Effects of different exercise training modalities on 24-hour ambulatory blood pressure in adults with hypertension: a network meta-analysis of randomised controlled trials

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ABSTRACT

Objective To compare the effects of exercise training modalities on 24-hour ambulatory blood pressure in adults with hypertension.

Design Systematic review and network meta-analysis.

Data sources MEDLINE, Embase, Cochrane Central and Regional Portal of the Virtual Health Library were systematically searched from November 2024 to August 2025.

Eligibility criteria for selecting studies Randomised controlled trials evaluating the effects of exercise training (intervention duration ≥4 weeks) compared with a non-exercise control condition or another exercise modality on 24-hour systolic and diastolic blood pressure were included.

Results 31 trials were included, with 67 arms and 1345 participants. In the network meta-analysis, compared with the control, combined training (mean difference (MD) −6.18 mm Hg, 95% credible interval (CrI) −11.45 to −1.21), aerobic training (MD −4.73 mm Hg, 95% CrI −7.53 to −2.01), and high-intensity interval training (MD −5.71 mm Hg, 95% CrI −11.31 to −0.002) reduced 24-hour systolic blood pressure. Reductions in 24-hour diastolic blood pressure were observed with combined training (MD −3.94, 95% CrI −6.47 to −1.34), aerobic training (MD −2.76, 95% CrI −4.21 to −1.34), high-intensity interval training (MD −4.64, 95% CrI −8.21 to −0.72) and pilates (MD −4.18, 95% CrI −7.18 to −1.17). Exercise-versus-exercise comparisons were inconclusive with respect to superiority between modalities.

Conclusion Aerobic training (continuous and interval) and combined training significantly reduced 24-hour blood pressure. Evidence for dynamic and isometric resistance training remains uncertain. Data on non-conventional exercise modalities such as pilates and recreational sports are limited and imprecise for the management of ambulatory blood pressure.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Exercise is recommended for the prevention and treatment of hypertension.
⇒ Ambulatory blood pressure is a stronger predictor than office blood pressure for cardiovascular events and mortality risk.

WHAT THIS STUDY ADDS

⇒ This study is the first comprehensive network meta-analysis comparing the effects of multiple exercise modalities on 24-hour ambulatory blood pressure.
⇒ Aerobic, combined and high-intensity interval training significantly reduced 24-hour blood pressure versus control.
⇒ There was no exercise modality demonstrating clear superiority over others, and comparative effectiveness remains uncertain.
⇒ Evidence on resistance training, isometric training and non-conventional exercise modalities remain limited and uncertain for the management of ambulatory blood pressure.
⇒ Combined training and high-intensity interval training are new alternatives to reduce 24-hour ambulatory blood pressure in adults with hypertension.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Current recommendations should include aerobic (continuous or interval training) or combined training as primary evidence-based interventions for reducing 24-hour ambulatory blood pressure in adults with hypertension.
⇒ Despite promising results for yoga, pilates and recreational sports, larger randomised trials using ambulatory monitoring are essential to confirm the efficacy of non-conventional exercise modalities in hypertension management.
⇒ The established benefits of resistance training for office blood pressure have yet to be confirmed by robust 24-hour ambulatory data, marking a critical priority for future research.

INTRODUCTION

Hypertension is the most prevalent modifiable cardiovascular risk factor and remains the leading cause of death and disability worldwide.[1 2] Lifestyle modifications, including regular exercise, have been extensively recommended as a cornerstone for blood pressure control,[3 4] with benefits comparable to those of antihypertensive medications.[5] While aerobic and resistance training are well-established interventions for reducing office blood pressure,[3 6] data derived from 24-hour ambulatory blood pressure monitoring (ABPM) provide a more nuanced perspective. Unlike isolated office measurements, ABPM captures blood pressure fluctuations during daily activities and sleep, allowing the identification of nocturnal dipping patterns and the detection of white coat or masked hypertension.[7 8] Although office blood pressure is a standard clinical tool, it fails to capture the dynamic fluctuations of the 24-hour cycle. Consequently, this continuous assessment offers superior prognostic value for mortality, cardiovascular risk[9 10] and a more comprehensive evaluation of the true physiological effects of exercise.

