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REVIEW

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Efficacy of lifestyle interventions to treat pediatric obesity: A systematic review and multivariate meta-analysis of randomized controlled trials

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Summary

The aim of this study was to provide a quantitative synthesis of the effects of randomized controlled pediatric lifestyle interventions in treating obesity among 11–17-year-old children. We conducted a systematic review and meta-analysis on the randomized controlled trials, consisting of actual exercise training and nutrition education, published between January 2000 and August 2022. The initial search yielded 2598 articles, with eight articles meeting the inclusion criteria. The articles were analyzed using a multivariate random effects model. The primary outcome variables were body mass index (BMI), standardized BMI (BMIz), and waist circumference (WC). Our analyses showed that lifestyle interventions were efficacious in improving BMI (−1.77 kg/m^2, 95% CI [−2.70, −0.83], $p < 0.001$), BMIz (−0.30, 95% CI [−0.45, −0.16], $p < 0.001$), and WC (−3.32 cm, 95% CI [−5.35, −1.29], $p < 0.001$) in children with overweight and obesity. In addition, moderation analyses suggested that the efficacy of the lifestyle interventions correlated positively with participants' weight status and was enhanced when an intervention was boosted with a longer intervention duration and higher frequency. In conclusion, the current evidence suggests that lifestyle interventions are efficacious in treating children with obesity. The available evidence further indicates that duration, frequency, along weight status, were moderating the effectiveness of these lifestyle interventions.

KEYWORDS

adolescents, effectiveness, overweight, weight gain

1 | INTRODUCTION

The prevalence of pediatric obesity has been recognized as one of the major public health challenges of the 21st century,[1,2] as pediatric obesity is associated with a myriad of morbidities, for example, cardiovascular diseases,[3,4] musculoskeletal disorders,[5] type II diabetes mellitus,[6] metabolic syndrome,[7] blood pressure,[8,9] and an increased likelihood of adverse psychological effects, for example, depression, low perceived health-related quality of life, emotional and behavioral disorders, body dissatisfaction, and low self-esteem.[10–12] Although pediatric obesity is a global challenge, there are approximately 14.4 million children suffering from obesity in the United States (US) alone.[13] This is problematic as the early development of overweight and obesity increases the risk of obesity in adulthood.[14–16] Obesity has concerning economic ramifications on the US economy,[17] with estimated yearly economic cost in the US alone being nearly $173 billion in 2019.[18]

Obesity is a complex and multifactorial disease intertwining environmental, genetics, and an unhealthy lifestyle (e.g., lack of physical activity and an unhealthy diet).[19,20] Due to this complexity,

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prevention, and treatment efforts for pediatric obesity are as multileveled and complex as their causes, and these changes require comprehensive lifestyle changes involving regular exercise and physical activity and healthy dietary behaviors.[21,22] Previous research has found lifestyle interventions, that is, interventions consisting of exercise, nutrition education, and behavior modifications, to be the preferred non-invasive strategy to prevent/treat pediatric obesity.[23–26] Evidence further suggests that compared with a single intervention approach (e.g., physical activity or diet only), combined exercise and diet interventions have better efficacy in treating overweight and obesity in children and adolescents.[23,24,27–29]

Several meta-analyses have reported that lifestyle interventions can be efficacious in improving children and adolescents' weight status, body mass index (BMI), waist circumference (WC), and reducing numerous metabolic risk factors, for example, low-density lipoprotein and fasting insulin.[11,30–34] Previous meta-analyses have suggested that pediatric lifestyle interventions can be efficacious in reducing BMI, with the effects ranging from $-0.09\ kg/m^2$ (95% CI [−0.16, −0.03]) to $-2.00\ kg/m^2$ (95% CI [−1.5, −2.5]).[29,35,36] In addition, Stoner et al. found lifestyle interventions to be effective in reducing participants' WC, with an average effect being around −3.00 cm (95% CI [−4.8, −1.30]).[29] However, a recent meta-analysis by Hamid and Sazlina ($k = 14$, age range 9–12 years) reviewing the studies from 2000 to 2017 found that, on average, lifestyle interventions did not have a statistically significant effect on standardized BMI (BMIz) and WC.[37] Similarly, research has shown inconsistency in the efficacy of obesity interventions conducted in the school environment.[35,36,38] For instance, a Connelly, Duaso, and Butler meta-analysis showed that 11 obesity trials were effective, whereas 17 were ineffective in reducing obesity.[38] One of the main factors distinguishing effective from ineffective trials is if the intervention included actual exercise rather than the recommendation of exercise. Similar conclusions can be drawn from the empirical study of McMurray et al.,[27] which examined school-based obesity prevention studies. Their results showed no statistically significant changes in BMI, but skinfold-measured fat reductions and oxygen consumption (VO2) max increases were greater in the combination of exercise and nutrition education group than in the education-only or control groups.

Our review of the current literature exposed several gaps in knowledge that warrant this meta-analytic review. First, the findings from the previous meta-analyses are inconsistent with the large heterogeneity in the sizes of effects.[17] This large heterogeneity may be partially due to the contents of different lifestyle interventions, as the interventions have varied greatly based on frequency (once to several times per week), duration (a few weeks to years), and the number of intervention components (e.g., physical activity, nutrition education, and behavior modification). Potential moderators (i.e., frequency and duration) are needed to explain such heterogeneity and identify the effective cut-point for the weight loss program. In addition, previous meta-analyses (i.e., fixed effects and random effects models) have failed to account for the within-study dependent effects that assume independence among the effect sizes to be pooled. Given this methodological limitation, it is challenging to establish robust results to determine the effectiveness of lifestyle interventions. Finally, a large portion of the published lifestyle interventions have not offered actual exercise training but exercise/physical activity recommendations or education about the benefits of exercise/physical activity. It has been shown that actual exercise, not a recommendation, is an important factor impacting the effectiveness of obesity interventions.[27,38] Therefore, for this meta-analytic review, we included only interventions comprising actual exercise training, as the effectiveness of "real" exercise versus exercise recommendation is likely to be different.

