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Effects of Different Exercise Interventions on Health Status in Overweight and Obese Children and Adolescents: A Network Meta-Analysis

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Background: While numerous studies have explored the effectiveness of exercise interventions in improving health outcomes in populations with obesity, comparisons of different exercise modalities remain limited. This study aimed to address this gap through a network meta-analysis (NMA) to evaluate the impact of various exercise modalities on health status in children and adolescents with overweight and obesity.

Methods: Two researchers (XC and KD) systematically searched databases including PubMed, Cochrane Library, Embase and others for randomized controlled trials (RCTs) published up to May 2024. The studies analyzed the effects of exercise interventions on body composition, lipid profiles, glucose metabolism, and cardiorespiratory fitness (CRF) in children and adolescents with overweight and obesity. Study quality was assessed using the Cochrane tools, and the random-effects NMA was conducted within a Bayesian framework.

Results: A total of 51 studies with 2263 participants were included, covering four exercise modalities: aerobic exercise (AE), resistance exercise (RE), combined exercise (CE), and high-intensity interval training (HIIT). HIIT was relatively more effective for improving CRF, including oxygen uptake peak (VO_{2peak}) [MD = 3.33, 95% CI (2.36, 4.26)] and heart rate (HR) [MD = −8.09, 95% CI (−10.92, −5.37)]. AE demonstrated substantial reductions in weight, body mass index (BMI), and waist circumference (WC). CE may be most effective in reducing body fat percentage (BF%), waist-to-hip ratio (WHR), and improving fat-free mass (FFM), as well as controlling fasting glucose (FG) and insulin resistance. RE showed a significant impact on improving lipid profiles.

Conclusion: HIIT is the relatively effective modality for enhancing CRF, while AE and CE are notably effective for improving body composition. RE is regarded as a preferable choice for lipid regulation, and CE tends to provide superior outcomes for glucose and insulin control. These findings provide comparative evidence for clinical and policy recommendations, though further high-quality research is needed for validation.

Keywords: exercise, overweight and obesity, adolescent and children, health status, network meta-analysis

Introduction

Improved living standards and changing dietary habits have made childhood overweight and obesity major global health challenges in the 21st century.[1,2] According to the World Health Organization (WHO), the prevalence of obesity among children and adolescents aged 5–19 years quadrupled from 2% in 1990 to 8% in 2022. Currently, over 390 million children and adolescents are overweight, with approximately 160 million classified as obese.[3,4] The health risks associated with overweight and obesity are substantial, including an increased likelihood of cardiovascular disease (CVD), type 2 diabetes (T2DM), musculoskeletal disorders (MSDs), and certain cancers, often leading to premature death or disability.[5,6] Economically, the burden is staggering: global obesity-related healthcare costs exceed $990 billion

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annually, accounting for more than 13% of total healthcare expenditures,[7,8] creating significant challenges for families and society.

The WHO emphasizes that pharmacological interventions face challenges, including high costs, complications, and counterfeit products.[9] In contrast, increasing physical activity offers significant benefits, including improved health and well-being, reduced healthcare burdens, and progress toward global non-communicable disease (NCD) targets and sustainable development goals.[10,11] Consequently, promoting dietary modifications and physical activity (PA) remains a key priority for NCD prevention.[12,13]

In recent years, research on the effects of dietary modifications and exercise interventions for preventing and managing overweight and obesity has grown significantly. Evidence indicates that high-intensity interval training (HIIT) significantly boosts oxygen uptake peak (VO_{2peak}) in individuals with overweight and obesity by increasing their heart rate (HR) and oxygen expenditure.[14] Aerobic exercise (AE) reduces the risk of T2DM by enhancing insulin sensitivity. Resistance exercise (RE) increases muscle mass and metabolic rate, thereby promoting fat burning and improving body composition. Combined exercise (CE) outperforms AE alone in reducing visceral fat and improving metabolic and inflammatory markers.[15] However, outcomes for adolescents with obesity are less consistent,[16,17] potentially due to small sample sizes, short intervention durations, variations in baseline weight, and age-related physiological changes. Traditional meta-analyses have explored these interventions but often yield inconsistent results and lack direct comparisons between different exercise modalities.[18,19] Network meta-analysis (NMA), or multiple treatment comparison meta-analysis, addresses these limitations by enabling simultaneous comparisons of three or more interventions. Even when direct comparisons are unavailable, NMA can estimate relative effectiveness and rank interventions, offering greater precision and a broader analytical scope.[20,21]

To date, no systematic review has comprehensively evaluated the effects of various exercise modalities on cardiorespiratory fitness (CRF), body composition, and metabolic indicators in children and adolescents with overweight and obesity. Existing NMAs primarily focus on AE, RE, and CE, often excluding HIIT. Furthermore, the relative effectiveness of different exercise types for specific health indicators in this population remains unclear. This study aimed to fill this gap by performing a network meta-analysis (NMA) from randomized controlled trials (RCTs) to compare the impacts of AE, RE, CE, and HIIT on health status, which is defined as the composite of CRF, body composition and metabolic outcomes. The findings will provide robust evidence to guide the selection of effective interventions for children and adolescents with overweight and obesity.

Materials and Methods

This systematic review and NMA followed the Preferred Reporting Items for Systematic Reviews and Network Meta-Analyses (PRISMA) guidelines[22] and was registered in the PROSPERO database (Registration No. CRD42024595872). Results were presented in accordance with the PRISMA extension for NMA (Supplementary Table S1). Ethical approval was not required, as the study utilized only previously published data.

Search Strategy

Two independent researchers (XC and KD) systematically searched nine major databases, including PubMed, Web of Science (WOS), EBSCO, Cochrane, Embase, Scopus, China National Knowledge Infrastructure (CNKI), Wanfang database, and VIP database, for RCTs on the effects of exercise on the health of children and adolescents with overweight and obesity. The search, conducted from database inception to May 4, 2024, used a combination of mesh words and free words such as “Exercise”, “Training”, “Physical activity”, “Overweight”, “Obesity”, “Child”, “Adolescent”, and “Health Status.” Additionally, meta-analyses, review articles, and reference lists were manually screened to identify studies potentially missed in the initial search. The detailed search strategy is outlined in Supplementary Table S2.

Inclusion and Exclusion Criteria

This systematic review applied the PISCO framework (Population, Intervention, Comparison, Outcome, Study Design) to establish inclusion criteria.[22] (1) Population: Participants aged 6–18 years classified as overweight or obesity (Overweight: BMI ≥ the 85th percentile for age and sex; Obesity: BMI ≥ the 95th percentile for age and sex).[23] (2)

Intervention: AE, RE, CE, or HIIT, with intervention durations of at least four weeks. (3) Comparison: Control groups with no exercise intervention or regular physical education programs. (4) Outcomes: Measures included CRF [VO_{2peak} (mL/kg/min), HR (bpm)], body composition metrics [weight (kg), body mass index (BMI, kg/m2), waist circumference (WC, cm), body fat percentage (BF%, percentage), fat-free mass (FFM, kg), waist-hip ratio (WHR)], and metabolic indicators [fasting glucose (FG, mmol/L), homeostatic model assessment of insulin resistance (HOMA-IR), insulin (mU/mL), triglycerides (TG, mg/dL), total cholesterol (TC, mg/dL), high-density lipoprotein (HDL, mg/dL), low-density lipoprotein (LDL, mg/dL)]. (5) Study Design: RCTs only. Exclusion criteria: Studies were excluded if (1) interventions included dietary control, (2) participants used medication or had non-communicable diseases (eg, hypertension, cancer, diabetes), (3) outcomes were irrelevant or not reported, (4) they were conference abstracts, case reports, or non-peer-reviewed papers, or (5) they involved ineligible age groups, non-RCT designs, incomplete data, or animal models.

Literature Screening and Data Extraction

Endnote X9 software was used for literature management, including computer-assisted removal of duplicates. Two researchers (XC and KD) independently screened articles based on titles, followed by abstract reviews and eligibility evaluations. Full-text articles were then assessed to determine inclusion. Discrepancies were resolved through consultation with a third researcher. Data extraction was performed independently by two authors (XC and YC) and included: (1) first author, (2) year of publication, (3) country, (4) intervention duration, (5) sample size, (6) gender ratio, (7) mean age, (8) exercise intervention details (frequency, intensity, duration, type), and (9) outcome measures. Disagreements were resolved through discussion or third-party consultation.

Risk of Bias Assessment

Two evaluators (XC and YC) independently assessed the risk of bias in the included studies using the Cochrane Risk of Bias Tool 2 (RoB 2).[24] Five domains were evaluated: randomization process, deviations from intended interventions, missing outcome data, measurement of the outcome and selective reporting. Each domain was classified as having high, moderate, or low risk of bias. Any discrepancies were resolved through consensus discussion with a third independent researcher. The bias assessment was conducted using the standardized RoB 2.0 Excel tool.

Statistical Analyses

This study utilized a Bayesian framework for random-effect NMA using the "gemtc" and "rjags" packages in R (version 4.3.0) and StataMP17.0.[25,26] Continuous variables were analyzed as mean differences (MD) with 95% confidence intervals (CI). For studies with multiple intervention time points, only the data from the initial and final time points were included. Statistical heterogeneity was evaluated using the I2 statistic. An I2 statistic >50% indicated significant heterogeneity.[27] Network diagrams illustrated relationships between exercise interventions, and league tables presented pairwise comparisons. Model convergence was assessed using trace plots, density plots, and convergence diagnostics. When closed loops appeared in the network diagram, nodal analysis was conducted for inconsistency testing. If $P > 0.05$, the consistency model was applied; otherwise, the inconsistency model was used.[28] Intervention efficacy was ranked using the surface under the cumulative ranking curve (SUCRA), with higher SUCRA values indicating better outcomes.[29] Publication bias was evaluated using comparison-adjusted funnel plots, and heterogeneity tests were performed for each outcome. Publication bias in the included studies were assessed via Egger's regression, with a P-value ≥0.05 suggesting no significant publication bias.

