

Systematic Review

The Effect of Exercise Interventions on Sleep Quality and Weight Loss in Individuals with Obesity: A Systematic Review and Meta-Analysis of Randomized Control Trials

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Abstract: This study evaluated the effects of exercise interventions on sleep quality and weight loss through a systematic literature review and meta-analysis. A comprehensive literature search was conducted across PubMed, Embase, Web of Science, and the Cochrane Library for publications up to December 2022. Only randomized controlled trials (RCTs) were included in the analysis. The Risk of Bias was assessed using the Cochrane Risk of Bias 2 (ROB 2) tool, and disagreements were resolved by consensus. Data synthesis and meta-analysis were performed using Comprehensive Meta-Analysis Version 4 (CMA version 4) software, with outcomes expressed as pooled effect sizes, odds ratios (ORs), and 95% confidence intervals (CIs). Seven RCTs encompassing 908 participants were analyzed. The meta-analysis indicated a significant improvement in sleep outcomes (OR = 3.93, 95% CI [2.04, 7.56], $p < 0.001$). The combined aerobic and resistance exercise regimen showed the most substantial effects on sleep quality. Additionally, four of the seven RCTs included in the weight loss analysis indicated a significant improvement in weight loss (OR = 2.58, 95% CI [1.79, 3.71], $p < 0.001$). Exercise interventions have a strong potential for improving sleep quality and weight loss in adults with obesity. Future studies should focus on developing optimized targeted strategies for sleep enhancement.

Keywords: obesity; exercise; RCTs; sleep quality; weight loss



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1. Introduction

Obesity has emerged as a global pandemic that poses significant health problems and economic burdens worldwide [1–4]. Obesity is associated with an increased risk of numerous chronic diseases, including type 2 diabetes, cardiovascular diseases, and certain cancers [5–11]. Besides the physical and metabolic complications associated with obesity, sleep disturbances are increasingly recognized as both a consequence of and a contributing factor to the obesity pandemic [12–15]. Continuing poor sleep status has been shown to disrupt hormonal balance related to appetite and alter glucose metabolism, thereby promoting weight gain [12,16–20]. The bidirectional relationship between sleep

and obesity underscores the importance of addressing sleep health in obesity prevention and intervention.

Exercise interventions have long been recognized as a cornerstone in the management of obesity, offering significant benefits in terms of weight loss and overall health improvements [21]. Structured exercise programs that incorporate both aerobic and resistance activities have yielded sustained weight loss in individuals with obesity, highlighting the critical role of tailored exercise regimens [22]. Regular physical activity has emerged as a promising approach to improving sleep outcomes. Exercise can modulate circadian rhythms, reduce stress, and promote the release of sleep-enhancing hormones such as serotonin and melatonin [23]. Aerobic training, resistance exercise, and mixed routines have demonstrated varying degrees of efficacy in promoting longer and deeper sleep. However, despite numerous studies exploring this connection, the findings are often inconsistent because of differences in exercise modalities, intervention durations, and participant adherence. Moreover, most existing studies have tended to isolate specific forms of exercise, leading to fragmented conclusions regarding their broader impact on sleep in populations with obesity.

Over the past few decades, several randomized controlled trials (RCTs) have examined the effects of exercise on sleep quality in various populations [24]. However, there is currently a lack of meta-analytical research examining the relationship between exercise and sleep quality, specifically in adults with obesity. This study addresses this gap, not only by exploring this relationship but also by evaluating the impact of exercise on weight loss, thereby providing practical data for obesity prevention. This study aimed to conduct a systematic review and meta-analysis of RCTs to provide a comprehensive understanding of the effects of exercise interventions on sleep quality and weight loss in adults with obesity.

2. Materials and Methods

2.1. Eligibility Criteria

The protocol of this systematic review and meta-analysis was registered with the PROSPERO International Prospective Register of Systematic Reviews (registration number: CRD42024617413; available from: https://www.crd.york.ac.uk/prospero/display_record.php?RecordID=617413, accessed on 6 December 2024). This study was conducted following Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [25] and the Cochrane Collaboration Handbook, applying the Population, Intervention, Comparison, and Outcome (PICO) framework, specifically adapted for exercise interventions targeting sleep quality in individuals with obesity. The criteria for inclusion were as follows: (1) studies involving only adults with obesity without any medical conditions except for those directly related to sleep disturbances or obesity; (2) physical activity interventions encompassing aerobic (e.g., walking, running, cycling) and resistance exercises (e.g., resistance training, strength exercises), as well as combined exercise regimens; (3) the presence of a control group that did not receive any exercise intervention or only received minimal intervention; (4) the measurement of sleep quality as a primary or secondary outcome; and (5) inclusion only of RCTs to ensure high-quality evidence.

