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Effect of aerobic exercise on waist circumference in adults with overweight or obesity: A systematic review and meta-analysis

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Summary

Excess visceral adiposity contributes to elevated cardiometabolic risk, and waist circumference is commonly used as a surrogate measure of visceral adipose tissue. Although regular aerobic exercise is known to improve abdominal obesity, its effect on waist circumference is unclear. A systematic review and meta-analysis was performed to determine (1) the effect of aerobic exercise on waist circumference in adults with overweight or obesity; (2) the association between any change in waist circumference and change in visceral adipose tissue and/or bodyweight with aerobic exercise interventions; and (3) if reductions in waist circumference with exercise are moderated by clinical characteristics or components of aerobic exercise prescription. Twenty-five randomized controlled trials (1686 participants) were included. Regular aerobic exercise significantly reduced waist circumference by 3.2 cm (95% confidence interval [CI] −3.86, −2.51, $p \leq 0.001$) versus control. Change in waist circumference was associated with change in visceral adipose tissue ($\beta = 4.02$; 95% CI 1.37, 6.66, $p = 0.004$), and vigorous intensity produced superior reduction (−4.2 cm, 95% CI −4.99, −3.42, $p < 0.0001$) in waist circumference compared with moderate intensity (−2.50 cm, 95% CI −3.22, −1.79, $p = 0.058$). These findings suggest regular aerobic exercise results in modest reductions in waist circumference and associated

Abbreviations: ACSM, American College of Sports Medicine; AEx, aerobic exercise; BW, bodyweight; CON, control group; CRF, cardiorespiratory fitness; CT, computed tomography; ESSA, Exercise and Sport Science Australia; FITT, frequency, intensity, time, type; GRADE, Grading of Recommendations, Assessment, Development and Evaluations; HIIT, high-intensity interval training; HR_{max}, maximum heart rate; HR_{peak}, peak heart rate; HRR, heart rate reserve; IL-6, interleukin-6; METs, metabolic equivalents; MOD, moderate intensity; MRI, magnetic resonance imaging; PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-analyses; PROSPERO, International Prospective Register of Systematic Reviews; RCT, randomized controlled trial; REML, restricted maximum-likelihood estimation; REx, resistance exercise; RMD, raw mean difference; RoB, Risk of Bias; RPE, rate of perceived exertion; TNF-α, tumor necrosis factor-alpha; VAT, visceral adipose tissue; VIG, vigorous intensity; VO_{2max}, maximum oxygen uptake; VO_{2peak}, peak oxygen uptake; WC, waist circumference.

visceral adipose tissue and that higher intensity exercise may offer superior benefit to moderate intensity.

KEYWORDS
abdominal obesity, physical activity, visceral adiposity, weight loss

1 | INTRODUCTION

Obesity is a threat to global population health, both in prevalence and in disease burden. Recent estimates suggest that over 2 billion people have overweight or obesity.[1] People with overweight or obesity have an elevated cardiovascular[2,3] and metabolic disease,[4] musculoskeletal,[5–7] and cancer risk profile.[8–10] However, evidence suggests that abdominal obesity, specifically excess adipose tissue stored around the viscera as visceral adipose tissue (VAT), is a stronger predictor of cardiovascular[11] and metabolic[12] morbidity and mortality than obesity.[13] Mechanisms proposed for the increased risk of morbidity and mortality include maladaptive changes to macrophages, reduced production of anti-inflammatory adipokines (e.g., adiponectin), an increase in inflammatory cytokines (e.g., tumor necrosis factor-alpha [TNF-α] and interleukin-6 [IL-6]), and abnormal hypertrophy of adipocytes, all contributing to an inflammatory state.[14]

Clinically, magnetic resonance imaging (MRI) and computed tomography (CT) imaging remain the most valid estimates of abdominal adiposity and VAT.[15–19] However, these imaging resources are rarely available to health professionals outside of research settings. Therefore, waist circumference (WC) is commonly used as a surrogate measure for VAT[20,21] and, as such, makes changes in inferred abdominal adiposity and VAT more feasible outcomes to monitor clinically.