Results

Literature Selection

A total of 5364 eligible studies were screened from nine databases. Two researchers (XC and KD) excluded duplicates and irrelevant studies by screening titles and abstracts. Then, a full-text review was conducted on 316 studies and 265 articles that did not meet the criteria were excluded. Finally, 51 studies were included in the NMA.[30–80] The literature screening flow chart shown in Figure 1.

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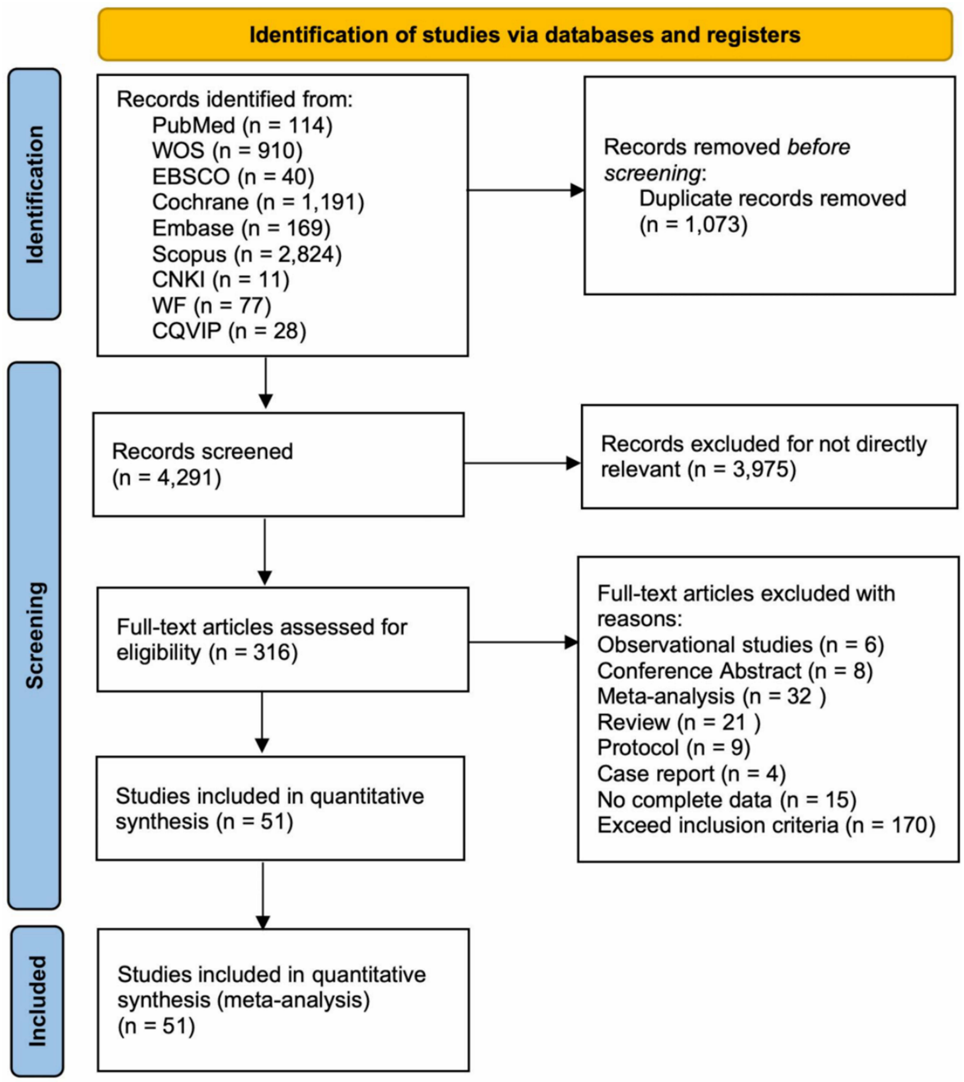

Figure 1 Flow diagram of study selection.
Abbreviations: CNKI, China National Knowledge Infrastructure; CQVIP, Chinese Science and Technology Periodical Database; WF, WanFang Database; WOS, Web Of Science.

Characteristics of the Included Studies

The included studies were conducted across 15 countries, with 65% (33 articles) originating from developing nations, including 18 from China. Developed countries accounted for 35%, with the United States and South Korea contributing four articles each. In total, 2263 participants with overweight or obesity were involved. Seven studies exclusively recruited females, 14 focused on males, and 9 did not specify gender ratios. The mean participant age was 11.5 ± 5.5 years. Study durations ranged from 4 to 24 weeks, with 71% (36 studies) reporting interventions lasting over 12 weeks, typically consisting of three sessions per week. Fourteen studies included two intervention groups, while five included three groups. Baseline outcomes included CRF measures (VO_{2peak}, HR), body composition metrics (weight, BMI, WC, BF%, FFM, WHR), and metabolic indicators (FG, HOMA-IR, insulin, TG, TC, HDL, LDL). Detailed study characteristics are presented in Table 1.

Risk of Bias and Publication Bias of Included Studies

Supplementary Figures S1 and S2 summarize the risk of bias assessments for the 51 included studies, which were evaluated across five domains: random sequence generation and allocation concealment, deviated interventions, blinding

Table 1 Summary of Studies Included in Network Meta-Analysis Indicating the Exercise Intervention Used and the Outcome Measures Reported for Comparison Within the Analysis

Study	Country	Duration (Weeks)	Sample N/ M/F	Mean Age (SD)	Exercise Category	Summary Description of Exercise Intervention Frequency, Intensity, Time and Type (F.I.T.T).	Outcome Measures Reported
Tas et al, 2023[30]	USA	4	6/2/4	15.4 ± 1.0	CON	No exercise	Weight; BF%; FFM; VO_{2peak}; FG; Insulin; HOMA-IR; TC; HDL; LDL; TG
			31/14/17	15.2 ± 1.5	HIIT	3 times $week^{-1}$; 45min; 10 × 1-min intervals (elliptical machine, bike, treadmill); 80%-90% VO_{2peak}; 2min active recovery (walking)	
Ye[a], 2023[31]	China	9	30/15/15	8-9	CON	General physical education	BF%; BMI; WC; WHR; HR
			30/15/15	8-9	CE	5 times $week^{-1}$; 40min aerobic games and 30min strength exercises; 164 ± 14b/min THR	
Cao et al, 2022[32]	China	12	20/10/10	10.9 ± 0.4	CON	General physical education	Weight; BF%; BMI; VO_{2peak}; FFM
			20/10/10	11.2 ± 0.7	HIIT	3 times $week^{-1}$; 18min; 3 × (8 × 15s) high-intensity running; 100% MAS, 80–90% HR_{max}; 3 × (8 × 15s) active recovery, 50% MAS; 3 × 3min rest	
Comeras-Chueca et al[a], 2022[33]	Spain	20	8/-/-	9-11	CON	No exercise	Weight; BMI; BF%; FFM; VO_{2peak}
			20/-/-	9-11	CE	3 times $week^{-1}$; 4 × 8min active video games; 13min multicomponent exercise; 5.4 ± 1.1 MET	
Comeras-Chueca et al[a], 2022-1[34]	Spain	20	8/-/-	9-12	CON	No exercise	Weight; BMI; FFM
			21/-/-	9-12	CE	3 times $week^{-1}$; 4 × 8min active video games; 13min multicomponent exercise; 5.4 ± 1.1 MET	
Ji et al, 2022[35]	China	4	20/-/-	15 ± 1.12	CON	No exercise	Weight; BF%
			20/-/-	15 ± 1.08	AE	40min; treadmill, dynamic bicycle, elliptical machine, etc; 40min sports games (pedal, field run, etc); 60%-80% V_{max}	
Khaliltahmasebi et al, 2022[36]	Iran	12	12/12/0	12 ± 1	CON	No exercise	Weight; BF%; VO_{2peak}; BMI; TC; HDL; LDL; TG
			13/13/0	12 ± 1	HIIT	3 times $week^{-1}$; 20–45min; 2–4 × (5 × 30s running/30s active recovery); 85%-100% MAS; 5min rest	
			13/13/0	12 ± 1	CE	3 times $week^{-1}$; 10–20min running and resistance exercise (3 × 30s-60s); 30–35min futsal training	
Meng et al, 2022[37]	China	12	13/13/0	11.0 ± 0.7	CON	General physical education	BF%; BMI; FFM; WC; VO_{2peak}; FG; Insulin; HOMA-IR; TC; HDL; LDL; TG
			12/12/0	11.4 ± 0.8	HIIT	3 times $week^{-1}$; 11min; 2 × (8 × 15s) running; 90%-100% MAS; 80%-90% HR_{max}; 8 × 15s active recovery; 50% MAS; 40%-60% HR_{max}; 3min rest	
			11/11/0	11.2 ± 0.7	HIIT	3 times $week^{-1}$; 30min interval running; 60%-70% MAS	

(*Continued*)

Table 1 (Continued).