2.2. Search Strategies and Selection Process

Keyword searches were conducted in December 2022 and re-checked before finalizing the analysis in December 2024. Data collection focused on articles from PubMed, Embase, Web of Science, and Cochrane Library using a combination of search terms related to sleep quality ("sleep quality", "sleep disturbance", "dyssomnia" or "sleep deprivation"), obesity ("obesity", "overweight", or "obese"), and exercise ("exercise", "physical activity", "training", "fitness", "resistance training", "endurance training", "running", "jogging",

“yoga”, “taichi”, “cycling”, “ergometer” or “bicycle”) (Table S1). Based on established selection criteria, interventions involving treatments other than exercise, such as drug administration, physical therapy, and medical device use, were excluded. Studies that did not specify exercise modalities, lacked a relevant control group or had insufficiently detailed data were excluded. Conference abstracts were excluded because of limited information, making them unsuitable for a thorough quality evaluation. Studies without full-text availability and review articles were also excluded.

2.3. Data Extraction

Criteria for literature selection and exclusion were collaboratively developed and reviewed by a team of researchers with expertise in exercise, nutrition, and biochemistry. The process of collecting and selecting individual studies for inclusion in the research was facilitated using the EndNote (Version 21.4.0.18113) software, while data coding from the included studies was performed using Excel. Any discrepancies during the study selection process were rechecked and resolved through discussions with a second reviewer to ensure consensus. Studies that did not align with the independent or dependent variables relevant to the topic of this study or lacked sufficient similarity were excluded.

2.4. Data Analysis

Data on the general characteristics of the studies, including authorship, publication year, patient population, study design, patient age, and participant count, were extracted. Specific details of the exercise intervention programs were documented using Microsoft Excel, covering the intervention type, duration, frequency, timing, and measured outcomes. Heterogeneity testing and publication bias assessments were conducted during quantitative synthesis through a meta-analysis. In parallel, a qualitative synthesis was performed through a systematic literature review to comprehensively review the general characteristics of the studies. The extracted data were organized and processed according to the requirements of each analysis. For the meta-analysis, data compiled into Excel sheets were subsequently analyzed using the Comprehensive Meta-Analysis Version 4 (CMA version 4) software.

2.5. Quality Assessment

This section presents a comprehensive assessment of the potential biases that could affect the internal validity and reliability of our study. Guided by Cochrane’s Risk of Bias 2 (ROB 2) tool [26] and using the Review Manager (RevMan) software (Version 5.4), multiple domains, including the randomization process, deviations from intended interventions, missing outcome data, measurement of outcomes, and selection of reported results, were evaluated. These domains were carefully examined to identify and mitigate potential biases that could influence the study methodology, data collection, and analysis. Risk-of bias assessments were independently conducted by two reviewers with expertise in exercise nutrition biochemistry to ensure objectivity and consensus.

2.6. Effect Size and Data Calculation

This meta-analysis used continuous measures to compare outcomes across different measurement methods, utilizing odds ratios (ORs) and 95% confidence intervals (CIs). This study analyzed the average effect size of the exercise interventions using a random-effects model because of the diversity of exercise modalities, including aerobic and resistance activities. A random-effects model was employed to account for variations among studies, reflecting the broad range of exercise types and their potential impact on sleep quality.

3. Results

3.1. Characteristics of Selected Studies

Keywords related to exercise interventions were employed separately during the search process, yielding 4939 records, which were managed using EndNote. After identifying and removing 1071 duplicates, 3868 records remained for review. Specifically, the search retrieved 1950 studies from PubMed, 1404 from Embase, 1171 from the Web of Science, and 414 from the Cochrane Library. Following a systematic screening process, seven studies with 908 participants met all the inclusion criteria and were selected for meta-analysis. The flow chart showing the selection process for this study is shown in Figure 1. All participants had a BMI of 25 or higher. Additional inclusion criteria encompassed a waist circumference of ≥ 102 cm for men and ≥ 88 cm for women, Pittsburgh Sleep Quality Index (PSQI) [27] scores greater than 5, body fat percentages exceeding 30%, significant sleep disturbances, untreated moderate to severe obstructive sleep apnea (OSA), and insomnia symptoms persisting for more than three months.