Several treatment approaches exist to reduce bodyweight (BW) or VAT. Surgery[22,23] and pharmaceutical therapy[24] are considered suitable, particularly for individuals with morbid obesity and/or comorbidities. However, cost, healthcare coverage,[25] and safety concerns[26] are common barriers to their uptake. Evidence shows that lifestyle modification, through diet and/or exercise, is effective for reducing BW and VAT and is the first line of therapy for most people.[27]

Current obesity management guidelines emphasize the importance of exercise volume (a function of the weekly frequency and exercise bout time) rather than intensity and recommend that a minimum of 250–300 min[28,29] and as much as 300–420 min[30] of moderate–vigorous aerobic exercise (AEx) needs to be accumulated each week for meaningful weight loss in adults. Several reviews suggest that a reduction in energy intake[31] and/or AEx[32–36] is associated with a decrease in VAT.[37,38] In a recent review, Neeland and colleagues estimated potential VAT reductions of ∼15%–25%, when weight loss of ∼5% is achieved via such lifestyle interventions.[39]

In the absence of weight loss, a reduction of VAT through exercise alone also appears to be typical. The current evidence confirms that VAT reduction is generally achieved with regular AEx,[33–35,40,41] although the data concerning resistance exercise (REx) training are less conclusive.[34,35,41–43] Recent reviews also suggest that AEx of moderate or vigorous intensity appears efficacious for reducing VAT[41,44] and that there may also be positive effects of aerobic high-intensity interval training (HIIT) interventions,[40,41,45] suggesting that intensity of AEx may be important in determining a VAT benefit. However, the evidence to support the use of HIIT for reducing WC appears positive but remains uncertain.[46] Further, WC is frequently measured as a secondary outcome in exercise intervention studies, yet consensus on the effect of regular AEx alone on WC for individuals who are overweight or obese is yet to be reached.[30] The components of exercise (frequency, intensity, time, type [FITT]) that are important for achieving WC reduction are also unclear. This leaves health professionals without clear understanding of which components are more important when prescribing AEx for individuals managing overweight or obesity, where reduction in abdominal adiposity (particularly VAT) is the goal.

Therefore, the aim of this systematic review was to determine (1) the effect of regular AEx on WC in adults with overweight or obesity; (2) the association between any change in WC and change in VAT and/or BW with exercise; and (3) if reductions in WC following exercise are moderated by clinical characteristics or components of AEx prescription.

2 | METHODS

This review is reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) (2009) statement guidelines[47] and was registered via the International Prospective Register of Systematic Reviews (PROSPERO). Minor revisions were made to the initial PROSPERO protocol, submitted in December 2021, which were not available at the time of submission (see Supporting Information S1).

A systematic search of five online databases (Medline, Embase, Cochrane [via OvidSP], Scopus, and SPORTDiscus) was conducted from the earliest record until March 10, 2021. Search terms and MeSH headings relating to "obesity," "aerobic exercise," "weight loss," "waist circumference," and "visceral adiposity" were combined (see Supporting Information S2 for all search strategies used). Search results were compiled for duplicate removal using EndNote (Version X9.3.2, Thompson Reuters, San Francisco, CA), before importation into Covidence (v1636) for title/abstract screening. This systematic review was limited to randomized controlled trials (RCTs) in human adults, with no language restrictions. Reference lists of all included papers and relevant reviews were manually searched for potentially eligible studies.

2.1 | Inclusion and exclusion criteria

2.1.1 | Inclusion

Population

Adults (female and male: ≥18 years): overweight (Caucasian: body mass index [BMI] 25–29.9 kg/m^2; Asian and South Asian: BMI ≥ 23–24.9 kg/m^2)[48] or obese (Caucasian: BMI ≥ 30 kg/m^2; Asian and South Asian: BMI ≥ 25 kg/m^2).[48]

Intervention/s

Studies were eligible for inclusion if they included an AEx only intervention of ≥8-week duration. Interventions had to be structured, either supervised (i.e., research center and gym based) OR unsupervised (e.g., self-directed).

Comparator

Comparator groups, at minimum, required an inactive OR unchanged activity-level control group. Trials, including a specific dietary intervention (i.e., low carbohydrate), were only included if the diet was not given to the AEx and control groups (i.e., Diet and AEx vs. AEx vs. CON). However, studies attempting to standardize participant energy intake using an isocaloric diet were included. Control groups with sham/placebo exercise were also included, whereby the exercise stimulus provided was not sufficient to produce physiological changes.