Study	Country	Duration (Weeks)	Sample N/ M/F	Mean Age (SD)	Exercise Category	Summary Description of Exercise Intervention Frequency, Intensity, Time and Type (F.I.T.T).	Outcome Measures Reported
Julian et al, 2022[38]	Portugal	16	11/5/6	13.2 ± 1.0	CON	No exercise	Weight; BMI; FFM; BF%
			19/8/11	13.0 ± 1.1	HIIT	2 times week^{-1}; 15min; 30s ergometer bicycle exercise; 30s active recovery; 75%-90% VO_{2peak}; 1 times week^{-1}; leisure time activities; 3×10 repetitions strength training; 1min inactive recovery; 3 × 4min rest; 65%-80% 10RM	
			19/7/12	13.0 ± 0.8	HIIT	2 times week^{-1}; 45min ergometer bicycle exercise; 60% VO_{2peak}; 1 times week^{-1}; leisure time activities; 3×10 repetitions strength training; 1min inactive recovery; 3 × 4min rest; 65%-80% 10RM	
Zhu et al[a], 2022[39]	China	12	25/10/15	13-15	CON	No exercise	Weight; BMI; BF%
			25/10/15	13-15	AE	Aerobic exercise	
Salus et al, 2022[40]	Estonia	12	14/14/0	13.7 ± 0.4	CON	No exercise	Weight; FFM; BF%; VO_{2peak}; WC
			14/14/0	13.1 ± 0.3	HIIT	3 times week^{-1}; 4–6 × 30s all-out cycling bouts; 4min active recovery; 75%-85%HR_{max}	
Liu 2022[41]	China	12	15/9/6	9.41 ± 1.19	CON	No exercise	Weight; BMI; FFM; BF%
			30/20/10	9.72 ± 1.39	CE	3-5 times week^{-1}; 60min; 4 × (fun physical training, control training, agility ladder training, core stability training, self-weight strength training); 60%-70%HR_{max}	
Bouamra et al, 2022[42]	Tunisia	9	12/-/-	12.8 ± 0.9	HIIT	3 times week^{-1}; 6–8min; 3–4 × (12 × 10s running, 10s passive rest); 3–4 × 3min passive recovery; 80%-110% V_{peak}	Weight; BF%; FFM; BMI; WC
			12/-/-	12.7 ± 0.9	RE	3 times week^{-1}; 6–8min; 3–4 × (3 × 10RM)	
			13/-/-	13.2 ± 0.9	CE	3 times week^{-1}; 1.5–2 × (10RM + 12 bouts HIIT)	
Yang[a], 2020[43]	China	8	20/10/10	12-14	CON	General physical education	Weight; BMI; BF%; FFM; HR
			20/10/10	12-14	CE	5 times week^{-1}; 90min; 50–52min football practice; 55–65% HR_{max}; 20min strength or endurance training	
Ma[a], 2020[44]	China	12	18/10/8	12-13	CON	5 times week^{-1}; 30min; Jog 1200 meters	Weight; BMI; HR
			18/10/8	12-13	AE	5 times week^{-1}; 30min calisthenics; 130–140b/min HR	
Paahoo et al, 2020[45]	Iran	12	15/-/-	11.20 ± 0.94	CON	No exercise	Weight; BMI; BF%; WHR; HDL; TG
			15/-/-	11.13 ± 0.99	HIIT	3 times week^{-1}; 45min; 3 × (10 × 10s) running-active rest; 100%-110% MAS; 3min recovery	
			15/-/-	10.86 ± 1.06	AE	3 times week^{-1}; 30min running; 40%-70% HRR	
Seabra et al[a], 2020[46]	Portugal	24	20/20/0	8-12	CON	2 times week^{-1}; 45–90min	Weight; WC; BF%; FG; Insulin; HOMA-IR; TC; HDL; LDL; TG
			20/20/0	8-12	AE	5 times week^{-1}; 60–90min school-based soccer practice; 78% HR_{max}	

Duft et al, 2020[47]	Brazil	12	19/9/10	14.72 ± 1.07	CON	No exercise	Weight; BMI; WC; BF%; FG; Insulin; HOMA-IR; TC; VO_{2peak}
			18/9/9	14.44 ± 1.04	CE	3 times week^{-1}; 30min; walking, running; 50%-85% VO_{2peak}; resistance training; 2×6-10 repetitions; 1–2min rest	
Ma, 2020-1[48]	China	8	15/15/0	13.90 ± 0.89	CON	3 times week^{-1}; broadcast gymnastics, ball games	Weight; BMI; FFM; BF%
			15/15/0	13.53 ± 0.72	CE	3 times week^{-1}; 6 × 20s exercise; 6 × 10s intervals; 85% HR_{max}; 20min jog, walk fast	
			15/15/0	13.40 ± 0.49	AE	3 times week^{-1}; 30–40min; run, jump rope; 60%-75% HR_{max}	
Vasconcellos et al, 2020[49]	Brazil	12	7/5/2	14.7 ± 2.3	CON	No exercise	Weight; BMI; WC; BF%; HDL; TG; FG
			6/4/2	13.9 ± 1.6	AE	3 times week^{-1}; 40min small-sided games (soccer); 84.5 ± 4.1% HR_{max}	
Ling[a], 2019[50]	China	24	100/50/50	6-9	CON	General physical education	Weight; BMI; HR
			100/50/50	6-9	AE	2 times week^{-1}; 90min dance sport; 130–150b/min HR	
Wang[a], 2019[51]	China	6	10/-/-	12-19	AE	5 times week^{-1}; 60min; 60%-70% HR_{max}; treadmill, ellipsometer	WHR; WC; Weight
			10/-/-	12-19	RE	5 times week^{-1}; 60min; 5 × [6 × (8–12 × 60%-80% 1RM)]; 5 × 45s rest	
			10/-/-	12-19	CE	5 times week^{-1}; 30min AE and 30min RE	
Moslehi, 2019[52]	Iran	8	10/10/0	10.93 ± 0.53	CON	No exercise	Weight; BMI; BF%; VO_{2peak}
			10/10/0	11.12 ± 0.51	AE	3 times week^{-1}; 25–40min football game; 65%-85% HRR	
			10/10/0	10.87 ± 0.54	AE	3 times week^{-1}; 25–40min running (treadmill); 65%-85% HRR	
Alves et al, 2019[53]	Portugal	10	10/-/-	14.77 ± 1.49	CON	General physical education	BMI; BF%; VO_{2peak}
			15/-/-	14.77 ± 1.49	CE	3 times week^{-1}; 40min; walk, ball games, bicycle; 10 min strength exercise; upper limbs, squats, trunk and lunges; 75% VO_{2max}	
			15/-/-	14.77 ± 1.49	CE	2 times week^{-1}; 40min; walk, ball games, bicycle; 10 min strength exercise; upper limbs, squats, trunk and lunges; 75% VO_{2max}	
Kim et al, 2019[54]	Korea	12	24/0/24	15 ± 1	CON	No exercise	Weight; BMI; BF%; FG; Insulin; HOMA-IR; WC
			24/0/24	15 ± 1	AE	5 times week^{-1}; 40min rope jumping variations; 40%-70% HRR	
Deldin et al, 2019[55]	USA	12	28/14/14	14.8 ± 1.5	RE	3 times week^{-1}; 60min; 1–2 × (8–12 repetitions); weight machines	Weight; BMI; FFM; WC
				14.8 ± 1.7			
			27/14/13	15.1 ± 1.7	AE	3 times week^{-1}; 60min; treadmills, ellipticals, stationary bikes; 50%-75% VO_{2peak}	
				14.9 ± 1.9			

(*Continued*)

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Table 1 (Continued).

Study	Country	Duration (Weeks)	Sample N/ M/F	Mean Age (SD)	Exercise Category	Summary Description of Exercise Intervention Frequency, Intensity, Time and Type (F.I.T.T).	Outcome Measures Reported
Lee et al, 2019[56]	Korea	24	38/13/25	14.4 ± 1.6	AE	3 times week^{-1}; 60min; treadmill, elliptical; 50%-65% VO_{2peak}	Weight; BMI; BF%; WC; FFM; FG
			40/15/25	14.4 ± 1.6	RE	3 times week^{-1}; 60min; 2 × (12–15 repetitions); weight machines	
			40/14/26	14.5 ± 1.7	CE	3 times week^{-1}; 30min AE and 30min RE	
Bharath et al, 2018[57]	USA	12	20/0/20	14.8 ± 1	CON	No exercise	Weight; BMI; BF%; FG; Insulin; WC; HOMA-IR; HR; VO_{2peak}
			20/0/20	14.6 ± 1	CE	5 times week^{-1}; 20min resistance training; 15–20 repetitions; 30min treadmill walking; 40%-70% HRR	
Zhang[a], 2018[58]	China	12	45/25/20	11-15	CON	2 times week^{-1}; General physical education	BMI
			45/25/20	11-15	AE	2 times week^{-1}; 120min; basketball training	
Cvetkovic et al[a], 2018[59]	Serbia	12	14/14/0	11-13	CON	2 times week^{-1}; General physical education	Weight; BMI; BF%; FFM
			11/11/0	11-13	HIIT	5 times week^{-1}; 3 × (10–20s running-inactive rest); 3min passive rest; 100% MAS	
			10/10/0	11-13	AE	5 times week^{-1}; 4 × 8min recreational football; 4 × 2min passive rest	
Chuensiri et al, 2018[60]	Thailand	12	11/11/0	10.6 ± 0.3	CON	No exercise	Weight; BMI; BF%; WC; HR; VO_{2peak}; TC; HDL; LDL; TG
			11/11/0	11.0 ± 0.3	HIIT	3 times week^{-1}; 8 × 2min cycling; 1min rest; 90% peak power output	
			15/15/0	11.1 ± 0.2	HIIT	3 times week^{-1}; 8 × 20s cycling; 10s rest; 170% peak power output	
Fiorilli et al, 2017[61]	Italy	22	12/-/-	12.67 ± 0.65	AE	3 times week^{-1}; 25–40min; cycle-ergometers and treadmills; 45%-55% HRR	Weight; BMI; WC; WHR; BF %; FFM; VO_{2peak}
			15/-/-	12.73 ± 0.70	CE	3 times week^{-1}; 3 × 13RM; 2min rest; 4min rest; 25–40min cycle-ergometers and treadmills; 45%-55% HRR	
			14/-/-	12.21 ± 0.43	CE	3 times week^{-1}; 3 × 9RM; 4min rest; 3min rest; 25–40min cycle-ergometers and treadmills; 45%-55% HRR	
Ramezani et al, 2017[62]	Iran	8	15/15/0	10.05 ± 1.41	CON	No exercise	TC; HDL; LDL; TG; FG
			15/15/0	10.05 ± 1.41	AE	4 times week^{-1}; 4–7 × 5min continuous running; 1 min rest; 50%-75% THR	
			15/15/0	10.05 ± 1.41	RE	4 times week^{-1}; 3×8 repetitions-1min rest; 1min rest; 50%-75% 1RM	
			15/15/0	10.05 ± 1.41	CE	4 times week^{-1}; 25–40min; 2 sessions of RE and 2 sessions of AE	
Wong et al, 2017[63]	Korea	12	15/0/15	15.3 ± 1.1	CON	No exercise	Weight; BMI; BF%; HOMA-IR; WC; FG; Insulin
			15/0/15	15.2 ± 1.2	CE	3 times week^{-1}; 20min resistance training (16–20 repetitions exercise); 30min treadmill walking; 40%-70% HRR	

