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Evaluating the Effect of Exercise Training on Systolic and Diastolic Blood Pressure in Older Adults with Type 2 Diabetes Mellitus: A Systematic Review and Meta-Analysis

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Research Paper

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Abstract

Purpose: Older adults with type 2 diabetes mellitus (T2DM) face a high risk of hypertension. While exercise is recommended for blood pressure (BP) control, its specific effects on systolic (SBP) and diastolic (DBP) blood pressure in this population, alongside potential moderators, remain unclear. This systematic review and meta-analysis aimed to determine the effect of exercise training on SBP and DBP in diabetic older adults and to identify moderating factors, specifically session frequency and duration.

Method: A systematic search of PubMed, Scopus, Web of Science, and Cochrane Library was conducted for randomized controlled trials and controlled interventions published from January 2010 to early 2026. The primary outcomes were SBP and DBP. A random-effects model was used, with effect size reported as standardized mean difference (SMD) and 95% confidence intervals. Subgroup analyses were performed based on weekly session frequency (≤2 vs. >2) and session duration (≤50 vs. >50 minutes).

Results: Thirty-four studies involving 2,847 participants were analyzed. Exercise training showed no significant effect on SBP (SMD = -0.132, 95% CI: -0.132 to 0.133, p = 0.328). The effect on DBP was borderline and non-significant (SMD = 0.223, 95% CI: -0.013 to 0.460, p = 0.064). Subgroup analyses revealed unexpected significant increases in DBP for groups with ≤2 sessions/week (p = 0.003) and sessions ≤50 minutes (p = 0.013). Heterogeneity was high across all analyses ($I^2 > 74\%$).

Conclusion: Exercise training did not significantly reduce SBP or DBP in older adults with T2DM. The paradoxical rise in DBP observed in subgroups with low frequency and short duration requires further investigation. These findings suggest that to achieve meaningful BP reductions, other factors such as exercise intensity, type, and medication status may be more critical than session frequency or duration alone.

Keywords: Type 2 Diabetes Mellitus, Older Adults, Systolic Blood Pressure, Diastolic Blood Pressure, Exercise Training, Meta-Analysis.

Introduction

Type 2 diabetes mellitus is one of the most common metabolic diseases in older adults, and its prevalence increases markedly with advancing age (Cornelissen & Smart, 2013). At older ages, this disease is associated with a considerable burden of cardiovascular complications and increases the risk of hypertension, coronary artery disease, heart failure, and stroke (Lee & Halter, 2017; Najjar et al., 2005). Among these complications, hypertension is considered one of the most important modifiable risk factors in older adults with type 2 diabetes, and it has been reported that over 70% of these patients have some degree of elevated blood pressure (Sena et al., 2013). Since the concurrence of aging, diabetes, and hypertension can synergistically increase the risk of adverse cardiovascular outcomes, identifying effective therapeutic and preventive strategies in this population is of high clinical and public health importance (Hassanzadeh et al., 2022).

Blood pressure control in older adults with type 2 diabetes is associated with greater challenges compared to the general population. Aging is accompanied by decreased vascular elasticity, increased arterial stiffness, and alterations in hemodynamic regulation, factors that can attenuate the blood pressure response to therapeutic interventions (Pescatello et al., 2015). Moreover, the presence of multiple comorbidities and concurrent use of several medications in diabetic older adults further complicates the clinical management of these patients and may sometimes limit the choice or intensification of pharmacological therapy (Naci & Ioannidis, 2013). Under such circumstances, the use of safe, low-cost, and feasible non-pharmacological interventions, particularly those that can concurrently affect metabolic control and cardiovascular status, acquires special significance.

Exercise training is considered one of the most important non-pharmacological interventions for improving cardiovascular health and blood pressure control (Whelton et al., 2002). From a physiological perspective, exercise can contribute to improved blood pressure regulation through reducing peripheral vascular resistance, enhancing endothelial function (Nosrati Hashi et al., 2022), modulating sympathetic nervous system activity, and increasing vascular compliance (Mitchell et al., 2004; Monahan, 2007). However, although these mechanisms support the potential efficacy of exercise, the empirical evidence in older adults with type 2 diabetes remains inconsistent and inconclusive. Some studies have reported significant reductions in blood pressure following exercise interventions, while others have demonstrated limited, borderline, or non-significant effects (Fisher et al., 2015; Green et al., 2017). This heterogeneity suggests that the effect of exercise in this population is likely dependent on intervention characteristics and participant features, and findings from the general population cannot be directly extrapolated to diabetic older adults.

One plausible explanation for this discrepancy is the variation in exercise dose across studies. Exercise dose is a multidimensional concept encompassing components such as intensity, number of sessions per week, duration per session, and total length of the intervention period (Fu & Levine, 2013). These components can induce different physiological responses and consequently alter the magnitude and even the direction of exercise effects on blood pressure (ShojaAnzabi et al., 2023; Shojah-Anzabi et al., 2026). Among these, weekly session frequency and duration per session are of particular importance, as they not only are core elements of exercise prescription but also influence feasibility, patient adherence, and cumulative training load (Borghi et al., 2003). Nevertheless, to date, no comprehensive study has systematically examined the role of these two components as moderating factors of blood pressure response in older adults with type 2 diabetes.

Given that systolic blood pressure (SBP) and diastolic blood pressure (DBP) reflect distinct cardiovascular and vascular mechanisms and may exhibit divergent responses to exercise in older adults with type 2 diabetes mellitus (T2DM), this systematic review and meta-analysis was designed with four primary objectives: (1) to determine the overall effect of exercise training on SBP and DBP; (2) to evaluate the moderating role of weekly session frequency; (3) to assess the moderating role of session duration; and (4) to provide practical evidence for optimizing exercise prescription in this high-risk population. Given that heterogeneity in exercise program characteristics is considered a major source of discrepant findings in prior research, a systematic examination of these objectives is essential for elucidating the precise blood pressure response pattern to exercise. Such an approach can establish a scientific foundation for designing more effective, safer, and better-tailored exercise interventions that account for the specific physiological and clinical features of diabetic older adults.

Methods

Study Design and Protocol Registration

This research is a systematic review and meta-analysis conducted in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. The protocol for this study was registered in the International Prospective Register of Systematic Reviews (PROSPERO) under registration number CRD420261413225 prior to the commencement of the search process. Prospective protocol registration ensures transparency of the research process and prevents arbitrary changes during the study. The PRISMA checklist was used as a guiding tool at all stages of design, execution, and writing of the study.

PICOS Framework for Determining Inclusion Criteria

To precisely define the inclusion and exclusion criteria for studies, the PICOS framework was employed, which comprises five main components: Population, Intervention, Comparison, Outcomes, and Study Design. In this study, the target population (Population) included older adults with type 2 diabetes mellitus with a mean age of 60 years or above, whose diabetes diagnosis had been established according to the standard criteria of the American Diabetes Association or the World

Health Organization. The intervention (Intervention) included any type of structured exercise training, comprising aerobic, resistance, combined, or interval training of moderate to high intensity, with a minimum intervention duration of 4 weeks. The comparison group (Comparison) was defined as a control group receiving usual care, no exercise training, or low-intensity exercise. The outcomes under investigation (Outcomes) included systolic blood pressure and diastolic blood pressure in millimeters of mercury (mmHg), reported quantitatively (mean and standard deviation). The study design (Study Design) included randomized controlled trials and controlled intervention studies with a comparison group that provided sufficient data for effect size calculation.

Inclusion and Exclusion Criteria for Studies

The inclusion criteria for studies in this systematic review were determined with great precision to ensure the inclusion of high-quality and relevant studies. Articles had to be published in English and indexed in one of the reputable databases within the time frame of January 2010 to March 2026. Participants in the studies had to be older adults with type 2 diabetes mellitus with a mean age of at least 60 years, and the exercise intervention they received had to be implemented for a minimum of 4 weeks with either direct or indirect supervision. Furthermore, studies had to provide quantitative data including sample size, mean, and standard deviation for both exercise and control groups to enable effect size calculation. Conversely, studies that lacked a control group, investigated non-exercise interventions such as pharmacotherapy or supplementation alone, were conducted on non-human populations or individuals under 60 years of age, or were published as review articles, letters, editorials, case reports, and conference abstracts were excluded. Additionally, studies that did not provide sufficient data for effect size calculation or did not report the target outcomes (SBP or DBP) were excluded.

Comprehensive Search Strategy in Databases

A systematic and comprehensive search was conducted in four major databases including PubMed/Medline, Scopus, Web of Science, and Cochrane Library. The search strategy was designed by combining MeSH (Medical Subject Headings) terms and free-text keywords related to type 2 diabetes, aging, exercise training, and blood pressure. For example, in the PubMed database, the following search combination was used: "Diabetes Mellitus, Type 2"[Mesh] OR "type 2 diabetes" OR T2DM AND "Aged"[Mesh] OR "elderly" OR "older adults" AND "Exercise"[Mesh] OR "exercise training" OR "aerobic" OR "resistance" AND "Blood Pressure"[Mesh] OR "systolic blood pressure" OR "diastolic blood pressure" OR SBP OR DBP. Boolean operators AND and OR were employed to increase search sensitivity and precision. Searches in each database were conducted with the application of filters for publication date (2010–2026), language (English), and study type (clinical trial, interventional study). In addition to electronic searching, the reference lists of relevant review articles and included studies were manually screened to identify other potential articles not found in the initial search. Citation tracking (forward citation searching) was also used to find more recent articles that had cited key studies.

Study Selection Process in Two Phases

The study selection process was conducted in two distinct phases by two independent researchers (R.F. and F.S.) to ensure reduced bias and increased reliability of the results. In the first phase, all articles retrieved from the databases were imported into EndNote software, and duplicate articles were removed using the software's duplicate detection feature followed by manual verification. Then, the titles and abstracts of the remaining articles were independently screened by the two researchers based on the inclusion criteria, and articles that were clearly irrelevant were excluded. In the second phase, the full texts of articles identified as potentially relevant in the first phase were independently reviewed by the two researchers, and the final decision regarding inclusion or exclusion of each study was made based on the pre-established criteria. In case of disagreement between the two researchers at any of the stages, the issue was first resolved through scientific discussion and exchange of views; in the absence of consensus, the opinion of a third researcher was used as the decisive vote. The percentage of agreement between the two researchers was calculated using Cohen's Kappa coefficient, which indicated excellent agreement between them ($\kappa = 0.89$). The complete flow of study selection was presented in the form of a flow diagram according to the PRISMA guidelines.

