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Review

The effectiveness of physical activity interventions on blood pressure in children and adolescents: A systematic review and network meta-analysis

Q1 Mohamed A. Hassan [a,b], Wanjiang Zhou [a], Mingyi Ye [c], Hui He [c], Zan Gao [d,*]

[a] *School of Kinesiology, University of Minnesota-Twin Cities, Minneapolis, MN 55455, USA*
[b] *Department of Methods and Curriculum, Physical Education College for Men, Helwan University, Cairo 12552, Egypt*
[c] *China Institute of Sport and Health Science, Beijing Sport University, Beijing 100084, China*
[d] *Department of Kinesiology, Recreation, and Sport Studies, University of Tennessee, Knoxville, TN 37996, USA*

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Abstract

Background: High blood pressure (BP) is a major contributor to mortality and cardiovascular diseases. Despite the known benefits of exercise for reducing BP, it is crucial to identify the most effective physical activity (PA) intervention. This systematic review and network meta-analysis (NMA) aimed to evaluate the available evidence on the effectiveness of various PA interventions for reducing BP and to determine their hierarchy based on their impact on BP.

Methods: A search of PubMed, SPORTDiscus, PsycINFO, Web of Science, CINAHL, Cochrane, and Eric databases was conducted up to December 2022 for this systematic review and NMA. Randomized controlled trials and quasi-experimental studies targeting healthy children and adolescents aged 6−12 years old were included in this study. Only studies that compared controlled and intervention groups using PA or exercise as the major influence were included. We followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. Three independent investigators performed the literature screening, data extraction, and risk of bias assessment. We used Bayesian arm-based NMA to synthesize the data. The primary outcomes were systolic BP and diastolic BP. We calculated the mean differences (MDs) in systolic BP and diastolic BP before and after treatment. Mean treatment differences were estimated using NMA and random-effect models.

Results: We synthesized 27 studies involving 15,220 children and adolescents. PA combined with nutrition and behavior change was the most effective intervention for reducing both systolic BP and diastolic BP ((MD: −8.64, 95% credible interval (95%CI):−11.44 to −5.84); (MD: −6.75, 95%CI: −10.44 to −3.11)), followed by interventions with multiple components ((MD: −1.39, 95%CI: −1.94 to −0.84); (MD: −2.54, 95%CI: −4.89 to −0.29)).

Conclusion: Our findings suggest that PA interventions incorporating nutrition and behavior change, followed by interventions with multiple components, are most effective for reducing both systolic blood pressure and diastolic blood pressure in children and adolescents.

Keywords: Children; Diastolic blood pressure; Physical activity; Systolic blood pressure

1. Introduction

High blood pressure (HBP), or hypertension, occurs when the blood exerts too much pressure against the walls of blood vessels due to systolic and diastolic forces.[1] It is a significant risk factor for cardiovascular diseases, contributing to 10.1 million deaths and 208.1 million cases of overall disease burden worldwide in the past 2 decades.[2] The death rate attributable to HBP increased to 34.2% between 2009 and 2019,[3−5] with hypertension projected to affect 41% of US adults by 2030.[6,7] The economic burden of hypertension is expected to rise significantly, with direct costs projected to triple to USD 389.9 billion and indirect costs to double to USD 42 billion by 2030.[6,8,9] Around 50% of reported cases of hypertension have a genetic component,[10−12] while modifiable factors like lifestyle, diet, and physical activity (PA) contribute to the other half.[13,14]

The American Heart Association highlighted that the significance of HBP in children was previously underestimated.

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*Corresponding author.
E-mail address: zan@utk.edu (Z. Gao).

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Recent studies show that many children and adolescents in the United States face hypertension risks. Data reveals that 5% of this demographic has HBP, while 18% exhibit elevated BP.[15] Similarly, the Centers for Disease Control and Prevention reported that among youth aged 12−19, 1 in 25 has hypertension, and 1 in 10 experiences elevated BP.[16] Considering these findings, both American Heart Association and Centers for Disease Control and Prevention emphasize the increasing incidence of HBP in young individuals, which could lead to health complications in adulthood. As a result, it's imperative to implement preventive measures to counteract the rising trend of HBP in this age group. While medical research explores various approaches for monitoring and controlling genetically-based hypertension, non-medical approaches may be more feasible and effective in the interim.

Effective approaches for alleviating HBP in early ages, such as weight loss, healthy diet, and regular exercise, are achieved by controlling modifiable factors.[17] The lifestyle therapeutic changes can highly impact BP and reduce the possibility of being at risk of hypertension during childhood. Exercise and PA can lower the risk of cardiovascular disease and reduce elevated BP, according to numerous studies.[18−21] Low-to-moderate intensity PA has a positive impact, reducing both systolic BP (SBP) and diastolic BP (DBP),[22,23] and these effects have been observed across age groups.[24] Literature not only demonstrates a strong link between PA and reduced BP in adults but also reveals its positive impact on children. In particular, studies exploring the connection between PA and BP have underscored the importance of focusing on the duration of PA, suggesting it may be more critical than the intensity of the activity itself.[25]

Recent studies suggest that exercise can lower BP by about 5−8 mmHg.[26] Although extensive research has been conducted to define different PA interventions, studies suggest that including other modifiable factors, such as diet, education, and lifestyle, alongside exercise may be beneficial. Research has shown that healthy diet plans including fruit and vegetable intake can prevent elevation of BP in children.[27] Therefore, nutritional instructions are equally important for controlling BP, with certain nutrients such as protein and vitamin D known to help reduce BP. High sodium or alcohol consumption can increase BP.[28,29] However, studies have demonstrated that combining a PA program with nutritional instructions can significantly reduce BP.[30,31] Other factors, such as lifestyle changes like getting enough sleep, quitting smoking, and engaging in social activities, have also been investigated for their effects on lowering BP in various randomized controlled trials (RCTs) and observational studies.[32−34]

Although meta-analyses and reviews have emphasized the importance of PA and other approaches in reducing BP, it is unclear which component has the most significant impact on reducing BP. As a result, this review aims to systematically evaluate the available evidence on the effectiveness of different PA approaches in reducing BP and to determine the hierarchy of these interventions according to their impact on BP. This review also aims to inform health professionals, educators, and kinesiologists of the best PA intervention to prevent the increase of BP in children and adolescents.

2. Methods

This review was guided by Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement (PRISMA).[35]

2.1. Information sources and search strategies

Two investigators (WZ and MH) independently analyzed the selection process and screening of the studies included in this review. The search was conducted up to December 2022, and the following databases were searched: PubMed, SPORTDiscus, PsycINFO, Web of Science, CINAHL, Cochrane, and Eric. In the literature search process, the investigators used the following keywords: ("physical activity" OR activities OR training OR exercise OR "physical education" OR sport OR fitness) AND ("blood pressure" OR "diastolic Pressure" OR "systolic Pressure" OR hypertension OR "Pulse pressure") AND (child OR children OR kid OR pupil OR adolescent OR juvenile OR pediatric OR teenager OR student) AND (intervention OR "randomized controlled trial" OR "quasi-experimental").

2.2. Eligibility criteria

To determine the eligibility criteria, the investigators used the PICOS (aka., population, intervention, comparators, outcomes, and setting) framework,[36] which included the following criteria: (a) participants must be children and adolescents aged 6−12 years old; (b) only RCTs and quasi-experimental studies were eligible; (c) only studies that compared controlled and intervention groups using PA or exercise as the major influence were included; (d) studies reporting SBP, DBP, or both as outcomes were eligible; and (e) only studies published in English were included. It was agreed that preschool-age children would not be included due to the limited number of studies targeting that age group. Additionally, although 1 study reported SBP and DBP z-scores, it was excluded from this review due to the limited number of studies reporting *z*-scores.

2.3. Comparators

As the outcomes of the recruited studies were specified in 2 groups, SBP and DBP, the authors defined the comparators according to interventions with 2 or more treatment arms as following: (1) control group (e.g., usual care, regular PA curriculum, or waiting list); (2) PA only (e.g., traditional PA only or exercise-based programs); (3) PA + Education (e.g., intervention including exercise and informative PA sessions); (4) PA + Nutrition (e.g., intervention including exercise and informative nutrition sessions or diet programs combined); (5) PA + Nutrition + Behavior change (e.g., interventions combining exercise with both dieting program and psychological informative sessions; and (6) multiple components, in which an intervention arm includes 4 or more intervention components (e.g., PA + Education + Nutrition + Lifestyle or PA + Education + Nutrition + Social media).

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2.4. Data extraction and processing

The literature search involved 2 phases. In the first phase, 2 investigators (ZG and WZ) identified the search keywords, and Rayyan[37] was used to analyze studies based on the inclusion criteria and search keywords. In the second phase, a third investigator (MH) was included to conduct a second round of article search. The identified articles were screened again for potential exclusion due to insufficient data or irrelevant treatment processes. After screening the titles and abstracts, the potentially relevant studies were retrieved in full-text format and stored in a shared online Google folder that allowed for content editing and follow-up processes. Data extraction was performed by (MH), specifically including mean differences (MDs) and associated standard deviations. The accuracy of the included data was then verified by (ZG).

2.5. Network geometry

To gain insight into the structure of available evidence from network meta-analyses (NMAs), it is recommended to create a traditional network graph that displays the treatment options (represented by nodes) and the available direct comparisons (represented by edges). This network plot facilitates a better visualization of different comparisons and treatments targeted towards the defined comparators in this review. In this study, we created 1 network plot that included the 2 outcomes (SBP and DBP). Notably, the size of the nodes is proportional to the number of comparisons involving that treatment node, while the thickness of the edges indicates the number of studies that included the 2 connected treatments.