Son et al, 2017[64]	Korea	12	20/0/20	15 ± 1	CON	No exercise	Weight; BMI; BF%; HOMA-IR; WC; FG; Insulin
			20/0/20	15 ± 1	CE	3 times week^{-1}; 20min badminton; 30min various exercises (jump); 40%-70% HRR	
Nobre et al[a], 2016[65]	Brazil	12	19/19/0	7-9	CON	No exercise	Weight; BMI; BF%; FFM
			40/40/0	7-9	HIIT	2 times week^{-1}; 20min; 10–24×5 kinds of jumps	
Zehsaz et al, 2016[66]	Iran	16	16/16/0	10.3 ± 0.9	CON	No exercise	Weight; BMI; WC; BF%; FFM; FG; Insulin; HOMA-IR; TC; HDL; LDL; TG
			16/16/0	10. 8 ± 0.9	CE	2 times week^{-1}; 30–35min walking; 55%-75% HR_{max}; 55min rubber band exercises; 20 repetitions; 70% 1RM	
Racil et al, 2016[67]	Tunisia	12	19/0/19	16.9 ± 1.0	CON	No exercise	Weight; BF%; FFM; WC; FG; Insulin; VO_{2peak}; HOMA-IR
			26/0/26	16.5 ± 1.2	HIIT	3 times week^{-1}; 2min; 2 × 15s various jump-15s passive recovery; 2 × 30s-1min passive rest; 2 × (6–8 × 30s running); 100% vVO_{2peak}; 2 × 30s active recovery; 50% vVO_{2peak}; 2 × 4min passive rest	
			23/0/23	16.6 ± 0.9	HIIT	3 times week^{-1}; 2 × (6–8 × 30s running); 100% vVO_{2peak}; 2 × 30s active recovery; 50% vVO_{2peak}; 2 × 4min passive rest	
Racil et al, 2016 1[68]	Tunisia	12	14/0/14	14.2 ± 1.2	CON	No exercise	Weight; BF%; WC; FG; Insulin; HOMA-IR
			17/0/17	14.2 ± 1.2	HIIT	3 times week^{-1}; 3 × 4–8min (15s running/15s rest); 100%MAS; 3 × 3min passive recovery; 50%MAS	
			16/0/16	14.2 ± 1.2	HIIT	3 times week^{-1}; 3 × 4–8min (15s running/15s rest); 80%MAS; 3 × 3min passive recovery; 50%MAS	
Ning et al, 2016[69]	China	24	14/7/7	13.12 ± 1.32	CON	No exercise	BMI; WC; TC; HDL; LDL; TG
			14/7/7	13.12 ± 1.32	CE	3 times week^{-1}; 15min jog; 35min interval running; 30 × 3set sit-up; 10 × 3set push-up; 60%-70% VO_{2max}	
Tan et al, 2015[70]	China	10	13/13/0	9.4 ± 1.3	CON	No exercise	Weight; BMI; BF%; VO_{2peak}; FFM
			11/11/0	9.0 ± 0.9	AE	5 times week^{-1}; 40min PA (walking, running, ball movements); 1–2min rest	
Monteiro et al[a], 2015[71]	Brazil	20	16/8/8	11-17	CON	No exercise	Weight; TC; BMI; BF%; FFM; WC; HDL; LDL; TG
			14/9/5	11-17	CE	3 times week^{-1}; 30min; walking, running; 65%-85% VO_{2peak}; 30min resistance training; 1–2×10-20 repetitions; 55%-75% RM	
			18/10/8	11-17	AE	3 times week^{-1}; 50min; walking and running; 65%-85% VO_{2peak}	
Vasconcellos et al, 2015[72]	Portugal	12	10/6/4	14.8 ± 1.4	CON	No exercise	Weight; BMI; BF%; WC; FFM; VO_{2peak}; FG; Insulin; HOMA-IR; TC; HDL; LDL; TG
			10/8/2	14.1 ± 1.1	AE	3 times week^{-1}; 40min recreational football games	

(*Continued*)

Table 1 (Continued).

Study	Country	Duration (Weeks)	Sample N/ M/F	Mean Age (SD)	Exercise Category	Summary Description of Exercise Intervention Frequency, Intensity, Time and Type (F.I.T.T).	Outcome Measures Reported
Guo et al[a], 2015[73]	China	8	30/30/0	13-14	CON	No exercise	Weight; BMI; VO_{2peak}
			30/30/0	13-14	AE	5 times week^{-1}; 40min PA (walking, running, ball movements)	
Murphy et al, 2015[74]	USA	4	6/1/5	14.3 ± 1.2	AE	3-4 times week^{-1}; 30min running; 65% HR_{max}	BMI; VO_{2peak}; BF%
			7/2/5	13.7 ± 2.0	HIIT	3-4 times week^{-1}; 10 × 1min running; 80%-90% HR_{max}; 10 × 2min active recovery; 60% HR_{max}	
McNarry et al, 2015[75]	UK	6	11/-/-	9.3 ± 0.9	CON	General physical education; 1 times week^{-1}; 60min	Weight; BMI; VO_{2peak}
			15/-/-	9.3 ± 0.9	HIIT	3 times week^{-1}; 6min high-intensity games; 2min recovery	
Xing et al[a], 2015[76]	China	24	12/6/6	13-14	CON	No exercise	BMI; WC; TC; HDL; LDL; TG
			12/6/6	13-14	CE	3 times week^{-1}; 15min jog; 35min interval running; 3set × 30 sit-up; 3set × 10 burpee; 60%-70%VO_{2max}	
Tang et al[a], 2015[77]	China	19	30/18/12	8-9	CON	5 times week^{-1}; 26min broadcast gymnastics	Weight; BMI; WHR
			30/18/12	8-9	RE	5 times week^{-1}; 26min; 3 × jump rope, games, sit-ups, push-ups, back vibrating trunk	
Youssef et al, 2015[78]	France	12	9/0/9	16.3 ± 0.5	CON	No exercise	Weight; BMI; BF%; FFM; VO_{2peak}
			14/0/14	16.1 ± 0.3	AE	3 times week^{-1}; 90min group games (run, ball); 3 × (10 × 15s interval training running, 15s rest); 70%-100% HRR	
Mahgoub et al, 2015[79]	Egypt	8	15/5/10	13.73±1.03	AE	30min; walking; 50%-70% VO_{2peak}	TC; HDL; LDL; TG
			15/6/9	13.66±1.11	HIIT	30min; 10 × 2min running; 1min rest; 75%-80% VO_{2peak}	
Zhang[a], 2015[80]	China	12	14/14/0	6-11	CON	General physical education	Weight; BMI; BF%; WC; WHR
			20/20/0	6-11	CE	5 times week^{-1}; 15min strength training; jump, sit-up, burpee; 40min; running, orienteering, ball games; 125–167b/min THR	

Notes: -/-, gender not reported for specific groups. N, number; M, male; F, female. [a]Age range for entire study sample not mean (SD).

Abbreviations: AE, aerobic exercise; BF%, body fat percent; BMI, body mass index; CE, combined exercise; CON, control group; FFM, free fat mass; FG, fasting glucose; HDL, high-density lipoprotein; HIIT, high-intensity interval training; HOMA-IR, homeostatic model assessment of insulin resistance; HR, heart rate; HRR, heart rate reserve; LDL, low-density lipoprotein; MAS, maximal aerobic speed; MET, metabolic equivalent; PA, physical activities; RE, resistance exercise; RM, repetition maximum; TC, total cholesterol; TG, triglyceride; THR, target heart rate; VO_{2peak}, oxygen uptake peak; vVO_{2peak}, velocity at oxygen uptake peak; V_{max}, maximal velocity; V_{peak}, peak velocity value; WC, waist circumference; WHR, waist-hip ratio.

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of participants, providers and outcome assessment, incomplete outcome data and selective outcome reporting. Most studies demonstrated low risk in random sequence generation and allocation concealment, as they employed computer-generated randomization methods. Regarding deviations from intended interventions, the majority of studies showed low risk and documented good intervention compliance. However, two studies were rated as high risk for incomplete outcome data due to significant participant attrition, while four studies were deemed unclear in this domain. Fifteen studies exhibited unclear risk of selective reporting (primarily due to unverifiable unreported analyses, including potential negative results), with the remaining studies showing low risk.

Publication bias was assessed using comparison-corrected funnel plots for CRF, body composition, and metabolic profiles. Most studies were symmetrically distributed around the zero line, with regression lines parallel to the X-axis, indicating a low likelihood of publication bias (Supplementary Figures S3-S17). The results of Egger's regression are presented in Supplementary Table S3, with P ≥ 0.05, suggesting no statistically significant evidence of publication bias.