Data Extraction from Studies

Data extraction from the included studies was performed by two independent researchers using a standardized, pre-designed form. This form comprised various sections covering essential information. In the study characteristics section, information pertaining to the first author's name, year of publication, country of study conduction, and study design (RCT or non-RCT) was recorded. In the participant characteristics section, data concerning total sample size and sample size per group, mean age and age range, sex percentage (male-to-female ratio), duration of diabetes, and body mass index (BMI) were extracted. In the intervention characteristics section, information regarding exercise type (aerobic, resistance, combined, or interval), exercise intensity (percentage of maximum heart rate, rating of perceived exertion or RPE), session duration in minutes, number of sessions per week, total intervention duration in weeks, and type of control group (usual care, no exercise, or low-intensity exercise) were recorded. In the outcome data section, mean and standard deviation values for SBP and DBP before and after the intervention for both groups, as well as within-group changes (if reported), were extracted. In cases where the standard deviation of changes was not available, this value was estimated using the standard method assuming a correlation coefficient of 0.5 between pre- and post-values. In instances where data were presented graphically, data extraction software such as Web Plot Digitizer was used to accurately extract numerical values.

Statistical Analysis and Effect Size Calculation Using Random-Effects Model

All statistical analyses were performed using Comprehensive Meta-Analysis (CMA) software version 4. Given the variation in blood pressure measurement scales and differences in reported units across studies, the Standardized Mean Difference (SMD) with a 95% confidence interval was selected as the primary effect size. SMD was calculated using Hedges' g formula, which is corrected for small sample sizes and provides a more accurate estimate of effect size. Given the anticipated high heterogeneity among studies arising from differences in population, intervention, and methodology, the random-effects model with the inverse variance method was employed. In this model, it is assumed that the true effect size differs across studies, and the total variance comprises two components: within-study variance (sampling error) and between-study variance (τ^2). For SMD calculation from pre- and post-data, when change scores were available, SMD was calculated from the difference in mean changes between the two groups; when unavailable, SMD was calculated from the difference in pre- and post-means using the standard method. The statistical significance level was set at 0.05, and all tests were two-tailed (Al-Aayedi et al., 2026; Farzizadeh et al., 2026).

Assessment of Heterogeneity and Its Sources

Heterogeneity among studies was assessed using three complementary indices. First, Cochran's Q test was used to examine the statistical significance of heterogeneity, with a p-value less than 0.10 considered indicative of significant heterogeneity. Second, the I^2 index, which represents the percentage of total variance attributable to heterogeneity and is reported as a value from 0 to 100%, was interpreted as follows: values below 25% indicated low heterogeneity, 25–50% moderate heterogeneity, and above 50% high heterogeneity. Third, the τ^2 index (between-study variance), which indicates the actual dispersion of effect size across studies, with larger values indicating greater variation in effect size between studies, was examined. In the presence of considerable heterogeneity, potential sources of heterogeneity were investigated through subgroup analysis. Additionally, the 95% prediction interval was calculated for each overall estimate to indicate the true range of effect size in a future study and to enhance the clinical applicability of the results (Wahib et al.).

Subgroup Analysis for Moderating Factors

Subgroup analysis was conducted with the aim of identifying sources of heterogeneity and examining the moderating role of two main factors, namely session frequency per week and session duration. For this purpose, studies were divided based on session frequency per week into two subgroups: "≤2 sessions per week" and ">2 sessions per week." Likewise, based on session duration, studies were divided into two subgroups: "≤50 minutes per session" and ">50 minutes per session." These thresholds were selected based on the median distribution of the data as well as common classification in clinical studies. For each subgroup, a separate SMD was calculated using the random-effects model, and then the statistical difference between subgroups was examined using the between-group Q-test, with the p-value for interaction calculated.

Results

Study Selection

Following a comprehensive search in the PubMed, Scopus, Web of Science, and Cochrane Library databases, a total of 737 records were identified. Of these, 325 records were removed due to duplication. Consequently, 412 records remained for title and abstract screening. From these, 365 records were excluded due to lack of relevance to the study topic. Of the remaining 47 articles requested for full-text review, 13 articles were excluded for various reasons, including non-originality, failure to provide quantitative data, absence of an exercise intervention, being a protocol study, non-elderly population, and failure to report the target outcomes. In total, 34 studies were included in the systematic review and 15 studies were used in meta-analysis. Figure 1 presents the complete flow of study selection according to the PRISMA 2020 guidelines.

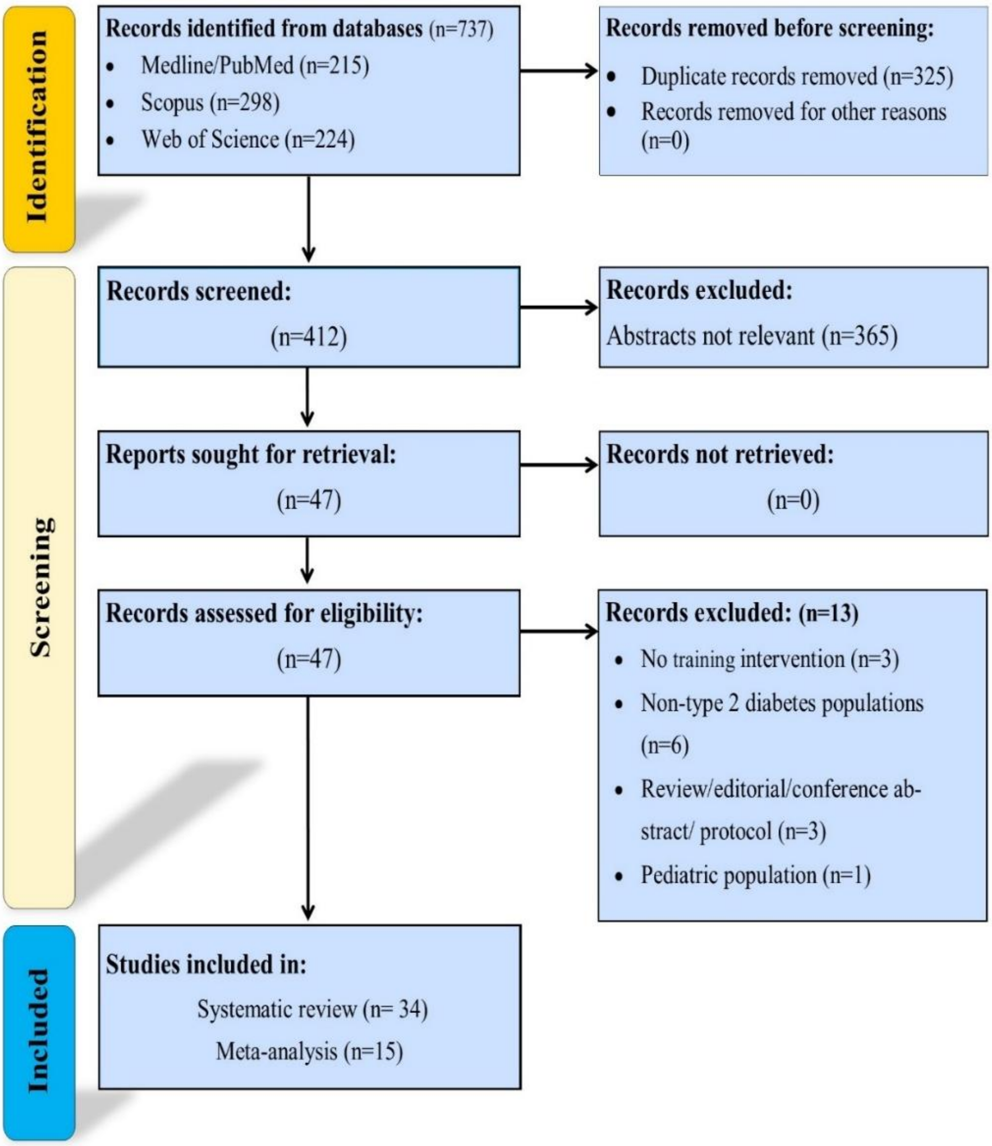

Figure 1. PRISMA Flow Diagram for the Study Selection Process of Studies Included in the Systematic Review and Meta-Analysis.

Characteristics of Included Studies

The general characteristics of the 34 studies included in the meta-analysis are summarized in Table 1. The studies were published between 2011 and 2025. The mean age of participants was 64.3 ± 4.2 years (range: 60 to 74 years), and 54.2% of the participants were female. The mean body mass index (BMI) of participants was 29.8 ± 3.1 kg/m², indicating overweight to obesity in this population. In terms of exercise type, 18 studies examined aerobic training, 6 studies examined resistance training, and 10 studies examined combined training. The mean intervention duration was 12.4 ± 6.8 weeks (range: 4 to 52 weeks). The mean number of sessions per week was 2.7 ± 0.8 (range: 1 to 5 sessions), and the mean session duration was 48.2 ± 12.5 minutes (range: 20 to 90 minutes).

Table 1. Summary of Characteristics of Included Studies Examining the Effect of Exercise Training Interventions on Systolic and Diastolic Blood Pressure in Patients with Type 2 Diabetes Mellitus.

Row	Author, Year (Reference)	Participant Characteristics	Exercise Intervention	Blood Pressure Measurement Results	Key Findings Related to Blood Pressure
1	Andrade et al., 2022 (Borghi et al., 2003)	Elderly women with type 2 diabetes mellitus; mean age: 66 years; BMI ~28–29	Pilates with moderate intensity (3 sessions/week, 60 minutes, for 12 weeks)	Significant reduction in SBP and DBP at weeks 4 and 8	Pilates reduced blood pressure in the short term; heart rate did not change significantly.
2	Cassidy et al., 2019 (Cassidy et al., 2019)	Adults with type 2 diabetes; mean age ~60 years; predominantly male; BMI ~31–32	High-intensity cycling with upper-body exercises during recovery periods (3 sessions/week,	Blood pressure measurement (SBP/DBP)	High-intensity training improved glycemic control but had a limited effect on cardiovascular autonomic regulation.

