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REVIEW

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The intensity paradox: A systematic review and meta-analysis of its impact on the cardiorespiratory fitness of older adults

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Abstract

Aim: The present systematic review and meta-analysis aimed to compare the effect of moderate- versus high-intensity aerobic exercise on cardiorespiratory fitness (CRF) in older adults, taking into account the volume of exercise completed.

Methods: The databases MEDLINE (Ovid), EMBASE (Ovid), and CENTRAL (Cochrane Library) were searched to identify randomized controlled trials (RCTs). Two reviewers extracted data and assessed bias. Comprehensive Meta-Analysis software calculated overall effect size, intensity differences, and performed meta-regression analyses using pre-to-post intervention or change scores of peak oxygen uptake ($\dot{V}O_2$peak). The review included 23 RCTs with 1332 older adults (intervention group: $n = 932$; control group: $n = 400$), divided into moderate-intensity (435 older adults) and high-intensity (476 older adults) groups.

Results: Meta-regression analysis showed a moderate, but not significant, relationship between exercise intensity and improvements in $\dot{V}O_2$peak after accounting for the completed exercise volume ($\beta = 0.31$, 95% CI = [−0.04; 0.67]). Additionally, studies comparing moderate- versus high-intensity revealed a small, but not significant, effect in favor of high-intensity (Hedges' $g = 0.20$, 95% CI = [−0.02; 0.41]). Finally, no significant differences in $\dot{V}O_2$peak improvements were found across exercise groups employing various methods, modalities, and intensity monitoring strategies.

Conclusion: Findings challenge the notion that high-intensity exercise is inherently superior and indicate that regular aerobic exercise, irrespective of the specific approach and intensity, provides the primary benefits to CRF in older adults. Future RCTs should prioritize valid and reliable methodologies for monitoring and reporting exercise volume and adherence among older adults.

KEYWORDS

aging, adherence, aerobic exercise, health, HIIT, individuality, public health, $\dot{V}O_2$peak

1 | INTRODUCTION

According to the 2019 revision of the world population prospects, older adults aged ≥65 will increase to approximately 1.6 billion by 2050 and comprise 16% of the world's population.[1] It has been estimated that these older adults may experience 23% of the global disease burden,[2] posing a major challenge to healthcare systems.[3] Hence, prolonging life expectancy raises concerns about whether these additional years are accompanied by a high quality of life in old age.[4,5]

Furthermore, aging is associated with a progressive decline in cardiorespiratory fitness (CRF), with a ~1% per year decrease in peak oxygen uptake ($\dot{V}O_2$peak) after the third decade of life, accelerating to 2%–3% per year after the sixth decade.[6,7] CRF is determined by the capacity of the cardiovascular and respiratory systems to supply oxygen-rich blood to skeletal muscles and the ability of these muscles to use oxygen for energy production, with $\dot{V}O_2$peak being the gold standard measurement.[8] Low levels of CRF increase risks of adverse health outcomes and diseases and will likely influence healthy aging and the quality of later life.[9-14] Conversely, higher levels of CRF are linked to reduced cardiovascular disease and premature mortality risks.[9-14] Importantly, regular physical activity and aerobic exercise consistent with current guideline recommendations (150 min/week at a moderate intensity or 75 min/week at vigorous intensity[15]) can significantly improve CRF and cardiometabolic risk factors in older adults.[16-19]

Despite these benefits, a significant portion of the older population does not meet the government's guidelines for physical activity.[20] The World Health Organization has revealed that 27.5% of adults worldwide do not meet the recommended level of physical activity to improve and protect their health, and both women and men become less active as they age.[21] Notably, the percentages are considerably higher in many countries; for instance, in the United States of America, 47% of males and 65% of females aged 70 years and older do not meet the recommended physical activity guidelines.[22] Such aversion to physical activity, particularly among older adults, poses a significant challenge to public health efforts to promote physical fitness and overall well-being in this demographic.

Moreover, the American College of Sports Medicine (ACSM) has suggested that principles of exercise prescription aimed at improving health and physical fitness should be guided by the FITT principle (frequency, intensity, time, and type), which determines total exercise volume when combined.[23] As part of the FITT principle, the intensity of aerobic exercise is an essential parameter for training prescription. A higher intensity of exercise has been suggested to promote greater increases in $\dot{V}O_2$peak in older adults.[24,25] Therefore, adherence to exercise prescriptions, particularly exercise intensity, is crucial to achieving the desired training stimulus required to improve CRF.[26,27] Nevertheless, most studies on CRF in older adults have focused more on exercise attendance than adherence, complicating the distinction between exercise intensities and methods.[28,29] Merely attending sessions does not guarantee adherence, as individuals may be present without fully engaging or adhering to the prescribed program, potentially resulting in limited progress in improving CRF. Thus, the attendance variable alone may provide limited insight into the actual adherence to the prescribed exercise intervention and do not enable precise quantification of completed exercise doses.[30]

In recent years, the quest to identify the most effective exercise method to enhance CRF in older adults has gained momentum. Traditional continuous endurance training, typically performed at moderate- to high-intensity (i.e., 60%–80% of maximum heart rate (HR_{max})), has been a cornerstone.[19] However, high-intensity interval training (HIIT), characterized by alternating high-intensity activity bouts with low-intensity recovery periods, has emerged as a promising alternative due to the greater time spent at higher intensities (i.e., >80% of HR_{max}).[31-33] Research comparing moderate-intensity continuous training (MICT) and HIIT has shown both to significantly and clinically meaningfully improve $\dot{V}O_2$peak in older adults, with HIIT seemingly yielding a greater effect.[25,34] Yet, no systematic review or meta-analysis has explored the impact of exercise intensity on CRF in older adults, irrespective of the exercise method, when accounting for completed exercise volume. Adherence to exercise prescriptions, especially intensity, is key to understanding the relationship between exercise intensity and CRF.

Thus, this systematic review and meta-analysis aimed to compare the effect of moderate- versus high-intensity aerobic exercise on CRF in older adults, taking into account the volume of exercise completed.

2 | MATERIALS AND METHODS

2.1 | Search strategy

This systematic review and meta-analysis was conducted and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement[35] and was registered in the International Prospective Register of Systematic Reviews (PROSPERO; registration number CRD42022370589). The systematic search used the following databases to identify eligible studies: Cochrane Central Register of Controlled Trials, CENTRAL (through the Cochrane Library), MEDLINE, and EMBASE, both via Ovid and searched simultaneously (Figure 1). The original literature search was conducted on October 21, 2022 and updated by e-mail alerts until May 9, 2023. The search was based on terms regarding population, intervention, outcome, and study design (PIO(S) terms). Population (P): home-dwelling older adults, both men and women (≥60 years); Intervention (I): physical exercise interventions involving an aerobic component; Outcome (O): CRF; and Study design (S): randomized controlled trials (RCTs). The complete search string can be found in Table S1 in Data S1.

A three-step search strategy was performed to identify published primary sources of evidence. A librarian and first author utilized the initial search, followed by inspections of articles already known to the research team. Next, the librarian conducted a second search using all identified text words and index terms (Medical Subject Headings and EMTREE terms) from the initial search, including databases. Third, the reference list of included articles was searched for additional sources. The third stage examined solely the reference lists of the sources selected from full-text articles by two agreements.

2.2 | Inclusion and exclusion criteria

The present systematic review and meta-analysis included RCTs of older adults (≥60 years), in which the impact of various exercise interventions, each containing an aerobic component, on CRF was evaluated. The control groups encompassed non-exercising and exercising groups. However, for inclusion in the meta-analysis comparing moderate- or high-intensity groups with non-exercising controls, the latter could not engage in systematic aerobic exercise. A necessary criterion for inclusion was the execution of a CRF test until exhaustion, conducted either directly through the assessment of $\dot{V}O_2$peak or indirectly via the estimation of $\dot{V}O_2$peak from a maximal exercise test until exhaustion. Additionally, a direct link between the test procedure and the intervention was required, such as a treadmill test used in the context of a walking or running intervention. This criterion was used to ensure a precise reference point for exercise intensity and accurately attribute CRF improvements to the specific exercise modality.