2.6. Statistical analysis

We utilized a Bayesian Arm-based NMA to better understand the probability of heterogeneity between studies and to infer the probability of ranking efficacy among treatment arms. This approach offers a more accurate depiction of the likelihood of treatment ranking. To conduct the analysis, we utilized the "BUGSnet" package developed by Béliveau et al.[38] In addition, the Markov Chain Monte Carlo sampling was performed using "JAGS".[39] Both packages were performed through R (Version 4.1.0; R Foundation for Statistical Computing, Vienna, Austria). Continuous outcomes were presented using the MD between baseline and post-treatment BP (SBP and DBP) and 95% credible intervals (95%CIs).

2.7. Risk of bias and quality of evidence

Following the guidelines of the Cochrane Risk-of-Bias Assessment,[35] 2 investigators (MH and WZ) assessed the risk of bias of the included studies. Investigators have analyzed the domains independently. Disagreements were resolved by consulting a third investigator (ZG). Domains assessed were selection bias, performance bias, detection bias, attrition bias, reporting bias, and other bias (Table 1).

Table 1
Cochrane risk of bias assessment for randomized controlled trials (low, high, unclear).

Study	Random sequence generation	Allocation concealment	Blinding of Participants and personnel	Blinding of outcome assessment	Incomplete outcome data addressed	Selective reporting
Angelopoulos et al. 2009	Low	Low	Unclear	Unclear	Low	Low
Hansen et al. 1991	High	High	High	Unclear	Low	Low
Henaghan et al. 2008	High	Low	Unclear	Unclear	Low	Low
Muros et al. 2014	Low	Unclear	High	Unclear	Low	Low
Reinhr et al. 2010	Low	High	High	High	Low	Low
Rocchini et al. 1988	Low	Unclear	Unclear	Low	Low	Low
Vandongen et al. 1995	Low	High	High	High	Low	Low
Walther et al. 2009	Low	Low	Unclear	Unclear	Low	Low
Willi et al. 2012	Low	High	High	Unclear	Low	Low
Yu et al. 2016	Low	Unclear	Unclear	Unclear	Low	Low
Gallotta et al. 2022	Low	High	Unclear	Unclear	Low	Low
Martinez vizcaino et al. 2021	Low	Low	Low	Low	Low	Low
Aguilar et al. 2009	Low	Low	Unclear	High	Low	Low
Harrell et al. 1996	Low	Low	Low	Low	Low	Low
Kriemler et al. 2010	Low	Low	Low	Low	Low	Low
Larsen et al. 2018	Low	Unclear	Unclear	Unclear	Low	Low
Reed et al. 2008	Low	Low	Unclear	Unclear	Low	Low
Resaland et al. 2016	Unclear	Unclear	Unclear	Low	Low	Low
Simon et al. 2008	Low	High	Unclear	Low	Low	Low
Taylor et al. 2007	High	High	Unclear	High	Low	Low
Vizcaino et al. 2008	Low	Low	Low	Low	Low	Low
Weigel et al. 2008	Low	Low	High	Unclear	Low	Low
Adab et al. 2017	Low	High	Low	Unclear	Low	Low
Graf et al. 2006	Low	Unclear	Unclear	Unclear	Low	Low
Harrell et al. 1998	Low	Low	Low	Low	Low	Low
Hrafnkelsson et al. 2014	Low	Unclear	Low	Low	Low	Low
Yin et al. 2005	Low	Low	Unclear	Low	Low	Low

Notes: High risk = was poorly described or not described within the study; Low risk = described adequately within the study; Unclear risk = described somewhat adequately within the study.

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3. Results

3.1. Search results and study characteristics

Based on the selection criteria, a total of 27 studies were eligible and included in this analysis (Fig. 1). The total sample size of the included studies was 15,220 children and adolescents, divided into 2 groups: 8679 (57%) in the intervention group and 8121 (53%) in the control group. The minimum mean age noted was 6.3 years,[40] while the maximum was 12.6 years.[41] The year of publishing ranged from 1988 to 2022. It is worth mentioning that 22 of 27 (81%) studies were published in the last 18 years. In terms of study location, the selected studies represented 15 countries: 5 studies from the USA[41–45]; 4 studies from Germany[46–49]; 4 studies from Spain[50–53]; 2 studies from the UK[40,54]; 2 studies from Denmark[55,56]; and 1 study from Greece[57]; Australia[58]; Hong Kong, China[59]; Switzerland[60]; Canada[61]; Norway[62]; France[63]; New Zealand[64]; Iceland[65]; and Italy.[66] Regarding type of intervention, 11 (41%) of the studies targeted PA only[47,51–53,55,56,59–62,66]; 6 (22%) targeted PA + Nutrition[40,42,50,57,58,64]; 4 (15%) targeted multiple components[43,44,49,65]; 3 (11%) targeted PA + Education[45,54,63]; and 3 (11%) targeted PA + Nutrition + Behavior change.[41,46,48]

3.2. Network geometry

A network plot was executed to represent all possible direct comparisons between treatments shown in Fig. 2. Closed loops were detected between (i.e., control, PA only, and PA + Nutrition) and (i.e., control, PA only, and PA + Education). Closed loops refer to direct comparisons including more than 2 comparators. Among all comparators, control and PA only are considered large and similar in size when compared to the rest of the comparators. Moreover, the thickest edge noted is illustrating the direct comparison between control and PA only comparators.

3.3. Network meta-analysis

First, in terms of modelling fit, 2 models were performed: a fixed-effects model and a random-effects model for SBP and DBP separately. Fig. 3 illustrates the identification of potential outliers. This plot of leverage values shows the corresponding effective number of parameters total residual deviance, and deviance information criterion (DIC). Those values can be used to determine the model choice. As shown in Figs. 3A and 3B, specifically random-effects models presented lower DIC, and the leverage values were visually presented in a better fit

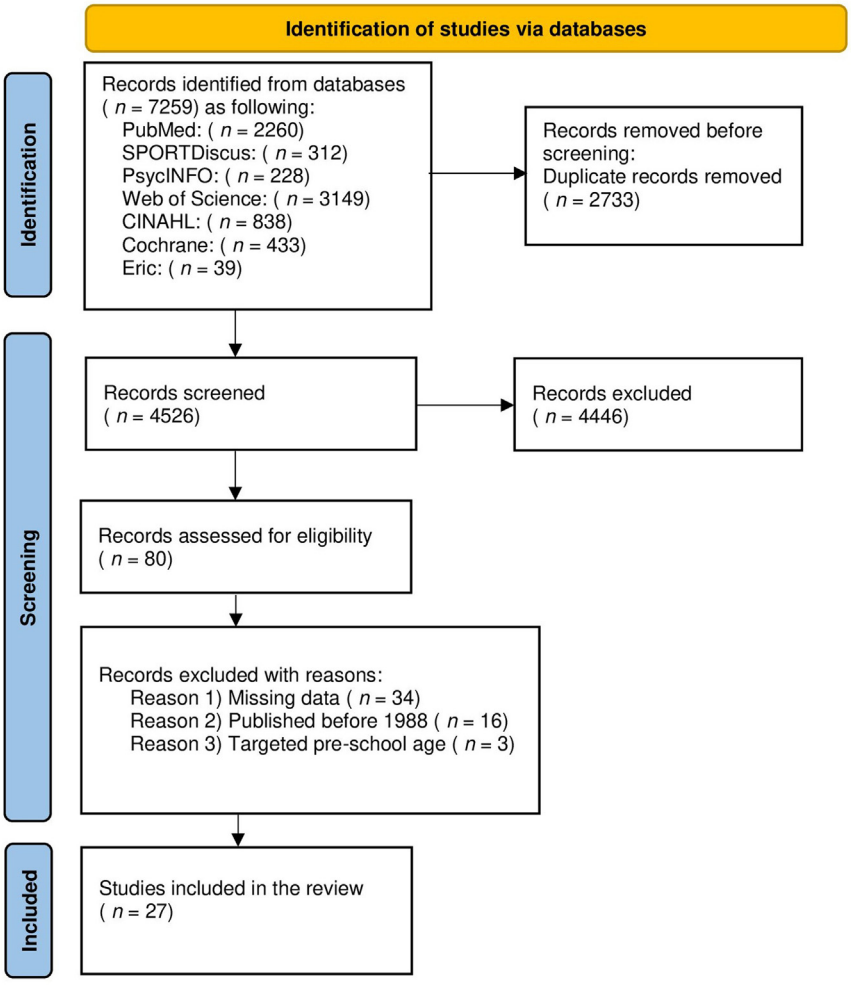

Fig. 1. PRISMA flow chart for systematic reviews.

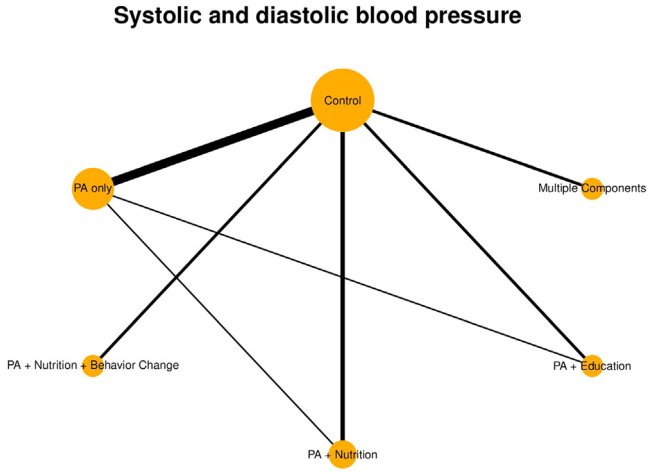

Fig. 2. Network plot for systolic and diastolic blood pressure. PA = physical activity.

with less outliers; thus, the random-effects models were chosen for both outcomes SBP and DBP.