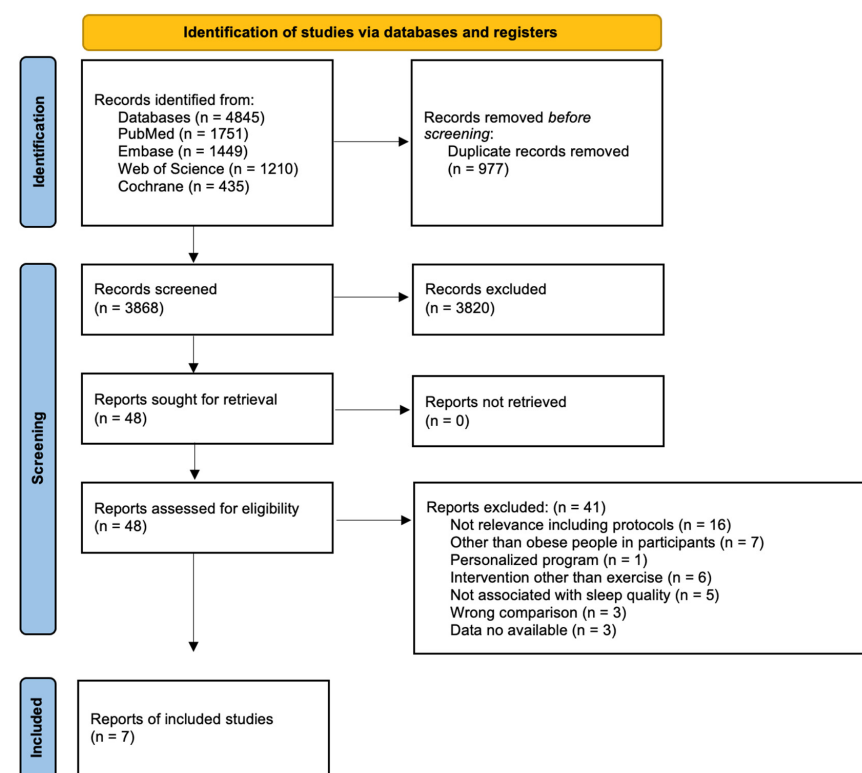


Figure 1. Flowchart of the study selection process.

3.2. Results of the Systematic Review

In the context of the literature selected for interventions involving exercise programs for individuals with obesity, seven studies were chosen. The detailed characteristics of these seven studies included in this systematic review are presented in Table 1. In total, 908 participants were included in the study. The distribution of intervention durations varied, with two studies conducted over 12 weeks, three studies lasting four months, and two studies extending to six months. The frequency of exercise interventions ranged from once to five times per week. Exercise duration also exhibited variability; aerobic exercises ranged from a minimum of 30 min to a maximum of 150 min per session, whereas combined aerobic and resistance regimens extended from 40 to 60 min per session. Regarding exercise intensity, one study involving aerobic exercise did not specify the intensity, five studies utilized moderate-to-high-intensity exercises ranging from 60% to 85% of maximum effort, and one study focused on resistance exercise with an intensity of 50–59%.

Table 1. Characteristics of studies included in this systematic review.