Studies including younger participants were also considered, provided they included results from an age-based sub-analysis including a subset of participants aged 60 or older. In addition, both supervised and unsupervised interventions were evaluated if exercise intensity during the intervention was measured. Hence, control of exercise intensity was imperative, and the achieved intensity was required to be reported using metrics such as $\%HR_{max}$, % heart rate reserve (HRR), % oxygen reserve ($\dot{V}O_2R$), $\%\dot{V}O_2$peak, or rating of perceived exertion (RPE) (i.e., the

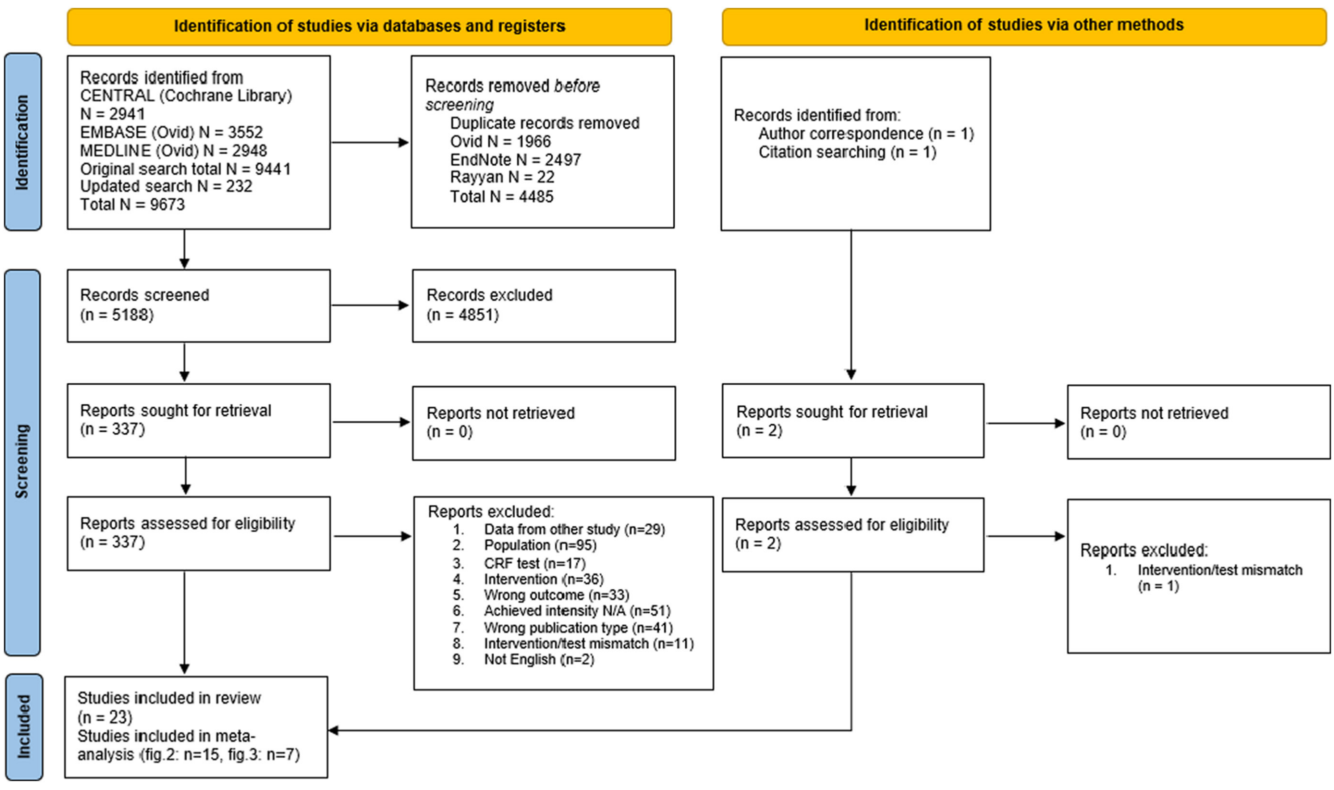

FIGURE 1 Flowchart of the systematic review and meta-analysis according to the PRISMA guidelines. Updated search: 09.05.2023.

6–20 RPE scale), or a well-defined and comprehensively described measure of exercise adherence (i.e., adherence to exercise prescription or specifically to intensity).

To ensure the sample's representativeness concerning the broader population, participants from diverse lifestyle backgrounds, varying BMIs, and different health statuses were considered. Conversely, studies which exclusively incorporated individuals with certain diseases or conditions, such as heart disease, coronary artery disease, COPD, cancer, diabetes, hypertension, cognitive impairment, or obesity, were excluded. Lastly, studies evaluating combined lifestyle interventions, for instance, interventions targeting both exercise and diet or including other medical/dietary supplements, were not considered.

2.3 | Study selection and data extraction

Two reviewers (SHF and JF) removed duplicates, screened titles and abstracts for eligibility and performed full-text assessments. After assessing eligible studies based on titles and abstracts, for the systematic review, three additional reviewers (SB, HLS, and SJEL) independently reviewed and accepted the decisions involving the inclusion of studies. Subsequently, the same procedure (review and acceptance of decisions) was repeated after assessing eligible studies based on full-text assessments. Details concerning study inclusion are provided in the flowchart above (Figure 1).

The reviewers SHF and JF independently extracted information regarding the study population: country, sample size, outcomes, age, and sex (Table 1). Furthermore, both reviewers independently extracted the characteristics of the exercise interventions, methods of $\dot{V}O_2$peak testing, adherence and attendance to exercise intervention, methods of controlling exercise intensity, achieved intensity, and pre- to post-intervention $\dot{V}O_2$peak scores or changes from baseline (in mL/kg/min or percentage) (Table 2).

The classification of exercise intensity groups was based on the ACSM guidelines.[23] The achievement of intensity served as the input for this classification, subsequently leading to the definition of two categories: moderate- and high-intensity. In the moderate-intensity group, the exercise methods included primary MICT as well as one dancing intervention. The high-intensity group encompassed high-intensity continuous training (HICT) and HIIT. Exercise intensity was indicated by metabolic equivalent of task (MET) values, with a range of 3.2–4.7 METs indicating moderate-intensity and 4.8–6.8 METs indicating high-intensity exercise. Studies including exercise groups with a MET value of ≤3.1 were excluded from the analysis. To provide an in-depth calculation of total exercise volume, the moderate- and high-intensity categories also incorporated sub-values of METs. The intensity classification table is presented in Table S1 in Data S1 for further reference.

Briefly, the weekly exercise volume was computed in the following manner: achieved exercise intensity (MET value) × session duration (main session) × (frequency × % attendance). To put this into perspective, if the achieved exercise intensity was at 70%–76% of HR_{max} (equating to 4.4 METs) performed for 30 min thrice a week, with an attendance of 80%, the calculation would be: 4.4 METs × 30 min × (three times per week × 0.8) = 317 MET minutes per week. For interval exercise groups, the session duration included exercise and recovery periods, reflecting the total time and intensity as described in the studies (e.g., 15 min exercising at 85% of HRpeak and 13 min recovery at 65% of HRpeak).

2.4 | Risk of bias assessment

Risk-of-bias assessment was performed by the two independent reviewers (SHF and JF) using TESTEX, a validated 15-item scale specific for assessing the risk of bias in exercise training studies.[36] Each study was rated according to 5 items on study quality and 10 items on reporting, with a maximum score of 15 points.

2.5 | Statistical analysis

To account for baseline differences in $\dot{V}O_2$peak, we used independent group differences to calculate effect sizes. The calculation of effect sizes was conducted through four distinct procedures, each dependent on the availability of specific data. First, pre- and post-intervention means, standard deviations (SD), sample sizes and pre-post correlations for both intervention and control groups were used to calculate effect sizes. In the second procedure, if SDs were not reported, the calculation was based on pre- and post-intervention means, the independent group's *p*-value, sample sizes, the number of tails, and pre-post correlations for both groups. The third procedure was employed when differences in means were reported. In this case, the mean difference, SDs, pre-post correlation, and the sample size of both the intervention and control groups were used to compute effect sizes. Lastly, if the mean difference SDs were not reported, the calculation was performed using the mean difference, the independent group's *p*-value, sample sizes, the number of tails, and pre-post correlations of both intervention and control groups. To account for small sample sizes, Hedges' *g* was calculated.[37] A study was considered an outlier and subsequently excluded from further analyses if the 95% CI of the calculated effect size did not overlap with the 95% CI

TABLE 1 Overview of the study characteristics in the systematic review.

Study	Country	Sample size incl. in analysis (*n*)	Primary outcome	Secondary outcome	Age range (years)	Female (%)
Andrade et al.[40]	Brazil	Cont.: 13 Bouts: 7	$\dot{V}O_2$peak Neuromuscular adaptations		60–75	100
Badenhop et al.[47]	USA	Low-int.: 11 High-int. 10	$\dot{V}O_2$peak		>60	67
Blumenthal et al.[61]	USA	AET: 31 CG: (yoga): 32 (waitlist): 34	$\dot{V}O_2$peak Psychological measures		60–83	51
Boileau et al.[53]	USA	AET: 58 CG: 67	$\dot{V}O_2$peak Endurance parameters		60–75	74
Bouaziz et al.[54]	France	AET: 27 CG: 29	$\dot{V}O_2$peak Endurance parameters		70–83	73
Brown et al.[48]	Australia	Cont.: 34 Bouts: 33 CG: 32	Cognitive function $\dot{V}O_2$peak		60–80	52
Bruseghini et al.[41b]	Italy	Cont.: 12 Bouts: 12	Physical activity level Total energy expenditure	$\dot{V}O_2$peak	65–75	0
Carroll et al.[55]	USA	AET: 18[a] CG: 9	$\dot{V}O_2$peak Head-up tilt	1RM strength	60–82	68
Dipietro et al.[49]	USA	Mod.-int.: 9 High-int.: 9 CG: 7	Insulin sensitivity $\dot{V}O_2$peak		62–84	100
Gass et al.[50]	Australia	Mod.-int.: 15 High-int.: 18 CG: 17	$\dot{V}O_2$peak Endurance parameters		65–75	0
Hagberg et al.[56]	USA	AET: 16[a] CG: 12	1RM strength	$\dot{V}O_2$peak	70–79	N/A
Hurley et al.[57]	UK	AET: 10 CG: 6	Small vessel function $\dot{V}O_2$peak		60–80	83
Martin-Willett et al.[42]	USA	Low-int.: 69 Mod.-int.: 80	Cognitive function $\dot{V}O_2$peak		≥60	85
Morris et al.[52]	New Zealand	Cont.: 10 Bouts: 10 CG: 5	$\dot{V}O_2$peak Cardiac output		60–70	0
Pogliaghi et al.[51]	Italy	Ski: 6 Cycle: 6 CG: 6	$\dot{V}O_2$peak VT_1	Crossover effect	65–75	0
Posner et al.[58]	USA	AET: 166 CG: 81	$\dot{V}O_2$peak VT_1		60–86	62
Rodrigues-Krause et al.[63]	Brazil	Walk: 10 Dance: 10 CG (stretching): 10	$\dot{V}O_2$peak	Body composition Functional and biochemical parameters	60–75	100
Simonsson et al.[43]	Sweden	Mod.-int.: 34 High-int.: 34	$\dot{V}O_2$peak Global cognitive function	Domain-specific cognitive functions Cardiovascular and muscular function quality of life	≥65	56