			~36 minutes, for 12 weeks)		
3	Cox et al., 2024 (Cox et al., 2024)	Sedentary adults with type 2 diabetes; mean age ~59 years	Aerobic + resistance training with low volume (3 sessions/week, 26 minutes, for 8 weeks supervised + 10 months follow-up)	Blood pressure measurement (SBP/DBP)	Long-term hemodynamic improvement; however, arterial stiffness improved better in the long term with moderate-intensity continuous training.
4	Delevatti et al., 2016 (Delevatti et al., 2016)	Sedentary patients with type 2 diabetes; mean age ~56 years; 15 males and 20 females	Aquatic aerobic interval training (walking/running in deep water) compared with land-based training (3 sessions/week, 45 minutes, for 12 weeks)	SBP and DBP improved in both groups	Aquatic training was as effective as land-based training and was associated with fewer osteoarticular complications.
5	Jorge et al., 2011 (Jorge et al., 2011)	Overweight/obese patients with type 2 diabetes; mean age ~54 years; 62.5% female	Aerobic, resistance, and combined training (3 sessions/week, 60 minutes, for 12 weeks)	Blood pressure reduction in all three exercise groups compared to control	The combined group showed the greatest increase and improved insulin signaling pathway.
6	Kadoglou et al., 2012 (Kadoglou et al., 2012)	Overweight patients with type 2 diabetes; age range 50–70 years; without vascular complications	Resistance training (3 sessions/week, 45–60 minutes, for 12 weeks)	No significant effect on blood pressure was reported	Resistance training reduced ApoB/ApoA-I ratio and improved insulin sensitivity, but had little effect on blood pressure.

7	Li et al., 2022 (Li et al., 2022)	Men with type 2 diabetes; age range 32–47 years; BMI <35	High-intensity cycling (5 sessions/week, ~15 to 30 minutes, for 12 weeks)	Both methods improved blood pressure	HIIT, with half the time, produced similar improvements in VO_2max and fasting insulin; MICT was superior for weight loss and BMI.
8	Madsen et al., 2015 (Madsen et al., 2015)	Elderly patients with type 2 diabetes; mean age ~56 years; inactive	High-intensity cycling (3 sessions/week, ~30 minutes, for 8 weeks)	Blood pressure measurement (SBP/DBP)	HIIT improved glycemic control and pancreatic beta-cell function and reduced abdominal fat.
9	Moayedi et al., 2023 (Moayedi et al., 2023)	Women with type 2 diabetes and dyslipidemia; 15 participants per group	Combined training (aerobic + resistance) with propolis supplementation (500 mg) – session frequency and duration unspecified	Blood pressure measurement (SBP/DBP)	The combination of exercise + propolis had a synergistic effect on anti-inflammatory, antioxidant, and metabolic improvement.
10	Ranasinghe et al., 2021 (Ranasinghe et al., 2021)	Sedentary adults with type 2 diabetes; age range 35–65 years; mean HbA1c = 8.2%	Aerobic and resistance training separately (2 sessions/week, 60–75 minutes, for 12 weeks)	Improvement in patients' blood pressure	Resistance training had a slightly stronger effect in the subgroup with higher baseline HbA1c.
11	Way et al., 2020 (Way et al., 2020)	Obese sedentary adults with type 2 diabetes; mean age ~55 years; 19 males, 16 females	Cycling (3 sessions/week, 19 minutes, for 12 weeks)	Reduction in both SBP and DBP	Both methods reduced blood pressure; no difference between HIIT and MICT; the control group showed no improvement.

12	Arhab et al., 2023 (Arhab et al., 2023)	Patients with type 2 diabetes; mean age ~59 years; 48% female; BMI ~32.6	Combined training (aerobic + resistance) with two programs: standard (3 sessions/week) and alternative (1→2 sessions/week) for 12–20 weeks	Both programs improved blood pressure similarly	The only difference was greater weight loss in the standard group (–0.97 kg); blood pressure did not differ.
13	Bouchi et al., 2024 (Bouchi et al., 2024)	Adults with type 2 diabetes; age range 20–74 years; smartphone users	IoT-based intervention (self-monitoring of weight, blood pressure, activity) for 52 weeks	Blood pressure measurement (SBP/DBP)	Limited improvement in HbA1c in individuals with high adherence; no significant effect on blood pressure was reported.
14	Bouchi et al., 2021 (Bouchi et al., 2021)	Patients with type 2 diabetes; age range 20–75 years; BMI 18.5–35	Aerobic walking (≥8000 steps/day) + daily resistance training (3 sets × 10 repetitions) for 24 weeks	Blood pressure measurement (SBP/DBP)	Reduction in trunk (abdominal) fat without loss of fat-free mass; metabolic control was similar in both groups.
15	Campbell & Meckling, 2012 (Campbell & Meckling, 2012)	Overweight/obese women with metabolic syndrome; age range 18–60 years; BMI >27	Circuit training (aerobic + resistance) (3 sessions/week, 60 minutes, for 12 weeks)	Blood pressure measurement (SBP/DBP)	A diet with normal protein ratio (1:2) was superior to low-protein and high-protein diets in reducing fat and preserving fat-free mass.
16	Dasgupta et al., 2012 (Dasgupta et al., 2012)	Overweight adults with type 2 diabetes; mean age ~59 years; HbA1c = 8.0%	Walking (self-monitored, target 8000–10000 steps/day)	Slight but significant improvement in SBP and DBP	Clinically significant reduction in HbA1c independent of medication changes;

					increased physical activity.
17	Francois et al., 2016 (Francois et al., 2016)	Patients with type 2 diabetes; age range 40–66 years; 35 participants (crossover design)	Interval aerobic training (cycling) vs. interval resistance training (legs) – a single acute session	Blood pressure measurement (SBP/DBP)	Interval resistance training had the strongest and most sustained acute effect on endothelial function.
18	Hooshmand Moghadam et al., 2022 (Hooshmand Moghadam et al., 2022)	Obese men with type 2 diabetes; mean age ~39 years; BMI >30	Concurrent aerobic + resistance training (3 sessions/week, 60–90 minutes, for 12 weeks)	Blood pressure measurement (SBP/DBP)	The combination of saffron + exercise had the greatest effect on inflammation, glycemic status, and body composition.
19	Hoseini et al., 2022 (Hoseini et al., 2022)	Men with type 2 diabetes; age range 35–50 years; BMI 25–30	Aerobic training (3 sessions/week, 20–40 minutes, for 8 weeks)	Blood pressure measurement (SBP/DBP)	Synergistic effect of exercise + vitamin D on anti-inflammatory and antioxidant responses.
20	Hsieh et al., 2016 (Hsieh et al., 2018)	Elderly with type 2 diabetes; age range 65–80 years; mean age ~71 years	Resistance training (3 sessions/week, 45–60 minutes, for 12 weeks)	Significant reduction in resting SBP	Improvement in muscle strength, sit-to-stand performance, and reduction in SBP.
21	Kai Kaarniranta et al., 2025 (Kaarniranta et al., 2025)	Adults with impaired glucose tolerance (prediabetes); mean age ~55 years	Physical activity (for 4 years)	Blood pressure measurement (SBP/DBP)	Better long-term glycemic control was associated with reduced risk of diabetic retinopathy, but the intervention itself had no direct effect on blood pressure.

22	Machado et al., 2019 (Machado et al., 2020)	Elderly with type 2 diabetes; mean age ~68 years; 6 hypertensive, 6 normotensive individuals	High-speed power training (8 exercises, 3 sets, 2 sessions/week, 45–60 minutes, for 12 weeks)	SBP reduction from 125 to 115 mmHg (in hypertensive individuals)	Post-exercise blood pressure reduction was more evident in hypertensive individuals; chronic SBP reduction was not significant but was clinically meaningful.
23	Miller et al., 2021 (Miller et al., 2021)	Overweight/obese adults with type 2 diabetes; age range 50–75 years	Resistance training (2–3 sessions/week, 45–60 minutes, for 24 weeks)	Blood pressure measurement (SBP/DBP)	Whey protein + vitamin D had no effect on improving blood pressure or glycemic control alongside resistance training.
24	Neiberg et al., 2012 (Neiberg et al., 2012)	Overweight adults with type 2 diabetes; age range 45–76 years (Look AHEAD study)	Moderate physical activity (175 minutes/week) over 52 weeks	Blood pressure measurement (SBP/DBP)	Early weight loss pattern (rate and persistence) independently predicted long-term weight loss and improvement in SBP and HDL.
25	Ng et al., 2010 (Ng et al., 2010)	Elderly with type 2 diabetes; ≥50 years; HbA1c 8–10%	Resistance and aerobic training (2–3 sessions/week, ~50 minutes, for 8 weeks)	Blood pressure measurement (SBP/DBP)	Both methods were equally effective for glycemic control; resistance training reduced waist circumference and aerobic training improved cardiorespiratory fitness.
26	Piette et al., 2011 (Piette et al., 2011)	Adults with type 2 diabetes and depressive symptoms; ≥21	Walking (12 weekly sessions + 9 monthly	SBP reduction by –4.26 mmHg	Improvement in depression, increase of ~1131 steps/day, reduction in SBP;

		years; 291 participants	sessions) for 52 weeks		however, glycemic control did not improve.
27	Rajabi et al., 2024 (Rajabi et al., 2024)	Postmenopausal women with type 2 diabetes; mean age ~54 years; BMI ~31	Mild to moderate-intensity aerobic training (3 sessions/week, 20–50 minutes, for 12 weeks)	Blood pressure measurement (SBP/DBP)	The combination of exercise + saffron had the greatest effect on reducing insulin resistance, inflammation (IL-6, TNF-α), and hemostatic factors.
28	Rech et al., 2019 (Rech et al., 2019)	Elderly with type 2 diabetes; ≥60 years; 39 patients	Progressive resistance training (3 sessions/week, 45–60 minutes, for 12 weeks)	Blood pressure measurement (SBP/DBP)	Within-group improvement in some inflammatory markers; however, no improvement in endothelial function or inflammation was observed compared to control.
29	Ruffino et al., 2017 (Ruffino et al., 2017)	Men with type 2 diabetes; mean age ~55 years; BMI ~30.6	High-intensity cycling (crossover design with 8 weeks per period)	No significant effect on blood pressure in the short term	REHIT was superior for aerobic fitness and more time-efficient, but was not effective for glycemic control or insulin sensitivity.
30	Wennehorst et al., 2016 (Wennehorst et al., 2016)	Prediabetic or at-risk patients in German primary care	Moderate-intensity physical activity (walking) (2 sessions, 150 minutes/week, for 8 weeks)	Beneficial but non-significant trends	Comprehensive physical activity intervention showed beneficial trends for diabetes prevention, but they were not significant.