Reference	Population				Intervention					Results	
	Sample Size (<i>n</i>)	Age (yr)	BMI (kg/m ²)	Health Status	Frequency/ Duration	Time	Type	Intensity	Comparison	Measurement	Summary of Findings
Dieli-conwright et al., 2021 [28]	91 women	52	≥25	body fat > 30%, waist circumference > 88 cm	2~3 × /week 4 months	~50 min AR ~80 min RT	AR = treadmill walking/running, stationary bicycle RT = circuit training	AR: 65~80% HRmax. RT: 60~80% of 1RM	Usual care	PSQI	Improved sleep quality and poor sleepers (50%)
E. Kline et al., 2012 [29]	437 women	45~75	25~43	postmenopausal, sedentary, 46% = significant sleep disturbance	3~4 × /week 6 months	-	AR = semirecumbent cycle ergometer and treadmill	gradually increased AR 4 kkw, 8 kkw, 12 kkw	Control	MOS	12 KKW = improvement in MOS SPI score
E. Kline et al., 2011 [30]	43	18~55	≥25	moderate-severity untreated OSA, sedentary	4 × /week AR 2 × /week RT 12 weeks	AR = 150 min RT = 2 sets of 10~12 rep.	AR = treadmill, bicycle ergometer, RT = 8 different exercise	AR = 60% HHR Gradually increased after 4 weeks	Control	Actigraphy PSG PSQI	Improved sleep quality in Actigraphy and PSQI
X. Tan et al., 2016 [31]	45 men	30~65	≥25	chronic insomnia symptoms (>3 months)	1~5 sessions/week 6 months	30~60 min/session	Nordic walking, other optional AR	60~75% of estimated HRmax	Control	BNSQ ESS	Improved sleep quality and difficulty in initiating sleep
Leonel et al., 2022 [32]	69	20~50	30~39.9	Inactive	16 weeks	60 min	AR = walking, running RT = 6 exercise involving large muscle	PG = 3 mesocycles NG = 50~59% HR, 2 × 10 ⁻¹² RM	Control	PSQI	PG, NG = Improved sleep quality but, not significant between groups
E. Mendham et al., 2021 [33]	45 women	20~35	30~40	inactive (no planned activity or exercise of >60 min/wk),	4 × /week 12 weeks	40~60 min	AR = dance, running, stepping RT = elasticated bands, free weights	AR = 75~85% HRpeak RT = 60~70% of HRpeak"	Control	Actigraphy PSQI	Improved sleep quality
T. Fritz et al., 2011 [34]	178	57~64	27.5~32	normal glucose tolerance, Type 2 diabetes mellitus	5 h/week 4 months	-	AR = Nordic walking with poles	-	Control	SWED-QUAL	Improved sleep quality with normal glucose tolerance and type 2 diabetes group

Note: AR = aerobic exercise; BMI = body mass index; BNSQ = Basic Nordic Sleep Questionnaire; ESS = Epworth Sleepiness Scale; HR = heart rate; HRmax = heart rate max; HRpeak = heart rate peak; KKW = kilocalories per kilogram of body weight per Week, MOS = Medical Outcomes Study Sleep Scale, OSA = Obstructive Sleep Apnea syndrome; PSG = Polysomnography, PSQI = Pittsburgh Sleep Quality Index, RT = Resistance Exercise, SWED-QUAL = Swedish health-related quality of life questionnaire, VAS = Visual Analog Scale, WHIIRS = Women's Health Initiative Insomnia Rating Scale.

3.3. Assessment of Quality of Research (ROB)

A risk of bias assessment was conducted for seven RCTs that evaluated the effects of exercise interventions on sleep quality among individuals with obesity. As depicted in Figure 2, all studies were assessed across five key domains using the ‘robvis’ software [35]: (D1) bias arising from the randomization process, (D2) bias due to deviations from intended interventions, (D3) bias due to missing outcome data, (D4) bias in the measurement of outcomes, and (D5) bias in the selection of reported results. Most studies exhibited a low risk across most domains, although concerns were noted in a few areas. Specifically, a few studies have reported concerns related to deviations from the intended interventions and outcome measurements. Overall, these assessments generally reflect robust findings with minor areas of potential bias, emphasizing the reliability of the evidence.