Second, as consistency is one of the main assumptions in NMA, we checked the inconsistency by fitting a random-effects inconsistency model and compared it with our random-effects consistency model. Figs. 4A and 5A show the consistency and inconsistency models for SBP and DBP, respectively. When assessing the fit of both models, we found that the inconsistency model had slightly less DIC than the consistency model in both SBP and DBP. This illustrates the possibility of inconsistency in the network. Further, we performed a plot of the posterior mean deviance of the individual data points between both models for SBP (Fig. 4B) and DBP (Fig. 5B). Both plots showed an agreement between the 2 models given that most of the leverage values are close to 0. However, the difference between both models' DIC seems relatively small, more caution should be considered with the consistency model.

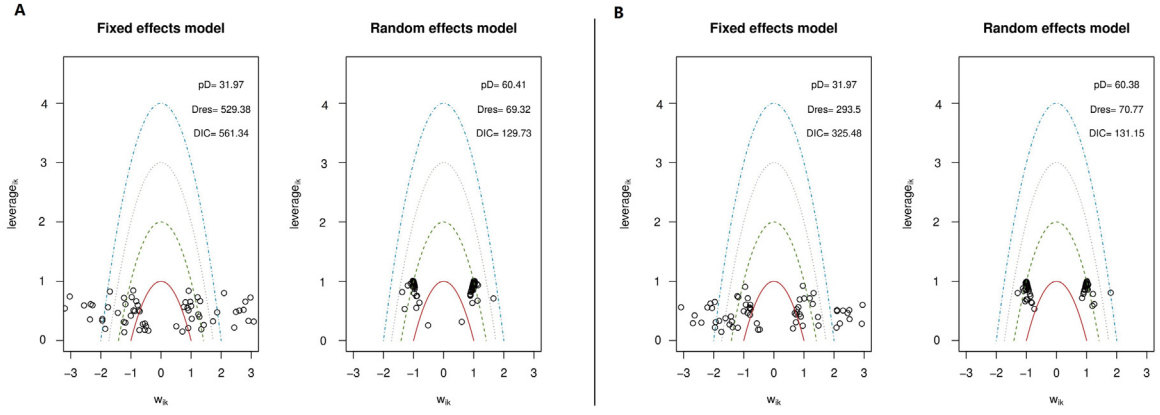

Fig. 3. Leverage plots and DIC for fixed and random effects models for systolic blood pressure (A) and diastolic blood pressure (B). pD = posterior mean deviance; Dres = deviance residual; DIC = deviance information criterion.

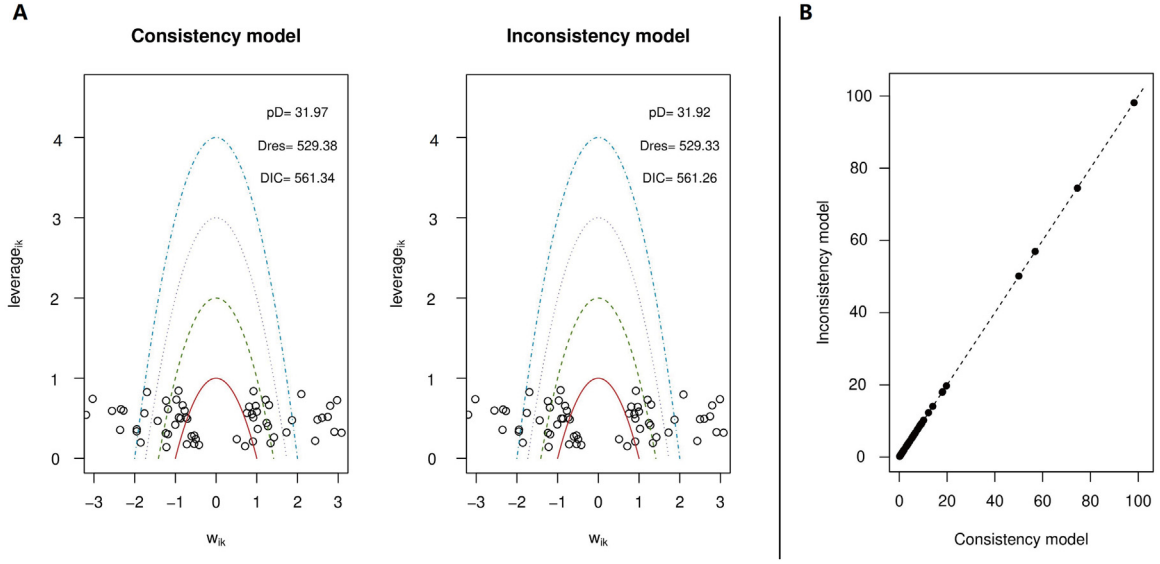

Fig. 4. Leverage plots and DIC for consistency and inconsistency model for SBP (A) and plot of the posterior mean deviance of inconsistency model against consistency model for SBP (B). Dres = deviance residual; DIC = deviance information criterion; pD = posterior mean deviance; SBP = systolic blood pressure.

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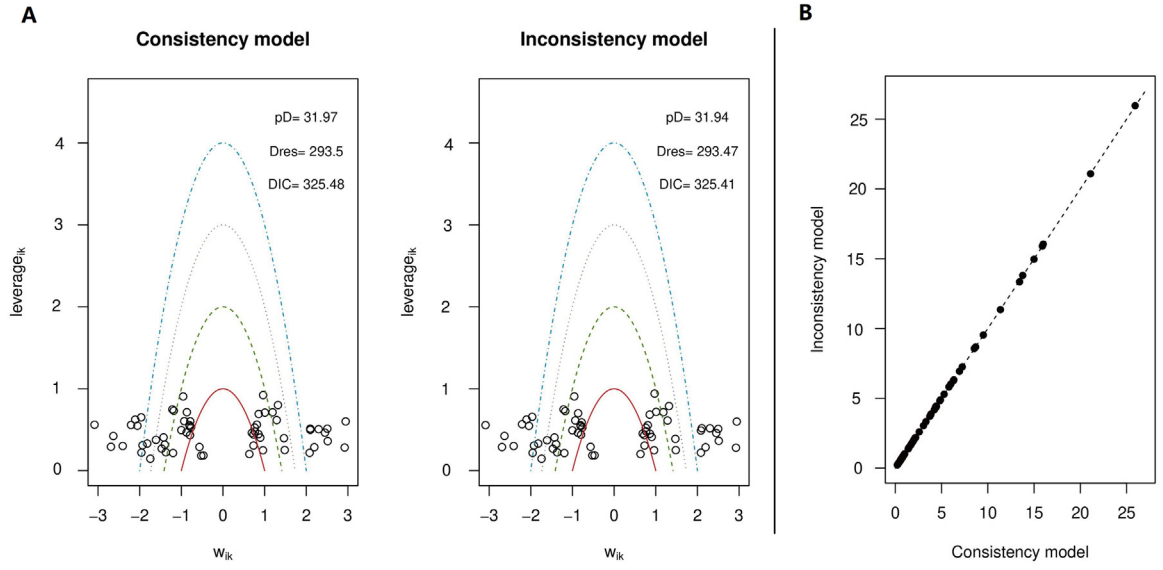

Fig. 5. Leverage plots and DIC for consistency and inconsistency model for DBP (A) and plot of the posterior mean deviance of inconsistency model against consistency model for DBP (B). DBP = diastolic blood pressure; Dres = deviance residual; DIC = deviance information criterion; pD = posterior mean deviance.

Third, with regards to ranking the treatments, we conducted a treatment rank probability analysis by comparing the posterior probabilities of ranking to determine the ranks of all treatments. Furthermore, we generated surface under the cumulative ranking curve (SUCRA) plots to visually display the percentage probability of ranking. For SBP, looking at treatment rank plot (Fig. 6A) and SUCRA plot (Fig. 6B), it is obvious that compared with the control group, PA + Nutrition + Behavior change interventions have remarkably decreased the SBP, and thus it is considered the best treatment. Surprisingly, the control group had a better ranking over PA + Education interventions, which ranked as the worst treatment. Similarly, in DBP, looking at treatment rank plot (Fig. 7A) and SUCRA plot (Fig. 7B), PA + Nutrition + Behavior change interventions were ranked as the best treatment, followed by Multiple Components interventions. Unlike SBP, the control group was the worst treatment illustrating the least effect on reducing DBP.