(Continues)

TABLE 1 (Continued)

Study	Country	Sample size incl. in analysis (*n*)	Primary outcome	Secondary outcome	Age range (years)	Female (%)
Tarumi et al.[59]	USA	AET: 36 CG: 37	Cognitive function $\dot{V}O_2$peak		60–80	75
Tavoian et al.[44]	USA	Cont.: 4[a] Bouts: 5	$\dot{V}O_2$peak Lower extremity muscular function Physical function		60–75	79
Voss et al.[45]	USA	Low-int.: 11 Mod.-int.: 22	Cognitive function $\dot{V}O_2$peak		60–80	60
Wang et al.[46]	USA	Low dose: 37 High dose: 35	Energy expenditure Body composition $\dot{V}O_2$peak		60–75	100
Warren et al.[60]	USA	AET:14 CG (calisthenics): 16	$\dot{V}O_2$peak		67–85	100

Abbreviations: 6-MWT, 6-minute walk test; AET, aerobic exercise training; CG, control group; cont., continuous; incl., included; int., intensity; mod., moderate; MTP, maximally tolerated power; *n*, number; $\dot{V}O_2$peak, peak oxygen uptake; VT, ventilatory threshold.

[a]Part of a study comparing the effect of different exercise modalities and only the purely aerobic group included.

[b]Included due to author correspondence.

of the overall effect size. In interpreting the effect sizes, we adhered to Cohen's convention; where an effect size of 0.2 was considered small, 0.5 was considered moderate, and 0.8 was considered large.[38] Given the anticipated heterogeneity of the samples and interventions, the effect sizes were pooled using a random effects model, which takes into account differences in effects between studies. The I^2 statistic was reported as an indicator of heterogeneity, with an I^2 of 25% representing low heterogeneity, 50% representing moderate heterogeneity, and 75% representing high heterogeneity.[39]

Meta-regression analysis was conducted to assess the association between exercise intensity and improvements in $\dot{V}O_2$peak, accounting for the total volume of exercise completed. Sub-group meta-regression analyses were also performed to examine the association of $\dot{V}O_2$peak with session duration, weekly exercise duration, weekly exercise volume, and intervention duration, the latter referring to the duration of the intervention period in weeks. Further sub-group meta-analyses were conducted to investigate the differences in effects between studies with various exercise- and intervention-related characteristics, including frequency of training sessions per week (2 times/week, 3 times/week, and 4–5 times/week), intensity categorized by MET values, exercise methods (MICT, HICT, and HIIT), exercise modalities (walking/running and cycling), and intensity monitoring methods (subjective, objective, and combination). In the meta-regression, β-values with 95% CI, Z-values, and p-values were presented. All analyses were conducted using the Comprehensive Meta-Analysis software, version 4 (National Institutes of Health, Bethesda, MD, USA).

Publication bias was investigated by inspecting the funnel plot and applying Duval and Tweedie's procedure. This procedure imputed missing studies to achieve symmetry around the center of the funnel plot, and the effect size was then recalculated based on this procedure. The presence of significant dispersion between the true effect size and the calculated effect size, as indicated by Egger's test, suggested publication bias. An alpha level of $p \leq 0.05$ was set as the criterion for statistical significance.

3 | RESULTS

3.1 | Study characteristics

The systematic literature search yielded 5188 unique records, of which 337 full texts were assessed for eligibility. In accordance with the established criteria, 23 RCTs were considered eligible for inclusion in the systematic review (Figure 1). All included studies provided sufficient data for effect size estimation. Nevertheless, eight studies[40-47] did not incorporate a non-exercising control group, excluding them from the overall meta-analysis (Figure 2). In addition, four[40,43,44,46] out of these eight studies undertook comparisons within similar intensity groups (i.e., high vs. high) based on the categories provided by the ACSM guidelines[23]; hence, they were not incorporated into the meta-analysis. Seven studies[41,42,47-51] presented results for both moderate- and high-intensity groups, making them eligible for inclusion in the meta-analysis comparison between these intensity categories (Figure 3). Out of these,

TABLE 2 Characteristics of the aerobic exercise interventions and methods for testing cardiorespiratory fitness.

Study	Protocol type	Group	Freq./wk.	Intended int. range	Int. cat.[a]	Int. monitoring	Achieved int.	Duration main session (min)	Attendance	Weekly min. and MET's	$\dot{V}O2_{peak}$ test	Pre-post $\dot{V}O2_{peak}$ (mL/kg/min)
Andrade et al. [40]	12 wk. Water-based (cont./bouts) Supervised	Cont. Bouts	2 2	RPE 13–16 RPE 16–18 (prog.)	High High	RPE RPE	RPE 13–16 (prog.) RPE 16–18 (prog.)	36 36	83% 82%	59 min 307 METs 59 min 272 METs	TM Direct	26.3 ± 3.7 pre 28.8 ± 5.1 post 24.1 ± 4.1 pre 26.0 ± 8.0 post
Badenhop et al. (1983)	9 wk. Cycling (count.) Supervised	Low High	3–4 3–4	30%–45% HRR 60%–75% HRR	Mod. High	HR Watts HR Watts	70.4% HR_{max}[b] 78.1% HR_{max}[b]	25 25	3.1/wk. 3.1/wk.	78 min 341 METs 78 min 411 METs	CE Direct	21.1 ± 3.6 pre 24.5 ± 4.8 post 20.6 ± 3.8 pre 23.7 ± 5.9 post
Badenhop et al. [47]	16 wk. Cycling (walking, ski erg.) (cont.) Supervised	AET	3	70% HRR	Mod.	HR RPE	13.4 ± 1.8 RPE	Cycling: 30 Walking/ski erg.: 15	96% Adherence HR: 88%	130 min 570 METs	CE Direct	19.4 ± 5.3 pre 21.4 ± 5.8 post
Boileau et al. (1999)	6 mo. Walking (cont.) Supervised	AET	3	50%–65% HRR (prog.)	High	RPE	50%–65% HRR (prog.)	15–40 (prog.)	Adherence by condition: 80%	84 min 411 METs	TM Direct	21.6 ± 3.25[b] pre 1.05 ± 1.47[b] diff.
Blumenthal et al. [61]	9.5 wk. Cycling (bouts) Supervised	AET	2	At VT_1	High	HR Watts	At VT_1 (~78% HR_{max})[b]	30	Adherence by condition: 95%	57 min 282 METs	CE Direct	22.9 ± N/A[b] pre 26.1 ± N/A[b] post
Brown et al. (2021)	6 mo. Cycling (cont./bouts) Supervised	Cont. Bouts	2 2	50%60% $\dot{V}O_2$peak/RPE 13 >80% $\dot{V}O_2$peak/RPE 18	Mod. High	Watts RPE Watts RPE	70.1% ± 16.3% peak power 120.6% ± 25.1% peak power	50 31	86% 86%	86 min 378 METs 53 min 243 METs	CE Direct	24.7 ± 6.9 pre 3.02 (1.79, 4.25) diff. 22.2 ± 6.3 pre 5.40 (4.00, 6.81) diff.
Boileau et al. [53]	8 wk. Cycling (cont./bouts) Supervised	Cont. Bouts	3 3	46%64% $\dot{V}O_2$peak 85-95% $\dot{V}O_2$peak	Mod. High	HR Watts HR Watts	70.6% HR_{max}[c] 85.2% HR_{max}/66.2% HR_{max}[c]	29[c] 13.4 + 11.42[c]	98%[c] 97%[c]	85 min 375 METs 72 min 326 METs	CE Direct	28.3 ± 6 pre 30.8 ± 6.1 post 29.9 ± 4.3 pre 32.7 ± 6.0 post
Carroll et al. (1995)	26 wk. Walking/stair climbing (cont.) Supervised	AET	3	40%70% HRR (prog.)	High	HR RPE	63.9 ± 5.2–77.9% ± 5.0% HRR (prog.)	20–40 (prog.)	N/A	105 min 617 METs	TM Direct	21.6 ± 4.1 pre 25.1 ± 5.1 post