Outcomes

For inclusion, studies must have included WC[20] and at least one direct measure of visceral adiposity,[49] that is, MRI[50] or CT.[51]

2.1.2 | Exclusion

Trials were excluded if participants were less than 18 years of age; had a BMI of "normal" weight (Caucasian: BMI 18.5–24.9 kg/m^2 or Asian and South Asian: BMI 18.5–22.9 kg/m^2)[48] or "underweight" (Caucasian: BMI < 18.5 kg/m^2 or Asian and South Asian: BMI < 18.5 kg/m^2)[48]; were allocated to a REx alone OR combined AEx and REx exercise intervention, where there was no "AEx" only AND "CON" group; or were receiving a structured dietary intervention for the duration of the study for purpose of an alternative intervention group (i.e., "diet" vs. "AEx"). Studies where participants received "diet" versus "diet + AEx" intervention; a surgical intervention (i.e., bariatric surgery); or drug therapy (including supplementation) as part of an intervention group were also excluded. Studies were not excluded if participants were taking pre-prescribed medication, unless it was known to interfere in one of the primary outcomes (i.e., anti-retroviral drugs).

2.2 | Study selection

The initial search was completed by one reviewer (AA). Duplicate removal was completed independently by two researchers (AA and KJR). Title/abstract and full-text screening were conducted independently by one reviewer (AA). Uncertainty or disagreement during the study screening and selection process was resolved by discussion with a second (SEK) and third (NAJ) reviewer.

2.3 | Data extraction

Two researchers (AA and KJR) independently completed data extraction on pre-designed templates. Data retrieved from each study included participant characteristics (sex, age, baseline BMI, and comorbidities); exercise intervention prescription (frequency, intensity, time, modality, and intervention duration); and WC, visceral adiposity, and BW. Raw numerical data collected from each study were presented as mean, standard deviation (SD), and change scores from pre- and post-intervention. Where values were presented as standard error of the mean, confidence intervals (CIs), or interquartiles, they were converted the data to SD. Where studies contained additional intervention arm that were not included (i.e., REx), only relevant group data were extracted. Two researchers (AA and NAJ) attempted to contact authors via email for missing data.

2.4 | Risk of Bias and GRADE assessment

The Cochrane Collaboration's Risk of Bias 2[52] (RoB2) was completed independently in a blinded manner by two reviewers (AA and AS), with discrepancies reviewed by a third (SEK). Studies were graded as having "low," "some concerns," or "high" for risk of bias across five domains (randomization, deviations from intervention, missing data, outcome measurement, and selection of reported result), after which an overall bias recommendation was generated by the Risk of Bias Excel tool.

The Grading of Recommendations, Assessment, Development and Evaluations (GRADE)[53] was completed by one reviewer (AA) and reviewed by a second (SEK). A GRADE score was provided based on criteria of certainty (number of studies, study design, risk of bias, inconsistency, indirectness, imprecision, and other considerations) and summary of findings (number of patients, effect, and certainty). The GRADE assessment was conducted in accordance with the GRADE Handbook.[54]

2.5 | Effect size calculation

Raw mean difference (RMD) values were extracted where reported or when data were provided by authors. Otherwise, the RMD was calculated by subtracting the mean change in the comparator group (CON) from the mean change in the experimental condition (AEx). Standardized effect sizes for VAT were calculated by dividing the RMD by the pooled SD at baseline[55,56] and then corrected for small sample bias (Hedges' *g*).

Data from McTiernan et al. (2007), where male and female data were reported separately, were combined. Where studies used numerous re-test time-points[57,58] during the intervention, data from the later time-point were used for the analysis. No studies used a follow-up and/or maintenance period, post-intervention. For analysis, the VIG–MOD intervention group from Zhang et al. (2016)[57] was classified as MOD intensity, using the average exercise intervention intensity, and coded using the American College of Sports Medicine (ACSM) guidelines.[29]

2.6 | Meta-analysis

A random effects meta-analysis was conducted in R (Version 4.1.1., The R Foundation for Statistical Computing, 2004–2021), using the metafor package (Version 3.0-2). There were 10 studies that included multiple intervention groups compared with one control group.[58–67] Because the same participants in the control group are compared, sampling errors are dependent and thus violate the assumption of independent effects. Thus, a multilevel meta-analysis was performed with the rma.mv function, with the insertion of a random argument to group effect sizes within levels of a nesting variable (i.e., multiple effects within a study). Effects from the same level/study receive the same random effect, whereas effects from different levels/studies are assumed to be independent. A mixed effects analysis then performed to model clustering or correlation that occurs within a level of the nesting variable. A restricted maximum-likelihood estimation (REML) was used, and a "*t*" test was specified.