Fourth, a league plot was generated to provide a comprehensive summary of the NMA results, indicating the significance of all interventions compared to both the control group and other treatments. In this plot, green cells represent better performance of a treatment compared to its comparator, while red cells indicate worse performance. The symbols (**) denote statistically significant differences between treatments and comparators at a 95% confidence level. For SBP, Fig. 8 illustrates statistically significant differences when comparing PA + Nutrition + Behavior change interventions with the control group (MD −8.64, 95%CI: −11.44 to −5.84), followed by the Multiple Component interventions (MD

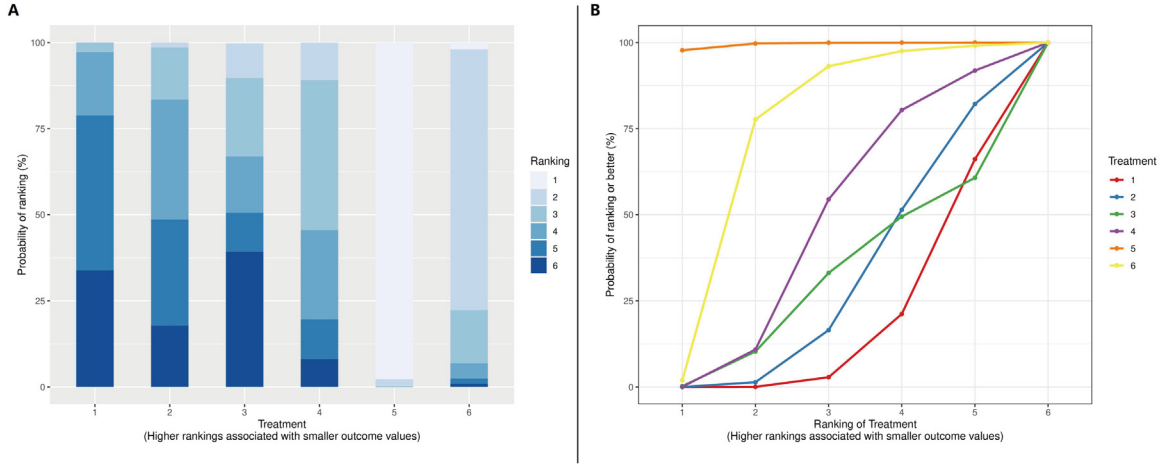

Fig. 6. SBP plot of treatment rank probabilities (A), SBP SUCRA plot (B). Treatments: 1 = control group; 2 = PA only; 3 = PA + Education; 4 = PA + Nutrition; 5 = PA + Nutrition +Behavior change; 6 = Multiple components. PA = physical activity; SBP = systolic blood pressure; SUCRA = surface under the cumulative ranking curve.

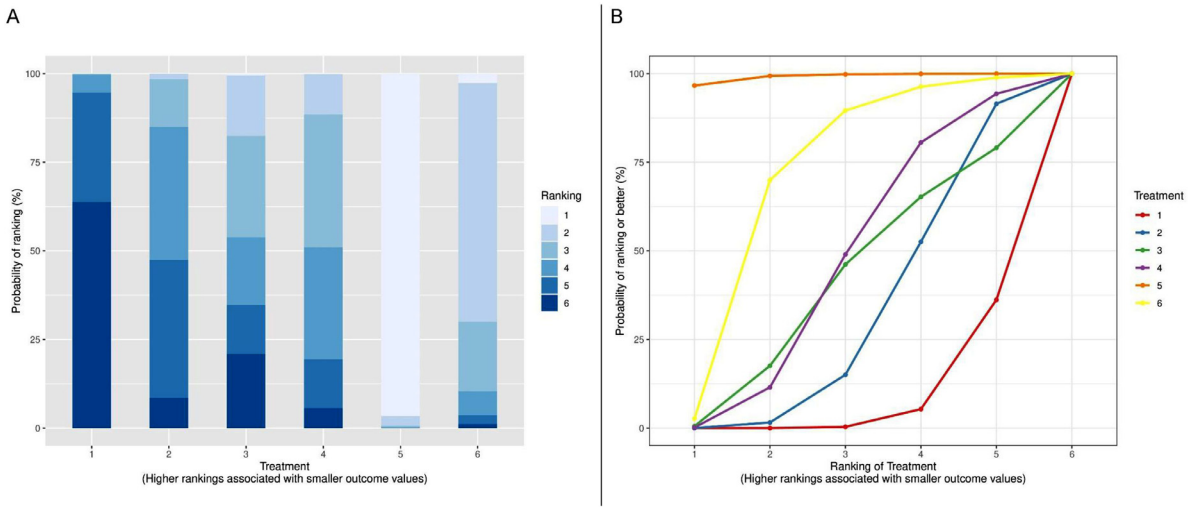

Fig. 7. DBP plot of treatment rank probabilities (A), DBP SUCRA plot (B).

Treatments: 1 = control group; 2 = PA only; 3 = PA + Education; 4 = PA + Nutrition; 5 = PA + Nutrition + Behavior change; 6 = Multiple components DBP = diastolic blood pressure; PA = physical activity; SUCRA = surface under the cumulative ranking curve.

−1.39, 95%Cl: −1.94 to −0.84). Inversely, comparing PA only interventions led to statistically significance differences but in favor of the comparator. For DBP, similar to SBP, PA + Nutrition + Behavior change interventions seem to be the best intervention for reducing DBP (MD −6.75, 95%CI: −10.44 to −3.11), followed by the Multiple Component interventions (MD −2.54, 95%CI: −4.89 to −0.29). In addition, other interventions (i.e., PA only, PA + Education, and PA + Nutrition) showed no significant difference when compared with the comparator (Fig. 9). Overall, multiple interventions comparisons illustrated statistically significant differences when compared with one another. However, SBP had more significant pairs of comparisons than DBP. In addition, to have a better visualization of MD differences with 95% CI between interventions, forest plots were performed for both SBP (Fig. 10A) and DBP (Fig. 10B). Both plots show approximately the same results, illustrating how PA + Nutrition + Behavior change interventions and multicomponent interventions remarkably reduced SBP and DBP.

Fifth, to test the presence of any publication bias, funnel plots were executed for both SBP (Fig. 11A) and DBP (Fig. 11B). While, both figures have an approximately symmetrical presentation of effect size estimates, Fig. 11A indicates a more precise symmetric distribution. Overall, the funnel plots indicate minimal publication bias or small sample effects.

Sixth, to test the reliability and stability of our results, we conducted a sensitivity analysis utilizing the "leave-one-out"

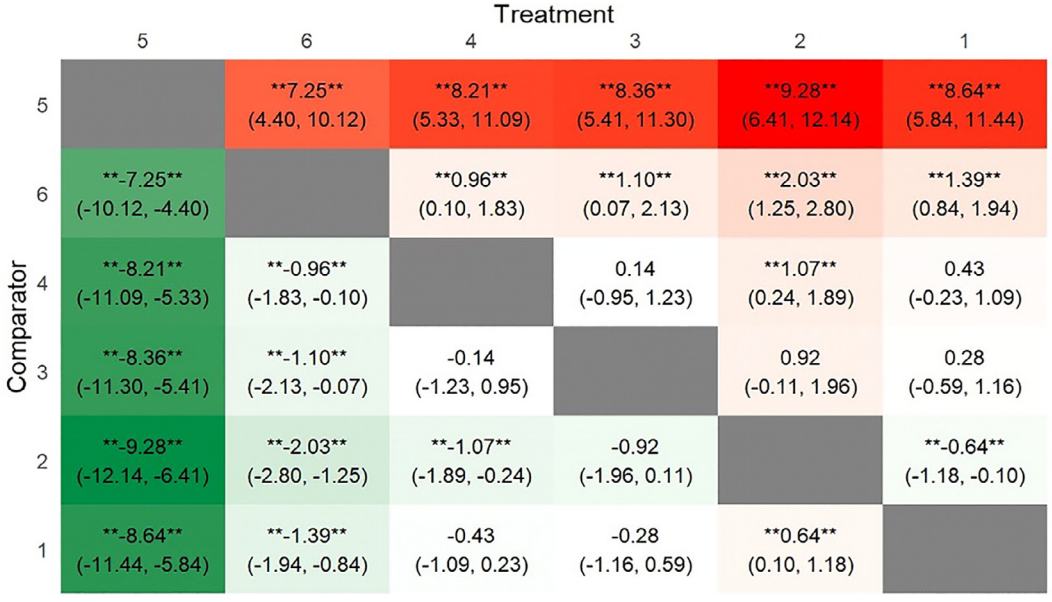

Fig. 8. League heat plot for all treatment in the network for SBP. Treatments: 1 = control group; 2 = PA only; 3 = PA + Education; 4 = PA + Nutrition; 5 = PA + Nutrition + Behavior change; 6 = Multiple components. PA = physical activity; SBP = systolic blood pressure.