(Continues)

TABLE 2 (Continued)

Study	Protocol type	Group	Freq./wk.	Intended int. range	Int. cat.[a]	Int. monitoring	Achieved int.	Duration main session (min)	Attendance	Weekly min. and MET's	$\dot{V}O2_{peak}$ test	Pre-post $\dot{V}O2_{peak}$ (mL/kg/min)
Bouaziz et al. [54]	9 mo. Walking (mini-trampolines, row erg., step aerobics) (cont.) Supervised	Mod. High	4 4	65% $\dot{V}O_2$peak 80% $\dot{V}O_2$peak	Mod. High	HR HR	~71% HR_{max}[b] ~83% HR_{max}[b]	68.2 ± 5.3[d] 63.4 ± 5.4[d]	91% Adherence HR: 100% Time: 85% 92% Adherence HR: 100% Time: 89%	211 min 929 METs 208 min 1101 METs	TM Direct	21.2 ± 3.4 pre 21.1 ± 3.0 post 21.4 ± 3.9 pre 21.0 ± 4.2 post
Gass et al. (2004)	12 wk. Cycling (cont.) Supervised	Mod. High	3 3	50% $\dot{V}O_2$peak 70% $\dot{V}O_2$peak	Mod. High	Watts HR Watts HR	58%69% peak power 91%97% peak power	44[b] 30	100% 100%	132 min 477 METs 90 min 477 METs	CE Direct	25.6 ± 3.5[b] pre 27.2 ± 3.5[b] post 26.7 ± 3.0[b] pre 28.9 ± 3.8[b] post
Brown et al. [48]	26 wk. Walking (cont./bouts) Supervised	AET	3	50%–85% $\dot{V}O_2$peak RPE 11-15 (prog.)	High	RPE	50%–85% $\dot{V}O_2$peak RPE 11–15 (prog.)	20–35 (prog.)	>95%	105 min 591 METs	TM Direct	22.5 ± 5.7 pre 27.1 ± 6.5 post
Hurley et al. (2019)	12 wk. Walking (cont.) Supervised	AET	4	50%70% HRR (prog.) (125 ± 10 HR)	High	HR	~83% HR_{max}[b] (125 ± 10 HR)	30–40 (prog.)	94%	146 min 718 METs	TM Direct	19.0 ± 3.1 pre 20.8 ± 2.9 post
Bruseghini et al. [41][c]	16 wk. Walking (cont./bouts) Supervised	Low Mod.	3 3	50% HR_{max} 60%95% HR_{max} (prog.)	Mod. High	HR HR	66.2% HR_{max} 79.5%–88.2% HR_{max}	30 30	98% 98%	89 min 319 METs 88 min 393 METs	TM Direct	25.1 ± 4.9 pre 25.1 ± 4.9[b] post 24.8 ± 5.3 pre 26.3 ± 5.4[b] post
Morris et al. (2002)	10 wk. Cycling (cont./bouts) Supervised	Cont. Bouts	3 3	70%75% $\dot{V}O_2$peak 70%75% $\dot{V}O_2$peak	High Low	Watts HR Watts HR	~83% HR_{max}[b] ~63% HR_{max}[b]	30 60	97% 97%	87 min 463 METs 175 min 489 METs	CE Direct	27.4 ± 3.79[b] pre 31.2 ± 3.79[b] post 28.4 ± 2.84[b] pre 32.2 ± 3.16[b] post
Carroll et al. [55]	12 wk. Ski/cycling erg (cont.) Supervised	Ski Cycle	3 3	At VT_1 At VT_1	Mod. High	Watts HR Watts HR	72 ± 8 - 76% ± 4% HR_{max} 79 ± 4–81% ± 4% HR_{max}	30 30	94% 94%	85 min 372 METs 85 min 448 METs	CE Ski erg. Direct	22.0 ± 2.6 pre 26.8 ± 2.3 post 29.1 ± 5.7 pre 34.6 ± 5.6 post
Posner et al. (1992)	16 wk. Cycling (cont.) Supervised	AET	3	70% HR_{max} (115 ± 15 HR)	Mod.	HR	~68% HR_{max}[b] (112 ± 12 HR)	30	81%	73 min 262 METs	CE Direct	22.2 ± 5.7 pre 23.9 ± 6.1 post
Dipietro et al. [49]	8 wk. Dancing (cont./bouts) Supervised	Dance	3	55%–69% $\dot{V}O_2$peak (prog.)	Mod.	HR	59% $\dot{V}O_2$peak/ 73% HR_{max}[d]	55	95%	157 min 690 METs	TM Direct	23.3 (20.8-25.8) pre 25.6 (23.4-27.8) post

TABLE 2 (Continued)

Study	Protocol type	Group	Freq./ wk.	Intended int. range	Int. cat.[a]	Int. monitoring	Achieved int.	Duration main session (min)	Attendance	Weekly min. and MET's	$\dot{V}O2_{peak}$ test	Pre-post $\dot{V}O2_{peak}$ (mL/kg/min)
Simonsson et al. (2023)	3 mo. Cycling (bouts) Supervised	Mod. High	2 2	RPE 15 70% HRR RPE 17 95% HRR	High High	Watts RPE HR	44%69% peak power 174%316% peak power	40 20	88% 88%	58 min 281 METs 18 min 82 METs	CE Direct	22.3 ± 4.6 pre 1.4 ± 2.4[b] diff. 23.6 ± 5.2 pre 1.4 ± 2.3[b] diff
Gass et al. [50]	12 mo. Walking (cont.) Supervised/ unsupervised Home-based	AET	3–5 (prog.)	75%90% HR_{max} (prog.)	High	HR Logb.	75%–90% HR_{max} (prog.)	30–40 (prog.)	Adherence by condition: 81%	130 min 737 METs	TM Direct	22.9 (21.8–23.9) pre 25.0 (23.9-26.1) post
Tavoian et al. (2021)b	12 wk. Cycling (cont./ bouts) Supervised	Cont. Bouts	3 3	50%75% HRR[e] (prog.) 50%–100% HRR[e] (prog.)	High High	HR RPE HR RPE	59.9%–69.9% HRR[c] (prog.) 62.9%–75.4% HRR[c] (prog.)	20–45[e] (prog.) 15–30[e] (prog.)	92%[e] 94%[e]	99 min 504 METs 56 min 320 METs	CE Direct	22.3 ± 3.2 pre 24.0 ± 5.9 post 19.4 ± 1.6 pre 21.7 ± 3.2 post
Hagberg et al. [56]	12 wk. Cycling (cont./ bouts) Supervised	Low Mod	3 3	<57% HR_{max} 64%–76% HR_{max}	Low Mod.	HR RPE HR RPE	58.2% ± 4.4% HR_{max} 65.7% ± 3.8% HR_{max}	40 20–40 (prog.)	97% 100%	116 min 233 METs 107 min 385 METs	CE Indirect	19.7 ± 5.3 pre 5.7 ± 4.7% diff. 19.9 ± 4.8 pre 6.5 ± 7.1% diff.
Wang et al. (2017)	4 mo. Walking (cont.) Supervised	Low dose High dose	3 3	118 ± 11 HR (74.2% HR_{max})[b] 119 ± 7 HR (74.4% HR_{max})[b]	Mod. Mod.	HR HR	~72% HR_{max}[b] (114 ± 11 HR) ~73% HR_{max}[b] (116 ± 10 HR)	105/wk. 160/wk.	Adherence HR: 97% Dose: 104% Adherence HR: 98% Dose: 99%	105 min 462 METs 160 min 704 METs	TM Direct	20.1 ± 4.1 pre 0.6 ± 2.8 diff. 20.1 ± 3.5 pre 2.3 ± 3.1 diff.
Hurley et al. [57]	12 wk. Walking (cont.) Supervised/ unsupervised	AET	5	60% HRR/ $\dot{V}O_2$peak	High	HR	60.0% ± 1.9% HRR 78.1% ± 1.3% HR_{max}	30-40 (prog.)	100%	188 min 994 METs	TM Direct	19.0 ± 3.29[b] pre 21.4 ± 3.62[b] post

Note: Weekly duration: main session duration × (frequency × % attendance). Weekly MET's: weekly duration × MET value representing achieved intensity.

Abbreviations: Cat, categories; CE, cycle ergometry; cont., continuous exercise; diff., difference; erg., ergometry; freq., frequency; HR, heart rate; HR_{max}, heart rate maximum; HRR, heart rate reserve; MET's, metabolic equivalents; min., minutes; N/A, not available; presc, prescription; prog, progression; RPE, rate of perceived exertion; TM, treadmill; $\dot{V}O_2$peak, peak oxygen uptake; VT, Ventilatory threshold; wk., weeks.

[a]Intensity categories based on achieved intensity and ACSM's guidelines.8

[b]Calculated based on information provided in the paper.

[c]Informed through author correspondence.

[d]Information from related publications.