Despite the well-documented benefits of exercise on blood pressure, significant gaps remain in the literature. Most existing systematic reviews and meta-analyses continue to rely predominantly on office blood pressure measurements.[6 11–13] To date, only a few reviews have specifically assessed the effects of exercise on ABPM.[14 15] Furthermore, the scope of available evidence is often restricted because many syntheses focus exclusively on conventional aerobic or resistance training, excluding emerging modalities such as yoga, pilates and recreational sports.[16 17]

While traditional meta-analyses have established the benefits of exercise for blood pressure control, their reliance on pairwise comparisons precludes simultaneous ranking of multiple interventions. Network meta-analysis (NMA) overcomes this by integrating direct and indirect evidence, yet its application in exercise science has yielded disparate findings. Notably, recent NMA data suggesting the superiority of isometric training for office blood pressure[17] contrast with broader evidence regarding ABPM. To date, no NMA has evaluated the effects of a comprehensive spectrum of physical activity on 24-hour blood pressure. This study is the first to synthesise evidence across conventional (aerobic, resistance, and combined) and non-conventional (yoga, pilates and recreational sports) modalities, specifically targeting 24-hour blood pressure outcomes in adults with hypertension.

METHODS

Protocol and reporting standards

This systematic review and NMA adhered to the extension of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses for NMA (PRISMA-NMA) guidelines[18] online supplemental file, section S0 . The protocol was prospectively registered with the International Prospective Register of Systematic Reviews (PROSPERO; CRD420250563177).

Eligibility criteria

We included randomised trials that evaluated the effects of structured exercise training on ambulatory blood pressure in adults (≥18 years) with hypertension. We defined hypertension according to the criteria of the American College of Cardiology/American Heart Association[19] as a 24-hour systolic blood pressure ≥130 mm Hg and/or diastolic blood pressure ≥80 mm Hg or current use of antihypertensive medication.

Studies were eligible if they met the following: (1) used a randomised parallel-group design; (2) enrolled adults with hypertension, as defined above; (3) implemented a structured exercise intervention lasting ≥4 weeks; (4) compared exercise with a non-exercise control (eg, usual care, waitlist, attention control) or another exercise modality; and (5) reported baseline and post-intervention data (or change values) for at least one of the following outcomes: 24-hour, daytime or nighttime systolic or diastolic ABPM.

Exercise was defined as 'planned, structured and repetitive bodily movements performed to improve or maintain one or more components of physical fitness'.[20] All protocols were reviewed and classified by modality (eg, aerobic continuous training, resistance, isometric, aerobic interval training, yoga, and recreational sports) to create interpretable nodes and support the geometry of the network to compare the mean differences between modalities (online supplemental table 1).

Studies were excluded if they: (1) combined exercise with other interventions known or likely to affect blood pressure (eg, diet, supplementation, behavioural counselling or medication changes); (2) used active controls with potential antihypertensive effects; or (3) used crossover designs. No language or publication year restrictions were imposed.

Information sources and search strategy

A comprehensive literature search was conducted to identify relevant randomised controlled trials (RCTs) published in any language. Four electronic databases were systematically searched from November 2024 to August 2025: MEDLINE (via PubMed), Embase, Cochrane Central Register of Controlled Trials (CENTRAL) and Regional Portal of the Virtual Health Library (VHL). No restrictions were applied with respect to publication date or language. The search strategy incorporated Medical Subject Headings (MeSH), Emtree terms and free-text keywords related to exercise, physical activity and ambulatory blood pressure. Boolean operators were used to maximise sensitivity without applying filters in the study design.

All the retrieved references were exported to EndNote X9 (Clarivate Analytics) for deduplication and reference management. Additionally, the reference lists of included studies and relevant systematic reviews were manually screened for additional eligible trials. The detailed search strategies for each database, including all terms and Boolean combinations, are provided in online supplemental S2.

Study selection and data extraction

Two reviewers (VMS and DMP) independently screened all the records using EndNote X9. Following automatic deduplication, the titles and abstracts were screened in duplicate. Full-text articles that were deemed potentially eligible were retrieved and independently assessed by the same reviewers. Discrepancies were resolved by consensus, with arbitration by a third reviewer (RF) when necessary. The reasons for study exclusion after the full-text assessment are summarised in online supplemental table S3.

Data extraction was performed independently by the same reviewers using a standardised Microsoft Excel spreadsheet. For each included trial, information was collected on bibliographic details (first author, year, and country), participant characteristics (mean age, sex distribution, baseline blood pressure), intervention and comparator features (sample size, exercise modality, frequency, intensity and duration) and outcomes of interest. These included 24-hour, daytime and nighttime systolic and diastolic ABPM measurements.

Trials with multiple eligible arms were fully included in the network provided that each arm represented a distinct and methodologically valid comparison. In such cases, care was taken to model multi-arm trials appropriately, ensure statistical coherence and avoid data duplication. All data were extracted according to the intention-to-treat principle, considering the final post-intervention follow-up values, to calculate the mean changes from baseline.