For the primary analysis, we compared the effect of AEx versus CON on WC, analyzed using the RMD, with variance estimated from the pooled SD. When the SDs of change scores were not reported, these were calculated using reported SE, 95% CI, or *p*-values or calculated using pre and post SDs using a correlation of 0.97 (estimated from studies where all SDs were available). Heterogeneity was assessed using *Q* statistic and I^2. The I^2 describes the percentage of variability due to heterogeneity across studies rather than sampling error (chance). Magnitude of heterogeneity was interpreted in accordance with recommendations from the Cochrane handbook.[68] The multilevel method allows for the estimation of heterogeneity at three levels: (1) at the participant level, (2) within studies, and (3) between studies. Publication bias was evaluated using a visual assessment of funnel plots (see Supporting Information S3 and S4). Consequentially, no studies were removed from the analysis. A *p*-value of <0.05 was considered statistically significant.

2.7 | Moderator analysis

Potential moderators were selected a priori based on empirical or logical rationale as to why they may moderate the effect of exercise on WC. Baseline age (years), BMI (kg/m^2), and cardiorespiratory fitness (CRF) (ml/kg/min) were entered as continuous variables. The moderating effect of sex was investigated as a binary variable in 14 studies that recruited women ($n = 9$)[61,63,66,67,69–74] or men ($n = 4$)[59,75–77] only. To investigate intervention characteristics, intensity was coded as "moderate" or "vigorous" according to the ACSM guidelines[29] using the intensity during the final week of training. Frequency was entered in days per week, whereas weekly total volume was calculated as the intended volume in the final week (final week frequency × session duration). Intervention duration was calculated in weeks, where any interventions reported in months were converted on the assumption that 1 month = 4 weeks. The moderating effects for change in BW (RMD) and change in VAT (standardized mean difference) were analyzed in univariable meta-regression models. For the moderator analysis of "change in VAT," L4/L5 VAT was used for data from Heydari et al. (2012),[75] and for Ross et al. (2004),[73] VAT area (cm^2) was used instead of volume.

VAT data were extracted from Lee et al.[66] using webplotdigitizer, whereas RMD for Jung et al. (2014)[71] was calculated using the reported percentage change. BW data were reported as median and interquartile range in one study,[69] which was excluded from BW calculations. Data from Blond et al.[58] were excluded from the calculation of SMD, as baseline SDs were not available. Data from Ross et al. (2000)[77] and Ross et al. (2004)[73] exercise-induced weight loss groups were used for analysis.

2.8 | Subgroup analyses

Due to a significant moderating effect of exercise intensity, two subgroup analyses were performed post hoc. First, the weighted mean difference for moderate and vigorous intensities was calculated as described above. Finally, where studies allowed for a direct comparison between moderate and vigorous intensities, a meta-analysis was performed to test for a direct effect of exercise intensity on WC.

3 | RESULTS

3.1 | Included studies

See Supprting Information S5 for the PRISMA flow chart. Once duplicates were removed, and all screening completed, 17 studies remained. An additional eight studies[63,66,69,74,78–81] were sourced from other reviews, taking the total to 25 RCTs. Two initially included studies[82,83] were excluded during data extraction, as we did not receive a response from the authors regarding missing data required for the primary outcome (WC). One other study[84] was excluded as it was a sub-study of one of the included studies,[79] where the primary and secondary outcomes were previously reported.

3.2 | Risk of Bias

See Figure S1 for overall summary and Figure S3 for individual studies of RoB2. High risk of bias was present across numerous studies due to a lack of blinding assessors to group allocation for the primary outcome (WC). There were some concerns of bias regarding details of randomization missing for numerous studies and a lack of detail around prior planned statistical analysis.