[e]Information from Data S1.

Study name	Comparison	Hedges's g	Lower limit	Upper limit	p-Value
Dipietro et al. (2006a)	Mod.	-0,167	-1,102	0,769	0,727
Posner et al. (1992)	Mod.	0,411	0,144	0,678	0,003
Brown et al. (2021a)	Mod.	0,509	0,024	0,993	0,040
Blumenthal et al. (1989)	Mod.	0,511	0,022	1,000	0,040
Gass et al. (2004a)	Mod.	0,591	-0,101	1,284	0,094
Pogliaghi et al. (2006a)	Mod.	1,657	0,420	2,894	0,009
Rodrigues-krause et al. (2018)	Mod.	1,756	0,755	2,756	0,001
Pooled		0,598	0,275	0,920	0,000
Dipietro et al. (2006b)	High	-0,210	-1,147	0,727	0,660
Tarumi et al. (2022)	High	0,391	-0,067	0,850	0,094
Hagberg et al. (1989)	High	0,722	-0,029	1,472	0,060
Gass et al. (2004b)	High	0,731	0,061	1,401	0,032
Warren et al. (1993)	High	0,749	0,026	1,472	0,042
Brown et al. (2021b)	High	0,768	0,270	1,266	0,003
Carroll et al. (1995)	High	0,949	0,133	1,765	0,023
Hurley et al. (2019)	High	0,998	-0,020	2,015	0,055
Bouaziz et al. (2018)	High	1,102	0,546	1,658	0,000
Pogliaghi et al. (2006b)	High	1,142	0,002	2,282	0,050
Boileau et al. (1999)	High	1,151	0,774	1,528	0,000
Morris et al. (2002b)	High	1,162	0,069	2,254	0,037
Pooled		0,816	0,610	1,022	0,000
Pooled overall		0,753	0,579	0,926	0,000

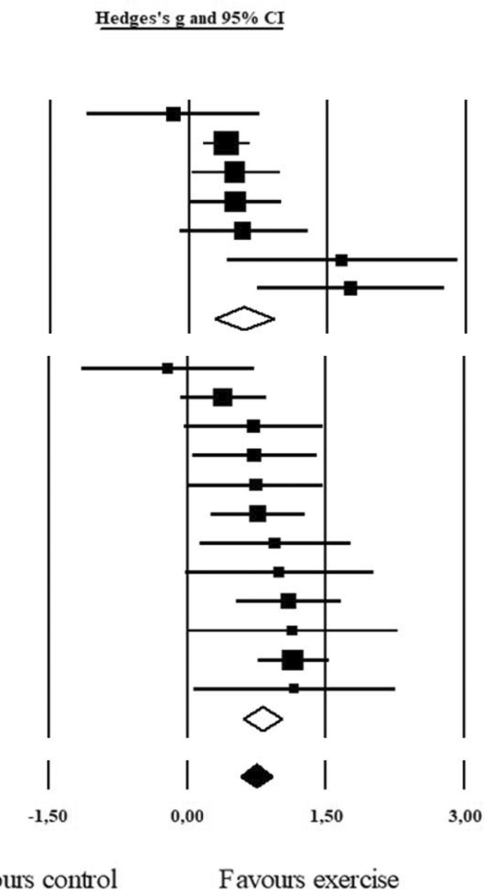

FIGURE 2 Pooled effects of aerobic exercise compared with non-exercising control on $\dot{V}O_2$peak. The results are presented as standardized mean differences with the respective 95% CI, where the size of the squares reflects the statistical weight of each study. CI, confidence interval; Mod, moderate-intensity; high, high-intensity.

four studies[48-51] also incorporated a non-exercising control group and were accordingly included in the overall meta-analysis, albeit separately (Figure 2).[62] Consequently, this led to an overall meta-analysis sample size of 15 studies with 19 comparisons, with an additional seven comparisons in the moderate- versus high-intensity meta-analysis (Data S1; Figure 1).

3.2 | Study population characteristics

The 23 studies in the systematic review encompassed 1332 older adults (9–247 older adults per study), with 932 in the intervention group and 400 in the control group (Table 1). Divided into intensity groups, the moderate-intensity group contained 435 older adults and the high-intensity group 476 older adults. Additionally, two studies[45,52] included a low-intensity group containing 21 older adults combined, which were not included in the analysis. The older adults ranged from 60 to 85 years, and ~65% of the participants were women. Baseline characteristics of mean $\dot{V}O_2$peak were 23.4 ± 3.1 mL/kg/min in the intervention group and 22.5 ± 3.3 mL/kg/min in the control group, respectively. Divided into intensity groups, the $\dot{V}O_2$peak were 23.3 ± 2.6 mL/kg/min in the moderate-intensity group and 23.4 ± 3.4 mL/kg/min in the high-intensity group, respectively.

3.3 | Exercise intervention characteristics

The systematic review comprised 16 two-armed RCTs[40-47,53-60] that compared aerobic exercise with either a passive or active control group or another exercise group (Table 1). An additional seven RCTs[48-62] were three-armed studies that compared various aerobic exercise intensities and modalities against a passive or active control group. In two instances,[59,60] the intervention involved a combination of supervised and unsupervised sessions, while 21

Study name	Hedges's g	Lower limit	Upper limit	p-Value
	Statistics for each study			
Dipietro et al. (2006)	-0,117	-0,998	0,764	0,795
Badenhop et al. (1983)	-0,054	-0,876	0,768	0,898
Bruseghini et al. (2020)	0,048	-0,725	0,821	0,903
Pogliaghi et al. (2006)	0,151	-0,895	1,197	0,777
Gass et al. (2004)	0,160	-0,510	0,829	0,640
Brown et al. (2021)	0,256	-0,219	0,732	0,291
Martin-Willett et al. (2020)	0,288	-0,034	0,610	0,079
Pooled	0,197	-0,018	0,412	0,073

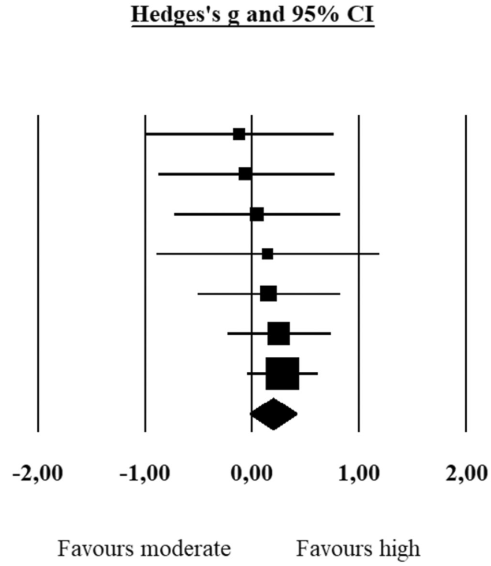

FIGURE 3 Pooled effects of moderate- versus high-intensity aerobic exercise on $\dot{V}O_2$peak. The results are presented as standardized mean differences with the respective 95% CI, where the size of the squares reflects the statistical weight of each study. CI, confidence interval; moderate, moderate-intensity; high, high-intensity.

studies[40-62] conducted exercise sessions under the supervision of an exercise instructor (Table 2).

The mean frequency of exercise across all studies was reported as 3.1 ± 0.7 days per week (range, 2–5 days per week). When differentiated by intensity, the moderate-intensity group had a mean frequency of 3.1 ± 1.3 days per week, and the high-intensity group had a mean frequency of 3.1 ± 1.7 days per week (Table 2).

Seven studies[41,42,47-51] made a comparative analysis between high- and moderate-intensity exercise. Moreover, three studies compared moderate-intensity[58,61,62] and seven studies high-intensity[53-57,59,60] exercises with a passive or active control group. Additionally, one study[45] compared low-intensity exercise with moderate-intensity, another[52] low-intensity with high-intensity, while four studies[40,43,44,46] compared similar intensity groups based on the categories provided by the ACSM guidelines[23] (Table 2).

The mean duration of exercise sessions was 35 ± 11 min (range, 20–68 min), with the mean intervention duration being 18 ± 11 weeks (range, 8–52 weeks). Upon stratifying into intensity groups, the moderate-intensity group had a mean session duration of 41 ± 14 min and a mean intervention duration of 17 ± 10 weeks. In comparison, the high-intensity group had a mean session duration of 32 ± 9 min and a mean intervention duration of 20 ± 13 weeks (Table 2).

When taking into account exercise attendance and adherence, the mean weekly exercise duration, excluding warm-up and cool-down periods, was 103 ± 46 min (range, 18–211 min), with the mean weekly exercise volume being 479 ± 226 MET minutes (range, 82–1101 MET minutes). After classification into intensity groups, the moderate-intensity group achieved a mean weekly exercise duration of 117 ± 44 min and a mean weekly exercise volume of 492 ± 206 MET minutes. Conversely, the high-intensity group achieved a mean weekly exercise duration of 96 ± 49 min and a mean weekly exercise volume of 476 ± 249 MET minutes (Table 2).