Data preparation and imputation procedures

Only outcome data corresponding to the final post-intervention follow-up were included in the synthesis, using the mean changes from baseline when available. For studies that reported mean changes with 95% confidence intervals (95% CI), standard errors were calculated from the CI width and subsequently converted to SD using the reported sample size. When the mean change, SD or CI was missing, it was estimated using the formulas recommended in the Cochrane Handbook for Systematic Reviews of Interventions.[21] To be conservative, the correlation was set to zero in these calculations. In addition, if no dispersion measure was available, SD for mean change (SD change) was either computed from available p values or imputed using the average SD change from other studies included in the meta-analysis. When two or more intervention arms within a study were deemed clinically and methodologically equivalent (eg, the same exercise modality, frequency, intensity and duration), they were combined to form a single group. Means were combined using weighted averages, and pooled SDs were calculated using the combined variance formula incorporating arm-specific sample sizes and SD. Studies reporting medians without means were excluded because the data could not be reliably transformed or modelled in the NMA. When studies reported ABPM outcomes at more than one follow-up time point, we consistently extracted the first available post-intervention assessment to ensure comparability across studies and avoid unit-of-analysis errors.

For studies with missing or unclear outcome data, the authors were contacted via email. Of the six authors contacted, three responded and provided requested information. No study was excluded due to missing data after unsuccessful contact attempts. A list of studies and their responses is presented in online supplemental S4.

Risk of bias and study quality assessment

The risk of bias and methodological quality were evaluated using the Tool for the Evaluation of Study Quality and Reporting in Exercise[22] (TESTEX), a 12-item scale with a maximum score of 15 points, specifically designed for trials involving exercise interventions. The scale comprises five elements that assess the quality of the study (eg, randomisation, concealment of allocation, blinding and statistical comparisons between groups) and seven elements related to reporting (eg, exercise intensity, adherence and adverse events). Two reviewers (VMS and DPM) independently assessed all the included trials. Discrepancies were resolved through discussion, and a third reviewer (RF) was consulted when a consensus could not be reached.

Data synthesis and statistical analysis

Bayesian NMA models were conducted using the *gemtc* and *rjags* packages in R version 4.4.1. A normal likelihood with an identity link function was specified, and consistency models were fitted. Four Markov chains were run with 10 000 adaptation iterations, followed by 10 000 sampling iterations with a thinning interval of 20. Convergence was assessed using trace plots, autocorrelation diagnostics and the Gelman-Rubin statistic. The fit of the model was evaluated using the deviance information criterion, which also guided the selection between fixed- and random-effects models.[23] All analyses followed an arm-based approach with each row representing a single treatment arm. The effect measure was the mean difference of the mean changes from baseline (we will simply call it MD) in ABPM (mm Hg) with 95% credible intervals (95% CrI) compared with control. The treatment ranking was based on the surface under the cumulative ranking curve (SUCRA) derived from posterior ranking probabilities. The SUCRA values were interpreted as the probability of each treatment being the most effective. Cumulative ranking curves and league tables were generated, and SUCRA plots were refined for publication.[24] The plausibility of the transitivity assumption was assessed conceptually by examining the distribution of key potential effect modifiers across treatment comparisons. Inconsistency was explored using the node-splitting approach to compare direct and indirect estimates for each contrast. A Bonferroni-adjusted threshold for statistical significance ($p<0.05$/number of comparisons) was applied as a control for multiple tests.[25] To aid in the interpretation of clinical relevance, we estimated the potential reduction in cardiovascular risk associated with a decrease of 2 mm Hg in systolic and diastolic ABPM.[9,10] Exploratory traditional pairwise meta-analyses were conducted to synthesise direct evidence for exercise versus control and exercise versus exercise comparisons, and full methodological details are reported in online supplemental S13.

Additional analyses

To assess possible publication bias, comparison-adjusted funnel plots were visually inspected, and Egger's regression tests were conducted for primary outcomes (24-hour systolic and diastolic ABPM). A p value <0.10 was considered indicative of the effects of small studies. Finally, the Confidence in Network Meta-Analysis (CINeMA) platform was used to assess confidence in NMA estimates in six domains: within-study bias, reporting bias, indirectness, imprecision, heterogeneity and incoherence.[26]

Equity, diversity and inclusion statement

The study encompassed all identified RCTs assessing exercise training for the management of ABPM, without imposing restrictions based on gender, race or ethnicity, or socioeconomic status. The review included adults of both sexes, across a range of ages. However, younger adults (<40 years) and older adults (>75 years) were underrepresented in the included trials. In addition, not all studies reported the distribution of participants by sex within intervention groups. These constraints hindered a more nuanced understanding of how exercise influences blood pressure across different age groups in men and women. The research team comprised two men and two women from diverse disciplinary backgrounds, including sports and exercise science, nutrition and statistics. VMS and DMS were PhD students. The research design, data extraction and analytical methods were applied consistently and were not adjusted according to the regional, educational or socioeconomic characteristics of the study population.