Network Meta-Analysis Results

The NMA included two CRF indicators (VO_{2peak}, HR), six anthropometric and body composition indicators (Weight, BMI, WC, BF%, FFM, WHR), and seven metabolism-related indicators (FG, HOMA-IR, Insulin, TG, TC, HDL, LDL). Figure 2 illustrates the NMA network for the efficacy of three or four exercise modalities on 12 indicators, while the remaining networks are presented in Supplementary Figure S18. In the network maps, each node represents a specific intervention, with node size proportional to the number of participants and line thickness reflecting the number of studies comparing the interventions. The SUCRA probability rankings for the effectiveness of various exercise modalities on health outcomes in children and adolescents with overweight and obesity are detailed in Supplementary Figures S19-S33.

Cardiorespiratory Fitness

CRF was assessed by VO_{2peak} and HR. Data from 19 studies (n = 666) involving three intervention types were included in the NMA for VO_{2peak}. Compared to the control group, AE [MD = 1.7, 95% CI (0.6, 2.9)], CE [MD = 2.2, 95% CI (0.9,

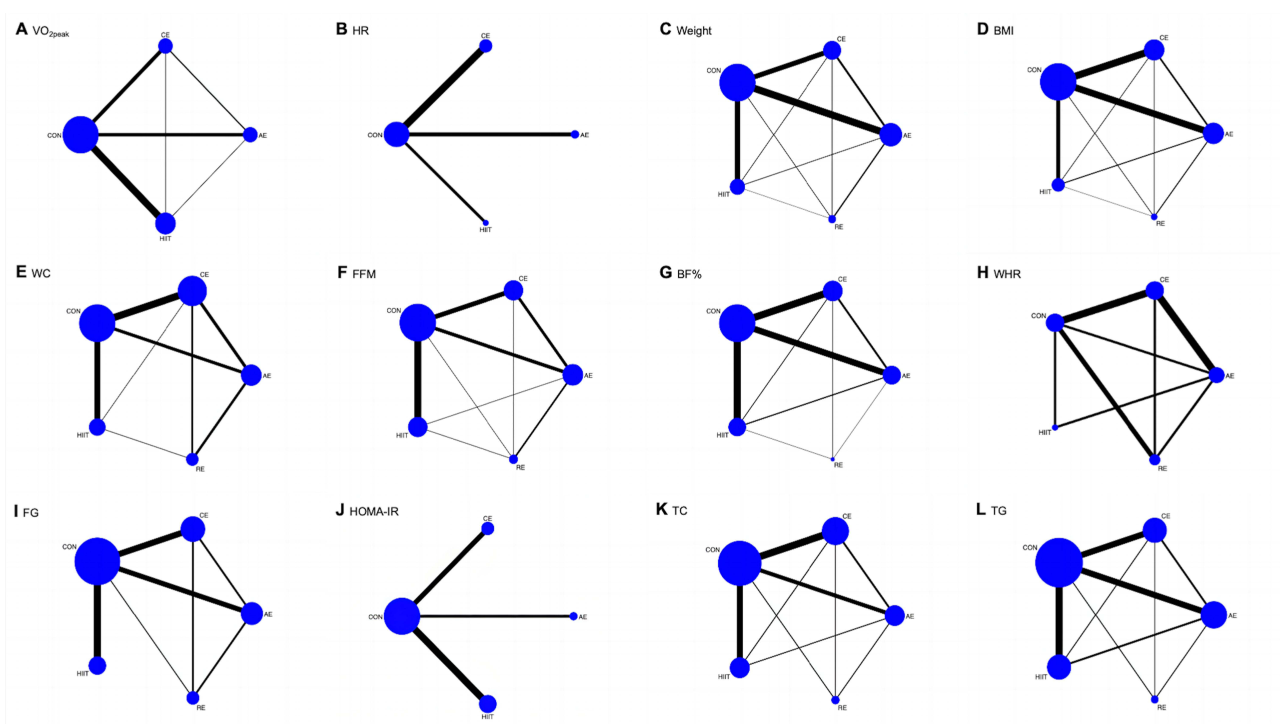

Figure 2 Network map of RCTs comparing the effects of different exercise interventions in individuals with overweight or obesity: (**A**) Oxygen uptake peak (VO_{2peak}); (**B**) Heart rate (HR); (**C**) Weight; (**D**) Body mass index (BMI); (**E**) Waist circumference (WC); (**F**) Free fat mass (FFM); (**G**) Body fat percent (BF%); (**H**) Waist-Hip ratio (WHR); (**I**) Fasting glucose (FG); (**J**) Homeostatic model assessment of insulin resistance (HOMA-IR); (**K**) Total cholesterol (TC); (**L**) Triglyceride (TG).
Abbreviations: AE, aerobic exercise; RE, resistance exercise; CE, combined exercise; HIIT, high-intensity interval training; CON, control group.

3.5)], and HIIT [MD = 3.3, 95% CI (2.4, 4.3)] led to improvements in VO_{2peak} with children and adolescents with overweight and obesity (Figure 3, Supplementary Figure S34). For HR, six studies reported data. Only the HIIT showed a significant reduction compared to the control group [MD = −8.1, 95% CI (−10.9, −5.4)] (Figure 3, Supplementary Figure S35). Pairwise comparisons revealed that HIIT was superior to AE [MD = 6.5, 95% CI (3.1, 9.9)] and CE [MD = 6.0, 95% CI (2.4, 9.6)] in reducing HR and outperformed other interventions in increasing VO_{2peak} (Figure 4). The SUCRA rankings indicated that, compared with other exercise methods, HIIT may be a more effective intervention for improving VO_{2peak} (SUCRA = 96.8) and reducing HR (SUCRA = 99.8) (Figure 5). Overall, HIIT showed significantly greater efficacy than other interventions for improving CRF.

Body Composition

A NMA on Weight and BMI included 42 studies (n = 1882) across four intervention types. Compared to the control group, all interventions produced a significant reduction in Weight: AE [MD = −3.7, 95% CI (−4.6, −2.8)], RE [MD = −2.8, 95% CI (−4.5, −1.2)], CE [MD = −3.5, 95% CI (−4.5, −2.4)], and HIIT [MD = −2.3, 95% CI (−3.4, −1.3)]. Similarly, BMI decreased significantly: AE [MD = −1.5, 95% CI (−2.1, −0.9)], RE [MD = −1.1, 95% CI (−2.2, −0.02)], CE [MD = −1.5, 95% CI (−2.1, −0.9)], and HIIT [MD = −1.0, 95% CI (−1.7, −0.3)]. For WC, data from 24 studies revealed significant improvements with AE [MD = −4.7, 95% CI (−6.1, −3.3)], RE [MD = −4.0, 95% CI (−5.7, −2.5)], CE [MD = −4.4, 95% CI (−5.4, −3.5)], and HIIT [MD = −2.9, 95% CI (−4.1, −1.6)] compared to controls (Figure 3, Supplementary Figures S36-S38). Pairwise comparisons indicated AE was most effective for reducing Weight, as shown in Figure 4. Among all the evaluated exercise methods, the SUCRA rankings indicated that AE was the most relatively effective intervention for Weight (SUCRA = 87.3), BMI (SUCRA = 80.2), and WC (SUCRA = 87.6) (Figure 5).

For body composition, 38, 22, and 6 studies evaluated BF%, FFM, and WHR, respectively. BF% significantly decreased with AE [MD = −2.4, 95% CI (−3.3, −1.5)], RE [MD = −2.6, 95% CI (−4.7, −0.4)], CE [MD = −3.0, 95% CI (−3.8, −2.1)], and HIIT [MD = −2.2, 95% CI (−3.0, −1.5)]. CE significantly improved FFM [MD = 1.0, 95% CI (0.1, 2.0)] and reduced WHR [MD = −0.04, 95% CI (−0.08, −0.003)] compared to controls (Figure 3, Supplementary Figures S39-S41). Pairwise comparisons showed CE had the greatest effect on increasing FFM (Figure 4). SUCRA rankings indicated CE as the most relatively effective intervention for reducing BF% (SUCRA = 84.8), increasing FFM (SUCRA = 95.4), and lowering WHR (SUCRA = 71.8) (Figure 5). The comprehensive results show that both AE and CE have demonstrated good effects in improving different aspects of body composition.

Metabolic Indicators

Blood Glucose and Insulin Indicators

FG, HOMA-IR, and insulin levels were assessed across 15 studies (n = 651) for FG and 12 studies for HOMA-IR and insulin. Compared to the control group, AE [MD = −0.36, 95% CI (−0.67, −0.06)], CE [MD = −0.50, 95% CI (−0.77, −0.22)], and HIIT [MD = −0.31, 95% CI (−0.58, −0.04)] significantly reduced FG levels. CE demonstrated the largest reduction in HOMA-IR [MD = −2.60, 95% CI (−4.00, −1.20)] and insulin levels [MD = −10.24, 95% CI (−14.88, −5.46)] compared to controls (Figure 3, Supplementary Figure S42-S45). Pairwise comparisons confirmed CE as the most effective intervention for improving FG and HOMA-IR, while RE showed greater efficacy in reducing TG and TC (Figure 4).

Lipid Indicators

TG, TC, HDL, and LDL levels were evaluated in 14, 13, 14, and 12 studies, respectively. TG levels significantly improved with AE [MD = −29.77, 95% CI (−48.91, −13.84)], CE [MD = −28.28, 95% CI (−49.74, −10.74)], and HIIT [MD = −31.83, 95% CI (−47.39, −15.96)]. For TC, CE [MD = −19.04, 95% CI (−37.50, −2.11)] and HIIT [MD = −21.51, 95% CI (−38.07, −4.68)] achieved significant reductions compared to controls. All intervention regimens tested had minimal or non-significant effects on HDL levels compared to baseline. AE [MD = −10.85, 95% CI (−22.68, −1.87)], CE [MD = −17.83, 95% CI (−26.50, −11.38)], and HIIT [MD = −17.04, 95% CI (−22.57, −11.32)] effectively lowered LDL levels (Figure 3, Supplementary Figure S45-S49). In summary, CE demonstrates favorable effects in blood glucose metabolism regulation. In terms of reducing lipid levels, RE shows marked advantages over other intervention methods.