This study aimed to summarize and examine the efficacy of randomized controlled pediatric lifestyle interventions, including the combination of exercise, nutrition education, and behavioral modification, in treating obesity among 11–17-year-old children with the use of a multilevel meta-analysis approach. Specifically, our first aim was to examine the efficacy of pediatric lifestyle interventions (combination of exercise, nutrition education, and behavioral modification) on participants' BMI, BMIz, and WC among children with overweight or obesity. Our secondary aim was to identify whether weight status, frequency, or intervention duration moderated the efficacy of pediatric lifestyle interventions.

2 | METHODS

2.1 | Protocol registration

This meta-analysis was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, and the study was pre-registered on the Open Science Framework (OSF) website (https://osf.io/sjpg5/).

2.2 | Literature search

To identify relevant articles, a systematic literature search was conducted, targeting the latest data published between January 2000 and the end of August 2022. The search encompassed several academic databases, including PUBMED, PsycINFO, CINAHL, Embase, Cochrane Reviews, and ProQuest Dissertations and Theses, as well as prepublication platforms such as OSF and preprint server psycarxiv. The specific time frame was selected to ensure the inclusion of recent research, reflecting the most up-to-date understanding and advancements in the field of pediatric obesity interventions. By including studies conducted over the past two decades, we aimed to capture current knowledge and provide insights into contemporary approaches and outcomes.

The applied search terms were broad, including combinations and synonyms of "child/children," "adolescence," "lifestyle/family/community," "obesity/weight loss/BMI/waist circumference," and "intervention/experiment/randomized/maintenance." The search strategy was completed using an electronic database. Additional studies were retrieved from the manual search, including reference lists of

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the relevant studies retrieved using database searches and the reference lists of the previous reviews in this area.

2.3 | Eligibility and exclusion criteria

The title, abstract, and keywords of the identified papers were screened by three independent reviewers. Citations and abstracts of all retrieved studies were downloaded to an Excel file. After removing duplicates, another three independent reviewers screened all abstracts using the eligibility criteria. If the decision could not be made based on the abstract of the article, the full article was read to make the assessment. Full-text screening was also conducted by three reviewers, and reasons for exclusions were recorded. A fourth reviewer was consulted to resolve conflicts at both phases of study selection.

Articles were included if they met the following criteria: (a) a randomized controlled trial (RCT) with a minimum of two treatment components (i.e., actual exercise/physical activity, nutrition and healthy eating education, or behavior modification) treating or preventing obesity; (b) participant age range from 11 to 17; (c) BMI of participants ≥ 85 percentile or ≥ 25 kg/m^2; (d) intervention took place in schools, primary care centers, hospitals, or other health institutions; and (e) the outcome measures were focused on BMI, BMIz, and/or WC. This review comprised interventions from January 2000 to August 2022.

Exclusion criteria included: (a) lifestyle interventions comprising surgeries or/and medications; (b) age < 11 or age > 17 years old; (c) prevention studies with normal weight participants; (d) insufficient data available to complete the meta-analysis and authors were unable to provide the requested data; (e) published in a language other than English.

2.4 | Data extraction and data synthesis

A data extraction form was developed based on the PRISMA (Table S1).[39] Two teams of coders (in total, four coders) established and completed a data extraction coding procedure of study characteristics. Interrater reliability was 0.95. The extraction of the data comprised the first author's name, publication year, country of publication, the number of effects, outcome information (BMI, BMIz, and WC), intervention (duration and frequency), and descriptive information about the sample, for example, education background and weight status. Five studies had missing data, and the authors of those studies were contacted three times by email. If the authors provided the data, the article was included in this review. In case of no reply, the study was excluded from this review. In total, none of the contacted authors replied, so five studies were excluded from the data pool. We extracted the data from the one providing the most detailed or complete information (e.g., in the case of final vs. preliminary reports on the same RCT) or we extracted the data from several papers if these reported complementary information on the same RCT (e.g., effects at different follow-up times since the start of intervention) when more than one paper was found relating to the same RCT, either. In addition, when RCTs had more than one intervention group (vs. the same control group), we extracted the data from each such group separately.

2.5 | Risk of bias assessment

We used the Cochrane Collaboration's Tool for the risks of bias that were assessed at the study level, focusing on selection (random sequence generation and concealment of allocation methods), attrition (completeness of outcome data), detection (blinding of outcome assessors), performance (blinding of participants and personnel), and reporting (selective reporting of outcome measures).[40] For each included study and type of bias, two reviewers independently ascribed a judgment for the risk of bias (low risk, high risk, and unclear). Conflicting judgments (one judgment disagreement) were discussed to reach an agreement together with a third independent judge.

2.6 | Statistical analysis

To estimate the effects, the pooled effect sizes were calculated using a multivariate maximum likelihood random effects model. The traditional random effects model, for example, the two-level multilevel model, is not applicable in this study, as RCTs are not contributing independent effects but dependent effects. Because these effect size estimates are nested within the RCTs, we adopted the meta-analytic multivariate approach to account for the dependence of the effect sizes.[41] Specifically, random effects were added for each outcome within each study, allowing the outcomes to be correlated and to establish different variances (variance–covariance matrix), hence boosting the power and precision of the pooled estimates derived.[41,42]

Statistical heterogeneity was tested by calculating the parameters of the I^2 and tau^2 statistics.[43] The I^2 statistic measures the proportion of the variance that can be accounted for by true differences in the effect size. I^2 thresholds have been proposed based on the Cochrane Collaboration interpretation, with 25%, 50%, and 75% representing low, moderate, and high variance, respectively. In addition, a likelihood ratio test examining the effect of tau^2 on all the outcomes was used as an indicator of the significance of between-study heterogeneity. A set of diagnostics, for example, Cook's distance by analyzing the distribution of studentized residuals, was conducted to identify potential outliers and influential cases that may influence observed heterogeneity.[44] The results of the diagnostic analyses, available in Table 1 of the supplementary document, indicate that potential outliers and influential cases did not significantly influence the heterogeneity observed in the study.