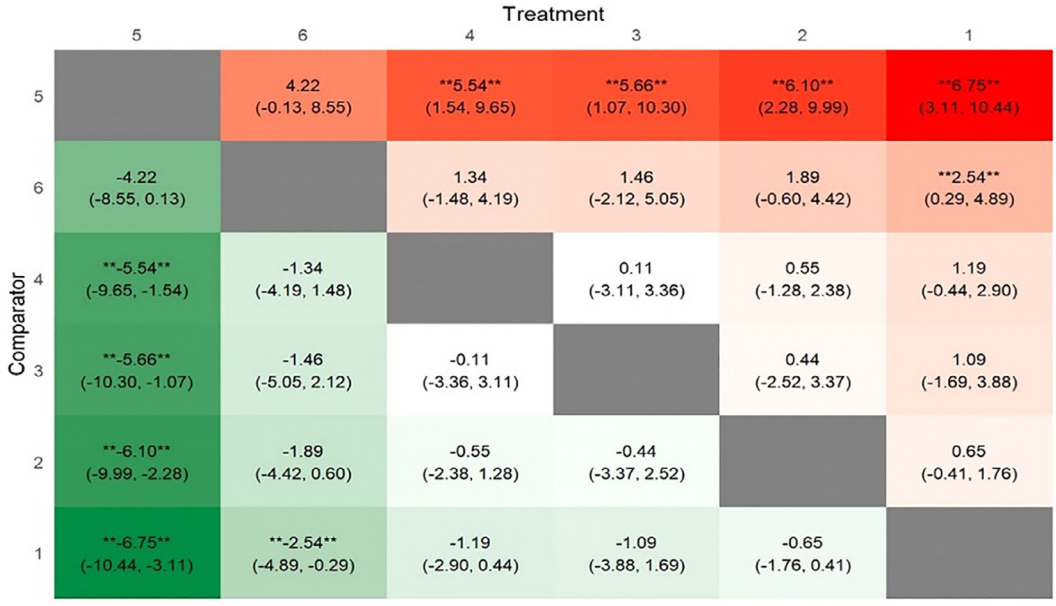

Fig. 9. League heat plot for all treatment in the network for DBP. Treatments: 1 = control group; 2 = PA only; 3 = PA + Education; 4 = PA + Nutrition; 5 = PA + Nutrition + Behavior change; 6 = Multiple components. DBP = diastolic blood pressure.

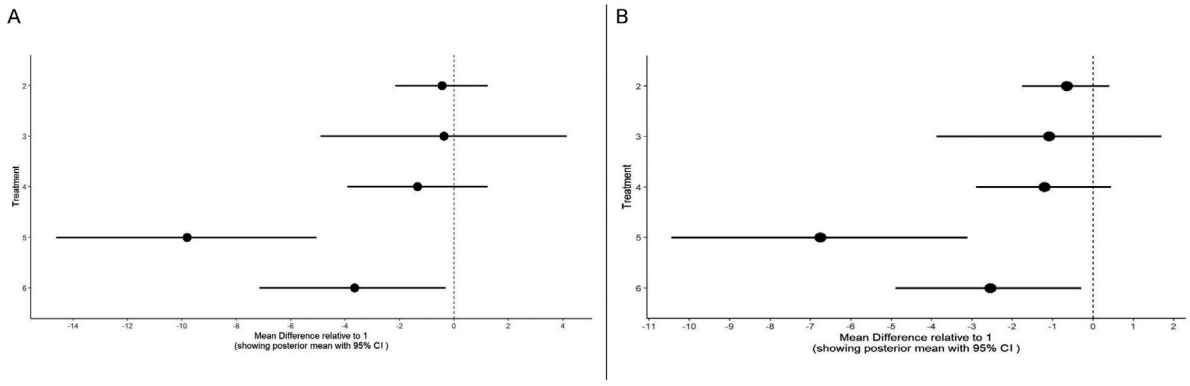

Fig. 10. Forest plot for all treatments compared to control group as reference for SBP (A) and DBP (B). Treatments: 1 = control group; 2 = PA only; 3 = PA + Education; 4 = PA + Nutrition; 5 = PA + Nutrition + Behavior change; 6 = Multiple components. DBP = diastolic blood pressure; PA = physical activity; SBP = systolic blood pressure

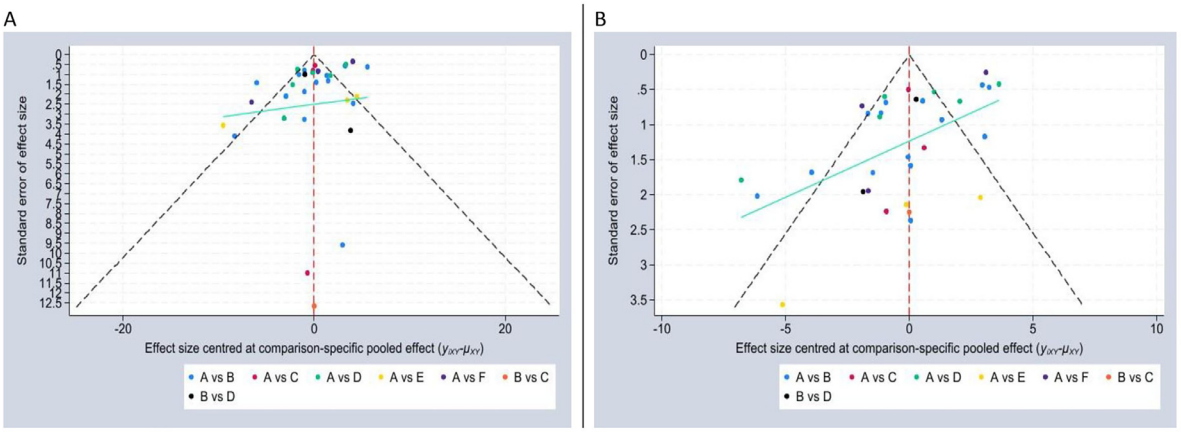

Fig. 11. Funnel plots of the effects of intervention arms on SBP (A) and DBP (B). DBP = diastolic blood pressure; SBP = systolic blood pressure.

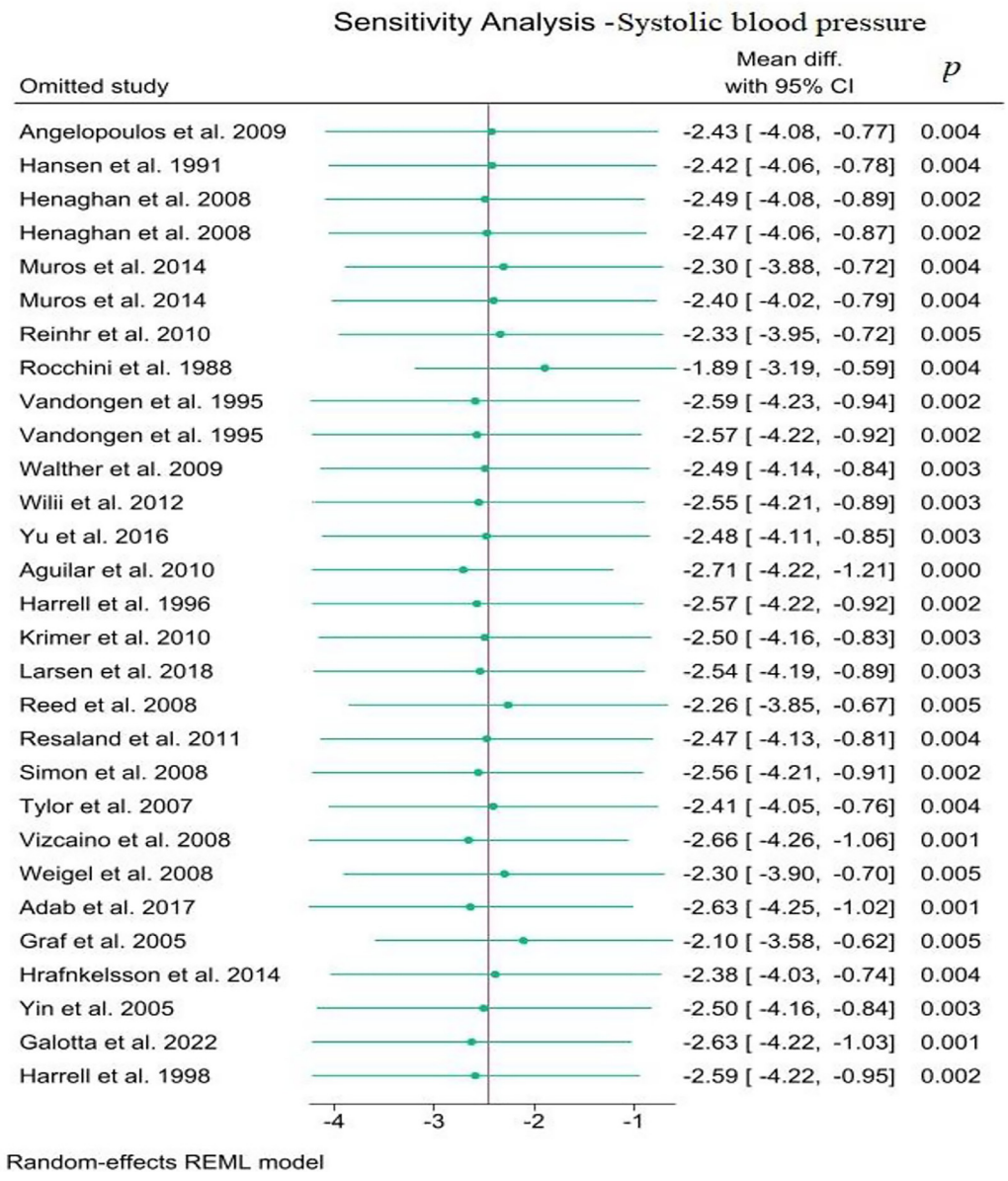

Fig. 12. Sensitivity analysis for SBP. SBP = systolic blood pressure.

method. Fig. 12 illustrates the sensitivity analysis for SBP, while Fig. 13 represents the sensitivity analysis for DBP. Both figures indicate conclusions that were not drastically changed in the analysis. All the results were of significance or marginal significance.

Finally, for the risk of bias assessment results shown in Table 1, among the 27 included studies, only 3 (11%) reported high risk in random sequence generation, while only 1 study had an unclear description of the randomization process. With reference to allocation concealment, 45% of the studies included had low risk of bias while the rest had either high or unclear reporting. Regarding blinding of participants, personnel, and outcome assessment, few studies were noted to have high risk of bias. Yet, several studies provided unclear reporting of the blinding process or failed to describe it at all. Lastly, all studies have adequately reported the outcome data addressed and provided low risk of bias within the selective reporting domain.

