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Effect of different types of exercise interventions on cardiometabolic risk factors: An umbrella review of systematic reviews and meta-analyses

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ABSTRACT

Purpose: Physical activity (PA) is important for the prevention and management of cardiovascular (CV) disease (CVD). We aim to investigate the effect of different types of exercise on cardiometabolic risk factors in these subjects with CV risk factors but no history of CVD is lacking.

Methods: PubMed and Scopus databases were searched up to November 2025 for systematic reviews and meta-analyses of randomized controlled trials (RCTs). The population studied referred to adults with at least one CV risk factor.

Results: 16 meta-analysis publications were included. Strong evidence for a benefit was found for i) aerobic exercise and waist circumference (WC) reduction compared to control group in males and females with metabolic syndrome [Mean Difference (MD) −3.44 (95% CI −4.81, −2.07) cm, ii) Tai Chi and SBP reduction after ≥6 months [MD −8.80 (95% CI −11.28, −6.32) mmHg], DBP reduction after 3 months [MD −7.58 (95% CI −8.56, −6.60) mmHg] and after ≥6 months of Tai Chi training [MD −4.62 (95% CI −6.09, −3.16) mmHg], and total cholesterol reduction following Tai Chi training in adult males and females with essential hypertension [MD −8.46 (−11.7, −5.4) mg/dL] compared to control group. HIIT, resistance, Yoga and Qigong training did not show any convincing evidence for a benefit in cardiometabolic parameters.

Conclusion: The most convincing evidence relates to a benefit from Aerobic or Tai Chi training mainly in SBP and DBP reduction and secondarily to WC and total cholesterol reduction. The role of HIIT, Resistance, Yoga and Qigong training in cardiometabolic health is uncertain.

1. Introduction

Atherosclerotic related cardiovascular (CV) disease (ASCVD) is ranking first across the conditions listed in the global burden of diseases.[1] Approximately 17 million deaths occur annually because of ASCVD.[2] Major CV risk factors include smoking, obesity, high blood pressure (BP), dyslipidemia, hyperglycemia, unhealthy diet, inadequate physical activity (PA) with sedentary lifestyle, and family history of ASCVD.[2,3] Hypertension seems to be responsible for 9.4 million deaths especially in low- or middle-income countries, where the number of undiagnosed, uncontrolled and untreated patients is much higher.[4] It is responsible for 45% of deaths from coronary heart disease (CHD) and 51% of deaths from stroke.[4] Metabolic syndrome (MetS) [a combination of at least 3 from the following: increased fasting blood glucose, low high-density lipoprotein cholesterol (HDL-c), high triglycerides (TG), high systolic (SBP)/diastolic (DBP) blood pressure and increased waist circumference (WC)] affects 35% of US adults [including people with type 2 diabetes (T2D)].[5–8]

PA is important for the prevention and management of a variety of chronic diseases including ASCVD.[5–9] PA is considered beneficial for obesity, hypertension, CHD, stroke, T2D and helps to maintain a normal body weight (BW).[10–12] More than 150 min of moderate [40–60% of maximal oxygen consumption (VO2max)] or 75 min of vigorous (60–85% VO2max) intensity exercise per week is recommended by the World Health Organization (WHO), the American College of Sports Medicine (ACSM) and the European Society of Cardiology (ESC) for healthy adults.[10] Common barriers to PA engagement such as the lack of time, low motivation and low adherence result in decreased

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achievement rates of these recommendations.[10]

PA seems to be a cornerstone for primary CV prevention in the lower CV risk population and has an important role in combination with pharmacotherapy in the higher CV risk groups.[13] Although there are several systematic reviews and meta-analyses.[14,15] which examine how PA influences specific CV risk factors, heterogeneity prevails as they assess mixed populations and diverse outcomes. What is currently lacking is a comprehensive overview which assesses the overall effect of different types of PA (aerobic exercise, resistance training, or high-intensity interval training) on people who already have at least one cardiometabolic risk factor, such as hypertension, obesity, dyslipidemia, or insulin resistance. With this umbrella review we aim to investigate the effect of different types of exercise on cardiometabolic risk factors in subjects with CV risk factors but no history of established ASCVD.

2. Methods

This umbrella review is registered in Open Science Framework (OSF) (Registration DOI: https://doi.org/10.17605/OSF.IO/D9J8C, October 25, 2023) and follows the Preferred Reporting Items for Overviews of Reviews (PRIOR) statement (Supplementary Table 3).[16] No amendments have been made to the protocol since its publication.

2.1. Literature search and screening

PubMed and Scopus databases have been systematically assessed until November 2025 for systematic reviews and meta-analyses of randomized controlled trials (RCTs) referring to cardiometabolic risk factors and types of exercise interventions. Two authors (CC and AB) independently searched the electronic databases, screening firstly the titles and abstracts, secondly the full texts and identified the meta-analyses that met the inclusion criteria (Fig. 1, Supplementary Table 1). Any discrepancy was resolved by a third author (GM).

2.2. Inclusion/exclusion criteria

Eligible articles were i) meta-analyses of RCTs, ii) written in English, iii) assessing a specific type of exercise intervention (such as aerobic, resistance, yoga, etc.), iv) including male or female adults (>18 years old) with one or more CV risk factors (such as dyslipidemia, obesity, hypertension, MetS, T2D). Exclusion criteria were i) non-systematic reviews, systematic reviews without meta-analysis and systematic reviews with meta-analyses but without the individual study data ii) publications assessing PA combined with medications, iii) publications including participants with alcohol abuse, iv) studies including participants with established ASCVD, v) studies including participants with any other chronic disease such as liver failure, chronic kidney disease, human immunodeficiency virus, cancer, or organ transplant.