A priori determined moderators, for example, weight status, frequency, and duration, were used in a linear regression analysis as univariate independent variables to explain the possible heterogeneous

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TABLE 1 Characteristics of included studies: results for BMI, BMIz, and WC outcomes.

First author (year), country	*N*	Characteristics	Intervention/comparator	Intervention duration	Outcomes	Main results
Arlinghaus et al. (2019), United States	243	Age: 12.02 ± 0.57 Gender: M: 100/203; F: 103/203 Ethnicity: Mexican-American Education: 6th–7th grade Inclusion: overweight or obesity (i.e., BMI percentile ≥ 85th percentile)	Intervention: exercise, nutrition, and behavior modification (0, 1, 3, and 5 days a week), 80% of time was spent on physical activity, and 20% was spent on nutrition Exercise: circuit-based physical activity Nutrition (e.g., traffic light diet) Behavior modification: (e.g., token economy system, goal setting, and self-monitoring) Comparator: No intervention Parental involvement: Yes	Intervention: 24 weeks Follow-up: None	BMI BMIz WC	Both the 3- and 5-day/week groups had significantly greater reductions in BMI and BMIz than the intervention control.
Davis et al. (2009), United State	54	Age: 15.5 ± 1.00 Gender: M: 28/54; F: 26/54 Ethnicity: Latino Inclusion: overweight or obesity (i.e., BMI percentile ≥ 85th percentile)	Intervention: nutrition (once per week, 60 min) and strength training (twice per week, 60 min), and motivational interview Nutrition: Veronica Atkins (e.g., added sugar <!0% total calorie in take) Exercise: resistance training Behavioral components: No Comparator: No intervention Parental involvement: No	Intervention: 16 weeks Follow-up: None	BMI BMIz	There were no statistically significant effects on BMI and BMIz.
Larsen et al. (2016), Demark	106	Age: 12.0 ± 0.40 Gender: M: 47/106; F: 50/106 Ethnicity: unknown Inclusion: overweight or obesity (i.e., BMI percentile ≥ 85th percentile)	Intervention: physical activity (7 days/week, 180 min), health diet (7 days/week, 60 min) and behavior modification Exercise: (e.g., dancing, team building) Nutrition: (e.g., health cook classes) Behavior modification: (e.g., theory and behavior changes) Comparator: standard intervention arm Parental involvement: No	Intervention: 6 weeks Follow-up: 52 weeks	BMI BMIz WC	After 6 weeks, there were statistically significant improvements in BMI. After 52 weeks, the intervention group have lower BMI and BMIz score.
Ounis et al. (2010), Germany	28	Age: 13.2 ± 0.70 Gender: M: 14/28; F: 14/28 Ethnicity: NA Inclusion: obesity (i.e., BMI percentile ≥ 97th percentile)	Intervention: physical activity (4 days/week, 90 min) and dietary (1 day/week, 240 min) Physical activity: (e.g., warming up, running, jumping, and playing with a balloon) Dietary: (e.g., health food restriction education) Behavioral components: No Comparator: No intervention Parental involvement: No	Intervention: 8 weeks Follow-up: No	BMI	There was a statistically significant reduction in BMI.
Patsopoulou et al. (2017), Greece	181	Age: 14.04 ± 0.80 Gender: M: 47/106; F: 50/106 Ethnicity: NA Inclusion: overweight or obesity (i.e., BMI percentile ≥ 85th percentile)	Intervention: physical activity (3 days/week, 45 min) and dietary (3 days/week, 15 min) Physical activity: (e.g., 50% team sports and 50% running games) Dietary: (e.g., cooking habits, general information about obesity) Behavioral components: No Parental involvement: Yes	Intervention: 24 weeks Follow-up: 12 weeks	BMI WC	There were statistically significant reductions in BMI, and WC.
Plavsic et al. (2020), Serbia	44	Age: 15.5 ± 1.50 Gender: unknown Ethnicity: NA Inclusion: overweight or obesity (i.e., BMI	Intervention: exercise (2 days/week, 43 min) dietary (0.5 times/week, 20–30) Exercise (walking or running) Dietary: nutrition education Behavioral components: No Comparator: No intervention Parental involvement: Yes	Intervention: 12 weeks Follow-up: 12 weeks	BMI BMIz WC	There were a statistically significant improvements in BMI, BMIz and WC.

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TABLE 1 (Continued)

First author (year), country	N	Characteristics	Intervention/comparator	Intervention duration	Outcomes	Main results
		percentile ≥ 85th percentile)				
Reinehr et al. (2009), Germany	66	Age: 11.5 ± 1.60 Gender: M: 40/66; F: 60/66 Ethnicity: NA Inclusion: overweight or obesity (i.e., BMI percentile ≥ 85th percentile)	Intervention: physical activity (1 day/week, 90 min) and nutrition education (30 min) and behavior counselling Physical activity: (e.g., ball game, jogging, trampoline jumping) Nutrition education: optimized mixed diet, and traffic light Behavior counselling: (e.g., systemic and solution-focused theories) Comparator: No intervention Parental involvement: No	Intervention: 24 weeks Follow-up: No	BMI WC	There was a statistically significant reduction in overweight, fat mass, waist circumference, and blood pressure.
Soltero et al. (2018), United State	136	Age: 15.3 ± 1.09 Gender: M: 62/136; F: 74/136 Ethnicity: Latino Inclusion: obesity (i.e., BMI percentile ≥ 95th percentile	Intervention: nutrition (1 day/week, 60 min), exercise (3 days/week, 60 min) and behavior modification Nutrition: nutrition education Exercise: aerobic activities, anaerobic activity, and resistance exercise Behavior modification: goal setting, self-modification Comparator: No intervention Parental involvement: Yes	Intervention: 12 weeks Follow-up:48 weeks	BMI WC	There was a statistically significant reduction in BMI and WC.