3.3 | GRADE assessment

See Figure 1 for summary of GRADE recommendations. [Correction added on 3 June 2022, after first online publication: The figure number citation in the preceding sentence was updated from 'S5' to '1'.] Overall, we graded the evidence with "low" certainty. Reasons for downgrading the certainty were based on a "serious" for risk of bias (multiple studies providing allocation concealment and lack of blinding to the primary WC outcome), inconsistency (high heterogeneity present [>75%][54] in the primary and sub-set analysis and variation in patient clinical characteristics), and imprecision (small sample sizes [total $n \le 300$] in most individual studies, and some individual studies had CIs overlapping line of "no effect" and/or wide CIs).

3.4 | Participant characteristics

A summary of participant characteristics is detailed in Table 1. Across all 25 studies, 1686 participants were recruited (AEx groups = 1019; CON = 699). Ten studies exclusively recruited females,[61,63,66,67,69–74] another four studies only recruited males,[59,75–77] and the remaining 11 studies recruited a combination of females and males.[57,58,60,62,64,65,78–81,85] Eight studies[57,63,66,67,69,71,72,74] specifically recruited participants of Asian ethnicities. Thirteen studies recruited otherwise apparently healthy participants with abdominal obesity.[58,60,65–67,70,72,73,75,76,78,80,85] Twelve studies recruited participants with existing comorbidities of type 2 diabetes,[63,64,69,71,74,81] non-alcoholic fatty liver disease,[57,79] metabolic syndrome,[61,62] non-dialyzed chronic kidney disease,[59] and hyperlipidemia.[77]

3.5 | Exercise characteristics

See Table 2 for a detailed summary of exercise intervention characteristics.

Exercise frequency varied from 3 to 7 days, with the 5 being the most commonly used (7/25 studies). Six studies[58,61,62,66,79,80] progressed the exercise frequency throughout the intervention (e.g., completed 3 days initially and progressively increased to 5 days by the end of the intervention). One study[65] had two different frequencies across three intervention arms (e.g., used 3 days/week in two intervention groups and 4 days in another). Overall, intensity measures were highly heterogeneous, using percentage of maximum oxygen uptake (%VO_{2max}), %$VO_{2peak\text{-}reserve}$, percentage of peak oxygen uptake (%VO_{2peak}), metabolic equivalents (METs), percentage of maximum heart rate (%HR_{max}), %heart rate reserve (HRR), %heart rate peak (HR_{peak}), and rate of perceived exertion (RPE). %HR_{max} (9/25 studies), METs (5/25 studies), and %VO_{2max} (3/25 studies) were the most commonly used units to prescribe exercise intensity. Three

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Question: Aerobic exercise compared to Control for waist circumference in human adults with overweight/obesity
Setting: Adults with overweight or obesity
Bibliography:

Certainty assessment							№ of patients		Effect		Certainty	Importance
№ of studies	Study design	Risk of bias	Inconsistency	Indirectness	Imprecision	Other considerations	Aerobic exercise	Control	Relative (95% CI)	Absolute (95% CI)		
Waist circumference (assessed with: Tape measure (cm))												
25	randomised trials	serious[a,b,c]	serious[d,e,f]	not serious[g,h,i,j]	serious[k,l]	strong association	1019	699	-	MD **3.2 cm lower** (3.87 lower to 2.52 lower)	⨁⨁◯◯ Low	IMPORTANT

CI: confidence interval; **MD:** mean difference

Explanations

a. Detection bias: Very few studies report blinding of assessors for the primary study outcome (wc).
b. Allocation bias: Most studies had a high risk of bias from not blinding participants, however, exercise studies are known to be harder to blind from.
c. Selection bias: Several studies were higher risk, due to not providing information about blinding of allocation concealment.
d. High heterogeneity (I2) present in the primary (AEX vs CON), and sub-set (MOD vs CON; VIG vs CON; MOD vs VIG) analysis.
e. Large variation in effect sizes between studies. Potentially explained by study samples, sample sizing, and intervention differences.
f. Confidence intervals overlapping in most studies.
g. Variety of age groups included.
h. Both male and female study participants included.
i. Participants in multiple studies had comorbidities, however this is typically quite common for people managing overweight or obesity.
j. Variety of intervention design (e.g., most studies prescribed within the current ACSM (2020) guidelines for overweight + obesity, but different FITT variables).
k. Most studies had small sample sizes.
l. Within study results sometimes had wide confidence intervals. However, overall result the CI is smaller.