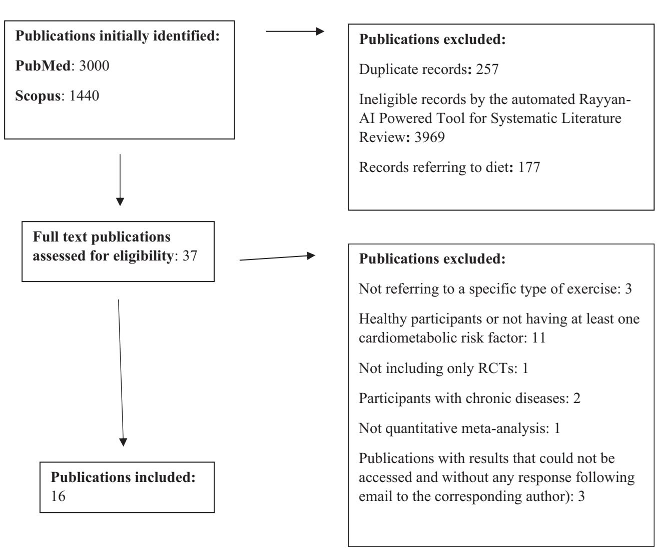

Fig. 1. Flowchart of the umbrella review.

2.3. Data extraction

We extracted the following information from each publication: i) at the meta-analysis level, data such as PMID or article number, first author's name, year of publication, type of PA (e.g. aerobic, resistance, yoga), population age, other distinctive population characteristics, outcome (cardiometabolic risk factors), meta-analysis metric [risk ratio (RR), odds ratio (OR), or hazard ratio (HR) for dichotomous, mean difference (MD) or standardized mean difference (SMD) for continuous outcomes], and number of primary studies in the meta-analysis, ii) at the primary study level, data such as first author's name, year of publication, association estimate and its measure of variation [such as standard error (SE), confidence interval (CI), *p*-value] and study sample size including control group and intervention group.

2.4. Quality assessment

The Assessment of Multiple Systematic Reviews 2 (AMSTAR 2) checklist was used to assess methodological quality and assign an overall rating to the included reviews. The AMSTAR 2 checklist is used as a practical critical appraisal tool by health professionals to help them rapidly assess the quality of systematic reviews of RCTs.[17]

2.5. Statistical analysis

This study followed an umbrella review methodology to evaluate associations between PA and cardiometabolic risk factors. For each meta-analysis included a summary effect estimate and corresponding 95% CI were calculated using an inverse variance weighted random-effects model, accounting for anticipated clinical and methodological differences among primary studies. Heterogeneity across studies was assessed using the I^2 statistic, while 95% prediction intervals (PI) were calculated to estimate the range of effects expected in future studies. Indication of small-study effects bias was examined using Egger's regression asymmetry test (significance threshold of 0.10), along with a comparison between the overall effect size and that of the most precise individual study. Additionally, an excess significance test was conducted to determine if the number of observed significant results exceeded what would be expected based on the statistical power of each study. This test was not applied if data were missing for more than 20% of the included studies. Nominally significant associations ($P < 0.05$) were categorized into four levels of evidence—strong, highly suggestive, suggestive, and weak—following criteria adapted from previous literature. Strong evidence required more than 500 cases, a highly significant P value ($\leq 10^{-6}$), low heterogeneity ($I^2 < 50\%$), PI excluding the null, and no signs of small-study effects or excess significance bias. Highly suggestive evidence was considered when sample size >500, $p < 10^{-6}$, largest study with a statistically significant effect and class I criteria not met. Suggestive evidence included analyses with over 500 cases and a P value $\leq 10^{-3}$. Associations not meeting these thresholds but still nominally significant were labeled weak (Supplementary Table 2).[18–20] Although the original standard required at least 1000 cases, this study used a lower threshold of 500 cases due to the limited number of relevant studies, with 500- and 1000-case thresholds tested in sensitivity analyses. Statistical analysis was performed in Stata version 16.

3. Results

3.1. Included studies

A total of 4440 records were identified (Fig. 1). Sixteen meta-analyses were included: 5 compared aerobic exercise vs. no exercise or any other lifestyle interventions,[21–25] 2 compared resistance training vs. no exercise intervention,[26,27] 2 compared Qigong vs. no Qigong exercise or no exercise at all,[3,6] 3 compared Tai Chi vs. no Tai Chi exercise or lifestyle intervention,[2,18,28] 2 compared Yoga vs. conventional care or no exercise,[7,8] 1 compared high intensity interval training (HIIT) vs. moderate intensity internal training (MIIT)[29] and 1 compared aerobic, resistance and combined training vs. no exercise intervention.[5]

Articles examined 115 associations with 15 different outcomes; among them the most common were SBP - DBP (13 articles), HDL-C (8 articles) and TG (7 articles). Study characteristics are shown in Table 1. Results (Table 2, Supplementary Table 4) were categorized based on the type of exercise (Aerobic Training, Resistance Training, Yoga, Tai Chi and Qigong Training) and presented according to the strength of the evidence.

Subgroup analysis was performed in only one meta-analysis referring to Tai Chi exercise.[28] These specific associations are included in our statistical analysis and are distinguished by two asterisks next to each one in the result tables.

Five records were rated as "Low", whereas the remaining 11 as "Critically Low" by using the AMSTAR-2 tool (Supplementary Table 5). As a sensitivity analysis we excluded 2 of the criteria in AMSTAR-2 tool, which were considered of lower priority for the purpose of this review. Specifically, following the exclusion of question 2 (*Did the report of the review contain an explicit statement that the review methods were established prior to the conduct of the review and did the report justify any significant deviations from the protocol?*) and question 7 (*Did the review authors provide a list of excluded studies and justify the exclusions?*) 2 records were rated as "High", 2 as "Moderate", 9 as "Low"and 3 as "Critically Low".

3.2. Aerobic training/high intensity interval training (HIIT)

There were 21 associations referring to Aerobic exercise, of which 1 was strong, 3 highly suggestive, 5 suggestive, 11 weak, and 8 not significant. In total, 1 association referring to WC compared to control group in males and females with METs but no T2D [MD: −3.44 (95% CI −4.81, −2.07) cm, 12 studies, I^2: 0%] was claimed to be strong. Three associations referring to SBP [MD: −4.75 (95% CI −6.53, −2.97) mmHg, 31 studies, I^2: 61%], DBP [MD: −3.17 (95% CI −4.42, −1.91) mmHg, 31 studies, I^2: 57%] showed difference from baseline between the intervention and control group in East Asian males & females with dyslipidemia, T2D, hypertension, obesity or METs, and WC [MD: −2.12 (95% CI −2.81, −1.44) cm, 2 studies, I^2: 1%] compared to control group in overweight adult males & females were claimed as highly suggestive. Five associations referring to reduction in SBP during daytime [MD: −3.17 (95% CI −5.03, −1.32) mmHg, 17 studies, I^2: 52%] and DBP during daytime [MD: −2,7 (95% CI −3.89, −1.51) mmHg, 17 studies, I^2: 34] in mixed population of adult males and females with normo/pre/hyper-tension [MD: −2.70 (95% CI −3.89, −1.51) mmHg, 17 studies, I^2: 34%], triglyceride reduction compared to baseline in East Asians males & females with dyslipidemia, T2D, hypertension, obesity or METs [MD: −13.72 (95% CI −20.02, −7.42) mg/dL, 26 studies, I^2: 0%], HbA1c reduction [MD: −0.51 (−0.73, −0.28) %, 16 studies, I^2: 54%] and CRP reduction [MD: −0.09 (−0.14, −0.04) mg/dL, 17 studies, I^2: 98%] compared to control group in adult males and females with T2D were claimed as suggestive.