4. Discussion

This NMA conducted a comprehensive analysis of the current evidence and available data to determine the efficacy of various interventions, such as PA, nutrition, education, and behavior change, for reducing BP. It provides a quantification of the comparative effectiveness of these interventions.

In essence, our hypothesis was that including additional components in an intervention beyond PA would lead to a more significant reduction in BP. This idea was supported by the outcomes of several studies, which showed that PA interventions alone did not provide enough evidence of BP reduction. For example, Sun and colleagues[67] systematically

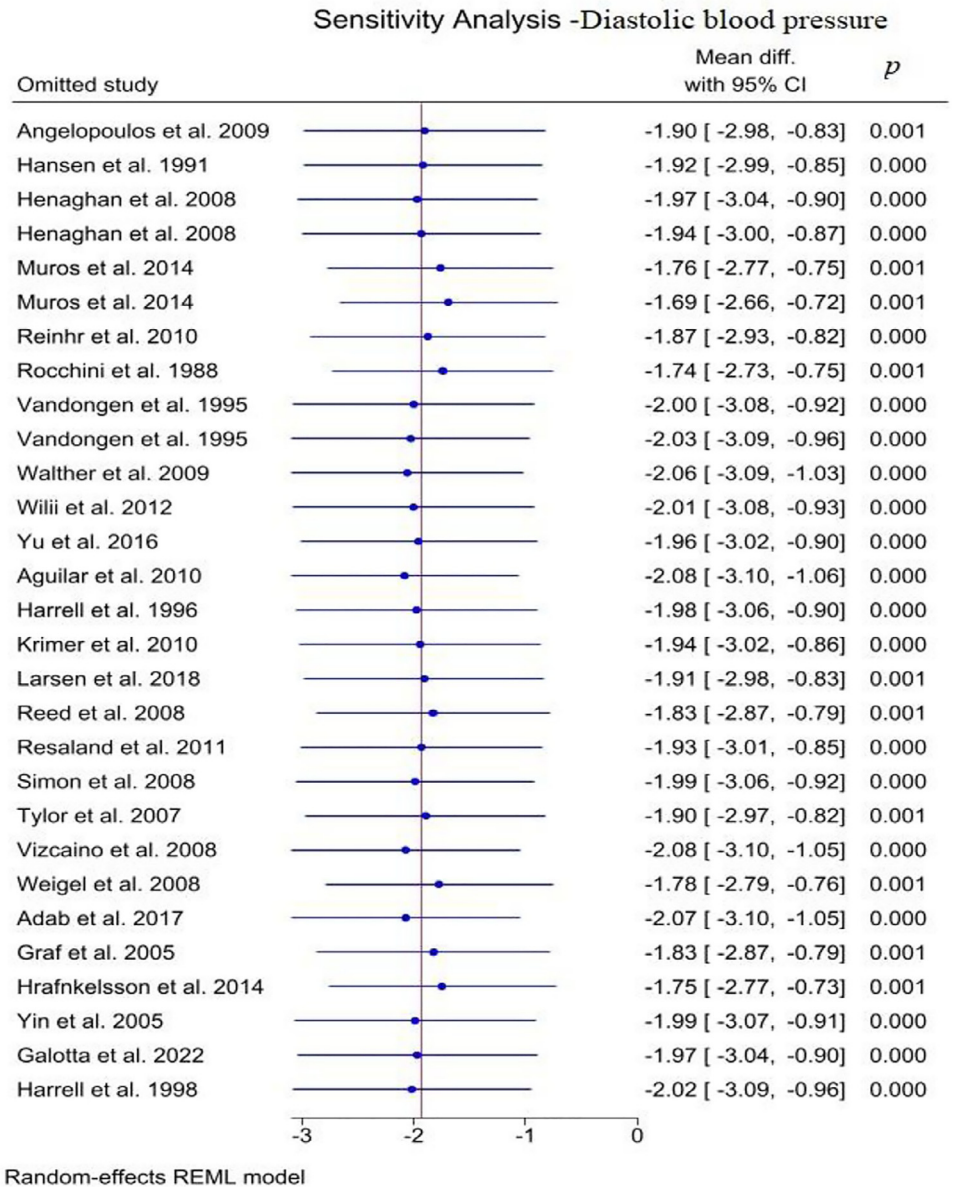

Fig. 13. Sensitivity analysis for DBP. DBP = diastolic blood pressure.

evaluated 18 RCTs on the effectiveness of school-based PA interventions on cardiometabolic markers in children and adolescents, including different PA doses and a combined total of 6207 participants. The results suggested the reduction of SBP and DBP was uncertain and required further evidence. Similarly, Pozuelo-Carrascosa et al.[68] conducted a meta-analysis of 19 RCTs on school-based PA interventions, which included 11,988 children aged 3–12 years. Kelley et al.[69] also conducted a meta-analysis of 12 RCTs on the effect of exercise on SBP and DBP in children and adolescents, which included 1266 participants. The results showed a decrease of approximately 1% and 3% in SBP and DBP, respectively. However, these findings were not significant in terms of the intervention length. In terms of the type and intensity of PA, other systematic reviews and meta-analyses have investigated the effect of resistance training on BP in pre-adolescents and adolescents and compared the effects of high-intensity and moderate-intensity training on BP. However, the results were also inconclusive in terms of reducing SBP and DBP.[70–72] These findings were in line with our results, which indicated that PA-only interventions may not be effective at reducing BP, as other interventions ranked higher in effectiveness.

Regarding the inclusion of additional components in PA interventions, Cai et al.[73] conducted a systematic review and meta-analysis to assess the effect of childhood obesity prevention programs on BP in children from developed countries. This review encompassed 23 studies that reported changes in SBP and DBP, and involved a total of 18,925 participants. The results indicated that interventions combining PA and diet yielded a greater and significant reduction in both SBP and DBP when compared to interventions focusing only on PA or diet. These findings are consistent with our own results, as interventions combining PA and Nutrition ranked higher than PA-only interventions in terms of reducing both SBP and

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DBP. Additionally, Oosterhoff et al.[74] conducted a multivariate multilevel meta-analysis of RCTs to evaluate the effectiveness of school-based lifestyle interventions (including PA, nutrition, education, diet, and multiple components) on body mass index and BP. The review included a total of 85 RCTs meeting the inclusion criteria. The results demonstrated significant beneficial changes in BP, with school-based lifestyle interventions leading to a significant reduction in both SBP and DBP. These findings are consistent with our results, suggesting that multi-component interventions may contribute to a reduction in BP.

The effectiveness of pharmaceutical interventions for reducing BP is now widely accepted. A myriad of clinical research, involving diverse drug treatments, has substantiated the benefits of clinical measures for those with or at risk for hypertension.[75] Conversely, studies on individuals with normal or slightly elevated BP have demonstrated the potential of non-drug strategies and dietary modifications to reduce BP.[76] Although non-pharmaceutical treatments have shown promising outcomes with good tolerability, there's an emphasis in the research on the importance of such strategies for mitigating hypertension risks, as we see reflected in various guidelines and recommendations.[77] In the NMA mentioned, the focus was on studies involving children and adolescents in school or combined school and home environments (Table 2). Most of these studies dealt with a generally healthy population, with only a few targeting obesity or those at cardiovascular disease risk. The findings suggest that interventions centered on PA combined with other modifiable factors might be a more efficient approach than relying solely on drug treatments. However, drawing a definitive conclusion regarding the most effective dietary program, PA guidelines, or behavioral changes remains challenging due to the diverse approaches present in the NMA. Additionally, with only 3 studies focusing on PA, nutrition, and behavioral change, a comprehensive definition of "behavior change" is elusive. Even though the studies in the NMA broadly define behavior change as participating in counseling sessions on coping strategies, ensuring healthy eating patterns, and providing information on food ingredients, further research is needed for a more robust definition.

Including additional components in PA interventions appears to enhance the positive effects of reducing BP. However, there is limited literature specifically examining the effectiveness of interventions combining PA, nutrition, and behavior change. Our findings suggest that such interventions are the most effective for reducing BP. This is consistent with previous research that has demonstrated the benefits of multi-component interventions for reducing BP. Our results highlight that, when combined, PA, nutrition, and behavior change are the most effective at reducing BP, with multi-component interventions ranking second in both SBP and DBP reduction. The key takeaway here is that an effective intervention for reducing BP should incorporate multiple components, such as PA, nutrition, and behavior change.

To our knowledge, this is the first NMA to combine existing literature on the effect of interventions (including PA and other components) at reducing BP in children and adolescents. Our results can be generalized since we included studies from 15 different countries with varying cultural differences, PA approaches, length, content, and included components. Furthermore, our study provides reliable and high-quality evidence that interventions that combine PA, nutrition, and behavior change are more effective and so are superior to other approaches. Nonetheless, our study has limitations. Firstly, some of the included studies have a high risk of bias; and there is slight inconsistency noted in the network, which calls for cautious consideration of our results. Secondly, while multi-component interventions ranked second best, more explanation and classification of the contained components are required. Thirdly, having a conclusive categorization of behavior change warrants more investigation. Finally, the frequency and content of PA-only interventions varied among included studies, hence the conclusive effect of PA alone remains unclear.