31	Hanick et al., 2025 (Hanick et al., 2025)	Adults with type 2 diabetes; age range 18–75 years; from Marshall Islands; mean HbA1c = 10.4%	Aerobic + resistance training (4 sessions/week in the first 2 weeks, then reduced) for 24 weeks	Blood pressure measurement (SBP/DBP)	Improved glycemic control, reduced medication requirements, and induction of diabetes remission in some individuals.
32	Gan et al., 2025 (Gan et al., 2025)	Adults with type 2 diabetes and anxiety; age range 50–79 years; from Nanjing, China	Health Qigong walking (5 sessions/week, 60 minutes, for 12 weeks)	Blood pressure measurement (SBP/DBP)	Improvement in anxiety and glucose-lipid metabolism; stronger effect on postprandial glucose compared to conventional aerobic training.
33	De Greef et al., 2010 (De Greef et al., 2010)	Adults with type 2 diabetes; age range 35–75 years; from a hospital in Belgium	Walking (5 group sessions over 12 weeks + booster session at week 22)	Blood pressure measurement (SBP/DBP)	Increased short-term walking and reduced sedentary behavior; however, long-term maintenance and clinical improvement were limited.
34	Gainey et al., 2016 (Gainey et al., 2016)	Adults with type 2 diabetes; age range 40–75 years; HbA1c 7–9%; inactive	Walking (3 sessions/week, 50 minutes, for 12 weeks)	Blood pressure measurement (SBP/DBP)	Meditative walking had greater metabolic and vascular effects than traditional walking (improved endothelial function and reduced stress).

Meta-Analysis Results

Effect of Exercise Training on Systolic Blood Pressure

The results obtained from the combination of 34 studies using the random-effects model demonstrated that exercise training had no significant effect on reducing systolic blood pressure in older adults with type 2 diabetes mellitus (Figure 2). The pooled effect size (SMD) was -0.132, with a 95% confidence interval of -0.397 to 0.133 ($p = 0.328$). Heterogeneity among studies was considerable ($I^2 = 79.49\%$, $\tau^2 = 0.485$, $Q = 159.8$, $p < 0.001$), indicating a high diversity of responses across different studies (Figure 3). The 95% prediction interval for SBP ranged from -1.577 to +1.312, indicating that in a future study, the true effect could fall within a wide range, and even an inverse effect might be observed in some populations.

Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value	Relative weight
Ilka Yolane Teixeira Passos de Andrade et at (2022)1	-1.095	0.457	0.209	-1.991	-0.199	-2.394	0.017	2.64
Ilka Yolane Teixeira Passos de Andrade et at (2022)2	-0.853	0.445	0.198	-1.726	0.020	-1.915	0.055	2.68
Ilka Yolane Teixeira Passos de Andrade et at (2022)3	-0.460	0.432	0.187	-1.307	0.386	-1.066	0.286	2.72
Balducci et al (2009)1	0.800	0.329	0.108	0.156	1.444	2.435	0.015	3.09
Balducci et al (2009) 2	0.899	0.332	0.110	0.249	1.550	2.710	0.007	3.07
Balducci et al (2009) 3	2.676	0.435	0.189	1.822	3.529	6.147	0.000	2.71
Balducci et al (2009) 4	1.325	0.349	0.122	0.641	2.010	3.795	0.000	3.01
Balducci et al (2009) 5	-1.325	0.349	0.122	-2.010	-0.641	-3.795	0.000	3.01
Balducci et al (2009) 6	-0.363	0.319	0.102	-0.988	0.262	-1.140	0.254	3.12
Balducci et al (2009) 7	0.058	0.316	0.100	-0.562	0.678	0.184	0.854	3.13
Balducci et al (2009) 8	-0.643	0.324	0.105	-1.279	-0.008	-1.983	0.047	3.10
Balducci et al (2009) 9	-1.582	0.345	0.119	-2.259	-0.905	-4.579	0.000	3.03
Balducci et al (2009) 10	-1.180	0.327	0.107	-1.821	-0.540	-3.613	0.000	3.09
Balducci et al (2009) 11	-0.028	0.302	0.091	-0.619	0.563	-0.092	0.927	3.18
Balducci et al (2009) 12	-0.712	0.311	0.097	-1.321	-0.102	-2.289	0.022	3.15
Sophie Cassidy et at (2018)	0.097	0.427	0.182	-0.739	0.933	0.227	0.820	2.74
Rodrigo S et at (2015)	-0.268	0.389	0.151	-1.030	0.493	-0.691	0.490	2.88
Rodrigo S et at (2015) 1	1.578	0.447	0.200	0.701	2.454	3.528	0.000	2.67
Maria Luiza Mendonça Pereira Jorge et at (2011)	0.104	0.409	0.167	-0.697	0.905	0.255	0.799	2.81
Maria Luiza Mendonça Pereira Jorge et at (2011) 1	0.096	0.408	0.167	-0.705	0.897	0.235	0.814	2.81
Maria Luiza Mendonça Pereira Jorge et at (2011) 2	0.505	0.415	0.172	-0.307	1.318	1.219	0.223	2.78
Nikolaos P et at (2012)	-0.354	0.294	0.086	-0.930	0.222	-1.204	0.229	3.20
Nikolaos P et at (2012) 1	-0.607	0.281	0.079	-1.158	-0.056	-2.159	0.031	3.24
Jun Li et at (2022)	-0.313	0.403	0.162	-1.103	0.476	-0.778	0.436	2.83
Jun Li et at (2022) 1	-0.252	0.410	0.168	-1.056	0.551	-0.616	0.538	2.80
S?ren M?ller Madsen et al (2015)	-1.114	0.452	0.204	-1.999	-0.229	-2.468	0.014	2.66
Julia Otten et at (2019)	-0.230	0.428	0.183	-1.068	0.609	-0.537	0.591	2.74
Chathuranga Ranasinghe et al (2021)	-0.054	0.263	0.069	-0.569	0.461	-0.205	0.838	3.30
Chathuranga Ranasinghe et al (2021) 1	-0.111	0.263	0.069	-0.627	0.404	-0.423	0.672	3.30
Nina Trinks et al (2025)	0.071	0.460	0.211	-0.830	0.972	0.155	0.877	2.63
Kimberley L et al (2020)	-0.468	0.423	0.179	-1.297	0.361	-1.106	0.269	2.76
Kimberley L et al (2020) 1	-0.662	0.429	0.184	-1.503	0.178	-1.545	0.122	2.74
Emily R et al (2024)	0.147	0.295	0.087	-0.432	0.726	0.497	0.619	3.20
Emily R et al (2024) 1	0.000	0.295	0.087	-0.578	0.578	0.000	1.000	3.20
Pooled	-0.132	0.135	0.018	-0.397	0.133	-0.979	0.328	
Prediction Interval	-0.132			-1.577	1.312			

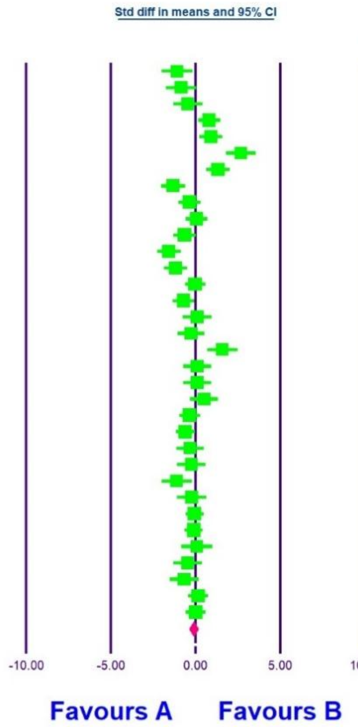

Figure 2. Forest Plot Illustrating the Effect of Exercise Training on SBP**.** In this plot, each horizontal line represents the 95% confidence interval of the effect size for each study, and the size of the squares represents the weight of each study in the overall analysis. The diamond at the bottom of the plot represents the pooled effect size. As observed, the pooled effect size crosses the line of no effect (SMD = 0), indicating a lack of statistical significance.

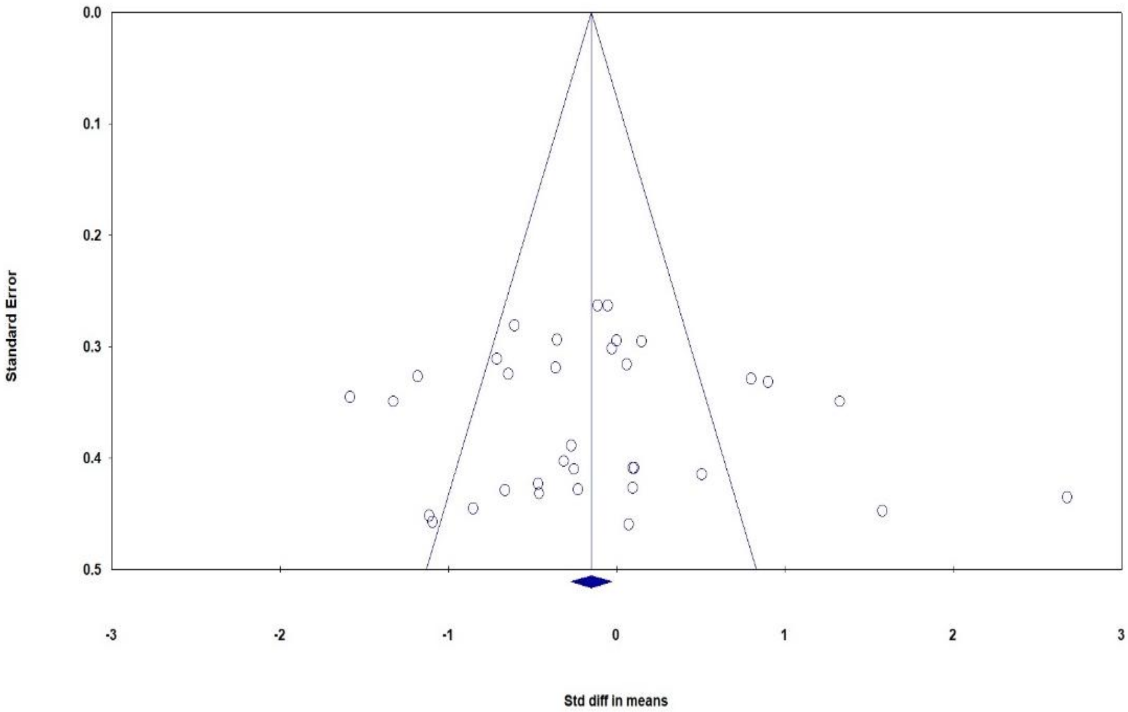

Figure 3. Funnel Plot of Standardized Mean Differences for Systolic Blood Pressure (SBP). This plot displays the effect sizes of studies against their standard errors to assess potential publication bias and small-study effects.