The 2 associations referring to HIIT were claimed as not significant.

3.3. Resistance training

There were 12 associations referring to Resistance Training, of which none was claimed strong, highly suggestive or suggestive, 4 were claimed weak and 8 not significant.

3.4. Tai Chi

There were 49 associations referring to Tai Chi, of which 4 were claimed strong, 2 highly suggestive, none as suggestive, 22 weak and 25 not significant. In total, 4 associations referring to reductions in DBP following 3 months of Tai Chi intervention [MD: −7.58 (95% CI −8.56, −6.60) mmHg, 6 studies, I^2: 0%] and ≥6 months [MD: −4.62 (95% CI −6.09, −3.16) mmHg, 6 studies, I^2: 0%], SBP following ≥6 months of Tai Chi intervention [MD: −8.80 (95% CI −11.28, −6.32) mmHg, 6 studies, I^2: 36%] and total cholesterol following Tai Chi intervention in adult males and females with essential hypertension compared to control group [MD: −8.46 (−11.7, −5.4) mg/dL, 5 studies, I^2: 50%] were claimed as strong, whereas 1 association referring to SBP reduction following 3 months of Tai Chi intervention [MD: −15.39 (95% CI −19.76, −11.01) mmHg, 6 studies, I^2: 93%] in adult males and females with essential hypertension and 1 association referring to HbA1c reduction following Tai Chi intervention in adult males and females with type 2 diabetes mellitus compared to control group [SMD: −0.73 (95% CI −0.98, −0.49), 10 studies, I^2: 70%] was claimed as highly suggestive.

3.5. Qigong training

There were 6 associations referring to Qigong Training, of which none was claimed strong, highly suggestive or suggestive, 1 was claimed weak and 5 not significant.

3.6. Yoga

There were 25 associations referring to Yoga, of which none was claimed strong, highly suggestive or suggestive, 9 were claimed weak and 16 not significant.

4. Discussion

We found that Aerobic or Tai Chi training may exert certain advantages in metabolic parameters with the most convincing evidence related to a benefit from SBP and DBP reduction and secondarily on cholesterol levels, WC and HbA1c in individuals with at least one CV risk factor.

Aerobic exercise is defined by the ACSM as a PA which can be maintained continuously in a rhythmic way and where large muscle groups are activated using energy extracted by aerobic metabolism. Cycling, dancing, hiking, jogging/long distance running, swimming and walking typically (but not exclusively) use aerobic metabolism.[30] HIIT was first applied to cardiac rehabilitation patients in 1972 and involves recovery period of light exercise among short periods of high intensity exercise.[9,10] Yoga is a combination of training, controlled breathing and relaxation. It is often combined with specific diet and lifestyle.[7] Tai Chi, originally born in China, is a mind and body exercise combining dance-like movements with musculoskeletal, breathing and meditation training. It adopts the ancient Chinese philosophy of wellness and works on a holistic level to improve physical flexibility and whole-body coordination.[2,18,31] Qigong, also coming from China, resembles Tai Chi's principles with the difference that Qigong has a more simplistic and repetitive choreographed movement.[31] Resistance training involves concentric, isometric, and eccentric muscle contractions providing higher resistive forces or loads of a lengthening muscle–tendon unit, thus increasing the range of motion. It can be based on aerobic, but most times uses a combination of aerobic and anaerobic metabolism.[32] Current ESC/ACC/AHA/WHO guidelines recommend 150–300 min/week of moderate-intensity aerobic activity divided in ≧3 days/week with <2 consecutive days without exercise, or vigorous training >75–150 min/week. In addition, they recommend resistance training 2–3 times/week, breaking up the extended amounts of time (>30 min) spent sitting, whereas for older adults flexibility - balance training is recommended for 2–3 times/week. Sedentary time should be reduced across all age

Table 1
Characteristics of included meta-analyses.

