioration of depressive symptoms [33]. High-intensity aerobic exercise places the body under excessive physiological stress, intensifying depressive pressure. It is often challenging to sustain for an extended period and proves more difficult to incorporate into daily life.

Impact analysis of aerobic exercise on depression indicators in different exercise durations among young people

The research findings indicate that both aerobic exercises lasting under 40 min and those exceeding 40 min have a positive impact on alleviating depression in young adults. Notably, aerobic exercises under 40 min demonstrate a more significant improvement. Gordon, B. A [34] suggests in their study involving adolescents with Chronic Fatigue Syndrome (CFS) that aerobic exercise lasting 20–40 min can improve depressive symptoms. Bouaziz, Walid [35] suggests in their study focusing on sedentary elderly individuals that 30 min of aerobic exercise can ameliorate depressive emotions in this population. Similarly, Hughes, C. W [13] suggests that engaging in aerobic exercise for 30–40 min significantly improved depressive symptoms in adolescents with severe depression. Fatigue and depression often occur together, with physical and mental fatigue intensifying depressive symptoms. Extended aerobic exercise consumes significant energy and nutrients, leading to psychological fatigue. Additionally, fatigue affects the regulation of mood-related factors like dopamine, brain norepinephrine, and cortisol hormones [36].

The three studies involving elderly and diseased populations suggest that these groups, with lower tolerance for exercise intensity, are prone to fatigue, leading to the onset of depressive symptoms. In a state of fatigue, dopamine levels decline, reducing feelings of pleasure and increasing norepinephrine secretion, thereby elevating heart rate and exacerbating depression. Similarly, fatigue stimulates the adrenal cortex to produce more cortisol hormones, and elevated cortisol levels worsen depressive symptoms. Therefore, shorter durations of aerobic exercise are more easily accepted, reducing the risk of exercise-induced fatigue and discomfort. This approach facilitates adherence to the exercise regimen, contributing to the establishment of a consistent exercise habit and ultimately improving depressive conditions. Contrarily, Kwok [37] suggests that intervention through 90 min of aerobic exercise can improve depressive symptoms in adult Parkinson's patients. Prolonged aerobic exercise continuously enhances cardiovascular capacity, boosts the body's fatigue resistance, and further stimulates neurotransmitter release and hormonal level changes, thereby more effectively ameliorating depressive conditions.

Impact analysis of aerobic exercise on depression indicators in different exercise periods among young people

The study concludes that aerobic exercise interventions lasting less than 6 weeks, 6–11 weeks, and over 12 weeks all contribute to improvements in depression among young adults. Notably, the most significant improvement is observed in the 6–11 week exercise duration. Gordon [34] suggests that adolescents can experience improved depressive symptoms after a 4-week aerobic exercise intervention, Short-term exercise rapidly induces mood enhancement, facilitated by the release of endogenous substances such as endorphins [38]. This results in a quick sense of pleasure and relaxation, accompanied by a rapid enhancement of cardiovascular capacity. It promotes increased delivery of oxygen and nutrients to muscle tissues, supporting neuronal generation and release, ultimately improving depressive symptoms. Tharani, G [16] suggests that an 8-week aerobic exercise intervention improves depressive symptoms in young women with dysmenorrhea. After 6–11 weeks of aerobic exercise, participants exhibit increased cardiovascular adaptability, enhanced physical adaptation, and heightened fat oxidation capacity, positively influencing stable energy levels and mood improvement [39]. During the 6–11 weeks aerobic exercise period, observable changes in muscle and joint adaptability can enhance the efficiency of exercise, reduce the risk of injury, and improve exercise sustainability and psychological well-being. Greenwood, Sharlene A [40] suggests that patients with chronic kidney disease experience improved depressive emotions after a 12-week aerobic exercise intervention. As the exercise progresses, observable adaptations in participants' physiological functions occur gradually. This not only provides short-term feelings of pleasure but also generates longer-term stable psychological effects. Additionally, it effectively enhances the basal metabolic rate and muscle adaptability, resulting in improved endurance and more effective exercise performance. This, in turn, boosts self-confidence and self-esteem, ultimately contributing to the amelioration of depression.

Contrastingly, an early study suggests that an optimal exercise duration should exceed 20 weeks [41]. Depression involves intricate neurochemical, hormonal, and physiological processes that necessitate a longer duration for transmission and triggering. Short to medium exercise periods may not induce substantial physiological adjustments, and the frequency and intensity of exercise during these periods might not sustain continuous adaptive changes in the body. Consequently, improvement in depressive conditions may be limited.

Limitations

In our study, there are some potential limitations that warrant consideration. Firstly, the stratification of our sample age range lacks granularity, potentially not adequately capturing the differences in various developmental stages among young individuals. Secondly, in terms of measuring aerobic exercise, our study comparatively focuses on a rather singular type of exercise and does not employ diverse methods to assess aerobic activity. This limitation may impact our comprehensive understanding of the effects of depression indicators across different age groups and types of aerobic exercises. Future research endeavors could aim for finer age stratification and employ a more comprehensive approach to measuring aerobic exercise, thereby enhancing our understanding of this field. Additionally, we observed a degree of heterogeneity in the included studies. Although meta-regression analyses can help identify potential sources of heterogeneity, the results of meta-regression analyses may be limited by these unreported factors because many original studies do not report in detail all the factors that could influence the size of the effect (such as the specific health status of the participants, the specific implementation details of the intervention, etc.).

Conclusion

Overall, both short (less than 40 min) and long (more than 40 min) periods of aerobic exercise were effective in improving depressive symptoms. However, the optimal duration of aerobic exercise may vary depending on the specific population and individual factors studied, such as age, health status, and exercise tolerance. Therefore, this study concluded that the most effective exercise regimen, 40 min of moderate-intensity aerobic exercise three times a week for 6 to 11 weeks, showed more significant improvement in depression indicators in individuals with depressive symptoms.

Abbreviations

BDNF	Brain-derived neurotrophic factor
HPA	Hypothalamic–pituitary–adrenal
MDD	Major depressive disorder
CRH	Corticotropin-releasing hormone
ACTH	Adrenocorticotropic hormone
BDI	Beck Depression Inventory
CGI	Clinical Global Impression
BDI-II	Beck Depression Inventory-II
CMAS-R	Children's Manifest Anxiety Scale-Revised
DASS-21	Depression Anxiety Stress Scales-21
BRUMS	Brunel Mood Scale
SCL-90	Symptom Checklist-90

Supplementary Information

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Supplementary Material 1

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Authors' contributions
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