Abbreviations: BMI, body mass index; BMIz, standardized BMI; WC, waist circumference.

effects of the outcomes. Multiple regression of the moderators and their interactions were not tested because of an inadequate number of effects for each outcome.[45]

To assess publication biases, we employed two methods: (1) utilizing the standard error of the observed outcomes as a predictor in a multivariate model, and (2) visually inspecting asymmetries in funnel plots and contour-enhanced funnel plots.[46] A *p*-value greater than 0.05 was considered a non-significant bias. All analyses were performed with R (version 4.2.2) with the package "dplyr, metafor, robumeta." The dataset and R-code utilized for the analyses can be accessed on the project OSF website: https://osf.io/sjpg5/.

3 | RESULTS

There were 2598 abstracts screened for eligibility, and 1180 duplicates were excluded (Figure 1). One hundred and two full-text articles were assessed, and 42 reviewed articles were deemed eligible for the full-text review. Further 34 studies were excluded after the careful assessment. The primary reasons for the exclusion were an absence of a control group ($k = 8$), lack of randomization ($k = 5$), an absence of nutrition ($k = 5$) or exercise groups ($k = 5$), missing data ($k = 6$), protocol paper ($k = 1$), review paper ($k = 1$), and age not eligible ($k = 3$). Finally, one protocol and one review paper were excluded, and three manuscripts did not meet the age eligibility. A total of eight studies were included in the meta-analysis (Figure 1).

3.1 | Qualitative characteristics of included studies

The characteristics of all eight studies are presented in Table 1. A total of 858 participants were included in the systematic review. Study sample sizes ranged from 28 to 243. Three of the reviews were conducted in the US,[47–49] two in Germany,[50,51] one in Greece,[52] one in Serbia,[53] and one in Denmark.[54] Four studies recruited participants in schools,[47,49,52,54] and two studies recruited using media and collaboration with medical practitioners.[51,53] The recruitment methods of the other two studies were unknown.[48,50]

Per our inclusion criteria, all the studies incorporated at least two intervention components: exercise/physical activity and nutrition education. Five studies included three components.[47–49,51,54] Four included studies that incorporated behavioral components (i.e., monitoring, goal setting, behavioral parenting skills, problem-solving, and motivational interviewing),[47,49,51,54] and three studies did not include a behavioral component.[48,50,52,53] The intervention design varied considerably. Intervention frequency ranged from one to seven times per week and duration from six to 24 weeks. Four of the studies had follow-up measurements ranging from 12 to 52 weeks.

3.2 | Risk of bias within studies

Table 2 presents a summary of the risk of bias within the included studies. Overall, bias within studies was mostly low or unclear risk. All

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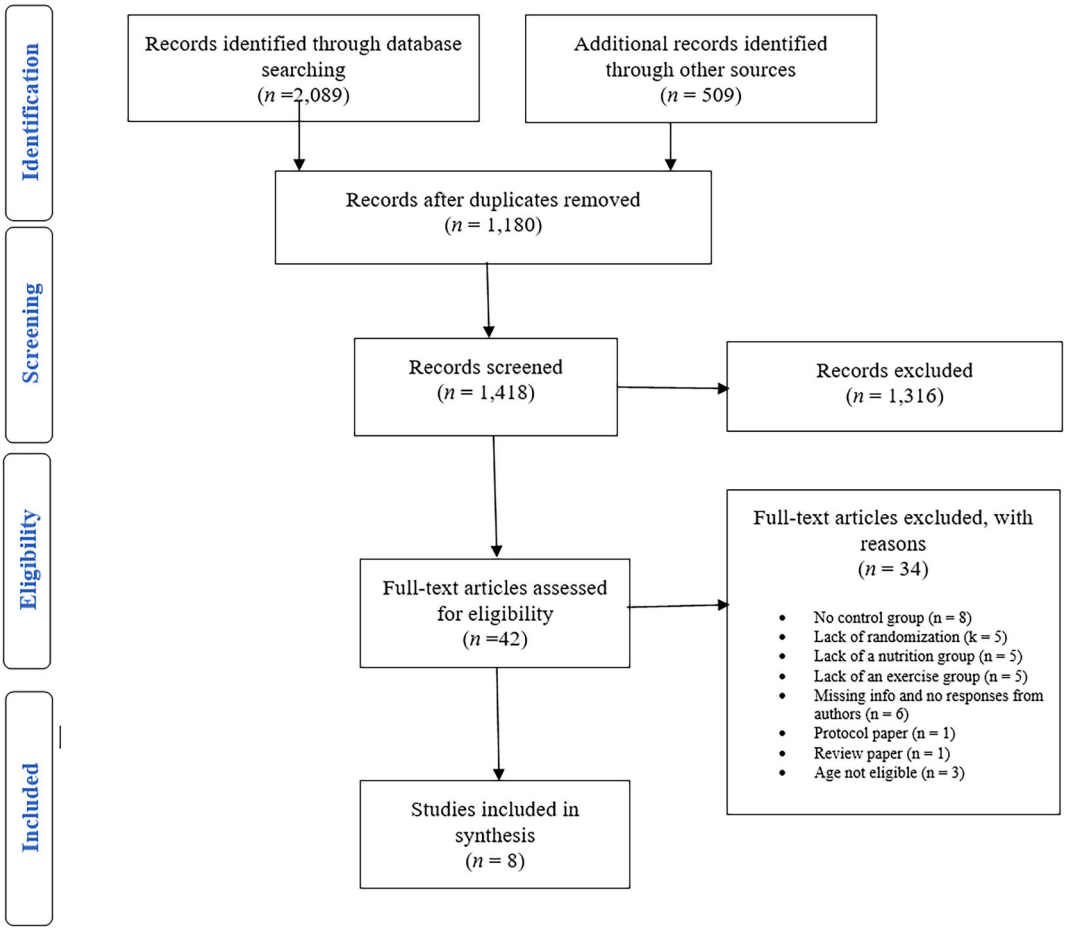