Author, year	Country/region	Number of included studies	Intervention	Comparison	Frequency (times per week)	Duration (minutes per time)	Intervention duration/ intervention follow-up	Intensity	Variables examined	Population	Total sample/ (male/ female)	Age (years)	Quality Assessment by modified AMSTAR 2 (excluding Q2 & Q7)
Sun et al. (2025)[28]	NR	14	Tai Chi	Conventional treatments (e.g., pharmacotherapy, basic health education) or alternative physical exercises	2–7	30–80	15 weeks/NR	NR	FBG, HbA1c, TC, TG, HDL-c, LDL-c, SBP, DBP, CRP	Male & female adults with T2DM	1311	46–65 (mean)	High
Papagianni et al. (2023)[24]	Saudi Arabia, Italy, Spain, France, Korea, Iran, USA, Brazil, Greece, UK, China, Pakistan, Germany	26	Aerobic Training	No exercise	3–5	30–90	12 weeks/54 weeks	Moderate to High	CRP, FBG, HbA1c, BW, BMI, Fat Mass, W/H	Adult Males & Females with T2D	1239/ NR	20–66 (mean)	Critically Low
Tao & Li (2023)[3]	China, Thailand	7	Qigong	No qigong or no exercise at all	4–7	30–60	12 weeks/24 weeks	NR	FBG, SBP, DBP, WC, BMI	Adult males & females with METs	486/NR	42–70 (mean)	Low
Luxuan et al. (2022)[2]	NR	7	Tai Chi	No intervention or conventional care or walking	3–5	45–60	NR	NR	SBP, DBP, TC, HDL-c, LDL-c, TG	Adult males & females hypertensive	693/NR	41–68 (mean)	Low
Liang et al. (2020)[18]	China	15	Tai Chi	No Tai Chi	1–8	30–120	NR	NR	FPG, SBP, DBP, TC, HDL-c, LDL-c, TG	Adult males & females with essential hypertension	1543 (827/ 716)	38–70 (mean)	High
Zou et al. (2019)[6]	China	9	Qigong	Exercise or no exercise	3–7	30–60	8 weeks/48 weeks	NR	SBP, DBP, TC, HDL-c, LDL-c, TG	Adult males & females with at least one CV risk factor	628/NR	35–75 (range), 53–62 (mean)	Low
Igarashi et al. (2019)[21]	Japan, Korea, China, Taiwan	25	Aerobic Training	No exercise, no other intervention	3–5	15–60	4 weeks/24 weeks	Moderate	TC, HDL-c, LDL-c, TG	East Asians males & females with dyslipidemia, T2D, hypertension, obesity or METs	994 (280/ 714)	54 ± 7 (mean)	Critically Low
Igarashi et al. (2018)[22]	Japan, South Korea, China, Taiwan	26	Aerobic Training	No exercise, no other intervention	2–6	30–60	10 weeks–48 weeks	Light	SBP, DBP	Adult males & females East Asian with dyslipidemia, T2D, hypertension, obesity, METs but no CVD	943 (368/ 575)	41–79 (range), 60 (mean)	Low
Costa et al. (2018)[29]	NR	9	HIIT	MIIT	3–4	15–40	4 weeks/16 weeks	High (vs. moderate)	SBP, DBP	Adult males & females with pre- or established hypertension	245 (159/ 86)	36–72 (mean)	Moderate
Wewege et al. (2018)[5]	NR	11	Aerobic, Resistance, Combined Training	No exercise	3–5	20–60	Aerobic, 12 weeks/52 weeks Resistance, 8	Aerobic, Moderate Resistance, Vigorous	FPG, HDL-c, TG, SBP, DBP, WC	Adult males & females with METs but no T2D	588/NR	38–60 (range), 51 (mean)	Moderate

(*continued on next page*)

Table 1 (*continued*)

Author, year	Country/region	Number of included studies	Intervention	Comparison	Frequency (times per week)	Duration (minutes per time)	Intervention duration/ intervention follow-up	Intensity	Variables examined	Population	Total sample/ (male/ female)	Age (years)	Quality Assessment by modified AMSTAR 2 (excluding Q2 & Q7)
							weeks/33 weeks						
Sousa et al. (2017)[27]	NR	5	Resistance Training	No exercise	3	NR	8–16 weeks	NR	SBP, DBP	Adult males and females pre- or hypertensive	229/NR	18–67,5 (mean)	Critically Low
Cramer et al. (2016)[7]	India, South Korea, China, USA	12	Yoga	Usual care	1–14 times	60–90	NR	NR	FPG, SBP, DBP, TG, HDL-c, WC	Adult males & females with METs	794/NR	48–62 (mean)	Low
Lemes et al. (2016)[26]	NR	7	Resistance Training	No exercise	3	45–150	12 weeks-9 months	Vigorous	SBP, DBP, WC, FPG, HDL-c, TG	Adult males & females with METs	519 (341/ 178)	43–67 (mean)	Low
Chu et al. (2016)[8]	NR	32	Yoga	Exercise or no exercise	1–7 times	15–90	NR	NR	SBP, DBP, HDL-c, LDL-c, BW, BMI, HR	Adult males & females with at least one cardiometabolic risk factor	2768/ NR	50 (mean)	Low
Cornelissen et al. (2013)[25]	USA, Belgium, Netherlands, Australia, UK, Japan, Germany, Brazil	15	Aerobic Endurance Training	No exercise	3	30–60	6 weeks–52 weeks	Moderate	SBP, DBP	Adult males & females with optimal BP, prehypertension or hypertension and no other concomitant disease	718/NR	22–69 (mean)	Low
Thorogood et al. (2011)[23]	USA, Norway, Japan, Brazil, Sweden, Israel, Netherlands	6	Aerobic Isolated Training	No exercise	NR	40–60	NR	Moderate	BP, BW, WC	Adult males & females overweight	1048 (759/ 299)	19–67 (range)	Low

BMI: Body Mass Index, BP: Blood Pressure, BW: Body Weight, CVD: Cardiovascular Disease, CRP: C-reactive protein, DBP: Diastolic Blood Pressure, FPG: Fasting Plasma Glucose, HbA1c: glycated hemoglobin, HDL-c: High Density Lipoprotein Cholesterol, HIIT: High-intensity interval training, HR: Heart Rate, LDL-c: Low Density Lipoprotein Cholesterol, METs: Metabolic Syndrome, MIIT: Moderate-intensity interval training, NR: not reported, SBP: Systolic Blood Pressure, TC: Total Cholesterol, TG: Triglycerides, T2D: Type 2 Diabetes, UK: United Kingdom, USA: United States of America, WC: Waist Circumference, W/H: Waist-Hip Ratio.

Table 2
Results for strong and highly suggestive evidence according to exercise type.