3.4 | Methods of CRF testing

The $\dot{V}O_2$peak was measured directly in 22 studies. Among these, 11 studies[40,42,46,49,53,55-57,59,62] implemented treadmill-based walking or running protocols, while 10[41,43,44,47,48,50,51,52,54,58,61] used a cycle ergometer. In addition, one study[51] used both ski and cycle ergometers and one[45] opted for an indirect approach, using symptom-limited maximal exercise testing on a cycle ergometer to derive an estimation of $\dot{V}O_2$peak (Table 2).

3.5 | Risk-of-bias assessment

The mean TESTEX score was 11.4 (range, 9–14) (Table 3). Six studies[40,43,44,54,59,62] reported blinding of the outcome assessors. Five studies[41,45,49,59,60] monitored physical activity in the control group, and six studies[40,43,48,54,59,62] used an intention-to-treat analysis. All studies reported some kind of intensity monitoring. Specifically, 16 studies[40-46,48,53-57,59,60,62] provided a clear plan for the progression of the prescribed exercise by increasing frequency, session duration, or intensity throughout the intervention period, aiming to adjust the relative total exercise volume for the participants. In three studies,[40,53,56] exercise intensity was controlled and regulated based on RPE. The percentage of HR_{max} was used in eight studies,[42,46,49,57,58,60,62] while a combination of watts and the percentage of HR_{max} was used in six studies.[41,47,50-52,54] Additionally, four studies[44,45,55,61] used a combination of RPE and percentage of HR_{max}, one study[48] used a combination of RPE and watts, and one study[43] used a combination of watts, RPE, and percentage of HR_{max}.

3.6 | Adherence and achieved exercise intensity

A total of 11 studies[40,42,43,45,48,50,51,55,56,60,61] clearly reported information on the achieved intensity during the intervention. Furthermore, an additional seven studies[46,47,49,52,54,57,58] provided sufficient information to calculate the achieved intensity. Two studies[41,44] provided the achieved exercise intensity through author correspondence, and one study[62] included sufficient information in a related publication.[63]

Regarding exercise adherence to the intervention, six studies[46,49,53,54,59,61] reported adherence rates. Among these studies, three[53,54,59] assessed adherence as "by condition," considering the total prescribed exercise frequency, duration, and intensity. One study[61] evaluated adherence specifically to intensity, another study[49] reported adherence to duration and intensity, and one study[46] assessed adherence to dose and intensity.

3.7 | Meta-regression analysis

The meta-regression analysis showed a moderate, but not statistically significant, relationship between exercise intensity and improvements in $\dot{V}O_2$peak after accounting for the completed exercise volume ($\beta = 0.31$, 95% CI = [−0.04; 0.67], $z = 1.74$).

3.8 | Meta-analyses and overall effects

There were no differences in $\dot{V}O_2$peak improvements between moderate- versus high-intensity exercise groups ($p = 0.26$) (Table 4). Additionally, when analyzing the studies that directly compared moderate- versus high-intensity, there was a small, but not statistically significant, effect in favor of high-intensity (Hedges' $g = 0.20$, 95% CI = [−0.02; 0.41]) (Figure 3). Within these particular studies, there was no association between total exercise volume performed and $\dot{V}O_2$peak improvements ($\beta = -0.00$, 95% CI = [−0.01; 0.01], $z = -0.10$).

A moderate-to-large positive effect was found on $\dot{V}O_2$peak for the overall pooled results (Hedges' $g = 0.75$, 95% CI = [0.58; 0.93]) (Table 4; Figure 2). Differentiated by intensity, a moderate-to-large positive effect was found on $\dot{V}O_2$peak for the moderate- and high-intensity group (Hedges' $g = 0.60$, 95% CI = [0.28; 0.92]; Hedges' $g = 0.82$, 95% CI = [0.61; 1.02], respectively) (Table 4; Figure 2).

3.9 | Sub-group analyses of associations with $\dot{V}O_2$peak improvements

Improvements in $\dot{V}O_2$peak did not differ across exercise groups with varying session frequencies ($p = 0.15$), exercise methods ($p = 0.08$), exercise modalities ($p = 0.40$), and intensity monitoring methods ($p = 0.13$) (Table 4). No association was observed between weekly exercise duration and volume completed with the improvement in $\dot{V}O_2$peak ($\beta = -0.00$, 95% CI = [−0.01; 0.00], $z = -1.66$; $\beta = -0.00$, 95% CI = [−0.00; 0.00], $z = -1.39$, respectively). A negative association was found between the intervention duration of the exercise groups and improvements in $\dot{V}O_2$peak ($\beta = -0.02$, 95% CI = [−0.03; −0.00], $z = -2.15$).

3.10 | Assessment of sensitivity, publication bias, and heterogeneity

A series of sensitivity analyses did not substantially change the results. The difference in $\dot{V}O_2$peak improvements between moderate- versus high-intensity (Figure 3) remained similar ($p > 0.05$) after removal of each of the included studies (Data S1; Figure 2). Egger's test for funnel plot asymmetry showed no evidence of publications bias in the overall meta-analysis (regression intercept = 0.94, $p = 0.20$) and was supported by visual inspection (Data S1; Figure 3). However, the Duval and Tweedie's trim and fill analysis method observed three missing studies to the left of the funnel plot, resulting in an adjusted effect size of 0.64 [0.51; 0.77]. In addition, Cochran's Q test for heterogeneity revealed a moderate heterogeneity ($Q = 31.64$, $p = 0.03$, $I^2 = 39.95$, and $T^2 = 0.06$), indicating potential between-study variance across the included studies.

TABLE 3 Study quality assessment of included studies using TESTEX scale.

	Study quality					Study reporting										
Study	**1**	**2**	**3**	**4**	**5**	**6a**	**6b**	**6c**	**7**	**8a**	**8b**	**9**	**10**	**11**	**12**	**Overall score**
Andrade et al.[40]	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	14
Badenhop et al.[47]	1	1	1	1	0	0	0	1	0	1	1	1	0	1	1	10
Blumenthal et al.[61]	1	1	0	1	0	1	0	1	0	1	1	1	0	1	1	10
Boileau et al.[53]	1	1	1	1	0	1	0	1	0	1	1	1	0	1	1	11
Bouaziz et al.[54]	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	14
Brown et al.[48]	1	1	1	1	0	1	1	1	1	1	1	1	0	1	1	13
Bruseghini et al.[41]	1	1	0	1	0	1	1	1	0	1	1	1	1	1	1	12
Carroll et al.[55]	1	1	0	1	0	1	0	0	0	1	1	1	0	1	1	9
Dipietro et al.[49]	1	1	0	1	0	1	0	1	0	1	1	1	1	1	1	11
Gass et al.[50]	1	1	0	1	0	1	1	1	0	1	1	1	0	1	1	11
Hagberg et al.[56]	1	1	0	1	0	0	0	1	0	1	1	1	0	1	1	9
Hurley et al.[57]	1	1	0	1	0	0	1	1	0	1	1	1	0	1	1	10
Martin-W. et al.[42]	1	1	1	1	0	0	0	1	0	1	1	1	0	1	1	10
Morris et al.[52]	1	1	0	1	0	1	0	1	0	1	1	1	0	1	1	10
Pogliaghi et al.[51]	1	1	0	0	0	1	1	1	0	1	1	1	0	1	1	10
Posner et al.[58]	1	1	0	1	0	1	1	1	0	1	1	1	0	1	1	11
Rodrigues-K. et al.[62]	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	14
Simonsson et al.[43]	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	14
Tarumi et al.[59]	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	14
Tavoian et al.[44]	1	1	1	1	1	0	1	1	0	1	1	1	0	1	1	12
Voss et al.[45]	1	1	0	1	0	1	0	1	0	1	1	1	1	1	1	11
Wang et al.[46]	1	1	0	1	0	0	1	1	0	1	1	1	0	1	1	10
Warren et al.[60]	1	1	1	1	0	1	1	1	0	1	1	1	1	1	1	13
Sum	23	23	11	22	6	16	14	22	6	23	23	23	5	23	23	11.4

Note: Overall TESTEX score (maximum 15 points)—higher scores indicate lower risk of bias. The summarized overall score is presented as a mean value. Criterion, study quality: 1, Eligibility; 2, Randomization; 3, Allocation concealed; 4, Groups similar at baseline and 5, Blinding of assessors. Criterion, study reporting: 6a, Outcome measures assessed >85% of participants; 6b, Reporting of adverse events; 6c, Reporting of attendance; 7, Intention-to-treat analysis; 8a, Reporting of between-group statistical comparisons for the primary outcome; 8b, Reporting of between-group statistical comparisons are reported for at least one secondary outcome; 9, Reporting of point estimates and measures of variability; 10, Activity monitoring in the control group; 11, Relative exercise intensity remained constant; 12, Exercise volume and energy expenditure can be calculated. (9) 1 point is given if an increase in intensity, session duration or frequency is reported or the relative exercise intensity is controlled and reported. (10) Any reporting on activity monitoring results in passive or active control participants, provided they are clearly defined as the "control group", earns a point.