FIGURE 1 Meta-analysis flowchart diagram demonstrating study selections for the meta-analysis.

studies provided minimal information about potential selection bias. Information about random sequence generation and allocation concealment was missing in all studies, which resulted in labeling the risk of selection bias as "unclear." Four of the eight studies included did not report the method used to randomize participants. It is unknown whether participants in these studies were aware of the characteristics of the different treatments, which may have influenced the primary outcomes of the subsequent studies. Five of the nine studies included the intention to treat analyses of the primary outcomes. Most studies ($k = 6$) reported that individuals assessing body weight and height were blinded to the participants. Blinding of participants or personnel was judged as irrelevant in these trials assessed, as it was not possible to blind the participants or personnel of the intervention trials that comprise a specific intervention and "usual care" control groups.

3.3 | Risk of bias across studies

Egger's test and a visual examination of the contour-enhanced funnel plots were conducted to detect publication bias. Based on the Egger's test, the mean change difference for BMI ($\beta = -0.88$, 95% CI [−2.28, −0.52], $p = 0.129$), the mean change difference for BMIz ($\beta = -0.79$, 95% CI [−3.48, −1.90], $p = 0.407$), and the mean change difference for WC ($\beta = -1.59$, 95% CI [−3.54, −0.35], $p = 0.086$. As all p-value were larger than 0.05, the Egger test revealed that no publication bias was found in all the outcome variables. The funnel plot and contour-enhanced funnel plots in Figure 2 show that the included studies are distributed evenly around the estimated effect size, indicating a lack of selective reporting or publication bias towards only significant results.

3.4 | Effects of the lifestyle intervention on BMI, BMIz, and WC

In the observed outcomes of eight studies, the mean estimates for BMI ranged from −4.30 to −0.20. Based on the multivariate model, the mean change difference between the intervention and control conditions for BMI was −1.77 kg/m^2, 95% CI [−2.70, −0.83], $p < 0.001$. The mean change difference differed significantly from zero but was strongly heterogeneous ($\chi^2(1) = 41.70$, $p < 0.001$, $tau^2 = 1.18$, $I^2 = 97.75\%$).

The observed outcomes of five studies revealed that the mean estimates for BMIz reduction ranged from −0.40 to 0.00. The

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TABLE 2 Risk of bias summary.

First author, citation	Random sequence generation		Allocation concealment		Attrition bias		Detection bias	
	Cochrane judgment	Supporting evidence	Cochrane judgment	Supporting evidence	Cochrane judgment	Supporting evidence	Cochrane judgment	Supporting evidence
Arlinghaus et al. (2019)	Low risk	A random number table was used to randomize the participants	Low risk	Generation of random sequence and enrollment conducted by research staff	Low risk	No participants drop out from the study	Low risk	Assessors were blinded to allocation
Davis et al. (2009)	Unclear	Method of randomization is not stated, but used. Randomization was blocked by gender	Unclear	Method not described	Unclear	Intention to treat analysis performed by assigning dropout (intervention 5/22; control 6/22)	Low risk	Assessors were blinded to allocation
Larsen et al. (2016)	Unclear	Method of randomization is not stated, but used. 1:1 ratio (intervention: control)	Unclear	Method not described	Low risk	Intention to treat analysis performed by assigning dropout (intervention 4/59; control 5/56)	Low risk	Assessors were blinded to allocation
Ounis et al. (2010)	Unclear	Method of randomization is not stated, but used.	Unclear	Method not described	Low risk	No participants drop out from the study	Unclear	Statement not described
Patsopoulou et al. (2017)	Unclear	Method of randomization is not stated, but used.	Unclear	Method not described	Low risk	Intention to treat analysis performed by assigning dropout (intervention 5/61; control 5/60)	Low risk	Assessors were blinded to allocation
Plavsic et al. (2019)	Low risk	Matched-paired block randomization using Excel 2013 (Microsoft, Redmond, Wash., USA)	Low risk	Generation of random sequence and enrollment conducted by independent doctor	Low risk	Intention to treat analysis performed by assigning dropout (intervention 3/22; control 2/22)	Unclear	Statement not described
Reinehr et al. (2009)	Low risk	Computer generated the random sequence	Low risk	Method not described	Low risk	Intention to treat analysis performed by assigning dropout (intervention 5/39; control 5/37)	Low risk	Assessors were blinded to allocation
Soltero et al. (2018)	Low risk	SPSS statistics software (Version 21; IBM Corp., Armonk., New York) generated the random sequence	Low risk	Generation of random sequence and enrollment conducted by research staff	Low risk	Intention to treat analysis performed by assigning dropout (intervention 8/67; control 4/69)	Low risk	Assessors were blinded to allocation