Author, year	Intervention	Comparison	Population	Outcome	Unit of measurement	Number of studies	Sample size	Meta-analysis metric	Random effect	P-value of random effects	Prediction intervals	Largest study effect	Excess significance bias	P-value for excess significance bias	I^2	Egger's test	Grade 500
Liang et al. 2020[18]	Tai Chi	No Tai Chi	Adult males & females with essential hypertension	DBP (3 months)	mmHg	6	620	MD	−7.58 (−8.56, −6.60)	3.61E−52	−8.96, −6.20	−6.40 (−8.32, −4.48)	6/6.00	1	0	0.505	Strong
Liang et al. 2020[18]	Tai Chi	No Tai Chi	Adult males & females with essential hypertension	SBP (≥6 months)	mmHg	6	729	MD	−8.80 (−11.28, −6.32)	5.76E−10	−14.94, −2.66	−10.86 (−13.93, −7.79)	3/5.99	NP	36	0.259	Strong
Liang et al. 2020[18]	Tai Chi	No Tai Chi	Adult males & females with essential hypertension	DBP (≥6 months)	mmHg	6	729	MD	−4.62 (−6.09, −3.16)	3.55E−12	−6.70, −2.55	−7.06 (−10.03, −4.09)	3/5.98	NP	0	0.997	Strong
Liang et al. 2020[18]	Tai Chi	No Tai Chi	Adult males & females with essential hypertension	TC	mg/dL	5	846	MD	−8.46 (−11.7, −5.4)	1.60E−07	−1.01, 0.06	−0.68 (−0.91, −0.45)	4/5.00	NP	50	0.218	Strong
Wewege et al. 2018[5]	Aerobic Exercise	No exercise	Adult males & females with METs but no T2D	WC	Cm	12	504	MD	−3.44 (−4.81, −2.07)	8.83E−07	−4.99, −1.88	−3.10 (−5.82, −0.38)	3/7.15	NP	0	0.548	Strong
Sun et al. 2025[28]	Tai Chi	Conventional treatments (e.g. basic health education) or alternative physical exercises	Male & female adults with T2D	HbA1c	–	10	942	SMD	−0.73 (−0.98, −0.49)	3,1E−09	−1.43, −0.04	−0.47 (−0.59, −0.35)	7/7.71	NP	70	0.084	Highly Suggestive
Liang et al. 2020[18]	Tai Chi	No Tai Chi	Adult males & females with essential hypertension	SBP (3 months)	mmHg	3	194	MD	−15.39 (−19.76, −11.01)	5.42E−12	−31.12, 0.35	−8.87 (−10.87, −6.87)	6/6.00	1	93	0.439	Highly suggestive
Igarashi et al. 2018[22] [a]	Aerobic Exercise	No exercise, no other intervention (diet or lifestyle change)	Adult males & females East Asian with dyslipidemia, T2D, hypertension, obesity, METs but no CVD	SBP	mmHg	31	1994	MD	−4.75 (−6.53, −2.97)	1.71E−07	−12.01, 2.52	−5.30 (−7.10, −3.50)	NA	NA	61	0.903	Highly suggestive
Igarashi et al. 2018[22a]	Aerobic Exercise	No exercise, no other intervention (diet or lifestyle change)	Adult males & females East Asian with dyslipidemia, T2D, hypertension, obesity, METs but no CVD	DBP	mmHg	31	1994	MD	−3.17 (−4.42, −1.91)	7.89E−07	−8.21, 1.88	−3.80 (−5.60, −2.00)	NA	NA	57	0.709	Highly suggestive
Thorogood et al. 2011[23]	Aerobic Exercise	No exercise	Adult males & females overweight	WC (6 months)	cm	2	717	MD	−2.12 (−2.81, −1.44)	1.19E−09	NA	−1.80 (−1.89, −1.71)	NA	NA	1	NA	Highly suggestive

DBP: Diastolic Blood Pressure, MD: Mean Difference, NA: Not Applicable, NP: Number of Positive Studies, SBP: Systolic Blood Pressure, T2D: Type 2 Diabetes, TC: Total Cholesterol, WC: Waist Circumstance, WMD: Weighted Mean Difference.

[a] Difference from baseline between the intervention and control group.

groups,[33–38] because not only limited PA but also sedentary behavior is associated with increased CV risk in healthy adults.[15]

So far, the evidence for any benefit driven from PA on the CV risk factors is focused particularly on lipids, blood pressure and HbA1c reduction. We found strong evidence for adults undergoing Tai Chi exercise for total cholesterol reduction compared to control group by 8 mg/dL. In contrast, none of the aerobic, HIIT, resistance, Yoga and Qigong training showed convincing (strong or highly suggestive) evidence for a benefit in lipid profile. Our findings differentiate from the latest scientific statement of AHA/ACC which reports a decrease of LDL-C by an average of 3–4 mg/dL following aerobic and 6 mg/dL following resistance PA, an increase in HDL-C by an average of 1–2 mg/dL following aerobic PA, and a decrease in triglycerides by an average of 4–12 mg/dL following aerobic and by 8 mg/dL following resistance PA in low/moderate risk individuals with elevated blood pressure and cholesterol.[13] These recommendations were based on a single meta-analysis assessing RCTs before 2005 for aerobic and before 2008 for resistance training in apparently healthy subjects (although this is not clearly stated in the reports).[39–41]

We found highly suggestive evidence for SBP reductions from aerobic exercise by approximately 5 mmHg and DBP by 3 mmHg from baseline. The same pattern was evident for Tai Chi exercise, where the magnitude of the effect was even greater (SBP: −9 mmHg, DBP: −5 mmHg compared to control group). In contrast, none of the HIIT, resistance training, Yoga and Qigong showed convincing evidence for a benefit in BP reduction. Significant reductions in SBP and DBP are reported in the latest network meta-analysis following isometric exercise training (−8.2/−4.0 mmHg), combined training (−6.0/−2.5 mmHg), dynamic resistance training (−4.6/−3.0 mmHg), aerobic exercise training (−4.5/−2.5 mmHg), and HIIT (−4.1/−2.5 mmHg).[42] An umbrella review showed consistent evidence for a benefit following isometric resistance training on SBP and DBP levels for normotensive as well as for hypertensive individuals.[43] In another umbrella review strong evidence is reported for an inverse dose–response relationship between PA and incident hypertension among adults with normal BP levels, and BP reduction among those with prehypertension or hypertension. The magnitude of BP reduction varied by resting BP, with greater benefits among those with prehypertension compared to normal BP levels.[44] The latest scientific statement of AHA/ACC reports a decrease of SBP and DBP following aerobic, resistance or combined PA by an average of 3 mmHg,[13] whereas the ESC scientific statement reports larger BP reductions in subjects with hypertension (SBP −7.6/DBP −4.7 mmHg) compared to high-normal BP (−1.9/−1.7 mmHg), or normal BP (−2.4/−2.6 mmHg) following aerobic PA. Additionally, the mean BP-lowering effect of resistance PA was −10.0/−5.8 mmHg (independently of the initial BP), which derives from a reduction of −4.3/−5.0 mmHg for subjects with hypertension, and from a reduction of −6.6/−3.0 mmHg for individuals with normal BP.[45] In a recent umbrella review SBP significantly reduced by −0.71 mmHg and DBP by −0.62 mmHg.[46] The benefits from aerobic, resistance and combined training in BP are partly attributed to an improvement in endothelium-dependent vasodilation, although exercise recommendations and prescriptions should be tailored based on the setting of the individuals, with variations depending on primary vs. secondary ASCVD prevention, or the existence of T2D.[47]