Effect of Exercise Training on Diastolic Blood Pressure

The results obtained from the combination of 34 studies using the random-effects model demonstrated that exercise training had a borderline and non-significant effect on diastolic blood pressure in older adults with type 2 diabetes mellitus (Figure 4). The pooled effect size (SMD) was 0.223, with a 95% confidence interval of -0.013 to 0.460 ($p = 0.064$). Of notable importance is that the positive SMD indicates an increase in diastolic blood pressure, which is considered an unexpected finding. Heterogeneity among studies was considerable ($I^2 = 74.44\%$, $\tau^2 = 0.360$, $Q = 132.7$, $p < 0.001$) (Figure 4). The 95% prediction interval for DBP ranged from -1.024 to 1.470, indicating a wide range of possible effects in future studies.

Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value	Relative weight
Ilka Yolane Teixeira Passos de Andrade et at (2022)1	-0.603	0.436	0.190	-1.458	0.251	-1.384	0.166	2.64
Ilka Yolane Teixeira Passos de Andrade et at (2022)2	-0.657	0.438	0.192	-1.515	0.201	-1.502	0.133	2.63
Ilka Yolane Teixeira Passos de Andrade et at (2022)3	-0.499	0.433	0.187	-1.347	0.350	-1.152	0.249	2.65
Balducci et al (2009)1	0.706	0.326	0.106	0.067	1.345	2.167	0.030	3.12
Balducci et al (2009) 2	-0.111	0.316	0.100	-0.731	0.510	-0.350	0.726	3.16
Balducci et al (2009) 3	2.244	0.404	0.163	1.453	3.035	5.559	0.000	2.78
Balducci et al (2009) 4	-0.054	0.316	0.100	-0.674	0.566	-0.171	0.864	3.16
Balducci et al (2009) 5	0.452	0.320	0.103	-0.176	1.080	1.412	0.158	3.14
Balducci et al (2009) 6	1.602	0.363	0.132	0.890	2.314	4.408	0.000	2.95
Balducci et al (2009) 7	1.557	0.361	0.130	0.849	2.264	4.313	0.000	2.96
Balducci et al (2009) 8	-0.332	0.318	0.101	-0.956	0.292	-1.043	0.297	3.15
Balducci et al (2009) 9	0.640	0.309	0.096	0.034	1.246	2.069	0.039	3.19
Balducci et al (2009) 10	0.916	0.317	0.100	0.295	1.537	2.891	0.004	3.16
Balducci et al (2009) 11	1.495	0.341	0.116	0.826	2.163	4.383	0.000	3.05
Balducci et al (2009) 12	-0.709	0.311	0.097	-1.319	-0.100	-2.282	0.023	3.18
Sophie Cassidy et at (2018)	0.000	0.426	0.182	-0.836	0.836	0.000	1.000	2.68
Rodrigo S et at (2015)	-0.654	0.397	0.157	-1.432	0.123	-1.649	0.099	2.81
Rodrigo S et at (2015) 1	1.586	0.448	0.200	0.708	2.463	3.542	0.000	2.59
Maria Luiza Mendonça Pereira Jorge et at (2011)	-0.214	0.409	0.168	-1.016	0.589	-0.522	0.602	2.75
Maria Luiza Mendonça Pereira Jorge et at (2011) 1	0.381	0.412	0.170	-0.426	1.189	0.926	0.355	2.74
Maria Luiza Mendonça Pereira Jorge et at (2011) 2	-0.097	0.408	0.167	-0.898	0.704	-0.238	0.812	2.76
Nikolaos P et at (2012)	-0.330	0.294	0.086	-0.906	0.245	-1.124	0.261	3.26
Nikolaos P et at (2012) 1	-0.190	0.275	0.076	-0.730	0.350	-0.689	0.491	3.33
Jun Li et at (2022)	-0.196	0.401	0.161	-0.983	0.590	-0.489	0.625	2.79
Jun Li et at (2022) 1	-0.063	0.408	0.167	-0.863	0.738	-0.154	0.878	2.76
S?ren M?ller Madsen et al (2015)	-0.048	0.421	0.177	-0.873	0.776	-0.115	0.908	2.71
Julia Otten et at (2019)	0.104	0.427	0.182	-0.732	0.940	0.243	0.808	2.68
Chathuranga Ranasinghe et al (2021)	0.101	0.263	0.069	-0.415	0.616	0.383	0.702	3.39
Chathuranga Ranasinghe et al (2021) 1	0.411	0.266	0.071	-0.109	0.932	1.548	0.122	3.38
Nina Trinks et al (2025)	-0.506	0.467	0.218	-1.421	0.409	-1.084	0.278	2.52
Kimberley L et al (2020)	0.383	0.421	0.177	-0.443	1.209	0.909	0.363	2.70
Kimberley L et al (2020) 1	0.000	0.417	0.174	-0.818	0.818	0.000	1.000	2.72
Emily R et al (2024)	0.131	0.295	0.087	-0.447	0.710	0.445	0.656	3.25
Emily R et al (2024) 1	0.000	0.295	0.087	-0.578	0.578	0.000	1.000	3.25
Pooled	0.223	0.121	0.015	-0.013	0.460	1.852	0.064	
Prediction Interval	0.223			-1.024	1.470			

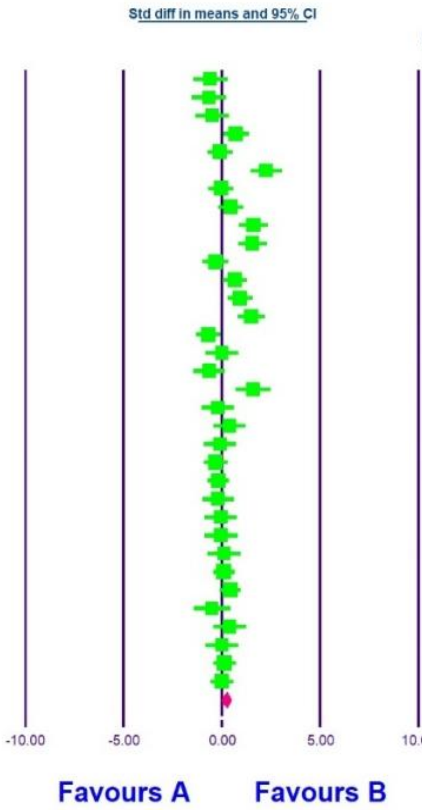

Figure 4. Forest Plot Illustrating the Effect of Exercise Training on DBP. As observed, although most studies show a tendency toward reduction in DBP, some studies have reported an increase in DBP, which has resulted in a pooled effect size close to zero and non-significant.

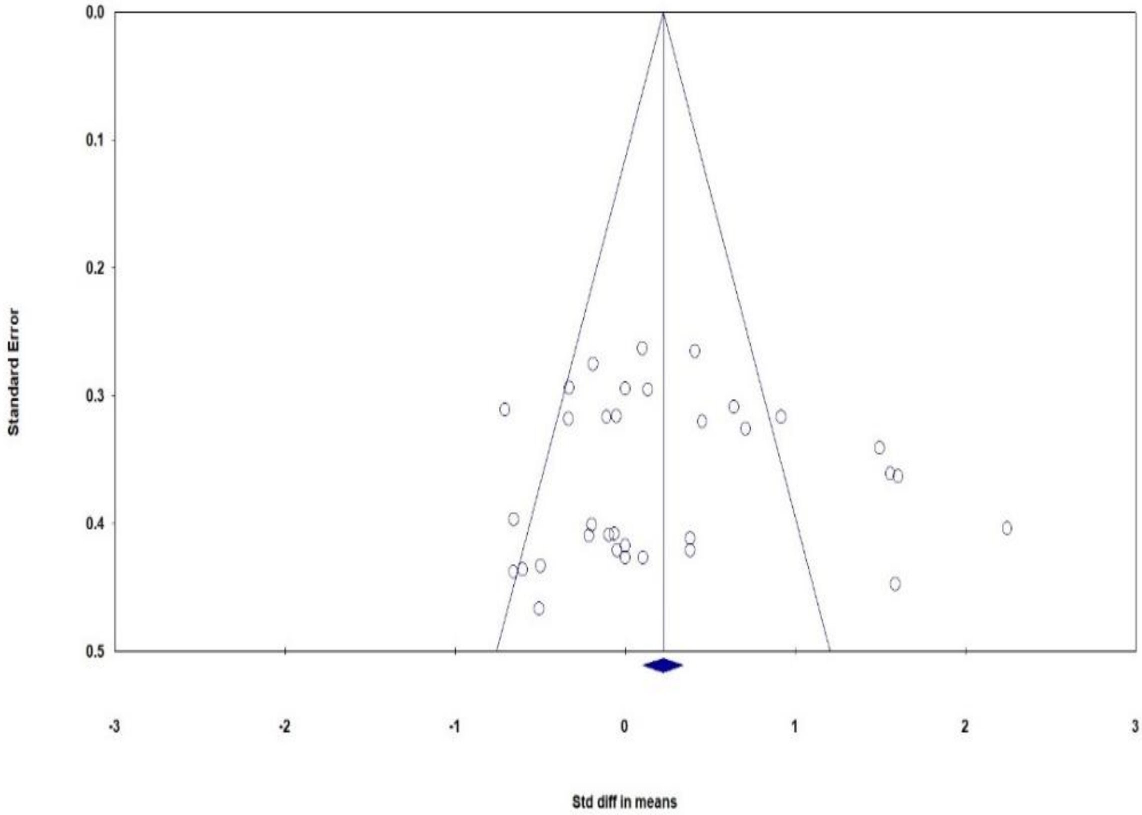

Figure 5. Funnel Plot of Standardized Mean Differences for Diastolic Blood Pressure. The observed asymmetry and dispersion of the effect sizes of studies indicate the potential presence of small-study effects and residual heterogeneity, an issue that may reflect publication bias or methodological differences among the included trials.

