

The Effect of Physical Activity on Lowering Blood Pressure among Adults with Prehypertension: A Meta-analysis of RCT Studies

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Abstract

Background: Different combinations of physical activity interventions (PAI) have been studied, and varying outcomes have been found in lowering BP among prehypertensive adults worldwide.

Objectives: A systematic review and meta-analysis evaluating the pooled effects of multiple PAI on reducing BP among prehypertensive.

Data Sources: A systematic search was performed on EBSCO -HOST, ERIC, Cochrane databases, PubMed, Medline, and Google Scholar through January 1, 2008, to August 10, 2024. Search terms were physical activity, lowering blood pressure, prehypertension, and randomized controlled trials. Random effects models estimated the PAI's effect on BP across selected sixteen RCT studies using heterogeneity, publication bias (funnel plot), Egger's test, and a Relative Risk, 95% CI, and p-value < 0.05.

Conclusions: Random-effects meta-regression coefficient indicated all the RCT studies had a risk-free bias. Homogeneity showed ($I^2_{SBP}=0\%$ and $I^2_{DBP}=0\%$), suggesting that 0% of the PAI effect variability was due to the actual study similarity and 100% is due to chance. The pooled estimate showed a significant lowering SBP/DBP in favor of PAI, ($RR_{SBP}=0.99$; 95% CI (0.99-1.00), $p=0.02$ and $RR_{DBP}=0.99$; 95% CI (0.98- 1.00), $p=0.04$) respectively.

Implications for Practice: The finding emphasized the magnitude of PAI that generates a 1% reduction of SBP/DBP among prehypertensive adults. Practitioners may accentuate the benefits of PAI including other lifestyle modification on lowering SBP/DBP among adults. Policymakers may use this finding to design public policy and program interventions to prevent the surge of hypertension and cardiovascular diseases.

Keywords

Prehypertension, Adult, Meta-analysis, Physical activity, SBP/DBP Reduction.

INTRODUCTION

Physical inactivity is a significant risk for prehypertension and, subsequently, cardiovascular disease; less active and fit adults have a 30% to 50% greater risk for high blood pressure [1,2]. Prehypertension is a silent major precursor and contributor to the world's burden of cardiovascular disease and coronary heart disease. An individual with prehypertension may frequently progress to hypertension and cardiovascular diseases [1,3,4]. Research studies indicated that there is a significant likely association with an increased risk of stroke, myocardial infarction, and heart failure [5,6], which causes a higher rate of death and disability in young women and men adults [7]. Young adults with prehypertension are known to be at high risk for developing hypertension and even for increasing cardiovascular risks [1,4,8]. Adults

are more exposed to cardiovascular disease risk factors and are less exposed to prevention efforts [9].

Distinct measures of secondary preventive approach, mainly regular physical activity (PA), have been studied and showed a more significant risk reduction of cardiovascular disease morbidity and mortality [10-12]. These studies have demonstrated a relevant reduction of prehypertension [13]. Studies have shown the protective effects of regular PA in reducing prehypertension among affected adults [14-16]. However, fewer investigations in meta-analysis demonstrated the pooled effect of PA associated with a decrease or increase in systolic blood pressure (SBP) and diastolic blood pressure (DBP) in the prehypertensive condition.



Another inquiry is the proportion of relative risk in SBP and DBP reduction after exercise (walking) intervention. It is still unclear whether patients diagnosed with prehypertension exposed to different types of PA increase or decrease their SBP and DBP and subsequently decrease cardiovascular events. The meta-analysis is a statistical technique for integrating quantitative findings from randomized control trial studies [17]; the goal is to assess the clinical effectiveness of physical activity intervention (PAI) by combining data from multiple randomized control trial (RCT) studies. Moreover, a precise estimate of the effect of exercise (walking) intervention, giving appropriate power to the size of the different RCTs included, is relevant to reducing the prevalence of prehypertension and cardiovascular disease. Therefore, this research study emphasizes a meta-analysis to demonstrate available evidence (i.e., Intervention effect) from different RCTs on the association of physical activity with reduced risk of a prehypertension event.