We found highly suggestive evidence for an improvement in glycemic control in terms ofHbA1c reduction following Tai Chi exercise. Furthermore, we found a decrease in WC compared to control group (which is usually associated with glycemic status) following aerobic exercise. Previous reports are in accordance to our findings, but the benefit in HbA1c reduction in T2D individuals was mainly attributed to aerobic exercise (−0.73%), resistance training (−0.57%), and their combination (−0.51%).[45] In the HART-D study, HbA1c was reduced by −0.34% following a combination of resistance plus aerobic training.[48] Yoga is equally reported to decrease HbA1c (−0.47% to −0.81%) and fasting blood glucose (−24 mg/dL) in T2D individuals.[45,47] For Tai Chi the reports are sparse, whereas Qigong showed no benefit.[49,50]

Individuals with at least one CV risk factor represent the population group which is more commonly advised by their physicians to adopt regular PA in order to eliminate these harmful CV factors. Our results showed that aerobic and Tai Chi training have a clinically meaningful benefit in SBP/DBP and total cholesterol levels, as well as WC. A reduction of 10 mg/dL in cholesterol levels is translated to 6% reduction in major adverse cardiovascular events, whereas a reduction in SBP/DBP by 10/5 mmHg, respectively, decrease by 25% the risk of major adverse cardiovascular events in primary prevention subjects.[51,52] It should be emphasized that our results, including those that are in accordance with previous publications and guidelines such as the reduction in SBP/DBP, total cholesterol levels and WC, or differentiate from them such as the lack of benefit on the rest of the lipid profile parameters derive from low or even critically low quality reports.

To our knowledge, this is the first time that an umbrella review comprehensively addresses the effect of various types of PA on the common cardiometabolic risk factors in adults with at least one CV risk factor but not established ASCVD. Previous umbrella reviews include SRMAs of various designs and not limited to RCTs. Moreover, they addressed selected PA types,[2] heterogeneous populations (healthy, or with specific CV risk factors, or established ASCVD), or assessed other outcomes indirectly related to ASCVD (such as flow mediated dilation).[43–45,47] The limitations of our study are the small number of meta-analyses' publications, the overlap of primary studies in some meta-analyses, as well as the low AMSTAR 2 quality assessment of the included SRMAs.

5. Conclusion

Different types of exercise may exert certain advantages in metabolic parameters in individuals with at least one CV risk factor. The most convincing evidence relates to a benefit in SBP and DBP reduction by Aerobic or Tai Chi training. Unfortunately, these findings derive from critically low or low quality of evidence. The role of HIIT, Resistance, Yoga and Qigong training in cardiometabolic health is uncertain. Further high-quality studies assessing how different types of exercise affect cardiometabolic risk factors on adults with cardiometabolic risk are eagerly needed.

CRediT authorship contribution statement

Christina Chatzi: Formal analysis, Investigation, Resources, Writing – original draft. **Georgios Markozannes:** Data curation, Formal analysis, Validation, Writing – review & editing. **Evangelia E. Ntzani:** Investigation, Methodology, Visualization. **Manfredi Rizzo:** Investigation, Methodology, Visualization. **Athanasios Basios:** Resources. **Aikaterini Kalampoki:** Methodology, Validation. **Konstantinos Tsilidis:** Investigation, Methodology, Visualization. **Konstantinos Makrilakis:** Investigation, Methodology, Validation. **Haralampos Milionis:** Investigation, Methodology, Visualization. **Iro Rapti:** Investigation, Methodology, Visualization. **Evangelos C. Rizos:** Conceptualization, Project administration, Writing – review & editing.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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References