FIGURE 1 Figure 1 Summary of GRADE recommendations [Correction added on 3 June 2022, after first online publication: Figure 1 has been moved earlier in the article and has a new caption.]

TABLE 1 Participant characteristics

Study	Participants	Sample (*n*)	Sex (F/M)	Age (mean ± SD)	BMI (kg/m^2) (mean ± SD)
Baria 2014	Men; non-dialyzed chronic kidney disease (Stages 3 and 4) and overweight	MOD[A]: 10 MOD[B]: 8 CON: 9	MOD[A]: 0/10 MOD[B]: 0/8 CON: 0/9	MOD[A]: 52.1 ± 11.4 MOD[B]: 50.8 ± 7.7 CON: 53.4 ± 9.6	MOD[A]: 30.8 ± 5.1 MOD[B]: 30.9 ± 3.9 CON: 29.6 ± 1.9
Blond 2019	Adults; healthy, physically inactive, overweight, or obese	CON: 14 MOD: 31 VIG: 24	CON: 6/8 MOD: 14/17 VIG: 12/12	CON: 35 ± 7 MOD: 32 ± 7 VIG: 36 ± 7	CON: 30.1 ± 2.9 MOD: 29.1 ± 2.0 VIG: 29.8 ± 2.5
Choi 2012	Asian women; sedentary, type 2 diabetes	MOD: 38 CON: 37	MOD: 38/0 CON: 37/0	MOD: 53.8 ± 7.2 CON: 55.0 ± 6.0	Total: 26.8 ± 2.4[a]
Cowan 2018	Adults; abdominal obesity, sedentary	MOD[C]: 24 MOD[D]: 31 VIG: 30 CON: 20	MOD[C]: 14/10 MOD[D]: 20/11 VIG: 19/11 CON: 10/10	MOD[C]: 52.5 ± 8.0 MOD[D]: 51.8 ± 8.3 VIG: 52.8 ± 7.4 CON: 55.1 ± 6.6	MOD[C]: 33.2 ± 4.3 MOD[D]: 32.6 ± 4.1 VIG: 32.5 ± 3.7 CON: 30.5 ± 3.6
DiPietro 1998	Healthy; older adults	MOD: 9 CON: 7	MOD: 7/2 CON: 6/1	MOD: 72 ± 3 CON: 73 ± 5.3	MOD: 27.5 ± 8.1 CON: 26.8 ± 4.5
Friedenreich 2011	Women; post-menopause, sedentary, weight range: normal to obese	VIG: 155 CON: 156	VIG: 155/0 CON: 156/0	VIG: 61.2 ± 5.4 CON: 60.6 ± 5.7	VIG: 29.1 ± 4.5 CON: 29.2 ± 4.3
Heydari 2012	Young men; inactive, overweight	HIIT: 20 CON: 18	HIIT: 0/20 CON: 0/18	HIIT: 24.7 ± 24 CON: 25.1 ± 17.9	HIIT: 28.4 ± 2.5 CON: 29 ± 4.1
Irving 2008	Middle-aged women; obese, metabolic syndrome, sedentary	CON: 7 MOD: 11 VIG: 9	CON: 7/0 MOD: 11/0 VIG: 9/0	Total sample: 51 ± 9	CON: 32.7 ± 3.8 MOD: 34.7 ± 7.5 VIG: 34.7 ± 6.8