4 | DISCUSSION

The main findings of the present systematic review and meta-analysis revealed no strong evidence to indicate significant differences in the effectiveness of moderate- versus high-intensity aerobic exercise interventions in improving $\dot{V}O_2$peak among older adults, taking into account the total exercise volume completed. When stratified by intensity, both moderate- and high-intensity exercise groups showed a moderate-to-large positive effect on $\dot{V}O_2$peak.

The sub-group analyses revealed no differences in $\dot{V}O_2$peak improvements among exercise groups with different session frequencies, exercise methods, exercise modalities, and intensity monitoring strategies. Moreover, no association was observed between weekly exercise duration and volume completed with improvement in $\dot{V}O_2$peak. Interestingly, a negative association was found between the session and intervention duration of the exercise groups and improvements in $\dot{V}O_2$peak, indicating that shorter session and intervention durations may lead to larger improvements in CRF in older adults.

TABLE 4 Pooled effects of aerobic exercise on $\dot{V}O_2$peak in older adults.

	n	Effect size, *g* (95% CI)	I^2	Between-group difference (*p*-value)
Intensity group				0.26
Moderate	7	0.60 (0.28; 0.92)	49.36*	
High	12	0.82 (0.61; 1.02)	15.73	
Overall	19	0.75 (0.58; 0.93)	40.83*	
Sub-group analyses				
Frequency				0.15
2	3	0.77 (0.44; 1.10)	19.60	
3	11	0.84 (0.58; 1.11)	46.66*	
4–5	5	0.38 (−0.01;0.76)	23.81	
Exercise method				0.08
MICT	6	0.47 (0.31; 0.95)	11.78	
HICT	9	0.78 (0.37; 0.90)	33.01	
HIIT	3	0.88 (0.34; 1.17)	0.00	
Exercise modality				0.40
Walking/running	10	0.77 (0.42; 1.12)	52.91*	
Cycling	8	0.60 (0.42; 0.77)	0.00	
Intensity monitoring				0.13
Subjective (RPE)	2	1.08 (0.74; 1.42)	0.29	
Objective (HR, watts)	13	0.72 (0.44; 1.00)	45.49*	
Combination	4	0.64 (0.37; 0.91)	0.00	
Meta-regression		***β*-value [95% CI]**	***Z*-value**	***p*-value**
Session duration (min)	19	−0.018 [−0.036; −0.001]	−2.05	0.04*
Completed weekly duration (min)	19	−0.004 [−0.008; 0.001]	−1.66	0.10
Completed volume (MET-min/week)	19	−0.001 [−0.001; 0.000]	−1.39	0.17
Intervention duration (weeks)	19	−0.017 [−0.033; −0.002]	−2.15	0.03*

Note: $^*p < 0.05$.

Abbreviations: CI, confidence interval; *g*, the Hedges' *g* statistics; HICT, high-intensity continuous training; HIIT, high-intensity interval training; I^2, heterogeneity; MET's, metabolic equivalents; MICT, moderate-intensity continuous training; *n*, number of exercise groups included in the analysis.

The results of this meta-analysis align with the consensus of previous findings, affirming the effect of both moderate- and high-intensity aerobic exercise in enhancing $\dot{V}O_2$peak in older adults.[25,34] Notably, in studies comparing moderate- versus high-intensity groups, the results are less favorable towards high-intensity aerobic exercise compared to previous findings (Figure 3). In the meta-analyses by Bouaziz et al.[25] and Poon et al.,[34] they demonstrate a superiority of HIIT over MICT in improving $\dot{V}O_2$peak in older adults and middle-aged to older adults, respectively. However, it should be noted that in the present study, the high-intensity group in the direct comparison analysis consisted of four studies performing HICT and three performing HIIT. This composition renders the analysis not directly comparable to the studies of Bouaziz et al.[25] and Poon et al.,[34] who compared HIIT against MICT. Nevertheless, the prescribed exercise intensity was similar across studies, ensuring comparability in terms of exercise intensity. In addition, the classification of the exercise intensity groups in the present study was based on the reported achieved intensity, enhancing the accuracy of group comparisons and reducing the possibility of comparing overlapping intensity groups.

Moreover, the meta-regression analysis in the present study, based on effect size estimations between exercise- and control groups (Figure 2), revealed no strong evidence to indicate significant differences in the effectiveness of moderate- versus high-intensity aerobic exercise interventions in improving $\dot{V}O_2$peak among older adults, taking into account the total exercise volume completed. These findings do not directly contradict results from Bouaziz et al.[25] and Poon et al.[34] but are less supportive of the possibility that high-intensity exercise is superior for improving $\dot{V}O_2$peak. This insight is particularly intriguing as it challenges the prevailing belief that high-intensity exercise is superior to moderate-intensity exercise.[25,34] The findings could have significant implications for exercise prescription, particularly for older adults who may find high-intensity exercise challenging or unappealing. Low-to-moderate-intensity exercise can enhance perceived pleasure due to the neuroendocrine response, whereas high-intensity exercises could be predominantly associated with feelings of displeasure.[64] Moreover, this sense of displeasure can continue in the post-exercise affective response, often overpowering the usual positive affective rebound related to the neuroendocrine response typically experienced post-exercise.[64,65] However, it is important to note that several studies have reported comparable or greater exercise enjoyment with HIIT than with MICT, indicating a potential preference for high-intensity exercise among some individuals.[66-68] Furthermore, HIIT has been described as a "time-efficient" exercise alternative, addressing a common barrier to exercise participation, namely the perceived lack of time.[69,70] Along these lines, HIIT can potentially induce CRF improvements similar to MICT with less time commitment. Therefore, the findings do not undermine the value of high-intensity exercise but rather reposition it as more equally effective as moderate-intensity exercise when considering improvements in $\dot{V}O_2$peak, provided the total exercise volume remains the same.

The findings of this meta-regression should be interpreted in the context of the inherent heterogeneity in CRF responses to exercise interventions, also known as the "trainability" of an individual. Notably, the variability in responses can be significant; some individuals show substantial improvements in CRF, often referred to as "responders," while others, known as "low-responders," show minimal or no improvements following the same apparent exercise training stimulus.[71] Our findings may represent averages or general trends within the population, but individual responses may still largely vary. For instance, while moderate- and high-intensity exercises appear more equally effective on average, individual responses may still vary depending on factors such as genetics/heredity, baseline phenotype, the homeostatic stress of each training session, training status, psychological stress, sleep, habitual physical activity, and nutrition, potentially affecting the overall results.[72] In a study by Byrd et al.,[73] individualized exercise prescriptions combining MICT and HIIT elicited significantly greater improvements in $\dot{V}O_2$max and reduced inter-individual variation compared to standardized MICT alone, highlighting the potential benefits of personalized MICT and HIIT regimens in addressing the issue of low-responders. The findings of the present meta-analysis revealed a more extensive spread in the $\dot{V}O_2$peak improvements among exercise groups in the moderate-intensity group compared to the high-intensity group, with significant heterogeneity observed only in the former (Table 4). Considering the inherent variability in CRF responses to exercise interventions, these results align with a study by Williams et al.,[71] who found that high-volume HIIT produced a higher percentage of responders (31%) compared to MICT (21%) when considering both the technical error of measurement (i.e., coefficient of variation of 5.6%) and the minimal clinically important difference (i.e., 3.5 mL/kg/min). Therefore, despite the fact that moderate- and high-intensity aerobic exercise can lead to similar $\dot{V}O_2$peak improvements, high-intensity aerobic exercise appears to induce more homogeneous improvements and, therefore, is an important consideration for the prescription of exercise in this (and any) population.

Although some may interpret the increases in $\dot{V}O_2$peak after moderate- and high-intensity exercises as relatively small, it is important to recognize the significant potential of these improvements. Viewing the results through the lens of individual health implications rather than just statistical significance reveals their actual value. For instance, in a study of 6213 men who underwent treadmill exercise testing and were monitored for an average of 6.2 ± 3.7 years, each 1-MET increase in exercise capacity led to a 12% improvement in survival.[74] MET is a convenient measure of $\dot{V}O_2$ levels, set against the resting $\dot{V}O_2$ consumption of 3.5 mL/kg/min.[75] In the present study, the average increase in $\dot{V}O_2$peak for the high-intensity group was 2.8 ± 1.6 mL/kg/min (~12%), equivalent to a gain of 0.8 METs, compared to the moderate-intensity group that saw an average increase in $\dot{V}O_2$peak of 2.1 ± 1.5 mL/kg/min (~9%), equivalent to a gain of 0.6 METs. These increases have substantial implications, especially when considering the protective role of fitness against cardio- and cerebrovascular disease associated with aging.[76] Thus, given the crucial role of CRF as a modifiable risk factor, identifying effective strategies to enhance $\dot{V}O_2$peak should be a health priority, particularly for older adults.[54]

Across the 18 RCTs included in the present meta-analysis, the moderate- and high-intensity groups exhibited heterogeneity in terms of the mean weekly exercise duration and volume completed. Despite this, on average, the two groups were quite similar, with mean weekly exercise duration and volume of ~114 min and ~483 MET minutes per week in the moderate-intensity group and ~111 min and ~549 MET minutes in the high-intensity group.