(blue)	Significance
(grey)	Significance
(light blue)	No Significance
(white)	No Significance

A	HR			
VO_{2peak}	AE	-0.47 (-3.58, 2.58)	-6.45 (-9.89, -3.1)	1.64 (-0.31, 3.63)
	-0.45 (-1.95, 1.09)	CE	-6 (-9.63, -2.35)	2.1 (-0.2, 4.51)
	-1.61 (-3.02, -0.09)	-1.16 (-2.7, 0.45)	HIIT	8.09 (5.37, 10.92)
	1.72 (0.58, 2.93)	2.17 (0.85, 3.51)	3.33 (2.36, 4.26)	CON

B	BMI				
Weight	AE	0.41 (-0.64, 1.45)	0.03 (-0.7, 0.75)	0.54 (-0.32, 1.39)	1.54 (0.96, 2.11)
	-0.87 (-2.52, 0.78)	RE	-0.38 (-1.52, 0.75)	0.13 (-1.12, 1.37)	1.13 (0.03, 2.23)
	-0.25 (-1.43, 0.93)	0.62 (-1.13, 2.37)	CE	0.51 (-0.34, 1.37)	1.51 (0.95, 2.07)
	-1.4 (-2.72, -0.09)	-0.53 (-2.41, 1.35)	-1.15 (-2.54, 0.24)	HIIT	1 (0.3, 1.7)
	-3.71 (-4.61, -2.82)	-2.84 (-4.49, -1.19)	-3.46 (-4.48, -2.45)	-2.31 (-3.36, -1.26)	CON

C	FFM				
BF%	AE	0.35 (-1.17, 1.86)	1.2 (0.11, 2.31)	-0.45 (-1.75, 0.86)	0.15 (-0.9, 1.21)
	0.16 (-2, 2.33)	RE	0.86 (-0.76, 2.47)	-0.79 (-2.56, 0.98)	-0.19 (-1.84, 1.46)
	0.55 (-0.51, 1.64)	0.39 (-1.72, 2.52)	CE	-1.65 (-2.9, -0.42)	-1.05 (-2.02, -0.09)
	-0.18 (-1.26, 0.93)	-0.34 (-2.59, 1.93)	-0.73 (-1.85, 0.38)	HIIT	0.6 (-0.3, 1.5)
	-2.4 (-3.27, -1.52)	-2.56 (-4.73, -0.39)	-2.95 (-3.84, -2.08)	-2.22 (-3.01, -1.46)	CON

D	WHR				
WC	AE	0.02 (-0.04, 0.09)	0 (-0.05, 0.05)	0 (-0.06, 0.07)	0.04 (0, 0.09)
	-0.61 (-1.79, 0.57)	RE	-0.02 (-0.08, 0.04)	-0.02 (-0.1, 0.06)	0.02 (-0.03, 0.08)
	-0.28 (-1.57, 1.03)	0.34 (-1.12, 1.79)	CE	0 (-0.07, 0.07)	0.04 (0, 0.08)
	-1.8 (-3.66, 0)	-1.18 (-3.19, 0.74)	-1.53 (-3.07, -0.03)	HIIT	0.04 (-0.02, 0.11)
	-4.65 (-6.11, -3.29)	-4.03 (-5.7, -2.51)	-4.37 (-5.39, -3.47)	-2.85 (-4.06, -1.65)	CON

E	FG				
HOMA-IR	AE	-0.09 (-0.57, 0.41)	-0.14 (-0.49, 0.23)	0.05 (-0.36, 0.46)	0.36 (0.06, 0.67)
	-	RE	-0.05 (-0.54, 0.44)	0.14 (-0.44, 0.7)	0.45 (-0.06, 0.94)
	1.27 (-1, 3.54)	-	CE	0.18 (-0.2, 0.57)	0.5 (0.22, 0.77)
	-0.16 (-2.31, 2.03)	-	-1.43 (-3.25, 0.43)	HIIT	0.31 (0.04, 0.58)
	-1.34 (-3.13, 0.48)	-	-2.61 (-3.98, -1.23)	-1.18 (-2.41, 0.03)	CON

F	TC				
TG	AE	-12.48 (-57.17, 34.94)	-2.61 (-26.01, 22.99)	-5.1 (-26.96, 20.79)	16.41 (-2.6, 39)
	3.59 (-38.99, 46.24)	RE	9.89 (-35.82, 54.62)	7.52 (-39.29, 54.44)	28.97 (-15.47, 73.56)
	-1.65 (-23.48, 21.78)	-5.13 (-47.47, 38.55)	CE	-2.52 (-24.2, 21.21)	19.04 (2.11, 37.5)
	2.17 (-20.23, 20.42)	-1.51 (-47.67, 41)	3.62 (-22.53, 24.77)	HIIT	21.51 (4.68, 38.07)
	-29.77 (-48.91, -13.84)	-33.38 (-77.06, 7.49)	-28.28 (-49.74, -10.74)	-31.83 (-47.39, -15.96)	CON

Figure 3 Matrix of the network meta-analysis results: (**A**) Oxygen uptake peak (VO_{2peak}) and Heart rate (HR); (**B**) Weight and Body mass index (BMI); (**C**) Body fat percent (BF%) and Free fat mass (FFM); (**D**) Waist circumference (WC) and Waist-Hip ratio (WHR); (**E**) Homeostatic model assessment of insulin resistance (HOMA-IR) and Fasting glucose (FG); (**F**) Triglyceride (TG) and Total cholesterol (TC).

Notes: -, No RE group reported data for this outcome. The league table demonstrates the relative efficacy for each pair of comparison showing the effect of exercise type in each row compared with exercise type in each column. Data are presented as mean differences (95% CI).

Abbreviations: AE, aerobic exercise; RE, resistance exercise; CE, combined exercise; HIIT, high-intensity interval training; CON, control group.

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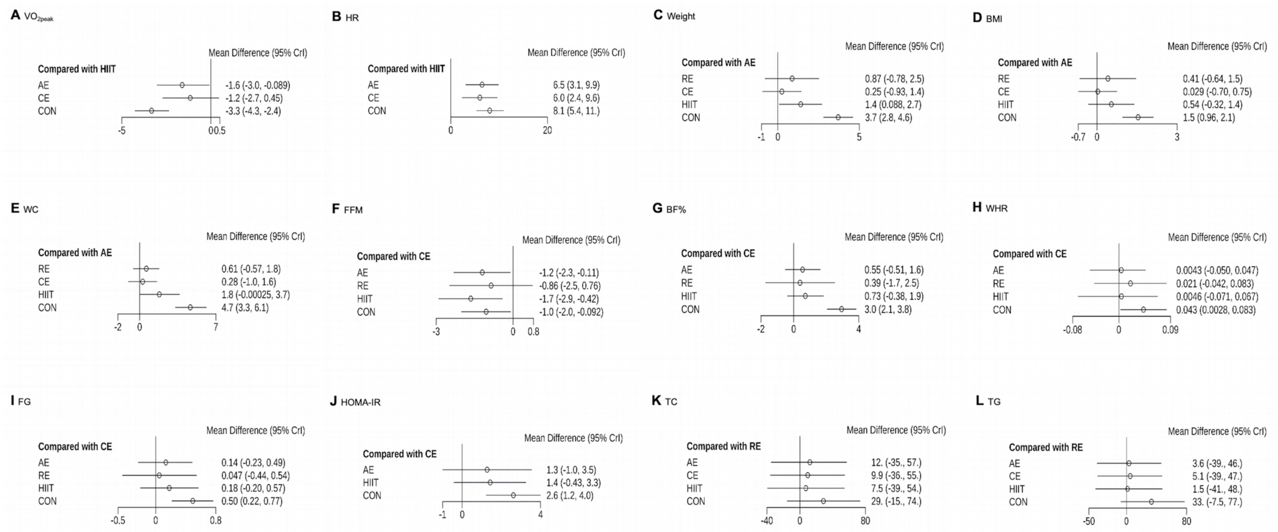

Figure 4 Forest plot of the results of network meta-analysis: (**A**) Oxygen uptake peak (VO_{2peak}); (**B**) Heart rate (HR); (**C**) Weight; (**D**) Body mass index (BMI); (**E**) Waist circumference (WC); (**F**) Free fat mass (FFM); (**G**) Body fat percent (BF%); (**H**) Waist-Hip ratio (WHR); (**I**) Fasting glucose (FG); (**J**) Homeostatic model assessment of insulin resistance (HOMA-IR); (**K**) Total cholesterol (TC); (**L**) Triglyceride (TG).

Abbreviations: AE, aerobic exercise; RE, resistance exercise; CE, combined exercise; HIIT, high-intensity interval training; CON, control group.