5. Conclusion

Although medication-based treatments are essential for young individuals with hypertension, non-drug strategies have demonstrated effectiveness for lowering BP among healthy youth. Thus, integrating PA with other alterable factors early on can serve as a protective shield against future health issues. Notably, interventions that amalgamate PA, nutrition, and behavioral adjustments tend to be notably superior at decreasing both SBP and DBP compared to interventions focused solely on PA. Moreover, further investigation is required to classify PA modalities in terms of content, length, and intensity before concluding that PA-only intervention is the least effective approach for reducing BP.

Authors' contributions

ZG contributed to the conceptualization, methodology, writing—original draft preparation, writing—review and editing, supervision, and project administration. MH contributed to the methodology, formal analysis, additional statistical analysis, investigation and data collection, data curation, writing—original draft preparation, and writing—review and editing. MY and HH did additional statistical analysis. WZ investigated and collected data. All authors have read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

Competing interests

The authors declare that they have no competing interests.

Supplementary materials

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.jshs.2024.01.004.

References

1. American Heart Association. *What is high blood pressure?* Available at: https://www.heart.org/en/health-topics/high-blood-pressure? [accessed 9.3.2023].
2. Forouzanfar MH, Afshin A, Alexander LT, et al. Global, regional, and national comparative risk assessment of 79 behavioural, environmental and occupational, and metabolic risks or clusters of risks, 1990−2015: A systematic analysis for the Global Burden of Disease Study 2015. *Lancet* 2016;**388**:1659–724.
3. Tsao CW, Aday AW, Almarzooq ZI, et al. Heart disease and stroke statistics—2022 update: a report from the American Heart Association. *Circulation* 2022;**145**:e153–639. doi:10.1161/CIR.0000000000001052.
4. The Centers for Disease Control and Prevention. *Heart Disease Statistics and Maps.* Available at: https://www.cdc.gov/heartdisease/statistics_maps.htm. [accessed 09.03.2023].
5. Fuchs FD, Whelton PK. High blood pressure and cardiovascular disease. *Hypertension* 2020;**75**:285–92.
6. Benjamin EJ, Blaha MJ, Chiuve SE, et al. Heart disease and stroke statistics—2017 update: a report from the American Heart Association. *Circulation* 2017;**135**:e146–603. doi:10.1161/CIR.0000000000000485.
7. Heidenreich PA, Trogdon JG, Khavjou OA, et al. Forecasting the future of cardiovascular disease in the United States: A policy statement from the American Heart Association. *Circulation* 2011;**123**:933–44.
8. Fields LE, Burt VL, Cutler JA, Hughes J, Roccella EJ, Sorlie P. The burden of adult hypertension in the United States 1999 to 2000: A rising tide. *Hypertension* 2004;**44**:398–404.
9. Chobanian AV, Bakris GL, Black HR, et al. Seventh report of the Joint National Committee on Prevention, Detection, Evaluation, and Treatment of High Blood Pressure. *Hypertension* 2003;**42**:1206–52.
10. Bress AP, Irvin MR, Muntner P. Genetics of blood pressure: New insights into a complex trait. *Am J Kidney Dis* 2017;**69**:723–5.
11. Ehret GB, Caulfield MJ. Genes for blood pressure: An opportunity to understand hypertension. *Eur Heart J* 2013;**34**:951–61.
12. Ehret GB, Munroe PB, Rice KM, et al. Genetic variants in novel pathways influence blood pressure and cardiovascular disease risk. *Nature* 2011;**478**:103–9.
13. Herrod PJ, Doleman B, Blackwell J, et al. Exercise and other non-pharmacological strategies to reduce blood pressure in older adults: A systematic review and meta-analysis. *J Am Soc Hypertens* 2018;**12**:248–67.
14. Roberts CK, Vaziri ND, Barnard RJ. Effect of diet and exercise intervention on blood pressure, insulin, oxidative stress, and nitric oxide availability. *Circulation* 2002;**106**:2530–2.
15. American Heart Association. *High Blood Pressure in Children.* Available at: https://www.heart.org/en/news/2020/05/13/high-blood-pressure-can-start-in-childhood-but-so-can-prevention [accessed 17.10.2023].
16. The Centers for Disease Control and Prevention. *High Blood Pressure in Kids and Teens*. Available at: https://www.cdc.gov/bloodpressure/youth.htm. [accessed 17.10.2023].
17. Riley M, Hernandez AK, Kuznia AL. High blood pressure in children and adolescents. *Am Fam Physician* 2018;**98**:486–94.
18. Boehme AK, Esenwa C, Elkind MSV. Stroke risk factors, genetics, and prevention. *Circ Res* 2017;**120**:472–95.
19. MartinezAguirre-Betolaza A, Mujika I, Fryer SM, et al. Effects of different aerobic exercise programs on cardiac autonomic modulation and hemodynamics in hypertension: Data from EXERDIET-HTA randomized trial. *J Hum Hypertens* 2020;**34**:709–18.
20. Zhou H, Wang S, Zhao C, He H. Effect of exercise on vascular function in hypertension patients: A meta-analysis of randomized controlled trials. *Front Cardiovasc Med* 2022;**9**: 1013490. doi:10.3389/fcvm.2022.1013490.
21. Dimeo F, Pagonas N, Seibert F, Arndt R, Zidek W, Westhoff TH. Aerobic exercise reduces blood pressure in resistant hypertension. *Hypertension* 2012;**60**:653–8.
22. de Souza Mesquita FO, Gambassi BB, de Oliveira Silva M, et al. Effect of high-intensity interval training on exercise capacity, blood pressure, and autonomic responses in patients with hypertension: A systematic review and meta-analysis. *Sports Health* 2023;**15**:571–8.
23. Gambassi BB, Queiroz C, Muniz D, et al. Acute effect of German volume training method on autonomic cardiac control of apparently Healthy Young. *Journal of Exercise Physiology online* 2019;**22**:49–57.
24. Gargallo P, Casaña J, Suso-Martí L, et al. Minimal dose of resistance exercise required to induce immediate hypotension effect in older adults with hypertension: Randomized cross-over controlled trial. *Int J Environ Res Public Health* 2022;**19**:14218. doi:10.3390/ijerph192114218.
25. Leary SD, Ness AR, Smith GD, et al. Physical activity and blood pressure in childhood: Findings from a population-based study. *Hypertension* 2008;**51**:92–8.
26. Pescatello LS, MacDonald HV, Lamberti L, Johnson BT. Exercise for hypertension: A prescription update integrating existing recommendations with emerging research. *Curr Hypertens Rep* 2015;**17**:87. doi:10.1007/s11906-015-0600-y.
27. Novotny R, Nigg CR, Li F, Wilkens LR. Pacific kids DASH for health (PacDASH) randomized, controlled trial with dash eating plan plus physical activity improves fruit and vegetable intake and diastolic blood pressure in children. *Child Obes* 2015;**11**:177–86.
28. Aaron KJ, Sanders PW. Role of dietary salt and potassium intake in cardiovascular health and disease: A review of the evidence. *Mayo Clin Proc* 2013;**88**:987–95.
29. Sacks FM, Svetkey LP, Vollmer WM, et al. Effects on blood pressure of reduced dietary sodium and the Dietary Approaches to Stop Hypertension (DASH) diet. Dash-Sodium Collaborative Research Group. *N Engl J Med* 2001;**344**:3–10.
30. Jurik R, Stastny P. Role of nutrition and exercise programs in reducing blood pressure: A systematic review. *J Clin Med* 2019;**8**:1393. doi:10.3390/jcm8091393.
31. Ndanuko RN, Tapsell LC, Charlton KE, Neale EP, Batterham MJ. Dietary patterns and blood pressure in adults: A systematic review and meta-analysis of randomized controlled trials. *Adv Nutr* 2016;**7**:76–89.
32. Limbachia J, Ajmeri M, Keating BJ, De Souza RJ, Anand SS. Effects of lifestyle interventions on cardiovascular risk factors in South Asians: A systematic review and meta-analysis. *BMJ Open* 2022;**12**: e059666. doi:10.1136/bmjopen-2021-059666.
33. Espinel E, Azancot MA, Gomez A, et al. Compliance to Multidisciplinary lifestyle intervention decreases blood pressure in patients with resistant hypertension: A cross-sectional pilot study. *J Clin Med* 2023;**12**:679. doi:10.3390/jcm12020679.
34. Nicoll R, Henein MY. Hypertension and lifestyle modification: How useful are the guidelines? *Br J Ge Pract* 2010;**60**:879–80.
35. Higgins JPT, Thomas J, Chandler J, et al. *Cochrane Handbook for Systematic Reviews of Interventions version 6.3 (updated February 2022).* Available at: https://training.cochrane.org/handbook. [accessed 17.10.2023].
36. Hutton B, Salanti G, Caldwell DM, et al. The PRISMA extension statement for reporting of systematic reviews incorporating network meta-analyses of health care interventions: Checklist and explanations. *Ann Intern Med* 2015;**162**:777–84.
37. Ouzzani M, Hammady H, Fedorowicz Z, Elmagarmid A. Rayyan-a web and mobile app for systematic reviews. *Syst Rev* 2016;**5**:210. doi:10.1186/s13643-016-0384-4.
38. Béliveau A, Boyne DJ, Slater J, Brenner D, Arora P. BUGSnet: An R package to facilitate the conduct and reporting of Bayesian network meta-analyses. *BMC Med Res Methodol* 2019;**19**:196. doi:10.1186/s12874-019-0829-2.
39. van Ravenzwaaij D, Cassey P, Brown SD. A simple introduction to Markov Chain Monte−Carlo sampling. *Psychon Bull Rev* 2018;**25**:143–54.
40. Adab P, Pallan M, Lancashire E, et al. Effectiveness of a childhood obesity prevention programme delivered through schools, targeting 6 and 7 year olds: Cluster randomised controlled trial (WAVES study). *BMJ* 2018;**360**:k211. doi:10.1136/bmj.k211BMJ.
41. Rocchini AP, Katch V, Anderson J, et al. Blood −pressure in obese adolescents: Effect of weight loss. *Pediatrics* 1988;**82**:16–23.
42. Yin Z, Gutin B, Johnson MH, et al. An environmental approach to obesity prevention in children: Medical college of Georgia FitKid project year 1 results. *Obes Res* 2005;**13**:2153–61.