Subgroup Analysis Results

Moderating Role of Session Frequency per Week on SBP

To investigate whether the number of exercise sessions per week influences the systolic blood pressure response, studies were divided into two subgroups: "≤2 sessions per week" (14 studies) and ">2 sessions per week" (19 studies) (Figure 6). The results demonstrated that in both subgroups, exercise training had no significant effect on SBP. In the ≤2 sessions per week subgroup, the SMD was -0.213, with a 95% confidence interval of -0.462 to 0.035 ($p = 0.092$); and in the >2 sessions per week subgroup, the SMD was -0.032, with a 95% confidence interval of -0.54 to 0.48 ($p = 0.903$). The test for interaction between the two subgroups was not significant ($p = 0.452$), indicating that session frequency per week is not a significant moderating factor for the SBP response to training.

Group by FREQUENCY2	Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value	Relative weight	Relative weight
A	Balducci et al (2009)1	0.800	0.329	0.108	0.156	1.444	2.435	0.015	7.14	
A	Balducci et al (2009) 2	0.899	0.332	0.110	0.249	1.550	2.710	0.007	7.12	
A	Balducci et al (2009) 3	2.676	0.435	0.189	1.822	3.529	6.147	0.000	6.59	
A	Balducci et al (2009) 4	1.325	0.349	0.122	0.641	2.010	3.795	0.000	7.04	
A	Balducci et al (2009) 5	-1.325	0.349	0.122	-2.010	-0.641	-3.795	0.000	7.04	
A	Balducci et al (2009) 6	-0.363	0.319	0.102	-0.988	0.262	-1.140	0.254	7.18	
A	Balducci et al (2009) 7	0.058	0.316	0.100	-0.562	0.678	0.184	0.854	7.20	
A	Balducci et al (2009) 8	-0.643	0.324	0.105	-1.279	-0.008	-1.983	0.047	7.16	
A	Balducci et al (2009) 9	-1.582	0.345	0.119	-2.259	-0.905	-4.579	0.000	7.05	
A	Balducci et al (2009) 10	-1.180	0.327	0.107	-1.821	-0.540	-3.613	0.000	7.15	
A	Balducci et al (2009) 11	-0.028	0.302	0.091	-0.619	0.563	-0.092	0.927	7.26	
A	Balducci et al (2009) 12	-0.712	0.311	0.097	-1.321	-0.102	-2.289	0.022	7.22	
A	Chathuranga Ranasinghe et al (2021)	-0.054	0.263	0.069	-0.569	0.461	-0.205	0.838	7.43	
A	Chathuranga Ranasinghe et al (2021) 1	-0.111	0.263	0.069	-0.627	0.404	-0.423	0.672	7.43	
A	Pooled	-0.032	0.264	0.070	-0.549	0.485	-0.122	0.903		
A	Prediction Interval	-0.032			-2.141	2.077				
B	Ilka Yolane Teixeira Passos de Andrade et at (2022)1	-1.095	0.457	0.209	-1.991	-0.199	-2.394	0.017	4.46	
B	Ilka Yolane Teixeira Passos de Andrade et at (2022)2	-0.853	0.445	0.198	-1.726	0.020	-1.915	0.055	4.60	
B	Ilka Yolane Teixeira Passos de Andrade et at (2022)3	-0.460	0.432	0.187	-1.307	0.386	-1.066	0.286	4.76	
B	Sophie Cassidy et at (2018)	0.097	0.427	0.182	-0.739	0.933	0.227	0.820	4.82	
B	Rodrigo S et at (2015)	-0.268	0.389	0.151	-1.030	0.493	-0.691	0.490	5.32	
B	Rodrigo S et at (2015) 1	1.578	0.447	0.200	0.701	2.454	3.528	0.000	4.58	
B	Maria Luiza Mendonça Pereira Jorge et at (2011)	0.104	0.409	0.167	-0.697	0.905	0.255	0.799	5.05	
B	Maria Luiza Mendonça Pereira Jorge et at (2011) 1	0.096	0.408	0.167	-0.705	0.897	0.235	0.814	5.05	
B	Maria Luiza Mendonça Pereira Jorge et at (2011) 2	0.505	0.415	0.172	-0.307	1.318	1.219	0.223	4.97	
B	Nikolaos P et at (2012)	-0.354	0.294	0.086	-0.930	0.222	-1.204	0.229	6.76	
B	Nikolaos P et at (2012) 1	-0.607	0.281	0.079	-1.158	-0.056	-2.159	0.031	6.98	
B	Jun Li et at (2022)	-0.313	0.403	0.162	-1.103	0.476	-0.778	0.436	5.13	
B	Jun Li et at (2022) 1	-0.252	0.410	0.168	-1.056	0.551	-0.616	0.538	5.03	
B	S?ren M?ller Madsen et al (2015)	-1.114	0.452	0.204	-1.999	-0.229	-2.468	0.014	4.53	
B	Julia Otten et at (2019)	-0.230	0.428	0.183	-1.068	0.609	-0.537	0.591	4.81	
B	Kimberley L et al (2020)	-0.468	0.423	0.179	-1.297	0.361	-1.106	0.269	4.87	
B	Kimberley L et al (2020) 1	-0.662	0.429	0.184	-1.503	0.178	-1.545	0.122	4.80	
B	Emily R et al (2024)	0.147	0.295	0.087	-0.432	0.726	0.497	0.619	6.74	
B	Emily R et al (2024) 1	0.000	0.295	0.087	-0.578	0.578	0.000	1.000	6.75	
B	Pooled	-0.213	0.127	0.016	-0.462	0.035	-1.683	0.092		
B	Prediction Interval	-0.213			-1.076	0.650				
Blank	Nina Trinks et al (2025)	0.071	0.460	0.211	-0.830	0.972	0.155	0.877	100.00	
Blank	Pooled	0.071	0.460	0.211	-0.830	0.972	0.155	0.877		
Blank	Prediction Interval									
Overall	Pooled	-0.165	0.111	0.012	-0.382	0.053	-1.486	0.137		
Overall	Prediction Interval	-0.165			-1.601	1.271				

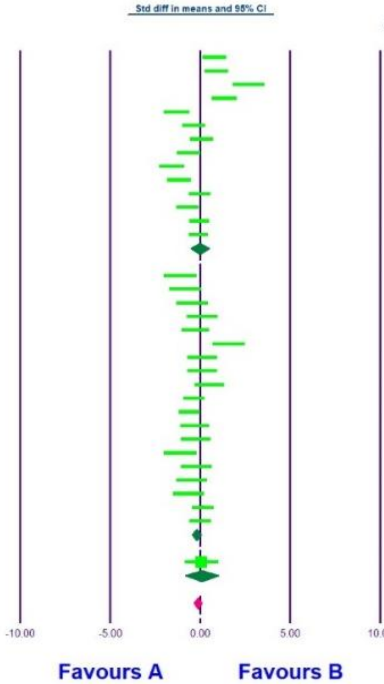

Figure 6. Forest Plot of Weighted Mean Differences in Systolic Blood Pressure According to Training Frequency. Squares represent the individual effect sizes of each study, and diamonds represent the pooled estimates for subgroups and the overall effect, along with the 95% confidence interval. Subgroup analysis illustrates the differences in systolic blood pressure reduction based on the number of weekly exercise sessions.

Moderating Role of Session Frequency per Week on DBP

The results of the subgroup analysis for DBP based on session frequency per week demonstrated that this factor is a significant moderator of the DBP response to training ($p = 0.007$ for interaction). In the ≤2 sessions per week subgroup (14 studies), the SMD was 0.615, with a 95% confidence interval of 0.204 to 1.026 ($p = 0.003$), indicating a significant increase in DBP (Figure 7). This unexpected finding suggests that in training programs with low session frequency, diastolic blood pressure increased rather than decreased. In the >2 sessions per week subgroup (20 studies), the SMD was -0.064, with a 95% confidence interval of -0.264 to 0.137 ($p = 0.534$), indicating no significant effect on DBP. Figure 7 presents the results of the subgroup analysis for DBP based on session frequency per week. The clear difference between the two subgroups and the opposite direction of effect (increase in the ≤2 sessions subgroup versus no change in the >2 sessions subgroup) are evident.

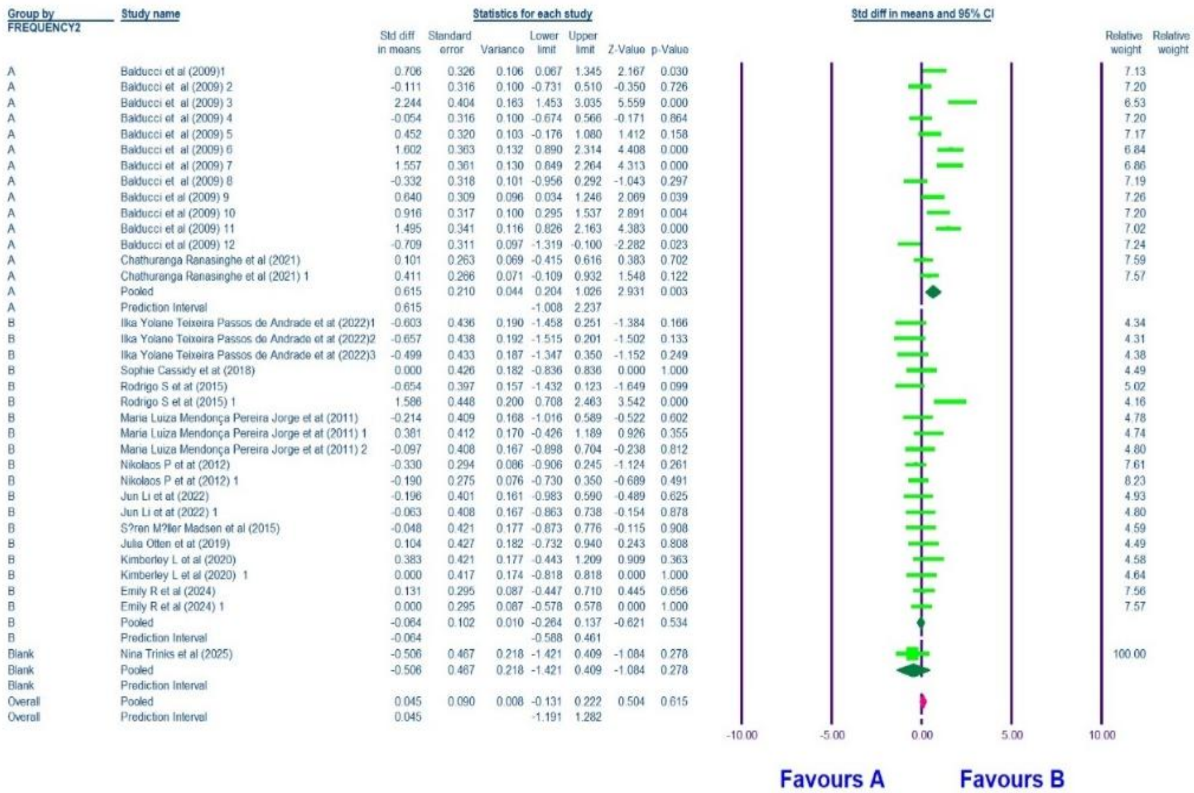

Figure 7. Forest Plot of Standardized Mean Differences for Diastolic Blood Pressure Stratified by Intervention Session Frequency (per Week). This plot displays the estimates for each study, the pooled effects within subgroups, and the overall effect, along with the 95% confidence interval.