RESULTS

Study selection and characteristics

A database search identified 5960 records. After removing 925 duplicates, 5035 unique titles and abstracts were screened. Of these, 75 full-text articles were assessed for eligibility, 44 were excluded for consensus-based reasons (online supplemental S3) and 31 RCTs were included in this systematic review. Twenty-nine RCTs contributed to the primary NMA of 24-hour systolic and diastolic ABPM, and 28 were included in the analysis of daytime and night-time ABPM outcomes (figure 1). Online supplemental file, section S7, lists the references and characteristics of the included studies, including sample features and details of the exercise intervention. In total, 67 intervention arms were analysed for primary NMA. The number of participants per

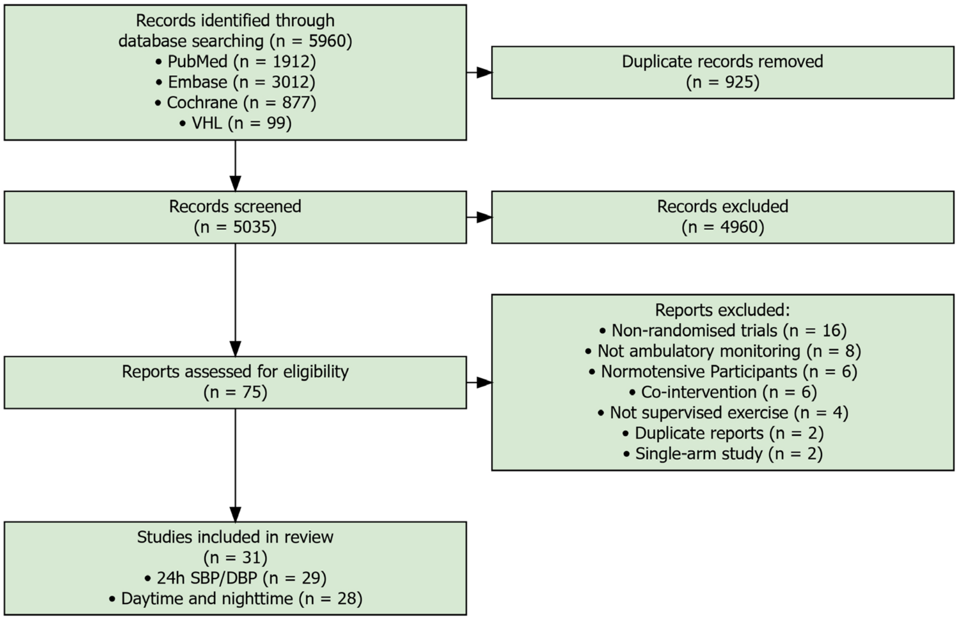

Figure 1 Study flow diagram. DBP, diastolic blood pressure; SBP, systolic blood pressure; VHL, Regional Portal of the Virtual Health Library.

arm ranged from five to 89, with a pooled sample of more than 1345 individuals. Baseline ABPM and mean age were broadly similar across nodes based on descriptive inspection of study characteristics (online supplemental table S7). Variability was observed in exercise prescription parameters, including intensity, volume and intervention duration. Reporting of antihypertensive medication use was incomplete in several trials.

Methodological quality of the included studies

Among the 31 included trials, the quality scores ranged from 6 to 13, with a median of 9 points. Most studies were rated as having moderate to high quality. Only one study scored ≤6 and was considered to have a high risk of bias. The most frequent methodological limitations were insufficient reporting of exercise adherence, lack of blinding of the outcome assessor and omission of adverse event data. The full scoring details and study-level summaries are presented in online supplemental table S8.

Network geometry

The NMA for 24-hour systolic and diastolic ABPM compared eight different exercise interventions: aerobic training (AERO), combined training (COMB), resistance training (RT), high-intensity interval training (HIIT), isometric training (ISO), pilates (PIL), yoga (YOGA), recreational sports (SPORTS) and a control condition (CON). All interventions were linked through direct or indirect comparisons, forming a single coherent network. CON was the most common comparator, directly connected to all exercise modalities, and contributed to the 25 study arms. AERO was the most frequently studied intervention (17 arms), followed by COMB (six arms), ISO (six arms) and RT (five arms). The most frequent direct comparisons were AERO versus CON (10 arms), COMB versus CON (five arms) and AERO