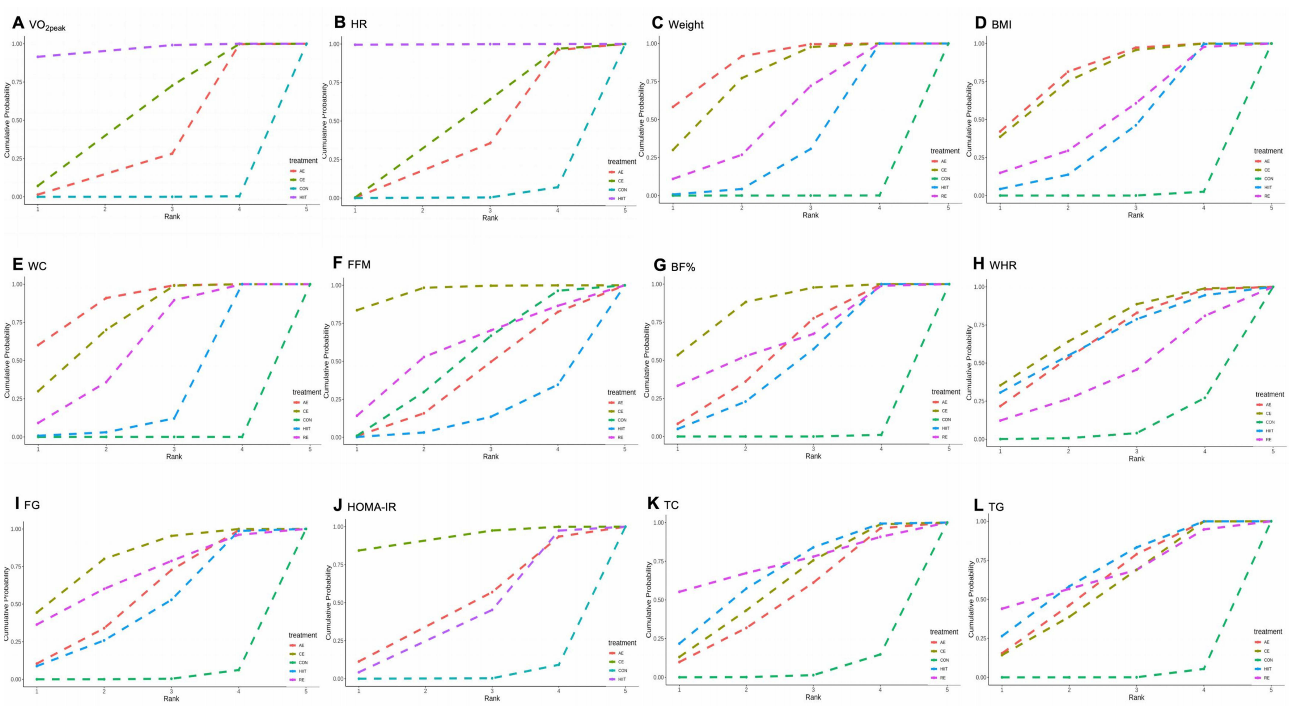

Figure 5 Cumulative ranking probability graph of the effectiveness of each exercise intervention: (**A**) Oxygen uptake peak (VO_{2peak}); (**B**) Heart rate (HR); (**C**) Weight; (**D**) Body mass index (BMI); (**E**) Waist circumference (WC); (**F**) Free fat mass (FFM); (**G**) Body fat percent (BF%); (**H**) Waist-Hip ratio (WHR); (**I**) Fasting glucose (FG); (**J**) Homeostatic model assessment of insulin resistance (HOMA-IR); (**K**) Total cholesterol (TC); (**L**) Triglyceride (TG).

Abbreviations: AE, aerobic exercise; RE, resistance exercise; CE, combined exercise; HIIT, high-intensity interval training; CON, control group.

SUCRA Rankings

SUCRA analysis identified that CE showed the maximum relative efficacy for improving FG (SUCRA = 79.9), HOMA-IR (SUCRA = 93.9), insulin (SUCRA = 95.3), and HDL (SUCRA = 69.4). RE was ranked highest for reducing TG (SUCRA = 67.0), TC (SUCRA = 72.8), and LDL (SUCRA = 72.5), though the magnitude of difference compared to other exercises was modest in some cases (Figure 5, Supplementary Figure S50). In addition, the summary of findings for detailed NMA results is shown in Table 2.

Coherence and Heterogeneity Analysis

The convergence diagnostics of the computational models, presented in Supplementary Figures S51-S65, showed that all scale reduction factor values approached 1, with trace and density plots exhibiting normal distributions. These findings indicate robust model convergence, as further supported by Supplementary Figures S66-S80. The DIC, I2, and other parameters of the random-effects model revealed minimal inconsistencies, confirming the reliability and stability of the results (Supplementary Table S4). Local consistency testing using nodal analysis demonstrated good agreement among direct, indirect, and network comparison results for all indicators (Supplementary Figures S81-S85). Additionally, heterogeneity test results, provided in Supplementary Figures S86-S100, further support the robustness of the analysis.

Discussion

This NMA offers a comprehensive analysis of exercise interventions for improving the health of children and adolescents with overweight and obesity. By synthesizing direct and indirect evidence from 51 RCTs involving 2263 participants, we compared four intervention types. The findings indicate that AE is the relatively effective for reducing Weight, BMI, and WC, while CE, combining aerobic and resistance exercise, excels in reducing BF%, increasing FFM, and lowering

Table 2 Summary of Findings for Network Meta-Analysis Results

Health Outcomes		Studies	Number of Participants	Most Effective Intervention	Relative Effect MD (95% CI) vs CON	SUCRA (%)
CRF	VO_{2peak}	19	666	HIIT	**3.33 (2.36, 4.26)**	96.8
	HR	6	413	HIIT	**−8.09 (−10.92, −5.37)**	99.8
Body composition	Weight	42	1882	AE	**−3.71 (−4.61, −2.82)**	87.3
	BMI	42	1883	AE	**−1.54 (−2.11, −0.96)**	80.2
	WC	24	991	AE	**−4.65 (−6.11, −3.29)**	87.6
	BF%	38	1391	CE	**−2.95 (−3.84, −2.08)**	84.8
	FFM	22	937	CE	**1.05 (0.09, 2.02)**	95.4
	WHR	6	307	CE	**−0.04 (−0.08, −0.003)**	71.8
Metabolic indicators	FG	15	651	CE	**−0.50 (−0.77, −0.22)**	79.9
	HOMA-IR	12	475	CE	**−2.61 (−3.98, −1.23)**	93.9
	Insulin	12	475	CE	**−10.24 (−14.88, −5.46)**	95.3
	TG	14	473	RE	−33.38 (−77.06, 7.49)	67.0
	TC	13	452	RE	−28.97 (−73.56, 15.47)	72.8
	HDL	14	473	CE	−4.03 (−1.92, 10.02)	69.4
	LDL	12	415	RE	−21.26 (−50.19, 7.77)	72.5

Notes: SUCRA is the cumulative ranking probability (0–100%). The higher the value, the better the effect of the intervention on this indicator. Bold indicates statistical significance. Total studies: 51 RCTs. Total Participants: 2263. Patient or population: Children and adolescents with overweight and obese. Interventions: AE, RE, CE, HIIT. Comparator (reference): CON. Outcomes: HR, VO_{2peak}, Weight, BMI, WC, BF%, FFM, WHR, FG, HOMA-IR, Insulin, TG, TC, HDL, LDL.
Abbreviations: AE, aerobic exercise; BF%, body fat percent; BMI, body mass index; CE, combined exercise; CON, control group; CRF, cardiorespiratory fitness; FFM, free fat mass; FG, fasting glucose; HDL, high-density lipoprotein; HIIT, high-intensity interval training; HOMA-IR, homeostatic model assessment of insulin resistance; HR, heart rate; LDL, low-density lipoprotein; MD, mean difference; RCTs, randomized controlled trials; RE, resistance exercise; SUCRA, surface under the cumulative ranking curve; TC, total cholesterol; TG, triglyceride; VO_{2peak}, oxygen uptake peak; WC, waist circumference; WHR, waist-hip ratio.

WHR. CE also emerged as a notably effective intervention for improving blood glucose and insulin control. HIIT demonstrated a significant impact on enhancing CRF, while RE proved optimal for improving lipid profiles.

CRF during childhood and adolescence is a critical predictor of future health and is independently associated with cardiovascular risk. High CRF in youth reduces the risk of CVD and premature mortality in adulthood. Our NMA findings identified HIIT as the most effective exercise modality for improving CRF in children and adolescents with overweight and obesity, surpassing AE, CE, and RE. These results align with previous studies.[81,82] For example, Kargarfard et al demonstrated that 8 weeks of HIIT improved VO_{2peak} by 4.72 mL/kg/min in male adolescents with normal and obesity, surpassing the effects of AE.[81] Similarly, Racil et al reported that HIIT was more effective than moderate-intensity interval training (MIIT) in enhancing CRF among adolescent girls with obesity.[82] The superior efficacy of HIIT may be attributed to its ability to increase oxygen utilization, elevate heart rate, and burn more calories in a shorter time.[83] This process enhances blood flow, improves cardiac function, and optimizes oxygen exchange in the lungs, thereby boosting CRF.[84] However, since adolescents are in a critical growth and development stage, their positive metabolic adaptations to physical exercise occur rapidly, yet the duration of such adaptive states is relatively transient. Based on the findings, this study suggests that when all other relevant conditions are optimized, sustained HIIT for a duration exceeding 12 weeks is more likely to yield favorable improvements in the CRF of adolescents with overweight or obesity. The change in VO_{2peak} induced by HIIT (3.33 mL/kg/min) exceeds the minimum clinically important difference (MCID) for children's CRF (1.5 mL/kg/min), can elevate the fitness category from "poor" to "moderate",[85] and thus confirms its clinical relevance. In addition, it is imperative to note that HIIT may not be suitable for individuals without prior training experience. During training, the principles of "medical priority, safety first, and psychological synchronization" and the training model of "low-impact, slow-progression, and fun-oriented" should be adhered to. Therefore, healthcare professionals should consider patients' physical condition and preferences when recommending exercise regimens to ensure safety and effectiveness in managing obesity.