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43. Willi SM, Hirst K, Jago R, et al. Cardiovascular risk factors in multi-ethnic middle school students: The HEALTHY primary prevention trial. *Pediatr Obes* 2012;**7**:230–9.
44. Harrell JS, Gansky SA, McMurray RG, Bangdiwala SI, Frauman AC, Bradley CB. School-based interventions improve heart health in children with multiple cardiovascular disease risk factors. *Pediatrics* 1998;**102**:371–80.
45. Harrell JS, Mcmurray RG, Bangdiwala SI, Frauman AC, Gansky SA, Bradley CB. Effects of a school-based intervention reduce cardiovascular disease risk factors in elementary-school children: The Cardiovascular Health in Children (CHIC) Study. *J Pediatr* 1996;**128**:797–805.
46. Reinehr T, Schaefer A, Winkel K, Finne E, Toschke AM, Kolip P. An effective lifestyle intervention in overweight children: Findings from a randomized controlled trial on "Obeldicks light.". *Clinical Nutrition* 2010;**29**:331–6.
47. Walther C, Gaede L, Adams V, et al. Effect of increased exercise in school children on physical fitness and endothelial progenitor cells: A prospective randomized trial. *Circulation* 2009;**120**:2251–9.
48. Weigel C, Kokocinski K, Lederer P, Dötsch J, Rascher W, Knerr I. Childhood obesity: Concept, feasibility, and interim results of a local group-based, long-term treatment program. *J Nutr Educ Behav* 2008;**40**:369–73.
49. Graf C, Rost SV, Koch B, et al. Data from the StEP TWO programme showing the effect on blood pressure and different parameters for obesity in overweight and obese primary school children. *Cardiol Young* 2005;**15**:291–8.
50. Muros JJ, Zabala M, Oliveras-López MJ, et al. Effect of physical activity, nutritional education, and consumption of extra virgin olive oil on lipid, physiological, and anthropometric profiles in a pediatric population. *J Phys Act Health* 2015;**12**:1245–52.
51. Salcedo Aguilar F, Martínez-Vizcaíno V, Sánchez López M, et al. Impact of an after-school physical activity program on obesity in children. *J Pediatrics* 2010;**157**:36–42.
52. Martínez Vizcaíno V, Salcedo Aguilar F, Franquelo Gutiérrez R, et al. Assessment of an after-school physical activity program to prevent obesity among 9- to 10-year-old children: A cluster randomized trial. *Int J Obes(Lond)* 2008;**32**:12–22.
53. Martínez-Vizcaíno V, Soriano-Cano A, Garrido-Miguel M, et al. The effectiveness of a high-intensity interval games intervention in schoolchildren: A cluster-randomized trial. *Scand J Med Sci Sports* 2022;**32**:765–81.
54. Henaghan J, Mcwhannell N, Foweather L, et al. The effect of structured exercise classes and a lifestyle intervention on cardiovascular risk factors in primary schoolchildren: An exploratory trial (The A-CLASS Project). *Pediatr Exerc Sci* 2008;**20**:169–80.
55. Larsen MN, Nielsen CM, Madsen M, et al. Cardiovascular adaptations after 10 months of intense school-based physical training for 8- to 10-year-old children. *Scand J Med Sci Sports* 2018;**28**:33–41.
56. Hansen HS, Froberg K, Hyldebrandt N, Nielsen JR. A controlled study of eight months of physical training and reduction of blood pressure in children: The Odense schoolchild study. *BMJ* 1991;**303**:682–5.
57. Angelopoulos PD, Milionis HJ, Grammatikaki E, Moschonis G, Manios Y. Changes in BMI and blood pressure after a school based intervention: The CHILDREN study. *Eur J Public Health* 2009;**19**:319–25.
58. Vandongen R, Jenner DA, Thompson C, et al. A controlled evaluation of a fitness and nutrition intervention program on cardiovascular health in 10- to 12-year-old children. *Prev Med* 1995;**24**:9–22.
59. Yu CCW, McManus AM, So HK. Effects of resistance training on cardiovascular health in non-obese active adolescents. *World J Clin Pediatr* 2016;**5**:293–300.
60. Kriemler S, Zahner L, Schindler C, et al. Effect of school based physical activity programme (KISS) on fitness and adiposity in primary schoolchildren: Cluster randomised controlled trial. *BMJ* 2010;**340**:c785. doi:10.1136/bmj.c785.
61. Reed KE, Warburton DER, Macdonald HM, Naylor PJ, McKay HA. Action Schools! BC: A school-based physical activity intervention designed to decrease cardiovascular disease risk factors in children. *Prev Med* 2008;**46**:525–31.
62. Resaland GK, Anderssen SA, Holme IM, Mamen A, Andersen LB. Effects of a 2-year school-based daily physical activity intervention on cardiovascular disease risk factors: The Sogndal school-intervention study. *Scand J Med Sci Sports* 2011;**21**:e122–31.
63. Simon C, Schweitzer B, Oujaa M, et al. Successful overweight prevention in adolescents by increasing physical activity: A 4-year randomized controlled intervention. *Int J Obes* 2008;**32**:1489–98.
64. Taylor RW, Mcauley KA, Barbezat W, Strong A, Williams SM, Mann JI. APPLE project: 2-y findings of a community-based obesity prevention program in primary school-age children. *Am J Clin Nutr* 2007;**86**:735–42.
65. Hrafnkelsson H, Magnusson KT, Thorsdottir I, Johannsson E, Sigurdsson EL. Result of school-based intervention on cardiovascular risk factors. *Scand J Prim Health Care* 2014;**32**:149–55.
66. Gallotta MC, Zimatore G, Cardinali L, et al. Physical Education on the beach: An alternative way to improve primary school children's skill- and health-related outcomes during the COVID-19 pandemic. *Int J Environ Res Public Health* 2022;**19**:3680. doi:10.3390/ijerph19063680.
67. Sun C, Pezic A, Tikellis G, et al. Effects of school-based interventions for direct delivery of physical activity on fitness and cardiometabolic markers in children and adolescents: A systematic review of randomized controlled trials. *Obesity Rev* 2013;**14**:818–38.
68. Pozuelo-Carrascosa DP, Cavero-Redondo I, Herráiz-Adillo Á, Díez-Fernández A, Sánchez-López M, Martínez-Vizcaíno V. School-based exercise programs and cardiometabolic risk factors: A meta-Analysis. *Pediatrics* 2018;**142**: e20181033. doi:10.1542/peds.2018-1033.
69. Kelley GA, Kelley KS, Tran ZV. The effects of exercise on resting blood pressure in children and adolescents: A meta-analysis of randomized controlled trials. *Prev Cardiol* 2003;**6**:8–16.
70. Guillem CM, Loaiza-Betancur AF, Rebullido TR, Faigenbaum AD, Chulvi-Medrano I. The effects of resistance training on blood pressure in preadolescents and adolescents: A systematic review and meta-analysis. *Int J Environ Res Public Health* 2020;**17**:7900. doi:10.3390/ijerph17217900.
71. Li L, Liu X, Shen F. Effects of high-intensity interval training versus moderate-intensity continuous training on blood pressure in patients with hypertension: A meta-analysis. *Medicine (Baltimore)* 2022;**101**:e32246. doi:10.1097/MD.0000000000032246.
72. Liu Z, Gao P, Gao AY, et al. Effectiveness of a Multifaceted intervention for prevention of obesity in primary school children in China: A cluster randomized clinical trial. *JAMA Pediatr* 2022;**176**: e214375. doi:10.1001/jamapediatrics.2021.4375.
73. Cai L, Wu Y, Wilson RF, Segal JB, Kim MT, Wang Y. Effect of childhood obesity prevention programs on blood pressure: A systematic review and meta-analysis. *Circulation* 2014;**129**:1832–9.
74. Oosterhoff M, Joore M, Ferreira I. The effects of school-based lifestyle interventions on body mass index and blood pressure: A multivariate multilevel meta-analysis of randomized controlled trials. *Obesity Reviews* 2016;**17**:1131–53.
75. Strilchuk L, Cincione RI, Fogacci F, Cicero AFG. Dietary interventions in blood pressure lowering: Current evidence in 2020. *Kardiol Pol* 2020;**78**:659–66.
76. Borghi C, Cicero AFG. Nutraceuticals with a clinically detectable blood pressure-lowering effect: A review of available randomized clinical trials and their meta-analyses. *Br J Clin Pharmacol* 2017;**83**:163–71.
77. Vitto CM, Lykins V JD, Wiles-Lafayette H, Aurora TK. Blood pressure assessment and treatment in the observation unit. *Curr Hypertens Rep* 2022;**24**:311–23.

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