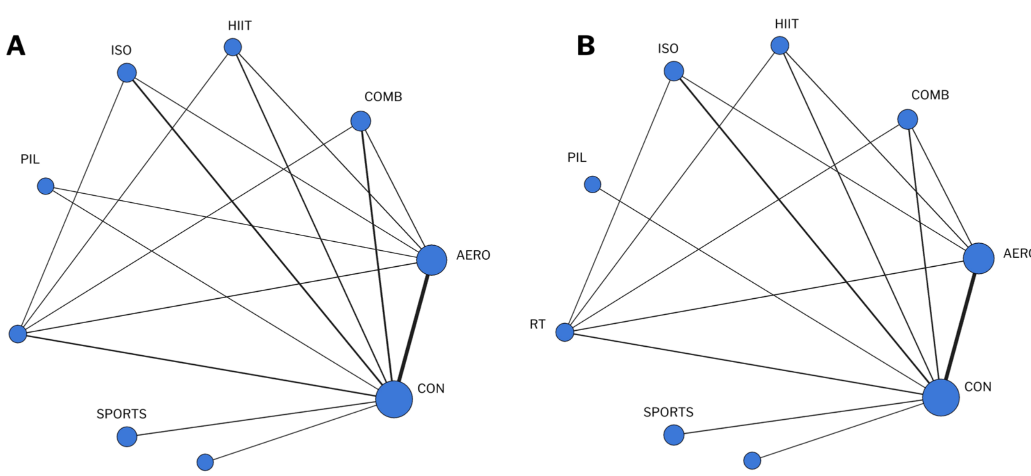

Figure 2 Network geometries of all included studies for the 24-hour (A) and for the daytime and nighttime (B) network meta-analyses. AERO, aerobic training; COMB, combined training; CON, control condition; HIIT, high-intensity interval training; ISO, isometric training; PIL, pilates; RT, resistance training; SPORTS, recreational sports; YOGA, yoga.

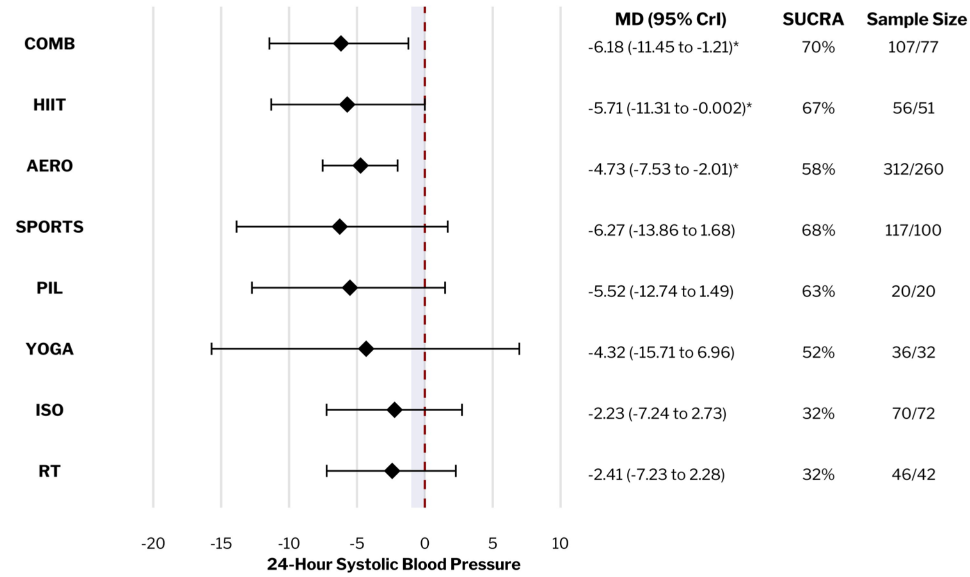

Figure 3 Network meta-analyses of different exercise modalities on 24-hour ambulatory systolic blood pressure compared with the control condition, with 95% credible intervals. AERO, aerobic training; COMB, combined training; HIIT, high-intensity interval training; ISO, isometric training; MD, mean changes from baseline versus control condition; PIL, pilates; RT, resistance training; SPORTS, recreational sports; SUCRA, surface under the cumulative ranking curve; YOGA, yoga.

versus RT (four arms). No interventions were excluded based on the sample size or network connectivity (figure 2).

The same network structure was applied to the daytime and nighttime ABPM analyses (figure 2). Although fewer studies contributed to these secondary outcomes, all interventions remained connected to CON, preserving the overall integrity of the network.

Primary outcomes

24-hour systolic and diastolic ambulatory blood pressure

Figure 3 presents the MDs in 24-hour systolic ABPM for each exercise modality compared with CON, alongside the SUCRA values and the number of contributing studies. Compared with CON, all interventions exceeded the predefined minimum clinically important difference of −2.00 mm Hg. However, only COMB (MD −6.18 mm Hg, 95% CrI −11.45 to −1.21), HIIT (MD −5.71 mm Hg, 95% CrI −11.31 to −0.002) and AERO (MD −4.73 mm Hg, 95% CrI −7.53 to −2.01) demonstrated significant differences. AERO was the most robust evidence with a 95% CrI entirely beyond −2.00 mm Hg (95% CrI −7.53 to −2.01). All other modalities, including PIL (−5.56 mm Hg), SPORTS (−6.40 mm Hg), ISO (−3.04 mm Hg), RT (−2.64 mm Hg) and YOGA (−4.50 mm Hg), had CrIs that included zero. According to the SUCRA values, COMB had the highest ranking probability (70%), followed by SPORTS (68%), HIIT (67%), and PIL (63%). AERO had a SUCRA value of 58%. YOGA ranked in the intermediate range (52%), whereas ISO and RT presented lower probabilities (32%). CON showed the lowest ranking (8%).