Irving 2009	Middle-aged adults; sedentary, obese, metabolic syndrome	CON: 10 MOD: 13 VIG: 11	CON: 6/4 MOD: 10/3 VIG: 8/3	CON: 49.2 ± 15.2 MOD: 49.2 ± 6.5 VIG: 49.0 ± 9.6	CON: 32.0 ± 3.5 MOD: 35.5 ± 7.9 VIG: 34.2 ± 6.0
Jung 2012	Overweight women; type 2 diabetes	CON: 12 MOD: 8 VIG: 8	CON: 12/0 MOD: 8/0 VIG: 8/0	CON: 55.5 ± 7.6 MOD: 56.8 ± 8.2 VIG: 48.4 ± 6.1	CON: 27.7 ± 3.4[a] MOD: 25.5 ± 1.5[a] VIG: 25.9 ± 1.6[a]
Jung 2014	Obese women; type 2 diabetes	MOD: 17 CON: 18	MOD: 17/0 CON: 18/0	MOD: 55.4 ± 3.5 CON: 57.6 ± 3.5	MOD: 26.0 ± 1.5[a] CON: 27.2 ± 2.1[a]
Karstoft 2013	Adults; type 2 diabetes	CON: 8 MOD: 12 HIIT: 12	CON: 3/5 MOD: 4/8 HIIT: 5/7	CON: 57.1 ± 8.5 MOD: 60.8 ± 7.6 HIIT: 57.5 ± 8.3	CON: 29.7 ± 5.4 MOD: 29.9 ± 5.5 HIIT: 29.0 ± 4.5
Keating 2015	Adults; sedentary, overweight or obese	CON: 12 VIG: 12 MOD[E]: 12 MOD[F]: 12	CON: 9/3 VIG: 6/6 MOD[E]: 7/5 MOD[F]: 9/3	CON: 39.1 ± 10.0 VIG: 44.2 ± 9.7 MOD[E]: 45.5 ± 8.0 MOD[F]: 45.6 ± 12.5	CON: 32.2 ± 4.8 VIG: 36.3 ± 5.9 MOD[E]: 33.9 ± 3.1 MOD[F]: 31.3 ± 2.8
Ku 2010	Overweight Korean women with type 2 diabetes	CON: 16 MOD: 15	CON: 16/0 MOD: 15/0	CON: 57.8 ± 8.1 MOD: 55.7 ± 7.0	CON: 27.4 ± 2.8 MOD: 27.1 ± 2.4
Lee 2012	Adults; Korean women, middle-aged, “healthy,” pre-menopausal, overweight, or obese, untrained	CON: 7 MOD: 8 VIG: 7	CON: 7/0 MOD: 8/0 VIG: 7/0	CON: 38.3 ± 4.9 MOD: 41.6 ± 4.5 VIG: 41.7 ± 4.3	CON: 27.3 ± 2.7[a] MOD: 27.4 ± 2.7[a] VIG: 25.4 ± 2.7[a]
Lesser 2016	Women; post-menopause, inactive, abdominal obesity	CON: 26 VIG: 23	CON: 26/0 VIG: 23/0	CON: 57.7 ± 6.1 VIG: 56.4 ± 6.9	CON: 28.9 ± 3.5[a] VIG: 29.9 ± 3.5[a]
McTiernan 2007	Adults; sedentary	VIG: 100 CON: 102	VIG: 49/51 CON: 51/51	VIG: 54.4 ± 7.1 (F); 56.2 ± 6.7 (M)	VIG: 28.9 ± 5.5 (F); 29.7 ± 3.7 (M)