Weight and BMI are primary indicators for assessing and managing obesity, while WC is a key marker of visceral fat and an independent predictor of all-cause mortality. BF% and FFM further reflect changes in body composition and are critical for evaluating the effectiveness of interventions.[83,86] Our findings indicate that AE is the relatively effective exercise intervention for reducing Weight, BMI, and WC in children and adolescents with overweight and obesity, while CE may be optimal for increasing FFM and reducing BF% and WHR. These results align with previous studies.[87–90] Research shows that AE significantly reduces Weight, BMI, and body fat, particularly in the trunk area.[87,88] For instance, Teng found that in middle school students with obesity, AE alone led to greater weight loss than AE combined with RE, while CE was more effective in reducing BF% and WHR due to RE's ability to reduce fat while increasing muscle mass.[89] Similarly, Li reported that a 4-week CE program reduced BF% by an average of 6.94% in primary school students with obesity.[90] The effectiveness of AE may be due to enhanced lipid oxidation and utilization of free fatty acids and glucose, which reduces adipocyte size and fat accumulation.[91,92] In contrast, RE builds lean mass and increases resting energy expenditure,[86] thereby complementing AE's fat-loss effects. The combination of AE and RE in CE produces a synergistic effect, significantly reducing BF% and increasing FFM in this population. This not only enhances bone density and reduces the risk of osteoporosis, but also improves motor ability and balance, reducing the risk of falls and injuries, thus exerting positive impacts on the long-term physical health and quality of life of children and adolescents with obesity. For populations aiming at rapid weight loss and reduction of visceral fat, AE can be used as the preferred modality, while CE may be a more optimal choice for those hoping to improve body composition and increase muscle mass. Furthermore, relevant studies have pointed out that a 5% reduction in BMI, and WC is associated with improvements in visceral fat and cardiometabolic risk.[93] The results of our study show that exercise led to an average reduction of approximately 4–6% in participants' BMI and a decrease of 4.7 cm in WC, which are close to the thresholds and benchmarks for clinical benefits. Therefore, it is recommended that clinicians incorporate these exercise interventions into the health management plans for children and adolescents with overweight and obesity. The effects should be evaluated by regularly monitoring relevant indicators, and the plans should be adjusted according to individual conditions to improve the success rate of treatment, enhance compliance and long-term participation, and lay the foundation for their long-term health.

Metabolic syndrome (MS) is a complex cluster of metabolic abnormalities characterized by obesity, hyperlipidemia, hepatic steatosis, and insulin resistance, posing significant health risks.[94] Individuals with overweight and obesity often experience poor glycemic control, increasing their risk of diabetes.[83] The American College of Sports Medicine recommends at least 150 minutes of moderate-intensity exercise per week to effectively lower blood lipid levels.[95] Our NMA results revealed that CE improves blood glucose and insulin levels in children and adolescents with overweight and obesity, while RE effectively reduces lipid levels. These findings align with existing research.[96–99] Chen et al reported that 12 weeks of CE lowered FG, TC, and LDL levels while increasing HDL in adolescents with obesity, reducing the risk of MS.[96] Other studies confirmed AE's role in reducing insulin resistance and inflammation.[97] Compared to AE, RE more effectively enhances basal metabolic rate, improves insulin resistance, and supports glycemic control and bone density in MS patients.[98] Additionally, HIIT combined with RE improves FG, LDL, and insulin sensitivity, while moderate-intensity continuous training (MICT) combined with RE effectively reduces TG.[99] The American Diabetes Association recommends RE at least twice weekly at mild-to-moderate intensity for T2DM management.[100] The efficacy of CE can be attributed to its ability to increase insulin receptor density, enhance the capacity of glucose transporter 4 (GLUT4) transport capacity on skeletal muscle membranes, regulate myokine secretion, improve insulin sensitivity, and control blood glucose. Furthermore, CE promotes adrenaline and norepinephrine secretion, increases lipoprotein lipase (LPL) activity, reduces visceral fat, enhances reverse cholesterol transport, and improves lipid metabolism.[98,101] Both RE and AE also regulate adipokines such as resistin, leptin, and lipocalin, reduce vascular inflammation, improve endothelial function, and mitigate hypertension, hyperglycemia, and hyperlipidemia in individuals with obesity or overweight.[101] Relevant studies have demonstrated that a reduction in TC of $\geq$10 mg/dL is associated with a significant decrease in the risk of atherosclerosis, and a reduction in TG of $\geq$30 mg/dL can lower the risk of non-alcoholic fatty liver disease.[102] The results of our study show that exercise promoted a reduction in TC of $\geq$29 mg/dL and a reduction in TG of $\geq$33 mg/dL in participants, which are consistent with the benchmarks for metabolic benefits. In addition, it is crucial to carry out lifestyle intervention (including reasonable diet and work–rest schedule, etc) and exercise therapy at an early stage. This approach can not only improve the current metabolic status (reducing the risk of MS) but also prevent and delay the progression of obesity and insulin resistance to T2DM, non-alcoholic fatty liver disease, and CVD (adult-onset chronic diseases). Clinicians should actively promote these intervention measures and provide continuous support and guidance for children and adolescents with overweight and obesity.

Strengths and Limitations

This study is the first to utilize NMA to evaluate the effects of various exercise modalities on the health status of children and adolescents with overweight and obesity. It provides a comprehensive analysis of multiple health indicators, including Weight, BMI, WC, BF%, FFM, WHR, HR, VO_{2peak}, blood glucose, insulin, and lipid profiles. By comparing the impacts of different exercise types on these indicators, the study offers valuable evidence for coaches, researchers, and policymakers to design effective exercise programs for this population.

However, certain limitations should be acknowledged. First, we postulate the transitivity assumption (ie, the validity of each comparison for inclusion in the network), while recognizing that heterogeneity in study populations (eg, age ranges spanning childhood to late adolescence, divergent baseline adiposity levels) and intervention protocols (eg, variations in duration and modality) may compromise this assumption. For instance, HIIT trials predominantly enrolled adolescent participants, whereas certain resistance exercise studies focused on preadolescents, potentially introducing developmental stage as a confounding variable. Although consistency checks revealed no significant inconsistencies, the statistical power to detect subtle violations of transitivity remains limited-particularly within comparison loops characterized by sparse data. Specifically, HR data lacked RE arm (encompassing only 6 studies and 3 interventions); networks for WHR included fewer than 10 RCTs; and LDL analyses were composed predominantly of small-scale studies from a single region. Consequently, results for these outcomes should be interpreted with caution, as sparse networks may lead to a reduction in result robustness and restrict the ability to detect inconsistencies. Beside, priority should also be given to the available direct evidence. Some outcomes (such as WHR) may not be suitable for NMA, and future research needs to increase the sample size in these areas to improve accuracy. Second, although the included studies were of moderate-to-high quality, the overall sample size remained relatively small, with a persistent lack of high-quality, large-sample studies. Additionally, variations in cultural factors (such as diet, lifestyle, and school systems) may increase the risk of bias. Despite statistical testing, regional journal, language bias and selective outcome reporting in small trials could influence pooled estimates. Therefore, the generalizability of the results requires careful consideration. Third, due to limited direct comparisons between some exercise interventions and the lack of follow-up data, long-term outcomes are not within the scope of the study, so the results should be interpreted with caution. Additionally, HIIT's high intensity may reduce adherence over time, whereas game-based AE (eg, active video games) demonstrates better engagement among youth. CE balances variety but requires longer sessions. Future studies should evaluate adherence patterns and explore preference-based tailoring to improve sustainability. Finally, beyond efficacy, real-world implementation barriers warrant consideration. Supervised HIIT necessitates specialized equipment (eg, treadmills, heart rate monitors) and trained personnel, increasing costs in community settings. Resistance training demands access to weights or resistance bands, posing challenges in resource-limited areas. In contrast, aerobic exercises (eg, walking, soccer) are more scalable but still require adherence monitoring. Future pragmatic trials should evaluate cost-effectiveness and feasibility of integrating these interventions into school or community programs with varying resource levels. Furthermore, this study focused solely on exercise types without age and gender stratification, so the results only represent the average effects of these subgroups. Future research could explore non-pharmacological interventions such as dietary and sleep modifications and assess the effects of exercise order, intensity, frequency, and duration on health outcomes in adolescents with overweight and obesity of different ages and genders.

Conclusion

In conclusion, our study demonstrates that different exercise modalities yield distinct benefits for various health indicators in children and adolescents with overweight and obesity. HIIT appears to be relatively effective in improving CRF, while AE excels in reducing Weight, BMI, and WC—findings for which our research provides relatively strong support. CE may be superior for decreasing body fat and increasing muscle mass. RE could be quite effective for improving lipid profiles, but the evidence in this domain is still somewhat limited and requires further validation. Additionally, CE seems to be an optimal intervention for managing blood glucose and insulin levels. While our NMA provides valuable evidence to guide the development of targeted exercise interventions, the limitations of indirect comparisons highlight the need for more robust RCTs and large-scale observational studies to validate these findings. Future research should focus on the precise design of personalized exercise programs to facilitate the translation of evidence into clinical practice.

Data Sharing Statement

The data generated and analyzed in this study are either included within the published article itself or can be found in the data repositories referenced. The review protocol was registered in PROSPERO (International Prospective Register of Systematic Reviews) under the registration number CRD42024595872 and is available at https://www.crd.york.ac.uk/prospero/#myprospero.

Ethics Approval and Informed Consent

Since this is a systematic review with network meta-analysis no ethical considerations are applicable.

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We hereby confirm that the manuscript submitted for publication is original and has not been previously published, except as an abstract or preprint in any language or format, nor has it been concurrently submitted for print or electronic publication elsewhere. We also attest that each individual listed as an author has made a significant contribution to the work, in line with the ICMJE authorship criteria, and is willing to accept public accountability for their contributions. Furthermore, all authors grant their consent for any investigation into potential misconduct that may be alleged in connection with the work.

Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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Disclosure

The authors report no conflicts of interest in this work.

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