Figure 4 presents the MDs in 24-hour diastolic ABPM for each exercise modality compared with CON, along with the SUCRA values and the number of contributing studies. Compared with the CON group, HIIT (MD −4.64 mm Hg, 95% CrI −8.21 to −0.72), PIL (MD −4.18 mm Hg, 95% CrI −7.18 to −1.17), COMB (MD −3.94 mm Hg, 95% CrI −6.47 to −1.34) and AERO (MD −2.76 mm Hg, 95% CrI −4.21 to −1.34) showed significant reductions, with 95% CrI excluding the null value. RT (MD −1.47 mm Hg), YOGA (MD −3.46 mm Hg), ISO (MD −2.43 mm Hg) and SPORTS (MD −2.81 mm Hg) had estimates with CrIs that included zero. Only RT did not achieve reductions exceeding the predefined minimal clinically important difference of −2.00 mm Hg compared with the CON group. No modality showed a 95% CrI fully surpassing the −2.00 mm Hg threshold. According to the SUCRA values, HIIT ranked highest (76%), followed by PIL (72%) and COMB (65%). YOGA (57%), ISO (53%), SPORTS (49%), AERO (44%) and RT (41%) ranked lower, whereas CON showed the lowest probability (2%).

Online supplemental figure S11 shows the rank probabilities for each intervention for 24-hour systolic and diastolic ABPM. COMB, SPORTS and HIIT were most likely to rank among the top three treatments for systolic ABPM. HIIT, PIL and COMB had the highest probabilities of being ranked among the top three treatments for diastolic ABPM.

The league table of the NMA results for exercise-versus-exercise comparisons is presented in online supplemental table S9 and shows no evidence of superiority between modalities, as all comparisons displayed overlapping 95% CrI. In the node-splitting analysis, only the 24-hour systolic ABPM outcome yielded p values <0.05 (COMB vs CON and COMB vs RT); however, neither comparison remained significant after applying the Bonferroni correction ($p<0.005$), and no inconsistencies were identified (online supplemental table S10).

Secondary outcomes: daytime and nighttime ambulatory blood pressure

Compared with the CON group, daytime systolic ABPM was reduced by COMB (MD −6.55 mm Hg, 95% CrI −11.90 to −1.29), AERO (MD −5.81 mm Hg, 95% CrI −8.45 to −3.13) and HIIT (MD −6.50 mm Hg, 95% CrI −12.04 to −0.67) compared with CON. All other modalities, including ISO, PIL, RT, SPORTS and YOGA, produced estimates with 95% CrI that included the null hypothesis. SUCRA rankings identified COMB as the top-ranked intervention (75%), followed by HIIT (75%) and AERO (72%). AERO was robust evidence with a 95% CrI entirely beyond −2.00 mm Hg (95% CrI −8.45 to −3.13).