Based on the meta-regression sub-analysis, no association was observed between weekly exercise duration and volume completed with improvement in $\dot{V}O_2$peak, indicating that the exercise groups with a higher exercise volume did not seem to have a superior improvement in $\dot{V}O_2$peak. The findings correspond with a meta-analysis by

Scribbans et al.,[77] who discovered no association between either session dose or total exercise volume and $\dot{V}O_2$peak improvements in healthy young adults. As described by the authors, these findings could be due to the homogeneity of the effect sizes for the studies evaluated, making it difficult to distinguish differences. Notably, the regression model in the present study seemed skewed by two studies[49,60] prescribing extensive interventions with high volumes, potentially leading to overtraining among the participants. However, on average, an exercise volume ranging from ~250 to ~700 MET minutes per week seemed to promote a similar improvement in $\dot{V}O_2$peak in older adults, even when accounting for the intensity classification and intervention duration. The lower range of this exercise volume corresponds to ~70 min per week of moderate-intensity exercise or ~40 min per week of high-intensity exercise.

Contrary to current guideline recommendations of at least 150 minutes of moderate-intensity aerobic exercise or 75 min of high-intensity exercise per week, or a mix of the two,[15] the findings of the present meta-regression highlight that significant improvements in CRF can be made with considerably less exercise volume if performed systematically over time. These findings agree with those by Bouaziz et al.,[25] who also discovered that substantial gains in CRF could be obtained in older adults with a lower than recommended moderate-intensity training session frequency. However, it is essential to acknowledge that although higher $\dot{V}O_2$peak levels are associated with decreased risks of cardiovascular disease and premature mortality,[78-81] it represents merely one among many health markers for older adults. As shown in a meta-analysis by Ekelund et al.,[82] maximal risk reductions in premature mortality occurred at about 24 min per day of moderate-to-vigorous intensity physical activity, supporting current recommendations.

Our analysis further revealed an interesting association between shorter session durations and improvements in $\dot{V}O_2$peak, which is inconsistent with the findings of a meta-analysis conducted by Huang et al.[24] This earlier study observed a dose–response relationship between increasing session duration and $\dot{V}O_2$peak in healthy older adults (67.4 ± 5.3 years) engaged in aerobic exercise. The contradiction between these findings may be attributable to various factors, including individual variations in the homeostatic stress associated with each training session.[72] Such differences could lead to varying exercise stimuli experienced by individuals, subsequently contributing to diverse adaptive responses throughout the training program. Additionally, recovery intervals between sessions in a standardized training program could differ among individuals due to training status, sleep patterns, psychological stress, and habitual physical activity levels.[72] When an imbalance arises between overall stress and recovery, individuals could experience fatigue, impaired adaptations, and even overtraining, thus contributing to variations in pre- and post-training responses.[72] Nevertheless, the findings raise intriguing questions about the optimal duration of exercise sessions for enhancing $\dot{V}O_2$peak in different populations.

In this meta-regression analysis, the greatest improvements in $\dot{V}O_2$peak were associated with exercise session durations of approximately 27.5 min. However, it is noteworthy that when accounting for the duration of the overall intervention, there was no significant association between session durations and improvements in $\dot{V}O_2$peak. This observation indicates that the overall duration of the intervention might be a critical factor influencing the efficacy of the exercise program. Furthermore, Huang et al.[24] reported a ceiling effect in their study, noting that the gain in $\dot{V}O_2$peak did not increase further after approximately 45 min of exercise per session. This indicates that there may be a threshold for session duration beyond which no additional benefits to $\dot{V}O_2$peak are seen.

The finding of less improvement in $\dot{V}O_2$peak in interventions with longer durations may be attributed to potentially lower adherence rates in longer-lasting exercise interventions.[83] However, in the context of this meta-analysis, all included studies controlled and reported the achieved exercise intensity, and all except one[55] reported an attendance or adherence rate of ≥80%. This indicates that participants in interventions with longer durations were still adhering to the exercise programs and in fact further supported by the observation that the completed weekly exercise volume was higher in interventions with extended durations (≥16 weeks = ~551 MET min per week versus ≤12 weeks = ~420 MET min per week). Notably, the regression model seemed skewed by the one study[49] reporting a negative $\dot{V}O_2$peak change following the intervention. This particular study also prescribed an extensive intervention with high volume, a previously discussed factor that could potentially explain the diminished $\dot{V}O_2$peak improvement. Importantly, when this study was excluded from the regression model, the negative association between intervention duration and $\dot{V}O_2$peak improvements was no longer present. Therefore, the findings could indicate that the physiological stimulus of aerobic exercise may become less effective at enhancing $\dot{V}O_2$peak in longer-lasting interventions.

Finally, there were no significant differences in $\dot{V}O_2$peak improvements among the exercise groups using various exercise methods, exercise modalities, and intensity monitoring strategies. These findings implies that the act of engaging in regular aerobic exercise itself, irrespective of the specific approach taken, provides the primary benefits to CRF.[84] Furthermore, this versatility of exercise methods and modalities can make physical activity more accessible and adaptable to individuals' preferences and circumstances, potentially improving adherence and long-term health outcomes.

4.1 | Strengths and limitations

The present study has several strengths, including systematic searches of three extensive databases and a specific focus on older adults from all lifestyle backgrounds, BMIs, and health statuses. We exclusively incorporated interventions with aerobic components; each reporting achieved intensity or adherence to exercise prescriptions. We used meta-regression analysis to investigate the relationship between exercise intensity and improvements in $\dot{V}O_2$peak, accounting for completed exercise volume. Our study also systematically investigated the role of FITT factors, along with exercise methods, modalities, and intensity-controlling methods. Furthermore, we restricted our inclusion to studies that conducted direct and indirect assessments of $\dot{V}O_2$peak to maximal exhaustion, strengthening the study's internal validity. In addition, we included only studies with a direct link between the test procedure and the intervention, such as a treadmill test paired with a walking or running intervention. Lastly, we conducted a quality assessment of the included RCTs and successfully calculated the completed weekly exercise volume in all included studies, adding to the study's robustness.

Several important limitations should, however, be noted. First, the heterogeneity among studies was moderate, possibly due to the diversity of sample sizes, characteristics of exercise methods and modalities, and various protocols used to assess $\dot{V}O_2$peak. Second, the number of studies included in the present meta-analysis to investigate differences in intervention characteristics, FITT factors, and associations with changes in $\dot{V}O_2$peak was relatively small. Moreover, potential bias might arise from the studies with smaller sample sizes, as significant changes may be more prominent due to individual variations rather than the overarching effectiveness of the exercise intervention. Lastly, using rigid cut-off values to define exercise intensity groups could lead to comparisons between studies with minor intensity differences when near the cut-off value. However, the cut-off values were based on the reported achieved intensity, making the comparison more robust.

5 | CONCLUSION

This systematic review and meta-analysis yield valuable insights into the relationship between aerobic exercise intensity and CRF improvements, measured by $\dot{V}O_2$peak, in older adults. Our findings challenge the notion that high-intensity exercise is inherently superior, as no strong evidence indicated significant differences in the effectiveness of moderate- versus high-intensity aerobic exercise interventions in improving $\dot{V}O_2$peak among older adults, taking into account the total exercise volume completed. Notably, considering the inherent variability in CRF responses to exercise interventions, high-intensity aerobic exercise appears to induce more homogeneous improvements. Consequently, the findings indicate that high-intensity aerobic exercise could be required for some individuals to enhance CRF. Furthermore, substantial CRF improvements can be achieved with exercise volumes lower than current recommendations, given that they are performed systematically over time. Finally, no significant differences in $\dot{V}O_2$peak improvements were found across exercise groups employing various methods, modalities, and intensity monitoring strategies. These findings indicate that regular aerobic exercise, irrespective of the specific approach and intensity, provides the primary benefits to CRF in older adults.

Future RCTs should prioritize reliable methodologies for monitoring and reporting exercise volume and adherence among older adults. These trials should develop strategies to promote adherence during and after interventions, with a particular focus on the post-intervention phase. Furthermore, integrating qualitative research methods can provide valuable insights into the subjective experiences of older adults, helping identify barriers and facilitators to exercise adherence. This information can inform the development of strategies to enhance engagement and ensure the long-term sustainability of exercise behaviors beyond the intervention period.

6 | PERSPECTIVES

For practitioners and policymakers, these findings highlight that it may be possible to achieve substantial improvements in CRF in older adults with exercise volumes lower than those currently recommended. Moreover, whether the exercise intensity is moderate or high, these improvements can be obtained, provided the total exercise volume is taken into account. This has significant implications for the formulation of exercise guidelines for older adults, and it provides more flexibility for tailoring exercise regimens to individual needs and capacities.

However, when recommending exercise regimens for older adults, it is also important to consider factors beyond $\dot{V}O_2$peak, such as the risk of injury, the enjoyment of the exercise, and the individual's overall health and fitness levels. Regular monitoring and adjustment of exercise regimens based on individual responses and preferences could further enhance adherence and effectiveness. Collectively, these findings can help to guide the development of more effective, inclusive, and individualized exercise interventions for older adults, ultimately promoting healthier and more active aging.

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The authors have no conflicts of interest relevant to this article to disclose.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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