The purpose of this meta-analysis RCT study was: (a) to establish whether there is evidence of a PAI effect on lowering SBP/DBP among prehypertensive adults; (b) to estimate the overall type of PAI estimate effect size (i.e., true effects across all studies) on lowering SBP and DBP, and (c) to examine whether the degree of variability in the true PAI effect is consistent across the sixteen studies. We selected a 95% confidence interval and a 5% significance level to compute the intervention effect. The meta-analysis findings are expected to corroborate or refute the association between SBP and DBP reduction and physical activity in adults with prehypertension.

MATERIALS AND METHODS

The CONSORT 2010 checklist guidelines for reporting parallel group randomized control trials [18] are applied for the literature search, study selection, data abstraction, summary measures calculation, and results synthesis. It was also used to assess the quality of the sixteen RCT studies. However, the preferred reporting items for systematic reviews and meta-analyses (PRISMA) statement checklist and flow diagram were used to report this meta-analysis's results [19].

Study Selection

A comprehensive search of the databases **CINAHL Plus with Full Text**, PubMed and Medline with Full Text (EBSCO -HOST), Google Scholar, Web of Science, Cochrane, and Eric databases through California State University, Los Angeles (CSULA) was conducted to identify all studies published between January 1, 2008, to August 10, 2024. The search terms used were physical activity, lowering blood pressure, prehypertension, and randomized controlled trials as subject headings in all fields. The search was also limited to randomized controlled trials, women and men adults aged 18 to 80 years. Additional search strategies included searches of the Google Scholar database and all references from articles that met eligibility criteria. To be included in this meta-analysis, a study had to meet the following criteria: (1) Study design: randomized controlled trial based on parallel: open or single, double-blind, and crossover double-blind or crossover open; (2) peer-reviewed English articles with original data; (3) participants having prehypertension without medication; (4) follow-up; (5) estimation of SBP and DBP values at baseline and the end of the intervention, (6) objective measurement of PA; and (7) at least one or more categories of PA. Sixteen articles met the eligibility criteria for inclusion in the meta-analysis (See Appendix A), and Figure 1 presented detailed information on the study selection process.

Data Abstraction and Quality Assessment

The Consort 2010 checklist was designed to facilitate the extraction process. For instance, the data abstraction encompassed

identification as a randomized trial in the title, a trial design including participants' allocation ratio, eligibility criteria, and intervention for each group with sufficient details. Sufficient details were age, gender, mean SBP and DBP value at baseline and after intervention for each group, prehypertension status, nature of physical activity, exercise intervention, follow-up duration, outcomes, and estimation event in SBP and DB. Study quality was judged by the proper score of different items from the CONSORT 2010 checklist, abstraction results were submitted to two colleagues as reviewers, and discrepancies were adjudicated by consensus and based on the CONSORT 2010 checklist and PRISMA statement checklist.

Data Analysis and Synthesis

The random-effects model hypothesizes that the overall physical activity's true effect is the same in all studies. It allows for generalization from the populations in the analysis to similar populations. The second hypothesis centered on estimating separate physical activity effects for each RCT study and evaluating the variability (i.e., the degree of heterogeneity or homogeneity) in the true PAI effects across selected trials. The individual study relative risk (RR) and the pooling overall RR based on a 95% confidence interval with a 5% significance level were computed for each outcome in the experimental group versus the control group after the intervention. Potential publication bias is assessed using the visual Begg's funnel plot, plotting the standard error against the natural log RR for each study [20,21]. Moreover, the Egger regression test is used for publication bias and the asymmetry of the regression equation in the l'Abbe plot [20]. As the funnel plot has some limitations, the researcher used one of the formal statistical methods to test for heterogeneity. The percentage of the variability across the five studies attributable to heterogeneity beyond the chance was estimated using I^2 statistics [22,23]. A two-tailed p-value less than 0.05 was statistically considered significant, and statistical analyses were performed using SPSS Meta-Analysis version 29.0 was used to perform the analysis.