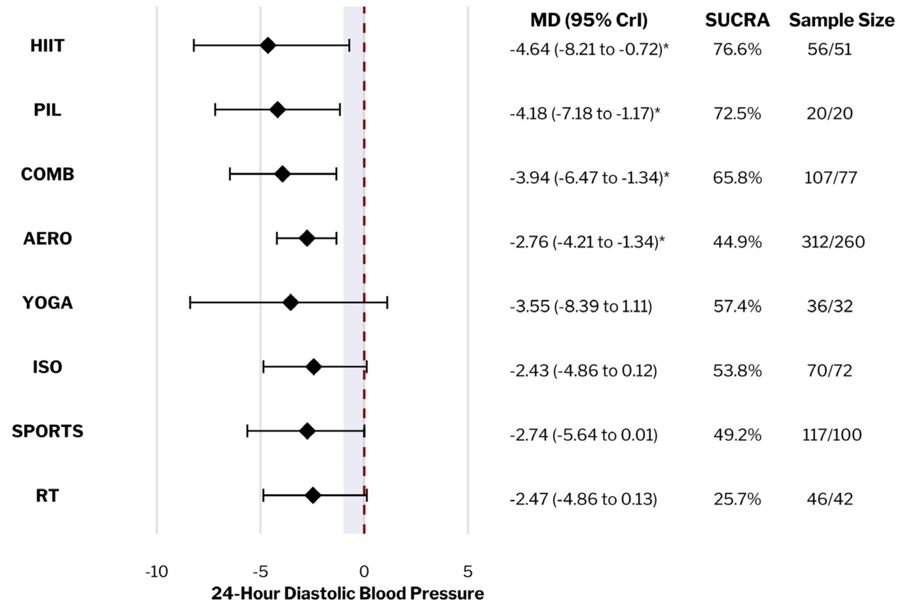

Figure 4 Network meta-analyses of different exercise modalities on 24-hour diastolic blood pressure compared with the control condition, with 95% credible intervals. AERO, aerobic training; COMB, combined training; HIIT, high-intensity interval training; ISO, isometric training; MD, mean changes from baseline versus control condition; PIL, pilates; RT, resistance training; SPORTS, recreational sports; SUCRA, surface under the cumulative ranking curve; YOGA, yoga.

For daytime diastolic ABPM, the SUCRA values favoured HIIT (92%) and AERO (67%). Among these, only HIIT (MD −6.53 mm Hg, 95% CrI −10.40 to −2.23) and AERO (MD −3.54 mm Hg, 95% CrI −5.05 to −2.01) had 95% CrI excluding the null, while estimates for the other modalities remained imprecise. AERO (95% CrI −5.05 to −2.01) and HIIT (95% CrI −10.40 to −2.23) showed robust evidence with a 95% CrI entirely beyond −2.00 mm Hg.

Regarding nighttime systolic ABPM, significant reductions were observed with AERO (MD −3.02 mm Hg, 95% CrI −5.44 to −0.78), COMB (MD −4.46 mmHg, 95% CrI −8.95 to −0.11) and SPORTS (MD −6.99 mm Hg, 95% CrI −13.58 to −0.61). The SUCRA rankings indicated the highest probability of effectiveness for SPORTS (83%), followed by HIIT (68%) and COMB (67%).

Night-time diastolic ABPM showed significant reductions with AERO (MD −1.96 mm Hg, 95% CrI −3.47 to −0.63), RT (MD −3.28 mm Hg, 95% CrI −6.74 to −0.75) and YOGA (MD −4.51 mm Hg, 95% CrI −8.79 to −0.02). The SUCRA rankings favoured YOGA (80%), RT (77%) and SPORTS (67%).

A complete summary of the results, including the SUCRA rankings, ranking curves and league table comparisons, is provided in online supplemental file 12. Traditional pairwise meta-analysis and forest plots are presented in online supplemental file 13.

Confidence in the NMA and publication bias

The credibility of the NMA estimates for the primary outcomes (24-hour systolic and diastolic ABPM) was assessed using the CINeMA framework. For 24-hour systolic ABPM, all comparisons were rated as having very low confidence, primarily due to concerns regarding bias and imprecision within the study, and in some cases there was substantial heterogeneity. For 24-hour diastolic ABPM, only the comparison between AERO and control was rated as low confidence, whereas all remaining comparisons were classified as very low confidence. The complete CINeMA ratings across domains for each comparison are presented in online supplemental file 14.

Publication bias was evaluated for the primary results (24-hour systolic and diastolic ABPM) using funnel plots and Egger's regression tests. For 24-hour systolic ABPM, Egger's test yielded a bias coefficient of −2.03 (p=0.27), whereas for 24-hour diastolic ABPM the coefficient was −3.51 (p=0.57), indicating that there was no statistically significant evidence of small study effects. Visual inspection of funnel plots revealed no notable asymmetry (online supplemental file 15). Overall, these results suggest a low likelihood of publication bias affecting the main outcomes of the review.

DISCUSSION

This NMA synthesised evidence from 31 RCTs comparing eight exercise modalities and their effects on ABPM in adults with hypertension. AERO showed consistent reductions in ABPM, reinforcing its established role in blood pressure control. Importantly, this study provides the first evidence that COMB and HIIT are effective in reducing 24-hour ABPM.

Our findings extend previous evidence based on office blood pressure[17] by identifying exercise modalities that effectively reduce ABPM, which is a more prognostic outcome.[9 10] In contrast to a previous NMA[17] that identified isometric training as the best exercise modality for office blood pressure reduction, we observed no significant effect of this exercise on ABPM. While office blood pressure studies frequently use large-muscle mass protocols such as wall squats, the ISO trials in this ABPM-focused NMA primarily employed short-term handgrip protocols. Similarly, dynamic resistance training did not significantly reduce ABPM in our NMA, in contrast to office blood pressure meta-analyses that reported reductions of 4–6 mm Hg.[11 13] This lack of effect may stem from low training intensities (<70% 1 rep max (1RM)) in the included trials, as higher intensities are more strongly associated with blood pressure lowering[12 27] than lower intensities. Together, these data suggest that dynamic or isometric resistance training should be viewed as a complementary rather than a first-line strategy for ABPM reduction in hypertensive individuals.