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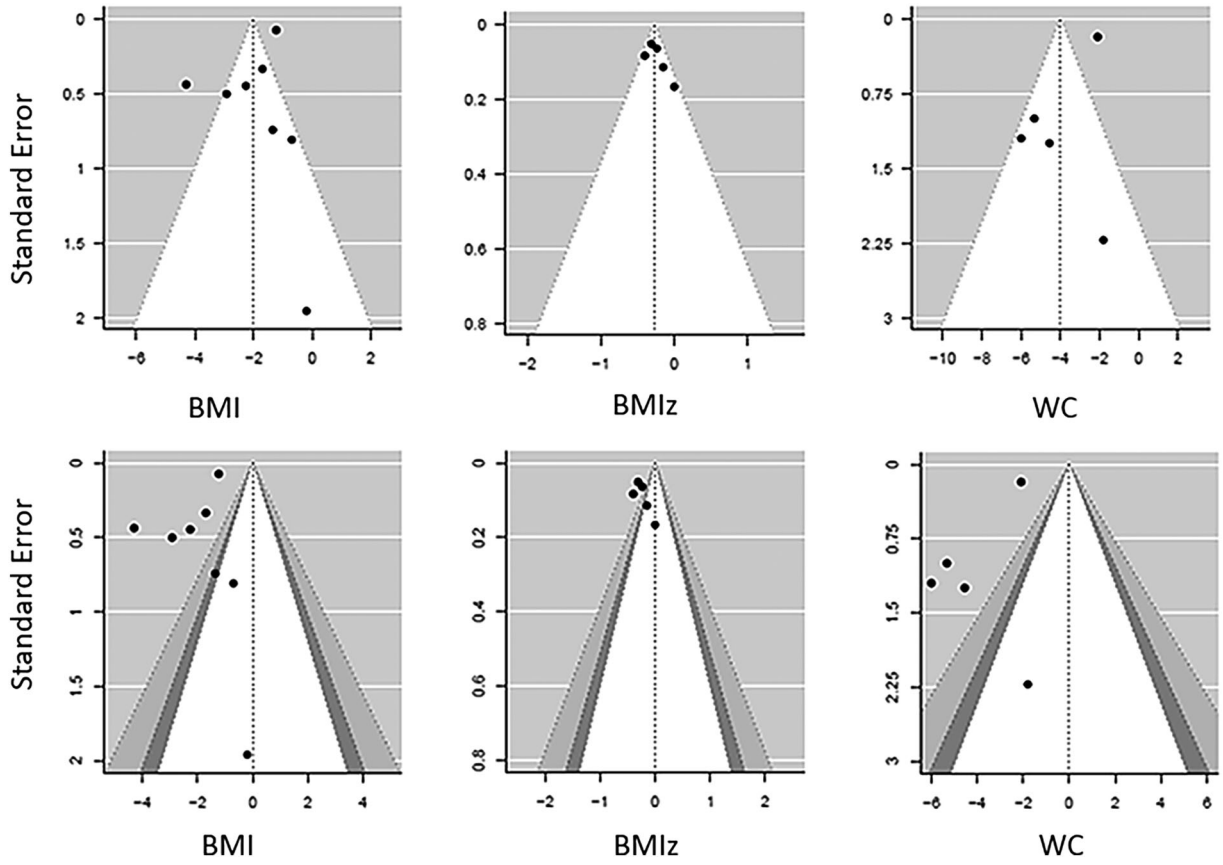

FIGURE 2 Funnel plot representations to determine publication bias.

mean change difference between the intervention and control conditions for BMI was −0.30, 95% CI [−0.45, −0.16], $p < 0.001$. The mean change difference differed significantly from zero but was strongly heterogeneous ($\chi^2(1) = 8.64$, $p = 0.003$, $tau^2 = 0.18$, $I^2 = 95.72\%$).

The observed outcomes of the reduction of the 5 studies for mean estimates for WC ranged from −6.00 to −1.80. The standardized mean change difference between the intervention and control conditions for WC was −3.32 cm, 95% CI [−5.35, −1.29], $p < 0.001$. The mean change difference differed significantly from zero but was strongly heterogeneous ($\chi^2(1) = 15.95$, $p < 0.001$, $tau^2 = 2.32$, $I^2 = 96.92\%$).

The individual effect sizes and their CIs and the mean change differences according to a meta-analytic multivariate model as well as independent two-level random effects models are displayed in Figure 3.

3.5 | Moderator effects

Separate univariable models were conducted to examine the moderator effect. Based on the significant likelihood ratio tests and high values of I^2 for all the outcomes, this indicates that the variability in the effects in BMI, BMIz, and WC did not occur based only on sampling errors. The between-study variances in relation to possible moderators were pursued on BMI, BMIz and WC. Three a priori determined moderators, for example, weight status, intervention frequency, and duration were used in the multivariate analyses. The individual effect sizes and their CIs for the independent studies are presented in Table 3.

Firstly, Table 3 showed that children with obesity had the most advantageous benefits from the intervention as their BMIz ($\beta = -0.22$, CI 95% [−0.48, 0.03], $p < 0.05$), but no statistically significant difference in BMI and WC. In addition, there is no statistically significant difference in overweight groups on all the outcome variables.

The analyses showed that intervention frequency was a statistically significant moderator. For frequency ≥ 3 times per week in BMI ($\beta = -2.02$, CI 95% [−3.80, −0.24], $p = 0.006$), BMIz ($\beta = -0.21$, CI 95% [−0.40, 0.02], $p = 0.004$), and WC ($\beta = -3.00$, CI 95% [−5.53, −0.47], $p = 0.011$). There is no statistically significant difference in all the outcome variables when frequency ≤ 2 times.