RESULTS OF THE META-ANALYSIS

Descriptive Results

The systematic search yielded 1475 articles, of which 287 were reviewed in full text and from which sixteen randomized controlled trials [16,24-30] reported in publications were identified (Figure 1). The sample characteristics of this meta-analysis included 1,419 adults who were not initially free from prehypertension (see Table 1). Of the 1,419 adults in the meta-analysis sample, 881 were men, and 538 were women. The trials were published between January 1, 2008, and August 31, 2024, and varied from 24 to 330 participants with an age range from 18 to 71 years old and a median of 140 participants. The trial duration ranged from 30 minutes to 48 weeks. The mean and standard deviation of SBP/DBP of the intervention and control groups after the intervention were respectively: (a) $M_{Exp\ Grp\ SBP} = 124.51, SD = 4.87$ and $M_{Exp\ Grp\ DBP} = 77.65, SD = 4.91$, and (b) for the control group, SBP/DBP mean and standard deviation were: $M_{Ctrl\ grp\ SBP} = 130.11, SD = 4.05$ and $M_{Ctrl\ grp\ DBP} = 81, SD = 4.72$. The sixteen RCTs included men and women; four were led in the USA, three were from China, five were from India, and one was from Nigeria, Egypt, Germany, Malaysia, Brazil, and Denmark. In this meta-analysis, several selected studies have conducted multiple interventions using diverse types of physical activities comparing to control groups [16,24,25,27-37].

Publication Bias

A straightforward way to assess publication bias's likely presence is to examine a funnel plot. The funnel plot (see Figure 1A & 1B) demonstrated that the distribution of SBP and DBP change estimates for each study was symmetrical around the pooled effect estimate for

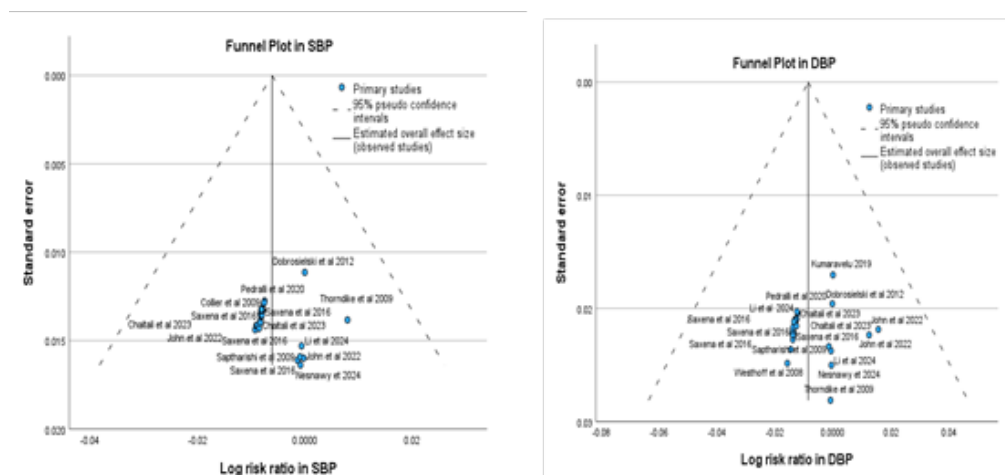


Figure 1A & 1B: A Symmetrical Funnel plot of 16 RCT Studies.