1. Naghavi M, Ong KL, Aali A, et al. Global burden of 288 causes of death and life expectancy decomposition in 204 countries and territories and 811 subnational locations, 1990–2021: a systematic analysis for the Global Burden of Disease Study 2021. *Lancet*. 2024;403:2100–2132. https://doi.org/10.1016/S0140-6736(24)00367-2.
2. Luxuan H, Weiwei Y, Kruszewski A, et al. The effect of tai chi exercise on hypertension and hyperlipidemia - a systematic study and meta-analysis. *Arch Budo*. 2022;18, 59.
3. Tao S, Li Z. Effects of qigong exercise on cardiovascular risk factors in patients with metabolic syndrome: a systematic review and meta-analysis. *Front Physiol*. 2023;14, 1092480. https://doi.org/10.3389/fphys.2023.1092480.
4. Loaiza-Betancur AF, Pérez Bedoya E, Montoya Dávila J, Chulvi-Medrano I. Effect of isometric resistance training on blood pressure values in a group of normotensive participants: a systematic review and meta-analysis. *Sports Health*. 2020;12: 256–262. https://doi.org/10.1177/1941738120908070.
5. Wewege MA, Thom JM, Rye KA, Parmenter BJ. Aerobic, resistance or combined training: a systematic review and meta-analysis of exercise to reduce cardiovascular risk in adults with metabolic syndrome. *Atherosclerosis*. 2018;274:162–171. https://doi.org/10.1016/j.atherosclerosis.2018.05.002.
6. Zou L, Zhang Y, Sasaki JE, et al. Wuqinxi qigong as an alternative exercise for improving risk factors associated with metabolic syndrome: a meta-analysis of randomized controlled trials. *Int J Environ Res Public Health*. 2019;16, 1396. https://doi.org/10.3390/ijerph16081396.
7. Cramer H, Langhorst J, Dobos G, Lauche R. Yoga for metabolic syndrome: a systematic review and meta-analysis. *Eur J Prev Cardiol*. 2016;23:1982–1993. https://doi.org/10.1177/2047487316665729.
8. Chu P, Gotink RA, Yeh GY, Goldie SJ, Hunink MGM. The effectiveness of yoga in modifying risk factors for cardiovascular disease and metabolic syndrome: a systematic review and meta-analysis of randomized controlled trials. *Eur J Prev Cardiol*. 2016;23:291–307. https://doi.org/10.1177/2047487314562741.
9. Weston KS, Wisløff U, Coombes JS. High-intensity interval training in patients with lifestyle-induced cardiometabolic disease: a systematic review and meta-analysis. *Br J Sports Med*. 2014;48:1227–1234. https://doi.org/10.1136/bjsports-2013-092576.
10. Batacan RB, Duncan MJ, Dalbo VJ, Tucker PS, Fenning AS. Effects of high-intensity interval training on cardiometabolic health: a systematic review and meta-analysis of intervention studies. *Br J Sports Med*. 2017;51:494–503. https://doi.org/10.1136/bjsports-2015-095841.
11. Danese E, Lippi G, Sanchis-Gomar F, et al. Physical exercise and DNA injury: good or evil? *Adv Clin Chem*. 2017;81:193–230. https://doi.org/10.1016/bs.acc.2017.01.005.
12. Pérez-Martínez P, Mikhailidis DP, Athyros VG, et al. Lifestyle recommendations for the prevention and management of metabolic syndrome: an international panel recommendation. *Nutr Rev*. 2017;75:307–326. https://doi.org/10.1093/nutrit/nux014.
13. Barone Gibbs B, Hivert MF, Jerome GJ, et al. Physical activity as a critical component of first-line treatment for elevated blood pressure or cholesterol: who, what, and how?: a scientific statement from the American Heart Association. *Hypertension*. 2021;78:e26–e37. https://doi.org/10.1161/HYP.0000000000000196.
14. Liang M, Pan Y, Zhong T, Zeng Y, Cheng ASK. Effects of aerobic, resistance, and combined exercise on metabolic syndrome parameters and cardiovascular risk factors: a systematic review and network meta-analysis. *Rev Cardiovasc Med*. 2021; 22:1523–1533. https://doi.org/10.31083/j.rcm2204156.
15. Liang Zd, Zhang M, Wang CZ, Yuan Y, Liang JH. Association between sedentary behavior, physical activity, and cardiovascular disease-related outcomes in adults-a meta-analysis and systematic review. *Front Public Health*. 2022;10, 1018460. https://doi.org/10.3389/fpubh.2022.1018460.
16. Gates M, Gates A, Pieper D, et al. Reporting guideline for overviews of reviews of healthcare interventions: development of the PRIOR statement. *BMJ*. 2022;378, e070849. https://doi.org/10.1136/bmj-2022-070849.
17. Shea BJ, Reeves BC, Wells G, et al. AMSTAR 2: a critical appraisal tool for systematic reviews that include randomised or non-randomised studies of healthcare interventions, or both. *BMJ*. 2017;358, j4008. https://doi.org/10.1136/bmj.j4008.
18. Liang H, Luo S, Chen X, Lu Y, Liu Z, Wei L. Effects of Tai Chi exercise on cardiovascular disease risk factors and quality of life in adults with essential hypertension: a meta-analysis. *Heart Lung*. 2020;49:353–363. https://doi.org/10.1016/j.hrtlng.2020.02.041.
19. Yiallourou A, Pantavou K, Markozannes G, et al. Non-genetic factors and breast cancer: an umbrella review of meta-analyses. *BMC Cancer*. 2024;24:903. https://doi.org/10.1186/s12885-024-12641-8.
20. Filis P, Markozannes G, Chan DS, et al. Grading the evidence for physical activity and any outcome in cancer survivors: an umbrella review of 740 meta-analytic associations. *Crit Rev Oncol Hematol*. 2025;207, 104602. https://doi.org/10.1016/j.critrevonc.2024.104602.
21. Igarashi Y, Akazawa N, Maeda S. Effects of aerobic exercise alone on lipids in healthy East Asians: a systematic review and meta-analysis. *J Atheroscler Thromb*. 2019;26:488–503. https://doi.org/10.5551/jat.45864.
22. Igarashi Y, Akazawa N, Maeda S. Regular aerobic exercise and blood pressure in East Asians: a meta-analysis of randomized controlled trials. *Clin Exp Hypertens*. 2018;40: 378–389. https://doi.org/10.1080/10641963.2017.1384483.
23. Thorogood A, Mottillo S, Shimony A, et al. Isolated aerobic exercise and weight loss: a systematic review and meta-analysis of randomized controlled trials. *Am J Med*. 2011;124:747–755. https://doi.org/10.1016/j.amjmed.2011.02.037.
24. Papagianni G, Panayiotou C, Vardas M, et al. The anti-inflammatory effects of aerobic exercise training in patients with type 2 diabetes: a systematic review and meta-analysis. *Cytokine*. 2023;164, 156157. https://doi.org/10.1016/j.cyto.2023.156157.
25. Cornelissen VA, Buys R, Smart NA. Endurance exercise beneficially affects ambulatory blood pressure: a systematic review and meta-analysis. *J Hypertens*. 2013;31:639–648. https://doi.org/10.1097/HJH.0b013e32835ca964.
26. Lemes ÍR, Ferreira PH, Linares SN, Machado AF, Pastre CM, Netto J. Resistance training reduces systolic blood pressure in metabolic syndrome: a systematic review and meta-analysis of randomised controlled trials. *Br J Sports Med*. 2016;50: 1438–1442. https://doi.org/10.1136/bjsports-2015-094715.
27. de Sousa EC, Abrahin O, Ferreira ALL, Rodrigues RP, Alves EAC, Vieira RP. Resistance training alone reduces systolic and diastolic blood pressure in prehypertensive and hypertensive individuals: meta-analysis. *Hypertens Res*. 2017; 40:927–931. https://doi.org/10.1038/hr.2017.69.
28. Sun Y, Li Q, Xue W. The effect of tai chi on glycemic control in type 2 diabetes mellitus: a meta-analysis of randomized controlled trials. *Front Endocrinol*. 2025;16, 1605253. https://doi.org/10.3389/fendo.2025.1605253.
29. Costa EC, Hay JL, Kehler DS, et al. Effects of high-intensity interval training versus moderate-intensity continuous training on blood pressure in adults with pre- to established hypertension: a systematic review and meta-analysis of randomized trials. *Sports Med*. 2018;48:2127–2142. https://doi.org/10.1007/s40279-018-0944-y.
30. Patel H, Alkhawam H, Madanieh R, Shah N, Kosmas CE, Vittorio TJ. Aerobic vs anaerobic exercise training effects on the cardiovascular system. *World J Cardiol*. 2017;9:134–138. https://doi.org/10.4330/wjc.v9.i2.134.
31. Lauche R, Peng W, Ferguson C, et al. Efficacy of tai chi and qigong for the prevention of stroke and stroke risk factors: a systematic review with meta-analysis. *Medicine (Baltimore)*. 2017;96, e8517. https://doi.org/10.1097/MD.0000000000008517.
32. Alizadeh S, Daneshjoo A, Zahiri A, et al. Resistance training induces improvements in range of motion: a systematic review and meta-analysis. *Sports Med*. 2023;53: 707–722. https://doi.org/10.1007/s40279-022-01804-x.
33. Pelliccia A, Sharma S, Gati S, et al. 2020 ESC guidelines on sports cardiology and exercise in patients with cardiovascular disease. *Eur Heart J*. 2021;42:17–96. https://doi.org/10.1093/eurheartj/ehaa605.
34. Arnett DK, Blumenthal RS, Albert MA, et al. 2019 ACC/AHA guideline on the primary prevention of cardiovascular disease: a report of the American College of Cardiology/American Heart Association Task Force on Clinical Practice Guidelines. *Circulation*. 2019;140:e596–e646. https://doi.org/10.1161/CIR.0000000000000678.
35. Young DR, Hivert MF, Alhassan S, et al. Sedentary behavior and cardiovascular morbidity and mortality: a science advisory from the American Heart Association. *Circulation*. 2016;134:e262–e279. https://doi.org/10.1161/CIR.0000000000000440.
36. Eckel RH, Jakicic JM, Ard JD, et al. 2013 AHA/ACC guideline on lifestyle management to reduce cardiovascular risk: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines. *Circulation*. 2014;129:S76–S99. https://doi.org/10.1161/01.cir.0000437740.48606.d1.
37. Strath SJ, Kaminsky LA, Ainsworth BE, et al. Guide to the assessment of physical activity: clinical and research applications: a scientific statement from the American Heart Association. *Circulation*. 2013;128:2259–2279. https://doi.org/10.1161/01.cir.0000435708.67487.da.
38. Fletcher GF, Ades PA, Kligfield P, et al. Exercise standards for testing and training: a scientific statement from the American Heart Association. *Circulation*. 2013;128: 873–934. https://doi.org/10.1161/CIR.0b013e31829b5b44.
39. Kelley GA, Kelley KS. Impact of progressive resistance training on lipids and lipoproteins in adults: a meta-analysis of randomized controlled trials. *Prev Med*. 2009;48:9–19. https://doi.org/10.1016/j.ypmed.2008.10.010.
40. Kelley GA, Kelley KS, Tran ZV. Aerobic exercise and lipids and lipoproteins in women: a meta-analysis of randomized controlled trials. *J Womens Health*. 2004;13: 1148–1164. https://doi.org/10.1089/jwh.2004.13.1148, 2002.
41. Kelley GA, Kelley KS. Aerobic exercise and lipids and lipoproteins in men: a meta-analysis of randomized controlled trials. *The Journal of Men's Health & Gender*. 2006; 3:61–70.
42. Edwards JJ, Deenmamode AHP, Griffiths M, et al. Exercise training and resting blood pressure: a large-scale pairwise and network meta-analysis of randomised controlled trials. *Br J Sports Med*. 2023;57:1317–1326. https://doi.org/10.1136/bjsports-2022-106503.
43. Wehrmann A, Tian EJ, Tyack EL, Kumar S. The evidence of effectiveness of isometric resistance training on the management of hypertension in adults: an umbrella review. *Blood Press Monit*. 2023;28:171–184. https://doi.org/10.1097/MBP.0000000000000655.