Finally, there was a statistically significant moderator effect for duration. Intervention >12 weeks ($\beta = -1.89$, CI 95% [−3.09, −0.69], $p < 0.001$), ($\beta = -0.30$, CI 95% [−0.49, −0.10], $p < 0.001$), and ($\beta = -4.14$, CI 95% [−6.90, −1.39], $p < 0.001$) were statistically significant to reduce BMI, BMIz, and WC, and intervention ≤ 12 weeks showed no statistically significant to increase BMI, BMIz, and WC.

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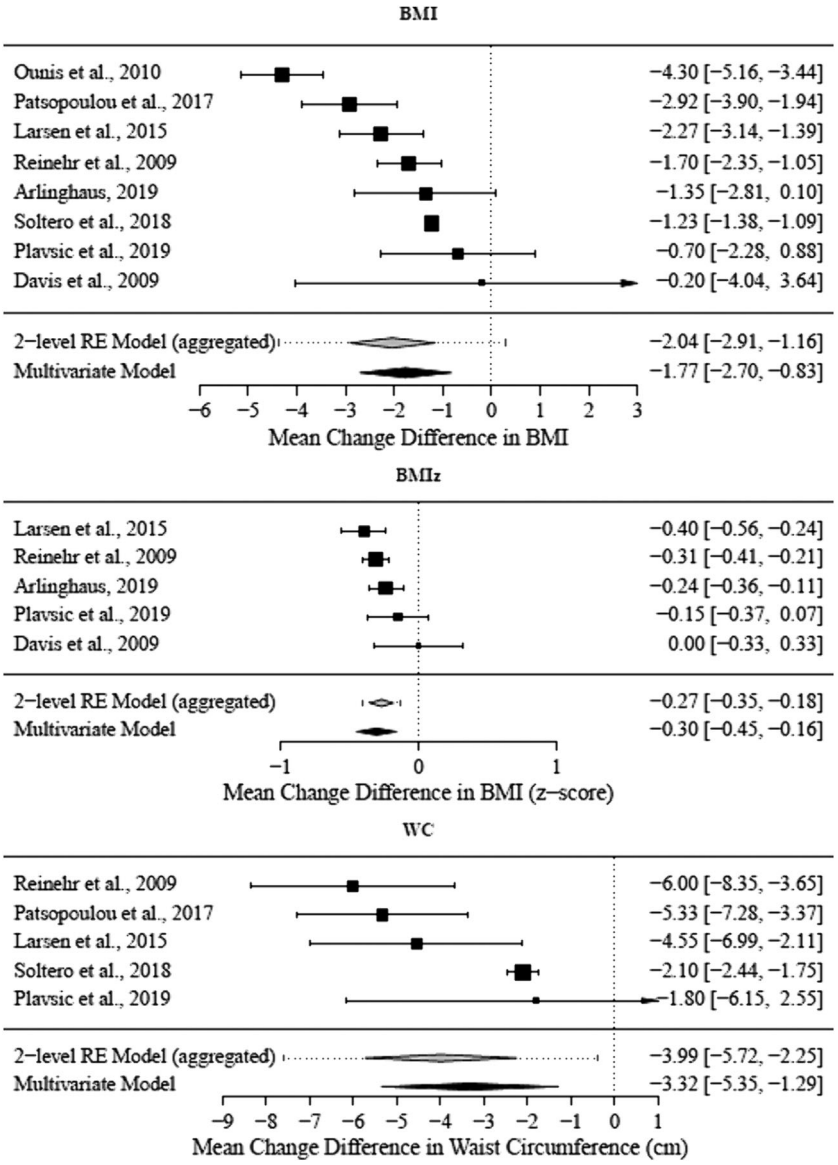

FIGURE 3 Forest plots for the outcome variables.

TABLE 3 Univariate moderator analysis BMI, BMIz, and WC.

	BMI		BMIz		WC	
	k	β (95% CI)	k	β (95% CI)	k	β (95% CI)
Weight status						
Overweight participants	7	−1.18 [−2.82, 0.47]	1	−0.39 [−0.78, −0.00]	6	−4.07 [−8.79, 0.64]
Obese participants	7	−2.36 [−4.97, 0.26]	7	−0.22 [−0.48, 0.03]*	3	−3.75 [−8.06, 0.57]
Frequency (times/per week)						
≤ 2 times	5	−1.95 [−2.18, −2.03]	2	0.19 [0.43, 0.04]	4	−2.76 [−5.87, −0.35]
≥ 3 times	5	−2.02 [−3.80, −0.24]**	6	−0.21 [−0.40, 0.02]**	3	−3.00 [−5.53, −0.47]*
Duration (total weeks)						
≤ 12 weeks	6	−1.66 [−2.84, −0.48]	3	−0.32 [−0.53, −0.11]	4	−3.31 [−5.53, −1.08]***
> 12 weeks	8	−1.89 [−3.09, −0.69]***	5	−0.30 [−0.49, −0.10]***	5	−4.14 [−6.90, −1.39]***

Abbreviations: BMI, body mass index; BMIz, standardized BMI; WC, waist circumference.
*$p < 0.05$, **$p < 0.01$, and ***$p < 0.001$.

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4 | DISCUSSION

This meta-analytic review was conducted to evaluate the efficacy of pediatric lifestyle interventions on the body composition of children with overweight and obesity. Due to numerous intervention designs, ranging from the content, frequency, to length, we used rigorous eligibility criteria and focused solely on the pediatric lifestyle interventions, including both nutrition education and actual, instead of a recommendation, exercise training. Our review found that pediatric lifestyle interventions were effective in improving the body composition of patients with overweight and obesity. Furthermore, moderator analyses suggested that the effects of the interventions were stronger when participants had at least three weekly meetings and the intervention duration was more than 12 weeks. Finally, our analyses suggested that pediatric lifestyle interventions were most beneficial for children with significant obesity compared with children with only modest overweight.