****Figure 1A & B:** Represent a funnel plot. It is a scatter plot of the effect estimates from the selected sixteen individual RCT studies against some measure of each study's size or precision. A standard error of the effect estimate on lowering SBP/DBP is chosen in this meta-analysis study as the measure of RCT study size and plotted on the vertical axis or solid vertical line (i.e., Corresponding a no-intervention effect). Figure 1A estimates the SBP, while 1 B estimates the BDP against the Vertical axis or solid vertical line. Most potent and larger RCT studies are on the top of the vertical axis, whereas the smaller RCT studies scatter more widely at the bottom, narrowing the spread among larger studies. In this meta-analysis, bias is absent. Between those selected RCT studies' heterogeneity, the scatter on both SBP/DBP was due to sampling variation alone, and the plot in SBP and DBP resembled a symmetrical inverted funnel. The funnel plot has some limitations; for example, detecting asymmetry or symmetry with eyes can sometimes be challenging (Terrin et al, 2005). As a result, Egger's regression test was used to test for publication bias. The analysis result demonstrated that the Egger regression equation intercepts differ from zero in SBP and DBP, confirming the absence of publication bias.

the trial comparing intervention with control. This suggests that the meta-analysis may have yet to miss some trials worldwide [20].

The funnel plot has some limitations; for example, detecting asymmetry with eyes can sometimes be challenging [38]. As a result, Egger's regression test, as one of the formal statistical methods, was used to test for publication bias. The analysis showed that the Egger regression equation intercepts differ from zero in SBP and DBP. In the SBP, Egger's test was $D/SE = -0.016$, $t = -0.50$, (95% CI = -0.83 to 0.50), $p = 0.61$, while in DBP, Egger's test was $D/SE = -0.006$, $t = -0.123$, (95% CI = -0.10 to 0.09), $p = 0.9$ which confirms the no-evidence of publication bias.

Random Effects Meta-Analysis

Multiple parameters were estimated to summarize evidence by assuming that the true effect of physical activity on prehypertension can vary from selected RCT studies. Moreover, the variation is due to heterogeneity.

The forest plot Weight Percentage

The analysis indicated that all the selected RCT studies worldwide contribute slightly equally to the pooled effects on lowering SBP/DBP after PAI. The weight percentage varies between 3% to 4% in SBP and 3.2% to 4% in DBP. Selected RCTs from China, India, and the USA have a larger sample size with width boxes and large confidence intervals, allotting greater weight to pooled effects.

Heterogeneity

The researcher used I^2 statistical value to determine whether there is a variation in the true effect of PAI on reducing SBP/DBP, consistent across the sixteen selected RCT studies [39]. Further, a rule was suggested to use the percentage to assess the presence of heterogeneity between the outcomes of RCTs. For instance, 25% corresponds to low heterogeneity, 50% to moderate, and 75% to high [40]. The analysis results showed in SBP/DBP in Figure 2A and 2B ($I^2_{SBP} = 0.0\%$ and $I^2_{DBP} = 0.0\%$) suggesting that 0.0% of the variability of PAI

effect is due to the actual study similarity (Homogeneity) and 100% is due to chance. The random effect model summary result of -0.01 (95% confidence interval -0.01% to -0.0) in SBP ($\chi^2_{SBP} = 2.387$, $df = 26$, $p = 1$); and the result of -0.01 (95% CI -0.02 to -0.01) in DBP ($\chi^2_{DBP} = 3.887$, $df = 26$, $p = 1$); provide an estimate of the average PAI effect, respectively. As the confidence interval does not contain zero, there is strong evidence that, on average, the physical activity effect is beneficial in lowering prehypertension among participants. These intervals are entirely below zero and show that physical activity is beneficial when applied in at least 95% of the adults with prehypertension, an important finding for clinical practice.

According to Higgins et al. [39] suggestions, when statistics is equal to zero, there is no heterogeneity among the outcomes of different studies, which means that in this meta-analysis study, there is homogeneity among the 16 RCTs related to the size of the PAI effect. The hypothesis of homogeneity between the PAI and the effects of lowering prehypertension was not rejected. The analysis confirmed a high level of homogeneity among the 16 RCTs. $Q = 2.36$, $df = 26$, $p\text{-value} = 0$.