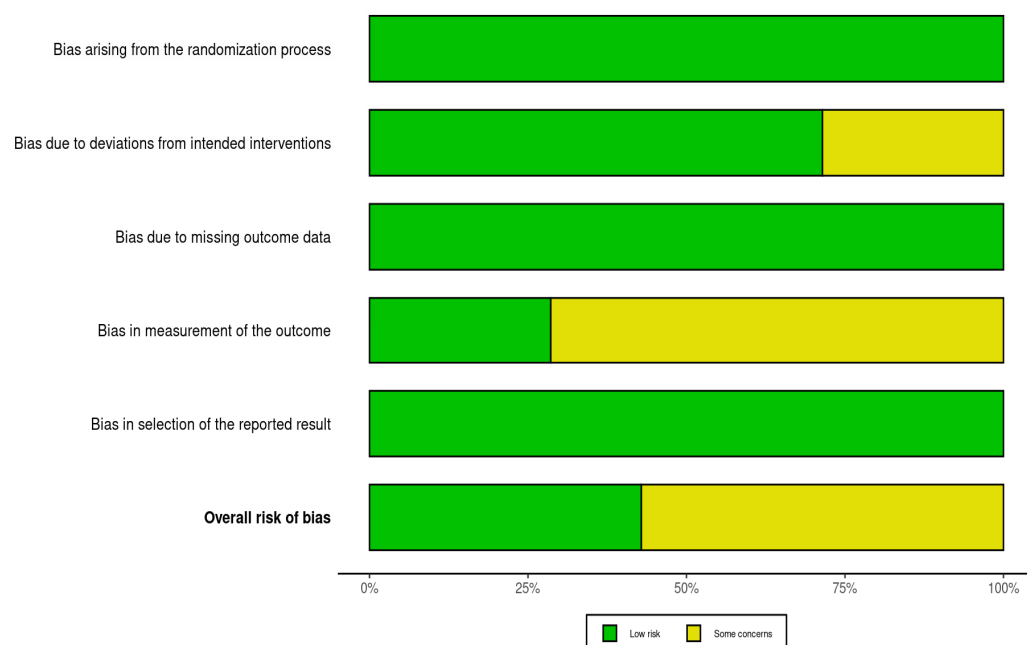
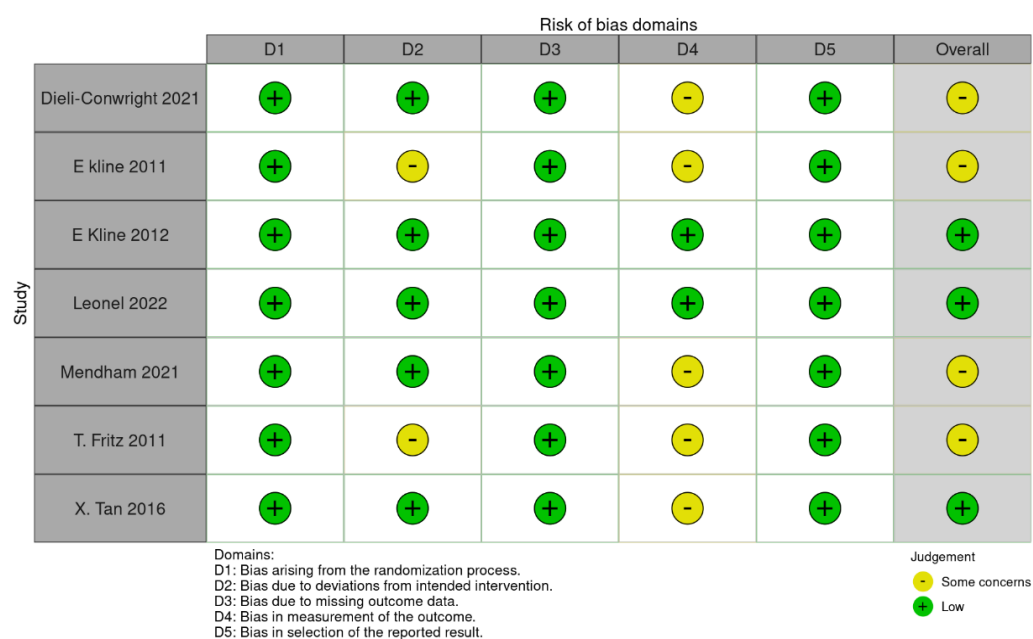


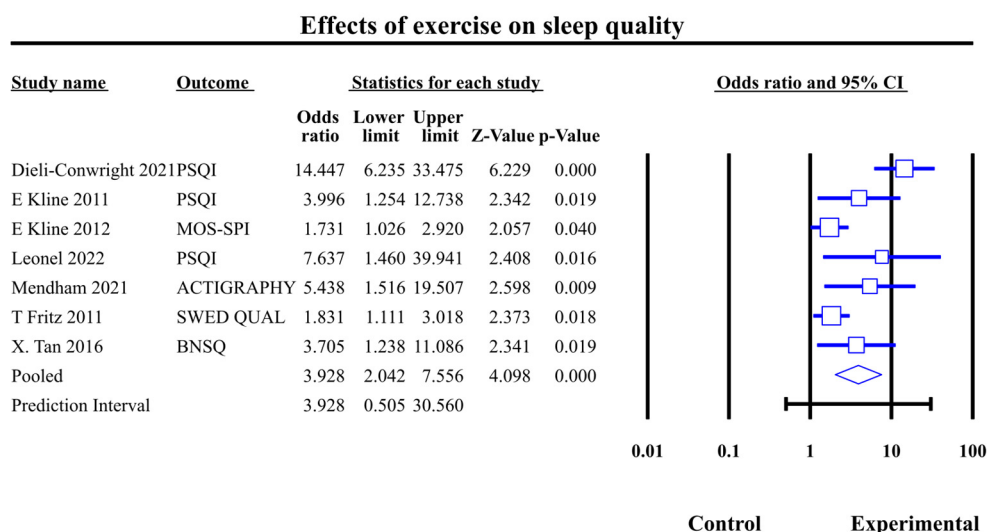
Figure 2. Quality appraisal of the studies included in the systematic review [28–34].