Moderating Role of Session Duration on SBP

To investigate the effect of session duration on SBP response, studies were divided into two subgroups: "≤50 minutes per session" (23 studies) and ">50 minutes per session" (10 studies). The results demonstrated that in both subgroups, exercise training had no significant effect on SBP. In the ≤50 minutes subgroup, the SMD was -0.094, with a 95% confidence interval of -0.468 to 0.280 (p =

0.622); and in the >50 minutes subgroup, the SMD was -0.206, with a 95% confidence interval of -0.454 to 0.043 (p = 0.105) (Figure 8). The test for interaction between the two subgroups was not significant (p = 0.425), indicating that session duration is not a significant moderating factor for the SBP response to training. Figure 8 presents the results of the subgroup analysis for SBP based on session duration.

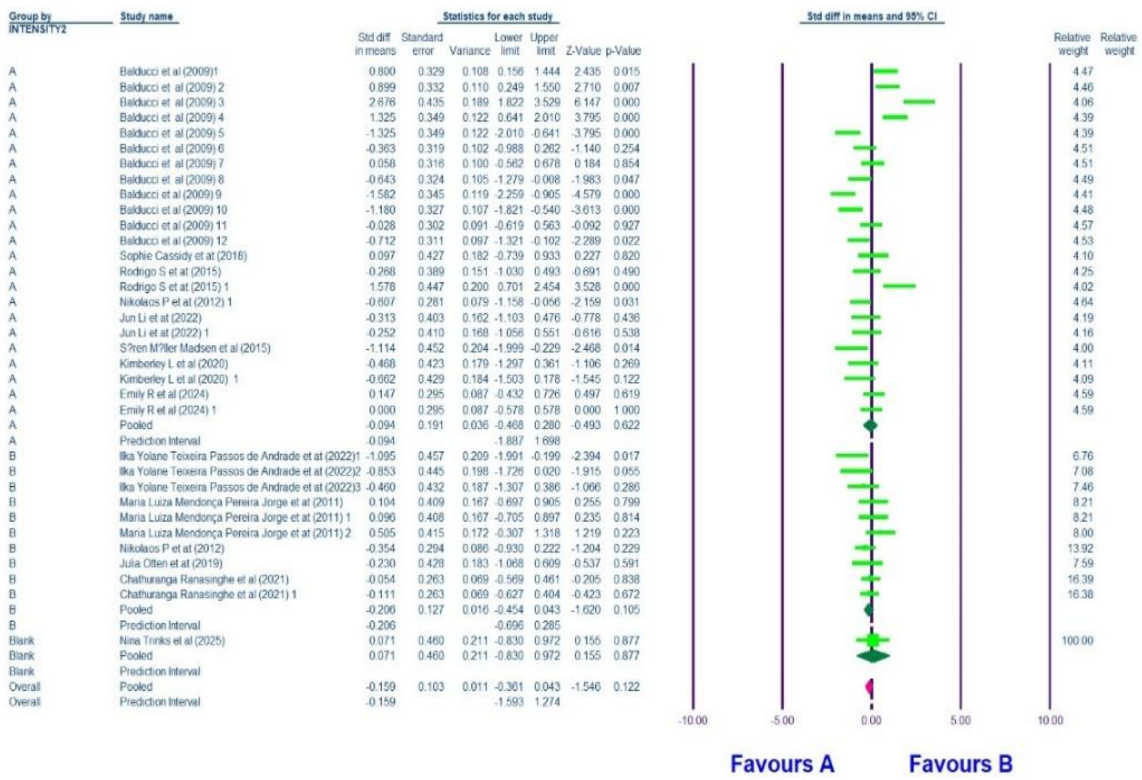

Figure 8. Forest Plot of the Meta-Analysis of the Effect of Exercise Intensity on Systolic Blood Pressure. Effect sizes are presented as standardized mean differences (SMD) with 95% confidence intervals (CI). Results of individual studies are displayed with squares, and pooled estimates for subgroups and the overall analysis are shown with diamonds.

Moderating Role of Session Duration on DBP

The results of the subgroup analysis for DBP based on session duration demonstrated that this factor is a significant moderator of the DBP response to training (p = 0.029 for interaction) (Figure 9). In the ≤50 minutes subgroup (23 studies), the SMD was 0.397, with a 95% confidence interval of 0.083 to 0.711 (p = 0.01), indicating a significant increase in DBP. In the >50 minutes subgroup (11 studies), the SMD was -0.073, with a 95% confidence interval of -0.311 to 0.165 (p = 0.548), indicating that the pooled effect size was not statistically significant.

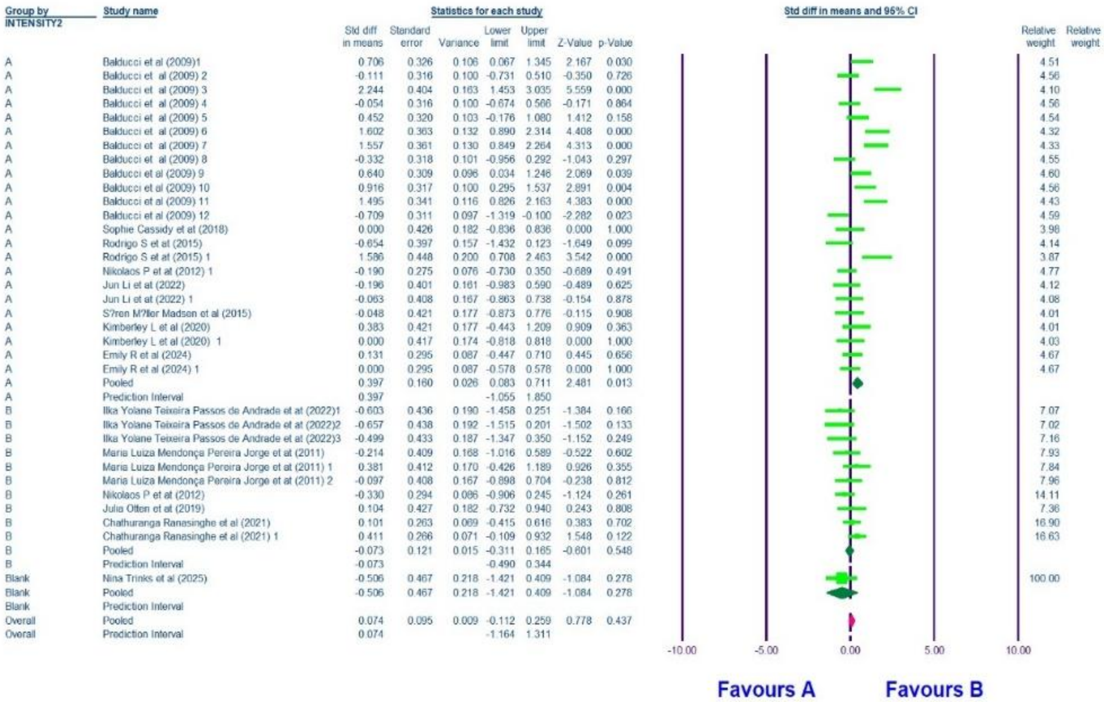

Figure 9. Forest Plot of Standardized Mean Differences for Diastolic Blood Pressure Based on Training Duration, Displaying Individual Study Estimates as well as Pooled Effects for Subgroups and the Overall Effect, along with the 95% Confidence Interval.

Discussion

Summary of Main Findings and General Interpretation

This systematic review and meta-analysis was conducted with the aim of investigating the effect of exercise training on systolic and diastolic blood pressure in older adults with type 2 diabetes mellitus and identifying the moderating role of weekly session frequency and session duration. The main findings of this study demonstrated that exercise training had no significant effect on reducing systolic blood pressure in this population (SMD = -0.132, 95% CI: -0.397 to 0.133, p = 0.328), and the effect on diastolic blood pressure was borderline and non-significant (SMD = 0.223, 95% CI: -0.013 to 0.460, p = 0.064), with the difference that the direction of effect was an increase rather than a decrease. Subgroup analysis revealed that weekly session frequency and session duration were significant moderating factors for the DBP response, such that in the subgroups with ≤2 sessions per week and ≤50 minutes per session, DBP was significantly increased (SMD = 0.615, p = 0.003 and SMD = 0.397, p = 0.013, respectively). In contrast, none of the moderating factors examined had a significant effect on the SBP response. The high statistical heterogeneity across all analyses (I^2 > 74%) indicates considerable diversity in blood pressure responses to training, which may arise from differences in exercise intensity, exercise type, patients' medication status, and other factors. These findings suggest that in diabetic older adults, the effects of training on blood pressure are far less pronounced than in the general population and may even be detrimental under certain circumstances; therefore, exercise prescription in this population should be conducted with greater precision and should focus on other goals such as glycemic control and improvement of lipid profile(Ruffino et al., 2017; Wennehorst et al., 2016).

Comparison with Previous Studies and Physiological Interpretation

The findings of this study regarding the lack of significant effect of exercise on SBP are consistent with some previous studies and in contradiction with others. The well-known meta-analysis by Cornelissen and Smart (2013) demonstrated that aerobic training significantly reduces SBP by 3.84 mmHg and DBP by 2.58 mmHg in the general population with hypertension; however, our study showed that these effects are not significantly observed in diabetic older adults(Cornelissen & Smart, 2013). This discrepancy can be attributed to several factors: First, the target population in our study (diabetic older adults) differs fundamentally from the general population, as aging is associated with structural and functional alterations in the cardiovascular system such as decreased vascular compliance, increased arterial stiffness, reduced beta-adrenergic responsiveness, and impaired endothelial function that attenuate the responsiveness to training. Second, the presence of type 2 diabetes itself is an independent factor in reducing vascular responsiveness to training, as diabetes is accompanied by increased oxidative stress, reduced nitric oxide production, increased chronic inflammation, and progression of atherosclerosis, all of which can attenuate the effects of exercise on blood pressure(Madsen et al., 2015); in other words, the "disease burden" in diabetic older adults is so substantial that the effects of exercise may be insufficient to overcome it(Cassidy et al., 2019). Third, many of the included studies involved patients who were concurrently using antihypertensive medications, which can influence training-induced blood pressure changes and complicate the isolation of the independent effect of exercise. Fourth, regarding DBP, our findings are consistent with some studies that have shown exercise exerts a greater effect on SBP than on DBP; however, our study demonstrated that even a moderate reduction in DBP is not observed in diabetic older adults, and in some subgroups, an increase in DBP is even seen, which may be attributable to reduced aortic and large-artery compliance in older adults, causing diastolic blood pressure to increase rather than decrease(Shoja Anzabi et al., 2026).