Intervention Effect Measure (Relative Risk)

In this study, Figures 2A and 2B presented the forest plot demonstrating visual displays of this meta-analysis results. The blue boxes demonstrated the PAI effect estimates with 95% CI, p-value, and weight from the selected RCT studies, while the red diamond showed the pooled effect estimate of all sixteen RCT studies. Each RCT is represented by a blue square box (the relative risk) and a horizontal line representing the 95% confidence interval for both SBP/DBP, respectively (Figure 2A & 2 B).

In Figure 2A, the analysis showed that in SBP, the relative risk of 20 on 26 PAI is less than one, except one PA intervention RR is more significant than one, and six RRs are equal to one. This result indicates that 20 PAI decreases the risk of SBP by 100 $(1 - 0.99) = 1\%$ but is not statistically significant ($p > 0.05$), and 95% CI of each PA intervention

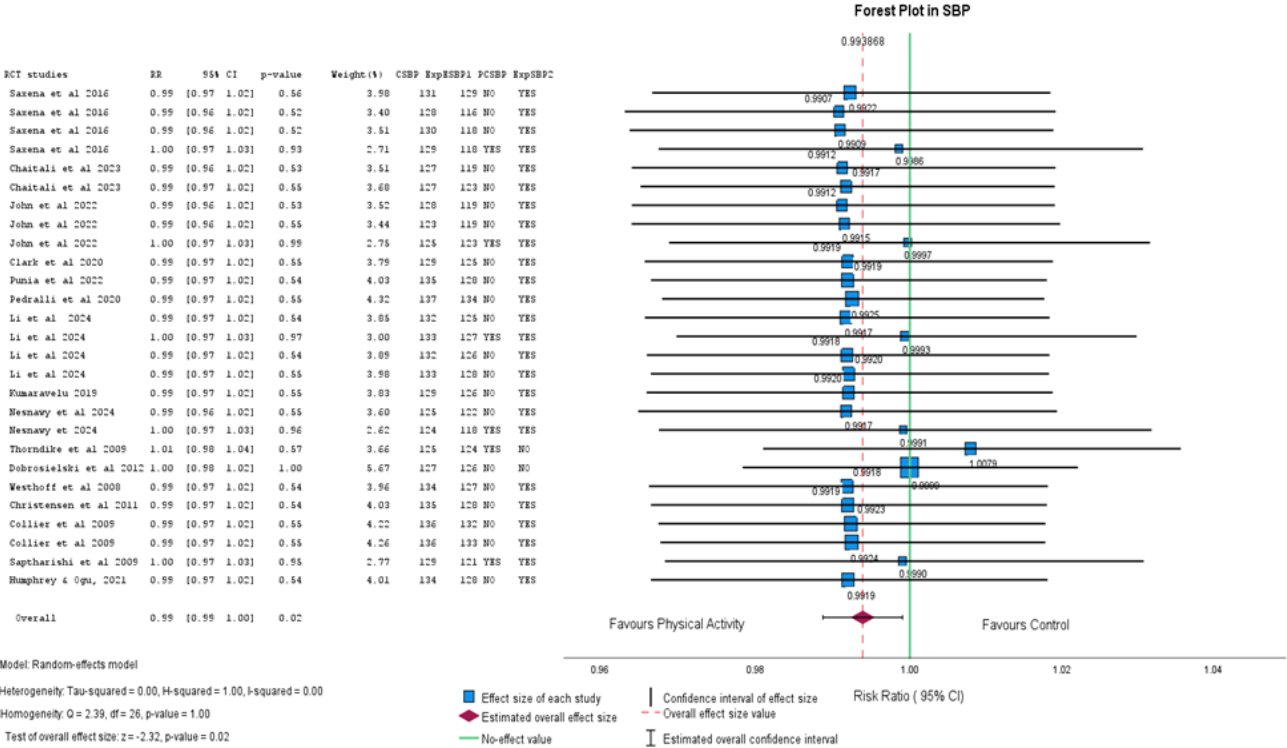


Figure 2A: Random Effects Meta-Analysis of 16 RCT Studies that Examined the Pooled Effect of Physical Activity Intervention on Lowering SBP Events in Adults with Prehypertension.