3.4. Meta-Analysis of Exercise Intervention on Sleep Quality

A meta-analysis was conducted to examine the effectiveness of exercise interventions on sleep quality, and the results are shown in Table 2 and Figure 3. The meta-analysis of exercise interventions on sleep quality revealed a pooled effect size of 3.93 (95% CI [2.04, 7.56]) for the random-effects model, with a Z-value of 4.10 and a *p*-value of 0.00, indicating a statistically significant improvement in sleep quality among participants in the intervention groups compared to controls. The analysis demonstrated a high level of heterogeneity, with an I^2 value of 74.71% and a *Q*-value of 23.73 ($p < 0.001$), indicating substantial variability among the included studies. This heterogeneity likely reflects differences in exercise modalities, such as aerobic versus resistance activities, varying frequencies, durations, intensity levels, and characteristics of the participants involved in each study. Given this high level of variability, caution is warranted when interpreting the pooled results, as they represent a broad spectrum of exercise interventions and their impact on sleep quality.

Table 2. Overall status of exercise intervention on sleep quality.

Model		Effect Size and 95% Interval			Test of Null (2-Tail)		Other Heterogeneity Statistics			
Model	Number studies	Point estimate	Lower limit	Upper limit	Z-value	<i>p</i> -value	Q-value	Df (Q)	<i>p</i> -value	I-squared
Fixed	7	2.833	2.113	3.798	6.961	0.000	23.728	6	0.001	74.713
Random	7	3.928	2.042	7.556	4.098	0.000				



Meta Analysis

Figure 3. Effects of exercise on sleep quality [28–34].

The fixed-effects model also yielded a statistically significant effect size of 2.83 (95% CI [2.11, 3.80]; $p = 0.00$). However, owing to the observed heterogeneity, the random-effects model was considered more appropriate for providing an estimate that accounts for the diversity among studies, offering a more generalized interpretation of the impact of exercise interventions on sleep quality.

3.5. Effects of Exercise Interventions on Weight Loss

A meta-analysis was conducted using four studies involving individuals with obesity to investigate the effects of exercise interventions on weight loss, and the results are shown in Table 3 and Figure 4. The results, summarized in Table 3 and Figure 4, indicate a pooled odds ratio (OR) of 2.39 with a 95% confidence interval (CI) of [1.58, 3.61] for both the fixed-

and random-effects models. This result was statistically significant, as evidenced by a Z-value of 4.148 and a *p*-value of 0.000, demonstrating a significant positive impact of exercise interventions on weight loss compared to control groups.

Table 3. Overall status of exercise intervention on weight loss.

Model		Effect Size and 95% Interval			Test of Null (2-Tail)		Other Heterogeneity Statistics			
Model	Number studies	Point estimate	Lower limit	Upper limit	Z-value	p-value	Q-value	Df (Q)	p-value	I-squared
Fixed	4	2.390	1.583	3.606	4.148	0.000	2.243	3	0.524	0.000
Random	4	2.390	1.583	3.606	4.148	0.000				

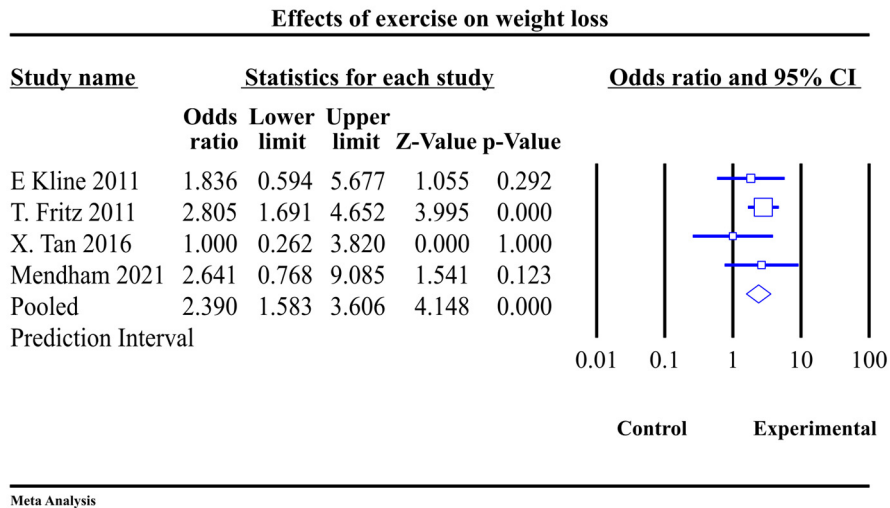


Figure 4. Effects of exercise on weight loss [30,31,33,34].