From a physiological perspective, the improvements in endothelial function and the reduction in total peripheral resistance resulting from sustained vasodilation, driven by increased shear stress during exercise, are more closely attributed to aerobic than resistance training.[28 29] Furthermore, resistance training may induce transient arterial stiffness due to high-pressure loads.[30 31] These mechanistic differences may explain the divergent findings observed between our NMA and previous reports. When comparing methodological characteristics of studies assessing office and ambulatory blood pressure, the observed discrepancies between our findings and previous NMAs may also be associated with the outcome assessment. While office-based measurements are widely utilised, their susceptibility to limited standardisation and a lack of specific power calculations could potentially inflate the main effects of some exercise modalities.[32–34] In contrast, ABPM-based trials of our study presented higher methodological quality and internal validity (average TESTEX score of 9/15). Previous large NMAs based on office blood pressure[5 17] assessed methodological quality in a subset of included trials, while the present review systematically evaluated the quality of all eligible studies. Therefore, our findings may reflect a more nuanced clinical reality, as ABPM minimises the precision bias and 'white-coat' effects often inherent in office settings,[8] providing a more rigorous basis for evaluating exercise efficacy.

General recommendations for blood pressure management do not pay much attention to strategies to motivate sedentary adults to start exercising or ensure adherence to physical activity over time.[3 4] Monotony during traditional exercise may lead to reduced adherence to exercise programmes.[35] In this context, non-conventional modalities may offer promising and potentially more engaging strategies to enhance exercise adherence.[36 37] This is the first NMA to integrate non-conventional modalities, such as PIL, YOGA and SPORTS, into the ABPM evidence base. SPORTS was associated with reductions in nighttime systolic ABPM, PIL with reductions in 24-hour diastolic ABPM, and YOGA with reductions in nighttime diastolic ABPM. These modalities also achieved relatively high SUCRA rankings, indicating favourable positions within the treatment hierarchy. However, this result reflects ranking probabilities rather than definitive clinical superiority, particularly when effect estimates overlap.[38 39] Due to wide CrIs, limited direct comparisons and predominantly low-to-very-low confidence ratings, these findings must be interpreted with caution.[40 41] Consequently, large-scale RCTs focusing on non-conventional exercise are essential to confirm these preliminary benefits on ABPM and inform future clinical practice.

The limitations of this study should be considered when interpreting the results. The conservative assumptions used in data imputation may have increased the imprecision of effect estimates, leading to wider CrIs for several comparisons. Although it should not overestimate the effect sizes, it likely contributed to the predominantly low or very low confidence ratings observed in the CINeMA assessment, particularly within the imprecision domain.[26] Sensitivity analyses exploring alternative correlation values or variance assumptions were not feasible due to incomplete reporting and the limited number of studies per comparison. Furthermore, to maximise the available evidence, trials with small sample sizes and studies lacking complete dispersion measures were included. The overall methodological quality was moderate to high (mean=9 of a maximum of 15 points on the TESTEX). Recurring limitations included the lack of blinding, underreporting of adverse events, limited adherence data and insufficient monitoring of the control group. Another limitation pertains to the inherent heterogeneity in the classification of exercise modalities within NMA. To maintain network connectivity, interventions were categorised into broad nodes based on modality. However, considerable variability was noted in terms of intensity, volume, session structure and follow-up across studies. Consequently, true dose- or intensity-dependent effects may have been attenuated, and the absence of clear effects should be interpreted with caution. Although key effect modifiers were judged sufficiently similar to support the transitivity assumption, heterogeneity in exercise prescription and incomplete reporting of medication use across trials may have introduced residual intransitivity, limiting the certainty of indirect comparisons. The small number of trials on HIIT, PIL and SPORTS limits definitive conclusions regarding their relative efficacy. Furthermore, substantial between-study variability and limited direct evidence for some modalities warrant cautious interpretation of comparative effectiveness. While AERO consistently demonstrated robust results across high-quality trials, the findings for COMB and HIIT remain promising but require confirmation through adequately powered, standardised RCTs to enhance the certainty of evidence for clinical practice.

CONCLUSION

Aerobic exercise training consistently reduced 24-hour, daytime and nighttime ambulatory blood pressure, reinforcing its central role in hypertension management. Combined training and high-intensity interval training were also associated with reductions in 24-hour ambulatory blood pressure, extending evidence beyond office-based measurements. In contrast, the evidence for resistance training, isometric exercise and non-conventional modalities remains limited and imprecise. Overall, aerobic exercise, combined training and high-intensity interval training show the most consistent signals of benefit based on current data. However, adequately powered randomised trials using ABPM are required to strengthen comparative inference and clarify the role of other exercise modalities.

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