This meta-analytic review showed that pediatric lifestyle interventions are effective in improving children's BMI. On average, children's participation in lifestyle interventions yielded a 1.77 kg/m^2 decline in their BMI. The size of this effect was similar to the findings of the previous meta-analyses.[29–31] Similarly, participants' BMIz and WC showed a 0.30 unit change and a 3.32 cm change for BMIz and WC, respectively. When comparing the WC effect sizes of this meta-analysis to the effects of the previous meta-analyses, the effect sizes of our study were larger.[11,29] Collectively, these findings suggest that lifestyle interventions, including the combination of actual exercise, nutrition education, and/or behavior modification, are an effective strategy to improve children's body composition and, as a result, reduce the risk for obesity-related diseases. It is noteworthy that, based on the findings of this study, lifestyle interventions with actual exercise can lead to larger effect sizes in BMI and WC compared with the interventions consisting of only an exercise recommendation. This finding is logical, as exercise adherence and intensity are likely to be greater in actual exercise training compared with an exercise recommendation.[55]

In regard to the moderating effects, our study showed that the weight status of the participants, as well as frequency and duration, impacted intervention efficacy. Our study suggests that the higher the weight status of the participant, the bigger the BMI reductions. This finding corroborated the previously reported findings that have shown that weight loss interventions yield the largest weight reductions in children with the highest levels of obesity. This finding is logical, as participants with obesity have more weight to lose before reaching a healthy weight zone. Maybe, more importantly, the moderation analyses showed that the interventions that were 12 weeks or longer and had at least three weekly meetings were more impactful in improving participants' body composition than interventions that were shorter in duration (<12 weeks) and met less frequently (<3 times per week). These findings corroborated the findings of the previous studies that have shown longer-lasting interventions to be more effective in reducing participants' BMI.[56–58] Our findings support recent guidance suggesting that interventions lasting 26 h or more over a period of 3–12 months can lead to clinically significant results.[55]

It is not clear which exercise modalities, that is, resistance training, aerobic exercise, sports-based physical activity, recreational-based physical activity, or a combination of several types, are the most effective prescriptions to improve children's body composition in both short- and long-term. Previous research has found that a combination of exercise, that is, resistance training and aerobic exercise, is the optimal mode of exercise to improve body composition in children and adolescents' populations.[59] Furthermore, investigations are needed to determine the most optimal modality for children and adolescents with obesity. Although basic physiological responses to exercise can be applied to children, it is likely that children's motivation varies greatly based on different types of exercises and physical activities.

4.1 | Strengths and limitations

There are several strengths associated with our study. First, this meta-analysis employed a comprehensive search strategy adhering to the PRISMA protocol, which is a recommended strategy to ensure research integrity.[39] Second, this study employed strict eligibility criteria to focus on the RCTs in the area of pediatric lifestyle interventions. Finally, this study utilized a multivariate approach to model dependencies arising from multiple groups and/or multiple time point comparisons within the studies. The multivariate random effects model approach allowed us to model the within-study dependencies without losing valuable information/data and thus yield more robust effect sizes, reducing type I errors.

The following limitations should be considered when interpreting the findings of this meta-analytic review. Despite the rigorous eligibility criteria, there was still a large heterogeneity in the effect sizes, which limits the interpretation and generalizability of the findings. This large heterogeneity was due to the factors that related to insufficiencies in reporting study designs, implementation, and analyses. While our inclusion criteria were strict, heterogeneity is a common challenge in systematic reviews, and it should be considered when interpreting the overall findings. Second, due to the rigorous eligibility criteria, our sample size was relatively small ($k = 8$). Although our focus on the randomized controlled studies and lifestyle interventions, including actual exercise (not allowing exercise/physical activity recommendations), reduced the heterogeneity of effect sizes, it negatively impacted the available sample size and the statistical power to detect statistically significant moderator effects. It should be noted that due to the small number of effects and the heightened risk for type 1 error, we did not pursue additional univariate moderator analyses. For example, most of the reviewed trials were mixed-sex interventions, but due to the aforementioned limitation, we could not test whether both sexes responded similarly to the interventions. Although our study indicated that the intervention scope or setting were not statistically significant moderators, we cannot unequivocally rule out the role of intervention scope or setting impacting intervention efficacy. In addition, other moderators might have been selected a priori. Third,

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the risk of bias was unclear in many studies, primarily because of a lack of provided information. Future lifestyle intervention studies should pay close attention to reporting information that relates to the evaluation of the risk of bias. Specifically, the Cochrane Collaboration Tool suggests reporting methods related to random sequence generation, allocation concealment, attrition bias, and detection bias to help determine the risks of bias.[40] The modified Egger's tests and funnel plots suggested that there is a possibility for publication bias with the retrieved studies. However, caution regarding the publication bias results should be taken as the number of analyzed studies was relatively small, and the heterogeneity among effects was high.[58] In addition, as the detected outlying studies were removed, there seemed to be no issue with publication bias. Finally, a limitation of the present review was that only published manuscripts in English were included in this review.

5 | CONCLUSIONS

In conclusion, lifestyle interventions comprising actual exercise training, nutrition education, and behavior modification had a moderate-to-large effect on BMI, BMIz, and WC in children with overweight and obesity. The effect was greater on higher BMI participants as well as when interventions were longer in duration (12 weeks or more), and weekly meetings were more frequent (three times or more per week). Thus, our recommendation for practitioners is to design interventions to include actual exercise instead of an exercise recommendation. In addition, the intervention duration needs to be at least 12 weeks, and the participants need to have at least three weekly sessions.

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CONFLICT OF INTEREST STATEMENT

All the authors and co-authors report no conflicts of interest related to the submitted manuscript. This systematic review was not funded by any sources.

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