The heterogeneity test revealed a Q-value of 2.243 with a *p*-value of 0.524, indicating low heterogeneity among the included studies. A Q-value lower than the degrees of freedom (df[Q]) further suggests homogeneity in the population effect sizes. Additionally, the *I*² value was 0%, indicating no observable heterogeneity. These results indicated a consistent effect across the studies included, suggesting that exercise interventions, regardless of the modality, produced broadly comparable improvements in weight loss.

This analysis focused solely on exercise interventions encompassing a range of exercise types, including aerobic and resistance activities, reflecting the consistent impact of such interventions on weight loss outcomes in individuals with obesity.

4. Discussion

The primary findings of our study are discussed. The overall analyses indicate that exercise interventions, particularly aerobic and resistance exercises, lead to notable improvements in sleep quality among adults with obesity. Moreover, exercise interventions, including Nordic walking and combined aerobic and resistance exercises, significantly contribute to weight loss in adults with obesity.

This study focused on sleep quality and weight loss to provide foundational data for intervention research in individuals with obesity. Consequently, the inclusion criteria were centered on aerobic and resistance exercises that are commonly used and effective in obesity intervention programs. Our data showed relatively higher heterogeneity (*I*² = 74.71%), reflecting variations in intensity, frequency, and exercise modalities among the exercise interventions related to sleep quality included in this study. Despite this higher heterogeneity, the overall meta-analysis demonstrated a substantially positive effect of exercise interventions on sleep quality, with effects observed to be 3.93 times higher in the treatment group than in the control group. The effects of the present study are similar to the data from

a meta-analysis to assess the effects of exercise interventions contained aerobic exercise (e.g., walking, cycling) among an adult to elderly population on sleep quality control, with a pooled mean difference of -2.19 , indicating a larger reduction in PSQI score [36].

Heterogeneity in exercise interventions arises from the diversity of exercise types, including single aerobic exercise, combined aerobic and resistance regimens, variations in adherence, and participant characteristics. Notably, our study showed that combined aerobic resistance exercises demonstrated a larger effect size in improving sleep quality, making them highly recommended for individuals with obesity [28,30]. Aerobic exercise primarily enhances the respiratory and cardiovascular systems, thereby reducing body temperature and inflammation, which promotes better sleep quality [37,38]. Additionally, aerobic exercise reduces stress and anxiety, promotes relaxation [39], and has shown promise in lowering cortisol levels, further enhancing sleep patterns [40]. One remarkable aspect of resistance exercise is its ability to improve sleep quality, which is essential for overall well-being [41]. Research has uncovered several mechanisms through which resistance exercise positively affects sleep. Resistance training can reduce sleep-disordered breathing, such as sleep apnea, by strengthening the muscles involved in respiration, thus maintaining open airways during sleep and preventing breathing interruptions. Further research is necessary to investigate the impact of combined aerobic and resistance exercises on sleep quality and to uncover the underlying mechanisms.

Our data showed that moderate-to-high-intensity exercises yielded the most notable improvements in sleep quality, consistent with existing literature highlighting their superiority over lower-intensity programs [42,43]. Therefore, the inclusion of both aerobic and resistance exercises may provide a broader range of benefits to sleep quality. High-intensity exercise can be challenging with aerobic exercise alone; however, combining aerobic exercise with resistance training facilitates moderate- and high-intensity workouts, offering significant advantages. In our study, combined exercise interventions produced greater improvements in sleep quality than aerobics-only programs. This finding aligns with those of previous studies demonstrating the additive benefits of incorporating resistance training along with aerobic activities [44,45].

The intervention durations in the included studies varied, with sessions ranging from 30 min to over 150 min per week and performed at moderate-to-high intensity. Consistent with previous research [36,40], our results highlight that even a single session of exercise lasting for a minimum of 30 min can significantly enhance sleep quality. Specifically, interventions that span longer durations, such as four–six months, have shown consistent and significant improvements in sleep outcomes [28,29,31,34]. Our findings align with those of previous meta-analyses by Kredlow et al. (2015) [46], who reported that regular physical activity over a longer duration contributes to more substantial and consistent improvements in sleep outcomes. This evidence suggests that, while short-term exercise can provide immediate benefits, sustained exercise interventions may be critical for long-term improvements in sleep quality.