44. Pescatello LS, Buchner DM, Jakicic JM, et al. Physical activity to prevent and treat hypertension: a systematic review. *Med Sci Sports Exerc*. 2019;51:1314–1323. https://doi.org/10.1249/MSS.0000000000001943.
45. Hanssen H, Boardman H, Deiseroth A, et al. Personalized exercise prescription in the prevention and treatment of arterial hypertension: a Consensus Document from the European Association of Preventive Cardiology (EAPC) and the ESC Council on Hypertension. *Eur J Prev Cardiol*. 2022;29:205–215. https://doi.org/10.1093/eurjpc/zwaa141.
46. Al-Mhanna SB, Franklin BA, Jakicic JM, et al. Impact of aerobic exercise on cardiometabolic health in patients with diabesity: a systematic review and meta-analysis of randomized controlled trials. *J Diabetes Complications*. 2025;39, 109203. https://doi.org/10.1016/j.jdiacomp.2025.109203.
47. Shivgulam ME, Liu H, Schwartz BD, et al. Impact of exercise training interventions on flow-mediated dilation in adults: an umbrella review. *Sports Med*. 2023;53:1161–1174. https://doi.org/10.1007/s40279-023-01837-w.
48. Church TS, Blair SN, Cocreham S, et al. Effects of aerobic and resistance training on hemoglobin A1c levels in patients with type 2 diabetes: a randomized controlled trial. *JAMA*. 2010;304:2253–2262. https://doi.org/10.1001/jama.2010.1710.
49. Pai LW, Li TC, Hwu YJ, Chang SC, Chen LL, Chang PY. The effectiveness of regular leisure-time physical activities on long-term glycemic control in people with type 2 diabetes: a systematic review and meta-analysis. *Diabetes Res Clin Pract*. 2016;113:77–85. https://doi.org/10.1016/j.diabres.2016.01.011.
50. Lee MS, Jun JH, Lim HJ, Lim HS. A systematic review and meta-analysis of tai chi for treating type 2 diabetes. *Maturitas*. 2015;80:14–23. https://doi.org/10.1016/j.maturitas.2014.09.008.
51. Burger PM, Dorresteijn JAN, Koudstaal S, et al. Course of the effects of LDL-cholesterol reduction on cardiovascular risk over time: a meta-analysis of 60 randomized controlled trials. *Atherosclerosis*. 2024;396. https://doi.org/10.1016/j.atherosclerosis.2024.118540.
52. Manta E, Thomopoulos C, Kariori M, et al. Revisiting cardiovascular benefits of blood pressure reduction in primary and secondary prevention: focus on targets and residual risk—a systematic review and meta-analysis. *Hypertension*. 2024;81:1076–1086. https://doi.org/10.1161/HYPERTENSIONAHA.123.22610.