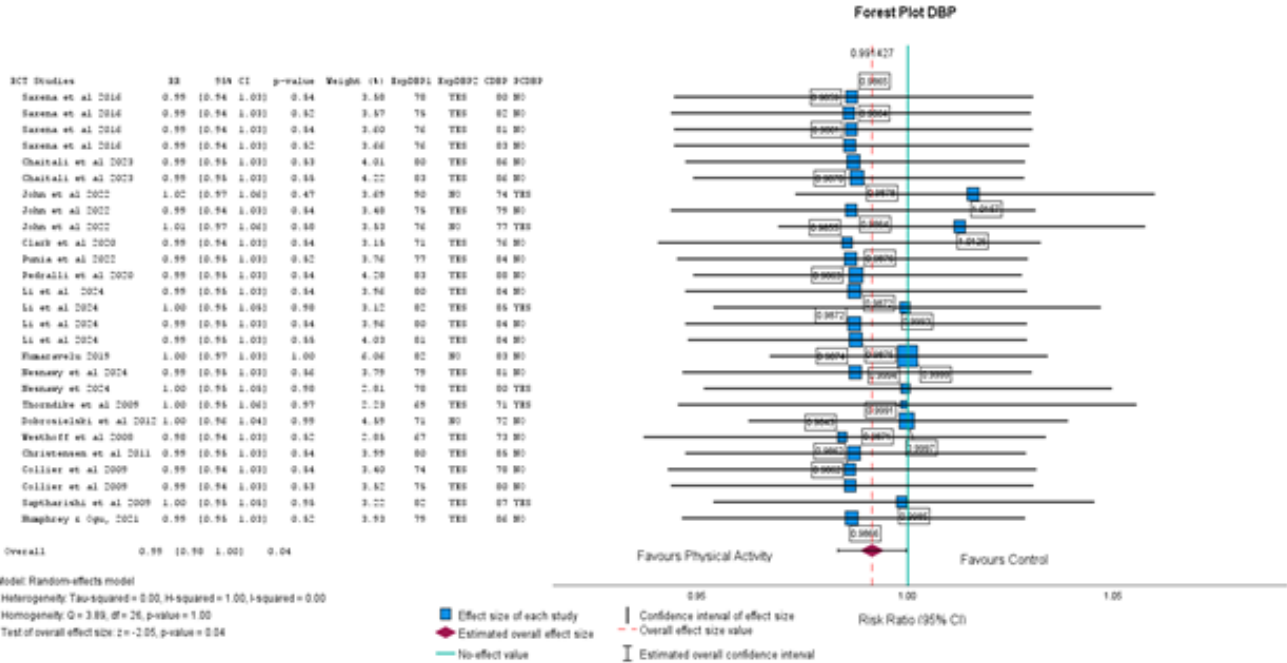


Figure 2B: Random Effects Meta-Analysis of 16 RCT Studies that Examined the Pooled Effect of Physical Activity Intervention on Lowering DBP Events in Adults with Prehypertension.