Our meta-analysis also found a beneficial effect of significant weight loss in adults with obesity. In our meta-analysis related to weight loss, the exercise types included two studies on high-intensity Nordic skiing and two studies on combined aerobic and resistance exercises. A recent meta-analysis of individuals with obesity revealed that aerobic exercise reduces body weight [47]. Another meta-analysis reported that high-intensity interval training reduced total fat mass [48]. Therefore, high-intensity exercise may be very effective not only for improving sleep quality but also for weight loss among adults with obesity. Despite the lack of data on lean body mass in our study, high-intensity exercises involving greater muscle use can prevent the loss of lean body mass when promoting obesity intervention programs [47].

There are potential mechanisms that could explain the effects of normal walking or combined aerobic and resistance exercises on weight loss observed in our study. Nordic walking is generally considered a moderate-to vigorous-intensity exercise [31]. It involves walking with specially designed poles that engage the upper-body muscles, providing a more comprehensive workout than regular walking. Thus, Nordic walking, or combined aerobic and resistance exercise, is relatively high-intensity and involves greater muscle use, which helps increase fatty acid oxidation and enhances skeletal muscle glucose metabolism, which leads to weight loss. Recently, Amare et al. (2024) demonstrated that aerobic training and combined aerobic and resistance training are more effective at reducing low-density lipoprotein levels. Moreover, resistance and combined training showed greater efficacy than aerobic training in reducing glucose intolerance among previously inactive older adults with obesity [49].

This study had several limitations. First, the number of selected studies was too limited to generalize our findings to adults with obesity. This systematic review and meta-analysis of RCTs evaluated the effects of exercise on sleep quality and weight loss in adults with obesity. The selection criteria were rigorously defined and enforced to ensure the inclusion of adults with obesity without any medical conditions, except those directly related to sleep disturbance or obesity. This study focused exclusively on adult participants because of the significant biological differences between adolescents and adults, such as hormonal variations, which can influence sleep quality indicators. Furthermore, data from the Sleep in America Poll [48] revealed that adolescents experience rapid changes in sleep duration and patterns as they grow older. Consequently, sleep quality may vary substantially even within the same adolescent cohort, leading to inconsistent results. Adolescents were excluded to ensure data consistency. Second, there were only four studies related to weight loss and, as a result, our meta-analysis did not allow subgroup analyses to compute the effect size by exercise type, intensity, or duration because of the limited number of studies used. Further studies on exercise type, intensity, and duration related to sleep quality need to be conducted. Third, owing to the lack of data, we did not control for nutritional factors that could influence sleep quality and weight loss. This omission limits our ability to disentangle the specific effects of exercise interventions from dietary influences on these outcomes. Fourth, the small sample sizes and tools used to assess sleep quality varied across studies, which makes it difficult to generalize the findings. Six of the seven studies relied on self-reported measures, such as the PSQI or BNSQ, which are valuable for large-scale populations, but do not capture objective sleep parameters (e.g., sleep latency, waking after sleep onset) measurable with tools like actigraphy. Sleep quality is a multifaceted condition defined by components such as sleep latency, duration, efficiency, and nighttime awakenings. Future research should emphasize the standardization of sleep quality definitions and use of objective measures to improve the generalizability of findings. Finally, the participants included in this meta-analysis were mainly adults with obesity and with no metabolic diseases, except for one study that included a small proportion of individuals with diabetes. Therefore, additional studies are required to identify other obese populations with coexisting conditions.

5. Conclusions

Exercise interventions have strong potential to improve sleep quality and weight loss in adults with obesity. This meta-analysis highlights that moderate to high-intensity exercise, particularly when combining aerobic and resistance training, is most effective. Sustained interventions lasting 12 weeks or more and session frequencies of 3 to 5 times per week with durations exceeding 30 min showed the greatest benefits. Future studies should focus on standardizing exercise protocols, exploring diverse regimens, and elucidating the

mechanisms underlying these improvements to develop optimized targeted strategies for sleep enhancement.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/app15010467/s1>, Table S1: Combinations of keywords used during electronic literature searches (last updated search 2024/12).

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