Interpretation of Unexpected Findings Regarding DBP

One of the intriguing yet concerning findings of this study was the significant increase in DBP in the subgroups with ≤2 sessions per week and ≤50 minutes per session, which can be interpreted in several ways. First, in older adults, the blood pressure response to exercise may differ from that in younger populations, as advancing age is associated with increased arterial stiffness and reduced baroreflex function, which can lead to abnormal blood pressure responses during and after exercise; in particular, reduced aortic and large-artery compliance may cause diastolic blood pressure to increase rather than decrease. Second, exercise training typically reduces peripheral vascular resistance and consequently lowers DBP; however, under certain conditions, especially in older adults with endothelial dysfunction, the vasodilatory response may be replaced by a vasoconstrictive response (the phenomenon of "exercise-induced vasoconstriction"), which could explain the increase in DBP in specific subgroups; in other words, in some individuals, exercise may induce vasoconstriction rather than vasodilation, leading to an increase in diastolic blood pressure. Third, in older adults with diabetes, baseline sympathetic nervous system activity is usually elevated, and moderate-to-high intensity exercise training can transiently further increase sympathetic activity, resulting in increased peripheral vascular resistance and consequently increased DBP; this transient increase may be more pronounced in studies with low session frequency and short session duration, which do not provide sufficient opportunity for long-term adaptations. Fourth, many diabetic older adults use beta-blockers or other antihypertensive medications that can influence the blood pressure response to training; for example, beta-blockers can reduce the heart rate response to exercise and cause patients to exert greater cardiovascular effort to achieve the desired exercise intensity, which may lead to increased DBP. Fifth, differences in blood pressure measurement methods (manual vs. automated, clinic-based vs. home measurement or ambulatory blood pressure monitoring) may also affect the results, and clinic measurements are generally higher than home or ambulatory measurements, with the "white-coat effect" potentially being more pronounced in older adults(Bouchi et al., 2024).

Did Low Session Frequency and Short Session Duration Produce Reverse Effects?

An important question raised by this study is why training programs with low session frequency (≤2 sessions per week) and short session duration (≤50 minutes) resulted in increased DBP. The answer can be sought in several physiological mechanisms. First, to induce cardiovascular adaptations, including blood pressure reduction, the body requires consistency and repetition of the training stimulus; training programs with only 2 sessions per week and short sessions may not provide sufficient stimulus to induce long-term adaptations such as reduced peripheral vascular resistance, improved endothelial function, and reduced sympathetic activity(Piri et al., 2022); in other words, these training programs may not lie within the "effective stimulus zone," and low-frequency, short-duration sessions may elicit only an acute (and sometimes unfavorable) response that, without adequate repetition, does not translate into long-term adaptation(Gan et al., 2025). Second, exercise training induces a transient increase in sympathetic nervous system activity and catecholamine release, leading to increased heart rate and vasoconstriction; in training programs with low session frequency and short session duration, acute sympathetic responses to exercise may not translate into long-term parasympathetic adaptations, and consequently, the net effect may be an increase in DBP, a finding consistent with the study by Fisher et al. (2015), which demonstrated that low-volume exercise training has no significant effect on blood pressure reduction and may even increase diastolic blood pressure in some cases(Fisher et al., 2015). Third, exercise training with sufficient volume can reduce arterial stiffness, which is one of the primary mechanisms of diastolic blood pressure reduction; however, low-frequency and short-duration sessions may be insufficient to induce these structural changes in the vascular wall, and conversely, irregular, low-volume physical activity may even exacerbate arterial stiffness due to mild increases in inflammation and oxidative stress(Shoja Anzabi et al., 2025). Fourth, in training programs with low frequency and short duration, patients may forget to take their antihypertensive medications before exercise, or medication adjustments may not be coordinated with the exercise program, which can lead to blood pressure fluctuations and increased DBP(Arhab et al., 2023).

Physiological Mechanisms and the Influence of Various Factors

To better understand the findings of this study, it is necessary to review the physiological mechanisms of the effect of exercise on blood pressure in diabetic older adults and the factors influencing them. Exercise training increases the number and diameter of capillaries in skeletal muscle (angiogenesis), leading to reduced peripheral vascular resistance and reduced DBP; however, in diabetic older adults, due to the presence of atherosclerosis and reduced vascular compliance, this angiogenic response may be limited. Furthermore, exercise increases nitric oxide (NO) production by endothelial cells, which is a potent vasodilator; however, in diabetic older adults, NO production is reduced due to increased oxidative stress and decreased eNOS enzyme activity; therefore, the effects of training on improving endothelial function may be limited in this population. Regular exercise training reduces resting sympathetic nervous system activity and increases parasympathetic activity, leading to reduced heart rate and reduced peripheral vascular resistance; however, in diabetic older adults, due to the presence of autonomic neuropathy, the sympathetic response to training may be abnormal and may increase rather than decrease, which could be one of the reasons for the increased DBP in the specific subgroups of our study(Neiberg et al., 2012). Exercise training reduces aortic and large-artery stiffness, which is particularly important for reducing systolic blood pressure; however, in diabetic older adults, arterial stiffness is markedly elevated due to glycation of extracellular matrix proteins (AGEs phenomenon), and its reduction requires high training volume and intensity, which may explain why the reduction in SBP was not significant in our study. Exercise intensity also plays an important role in the blood pressure response, and some studies have demonstrated that high-intensity training may have greater effects on blood pressure reduction than moderate-intensity training, although in older adults with risk of cardiovascular complications, it should be prescribed with caution. The type of training (aerobic, resistance, combined) can also influence the blood pressure response, and previous studies have shown that aerobic and combined training are more effective than resistance training alone in reducing blood pressure. Patients' medication status is also an important factor, as the effects of training on blood pressure are less pronounced in patients using antihypertensive medications compared to those not using them(Francois et al., 2016; Gainey et al., 2016). The duration of diabetes also influences the blood pressure response to training, such that patients with a longer duration of diabetes generally have more vascular complications and exhibit a diminished response to training. Baseline physical activity level of patients prior to the intervention can also influence the blood pressure response to training, as patients who were already active may show a smaller response to a new training program (ceiling effect), whereas inactive patients may show a greater response(Hanick et al., 2025).

Clinical Implications and Practical Recommendations

The findings of this study have important implications for physicians, exercise specialists, and diabetic older adult patients. First, exercise training as a general recommendation for blood pressure control in diabetic older adults is insufficient, and unlike in the general population where training is recognized as an effective strategy for blood pressure reduction, in diabetic older adults, the effects of training on blood pressure are far less pronounced and in some cases even reversed. However, this does not mean that training is not beneficial for these patients; rather, it means that the benefits of training in this population should be sought in other goals such as glycemic control, improvement of lipid profile, and reduction of inflammation, as the study demonstrated that exercise training had significant effects on reducing HbA1c, reducing LDL, increasing HDL, and reducing TNF-α in this population—all of which are important therapeutic targets in diabetes. Second, exercise dose (session frequency and session duration) is of critical importance, and training programs with low session frequency (≤2 sessions per week) and short session duration (≤50 minutes) were not only ineffective but were even detrimental in the case of DBP; therefore, to achieve beneficial effects on blood pressure, training volume must reach a certain threshold, which in this population is likely >2 sessions per week and >50 minutes per session. However, since subgroup analysis for SBP demonstrated that even the subgroup with >2 sessions per week had a non-significant SMD (-0.098), it appears that other factors such as exercise intensity and exercise type also play a role in this response(Ruffino et al., 2017). Third, for blood pressure control in diabetic older adults, combining exercise training with other interventions appears essential, including pharmacological therapy with antihypertensive medications under medical supervision, dietary management with reduced sodium intake, increased fruit and vegetable consumption, and adherence to the DASH diet, weight loss in cases of overweight or obesity, and stress management through stress reduction techniques such as meditation and yoga. Fourth, given the unexpected findings regarding increased DBP in specific subgroups, careful blood pressure monitoring in diabetic older adults initiating an exercise program is essential(Wennehorst et al., 2016); diastolic blood pressure should be closely monitored, and in the event of an unexplained increase, the exercise program should be modified; the use of 24-hour ambulatory blood pressure monitoring or home blood pressure measurement can provide more accurate information on the blood pressure response to training. Fifth, given that diabetic older adults typically have a fragile cardiovascular system, a gradual initiation of the exercise program and a slow progression of training volume and intensity are recommended to allow the body to gradually adapt to the training stimulus and to prevent adverse blood pressure responses.

Conclusion

This systematic review and meta-analysis demonstrated that exercise training has no significant effect on reducing systolic blood pressure in older adults with type 2 diabetes mellitus, and the effect on diastolic blood pressure is borderline and non-significant. The unexpected findings of increased DBP in subgroups with low session frequency (≤2 sessions per week) and short session duration (≤50 minutes) warrant special attention and indicate that in diabetic older adults, the effects of training on blood pressure are far less pronounced than in the general population and may even be detrimental under certain circumstances. These findings underscore the importance of targeted and precise exercise prescription based on specific therapeutic goals, careful blood pressure monitoring during the exercise program, and the combination of training with other interventions such as pharmacological therapy, dietary management, and weight loss. Despite limitations such as high heterogeneity and incomplete control of confounding factors, this study, with its large sample size and comprehensive subgroup analysis, provides valuable evidence for physicians, exercise specialists, and diabetic older adult patients. Finally, it is recommended that future research focus on exercise intensity, exercise type, interaction with medications, and duration of diabetes to achieve a better understanding of the factors influencing the blood pressure response to training in this specific population, and to enable the design of safer and more effective exercise programs for diabetic older adults.

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