****Figures 2A and 2B** are the forest plots presenting the visual displays of this meta-analysis outcomes. The blue boxes demonstrated the PA intervention effect estimates with 95% CI, p-value, and weight from the selected RCT studies. At the same time, the red diamond showed the pooled effect estimate of all sixteen RCT studies. Heterogeneity and the intervention pooled effect measure (Relative Risk) on lower SBP/DBP among adults with prehypertension. A statistical method and procedure were used to determine whether there is a variation in the true effect of physical activity intervention on reducing SBP/DBP, consistent across the sixteen selected RCT studies. The blue boxes showed the effect estimates from each selected RCT study, while the red diamond showed the pooled effect size result of all sixteen selected RCT studies. The green vertical line is the line of no effect (i.e, the position at which no apparent difference exists between the PA intervention group and the control group of the selected RCT study. The outcome of interest is lowering SBP/DBP (e.g, reducing); the results to the left of the green vertical line favor the PA intervention over the control. In this meta-analysis, the outcomes estimates are located to the left, which means that the outcome of interest (e.g, lowering) occurred more frequently in the intervention group than in the control group with Relative Risk less than one ($RR_{SBP} = 0.99$; 95% CI (0.99-1.00), $p = 0.02$; and $RR_{DBP} = 0.99$; 95% CI (0.98- 1.00), $p = 0.04$).

crosses the line of no effect ($RR = 1$). Like Figure 2B, 19 interventions indicated an RR below one ($RR = 0.99$), and six interventions displayed an RR equal to one ($RR = 1$). In contrast, two interventions revealed an RR above one ($RR > 1$). Compared to the results in Figure 2A, it is not statistically significant ($p > 0.05$), and 95% CI includes one and crosses the line of no effect. However, the red diamond boxes in Figures 2A & 2B showed the combined or pooled effects estimates results, indicating the pooled relative risk (RR) located to the left of the green vertical line is statically significant in favor the PAI over the control for lowering SBP/DBP events among adults with prehypertension; $RR_{SBP} = 0.99$; 95% CI (0.99-1.00), $p = 0.02$; and $RR_{DBP} = 0.99$; 95% CI (0.98- 1.00), $p = 0.04$; statistically significant, respectively. This result indicates that the pooled point estimate ($RR=0.99$) and the 95% CI lie entirely to the left of the green line of no effect, demonstrating $100 \times (1 - 0.99) \% = 1\%$ of SBP/DBP reduction is significantly in favor of PA intervention, $p = 0.02$ and $p = 0.04$ respectively. This finding also explained that there is a significant relationship between PAI and lowering SBP and DBP in adults diagnosed with prehypertension.

Furthermore, the results indicated that any RR of each selected RCT study in the right-side column of the Forest plot (Figure 2A & 2B) exceeds one. Each RCT study's whisker depicts the length of the confidence interval across the line of no effect, and each confidence interval contains the value one except the pooled 95% CI. All sixteen RCTs [25,28] have similar lengths of confidence intervals, and four RCTs [24,26] presented a significant sample with a narrower confidence interval. The longer the whiskers, the more comprehensive the CI, and the less precise the study results [40].

DISCUSSION

This present meta-analysis examined whether there is evidence of a physical activity intervention effect on lowering SBP/DBP among prehypertensive adults; a degree of variability in the actual physical activity intervention effect is consistent across the sixteen studies; and subsequently estimate the overall effects of physical activity intervention actual effect (i.e., true effects across all studies) on SBP and DBP reduction. The overall population size in this meta-analysis was 1,419 adults aged 18 to 71 years old, with both genders. For all RCT studies selected, the duration of follow-up ranged from 10 to 48 weeks. Various physical activities have been proven to be beneficial to adults with prehypertension and even cardiovascular diseases.

The United States 2024 physical activity guidelines showed that adult gender who participates in any amount of physical activity increased health benefits [41]. Current meta-analyses demonstrated evidence of the intervention effect of physical activity and risk of cardiovascular disease [42]. To hypothetically corroborate the effect of physical activity on SBP and DBP among prehypertensive adults, the investigators gave weight to the random effects of the sixteen selected RCT studies worldwide. This meta-analysis finding demonstrated a pooled significant relative risk of reduction of SBP and DBP among individual adult women and men diagnosed with prehypertension after diverse physical activity interventions. The sensitivity analysis suggested that the relative risk effect of physical activity in SBP and DBP was consistent across study types and analysis methods. This finding is consistent with the meta-analysis by Henkin et al. [43], which found an adequate estimate of resistance training on SBP/DBP reduction with 450 participants with prehypertension. The findings showed a 1% and 3% decrease in SBP and DBP, respectively [43]. Sousa et al. [44] also conducted a meta-analysis of 5 RCTs on the effect of physical activity intervention on SBP and DBP, which included 201 adults. Thus, the findings showed significant reductions for SBP (effect size = -0.97 , $p < 0.05$) and DBP (effect size = -0.60), $p < 0.05$ [44].

Regarding the heterogeneity, this meta-analysis found homogeneity, demonstrating that the variability of the effect of physical activity intervention is due to chance among all selected RCT studies worldwide. This finding is consistent with a current meta-analysis, which found homogeneity in SBP and DBP in all 5 RCTs, respectively [44]. As a dynamic aerobic physical activity, walking, running, jogging, yoga, and Thai-chi (i.e., 5-10 min; 10-20 min; 20-30min; 30-50 min; 60-120 min) involve significant muscle contractions of more than 50% of the body's total muscle mass [45,46]. Physical activity expends energy and has important public health implications, particularly for inactive adults with prehypertension. Our meta-analysis demonstrates how the percentage of physical activity contributes to lowering SBP and DBP across the 16 RCTs. Another recent meta-analysis [47] used 14 studies with 2451 participants and found that combining a healthy diet and physical activity had the highest mean SBP and DBP reduction. However, the recent meta-analysis did not provide a separate random effect of a healthy diet and PA on SBP and DBP, respectively.

STRENGTHS AND LIMITATIONS

The strengths of this meta-analysis included rigorous methods that adhered to PRISMA standards. In addition, the selected studies examined a wide range of physical activity interventions on SBP and DBP among adults with prehypertension worldwide (USA, China, India, Africa, Malaysia, Europe, Australia, and Brazil). This meta-analysis showed conclusive pooled effects of physical activity intervention on improving SBP/DBP reduction from 16 selected RCTs from diverse countries worldwide. Another strength is a significant association between physical activity intervention and lowering SBP and DBP among adults with prehypertension worldwide. Further, in this meta-analysis, there is also a homogeneous physical activity intervention effect in each selected RCT, which allowed the team investigator to draw generalized conclusions regarding the efficacy of PA interventions on SBP and DBP.

Nonetheless, there is a limitation in the review of peer-reviewed literature due to the potential unpublished meta-analysis articles. Bias and heterogeneity from the quality of original RCT studies included in the meta-analysis can impact the validity of the overall effect size. However, this meta-analysis of selected 16 RCTs was free from bias and heterogeneity, which allows us to extrapolate a generalized conclusive physical activity intervention effect on SBP/DBP reduction among adults with prehypertension.

CONCLUSION

This meta-analysis demonstrated a significant PA intervention pooled effect on SBP and DBP reduction among adults with prehypertension worldwide. Each selected RCT demonstrated no significant magnitude, $p > 0.05$, and the 95% confidence interval crossed the line of no effect, which included one. With the random effect output, the meta-analysis finding showed a 1% significantly reduced risk of SBP ($p < 0.02$) and DBP ($p < 0.04$) in the intervention compared to the control group. Lying entirely to the left side of the line of no effect ($RR=1$), the pooled estimate and the 95% indicate a magnitude statistical difference in the lowering SBP/DBP between groups. The absence of publication bias and heterogeneity among the RCT studies also explained this finding. On the other hand, this meta-analysis finding provided evidence for the association between physical activity and SBP and DBP reduction and subsequently reduced risk of prehypertension after the intervention among adults worldwide. Further, the risk of developing prehypertension tends to decrease if physical activity (e.g., 30 to 60 minutes, 60 to 120 minutes of any PA) is regularly maintained for a lifespan [41].

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