TABLE 1 (Continued)

Study	Participants	Sample (n)	Sex (F/M)	Age (mean ± SD)	BMI (kg/m^2) (mean ± SD)
				CON: 53.7 ± 5.6 (F); 56.6 ± 7.6 (M)	CON: 28.5 ± 4.8 (F); 30.1 ± 4.8 (M)
Moghadasi 2012	Middle-age men; sedentary; overweight or obese	VIG: 8	VIG: 0/8	Total sample: 41.18 ± 6.1	VIG: 30.96 ± 2.1
		CON: 8	CON: 0/8		CON: 32.03 ± 53
Pugh 2014	Adults; obese; sedentary; NAFLD	VIG: 13	VIG: 6/7	VIG: 48 (44, 51)[b]	VIG: 31 (30, 32)[b]
		CON: 8	CON: 4/4	CON: 47 (43, 51)[b]	CON: 30 (28, 31)[b]
Ross 2000	Men; obese; hyperlipidemia	VIG: 14	VIG: 0/14	VIG: 44.7 ± 7.6	VIG: 31.3 ± 2.3
		CON: 8	CON: 0/8	CON: 46.0 ± 10.9	CON: 30.7 ± 1.6
Ross 2004	Women; menopause	VIG: 12	VIG: 12/0	VIG: 41.3 ± 7.2	VIG: 32.9 ± 3.2
		CON: 10	CON: 10/0	CON: 43.7 ± 6.4	CON: 32.4 ± 2.8
Short 2003	Adults; healthy; sedentary	VIG: 41	VIG: 41	VIG: NR as group mean	VIG: 26.6 ± 2.4
		CON: 38	CON: 38	CON: NR as group mean	CON: 25.7 ± 1.8
Sigal 2007	Adults; type 2 diabetes, inactive	MOD: 60	MOD: 21/39	MOD: 53.9 ± 6.6	MOD: 35.6 ± 10.1
		CON: 63	CON: 22/41	CON: 54.8 ± 7.2	CON: 35.0 ± 9.5
Zhang 2015	Women; overweight	HIIT: 12	HIIT: 12/0	HIIT: 21.0 ± 1.0	HIIT: 25.8 ± 2.7[a]
		MOD: 12	MOD: 12/0	MOD: 20.6 ± 1.2	MOD: 26.0 ± 1.6[a]
		CON: 11	CON: 11/0	CON: 20.9 ± 1.0	CON: 25.4 ± 1.5[a]
Zhang 2016	Adults; NAFLD, central obesity	MOD: 73	MOD: 51/22	MOD: 54.4 ± 7.4	MOD: 28.1 ± 3.3[a]
		VIG–MOD: 73	VIG–MOD: 52/21	VIG–MOD: 53.2 ± 7.1	VIG–MOD: 27.9 ± 2.7
		CON: 74	CON: 46/28	CON: 54.0 ± 6.8	CON: 28.0 ± 2.7[a]

Abbreviations: BMI, body mass index; CON, control group; F, female; HIIT, high-intensity interval training group; M, male; MOD, moderate intensity group; NAFLD, non-alcoholic fatty liver disease; SD, standard deviation; VIG, vigorous intensity group.
[a]BMI (Asian ethnicities): overweight = 23.0–24.9; obese ≥ 25.0.
[b]BMI (Caucasian): overweight = 25.0–29.9; obese ≥ 30.0.

studies used energy expenditure alone to prescribe exercise volume.[58,60,64] Across the 25 included studies, there were 19 "moderate" and 15 "vigorous" intensity AEx groups,[29] with another 3 studies including HIIT protocols.[64,67,75] Exercise intensities prescribed ranged from 40% to 80% VO_{2max}, 50% to 70% $VO_{2peak\text{-}reserve}$, 50% to 75% VO_{2peak}, 3.6 to 6.0 METs, 55% to 85% HR_{max}, 50% to 80% HRR, 10 to 17 RPE, and 50% to 95% HR_{peak}. Walking, treadmill (walking, jogging, or running), and cycle ergometry were the most common exercise modalities. Using final week exercise prescription, only five[63,64,69,74,85] of the 24 studies complied with current (ACSM)[29] and Exercise and Sport Science Australia's (ESSA)[30] recommendations for weekly exercise volume for overweight and obesity.

Prescription for exercise duration ranged from 15 to 60 min (excluding warm-up and cool-down). The most common exercise session durations were 45 min[65,70,76,79,81] and 60 min.[63–65,69,71,74,85] The most frequent intervention length was 3 months (10/24 studies), followed by 4 months (6/25 studies), 12 months (3/25 studies), and 6 and 3.5 months (2/25 studies each). The majority of AEx groups in the included studies were supervised. Exercise adherence was reported in 15/25 studies, with 14 studies reporting an average of >85% adherence.[57,58,60,61,64,65,67,73,77,79,80] Nine studies did not report exercise adherence.[59,63,66,69–71,75,76,78]

3.6 | Effect of AEx versus CON on WC

See Figure 2 for a summary of the effect of AEx versus CON on WC. Data from all 25 studies (38 comparisons) were available. [Correction added on 3 June 2022, after first online publication: The figure number citation in the preceding sentence was updated from '1' to '2'.] Pooled analysis found a mean reduction of 3.2 cm (95% CI −3.87, −2.51, $t = -9.5$, $p \le 0.0001$) from AEx compared with CON. The upper bound 95% CI of −2.51 cm suggests the data are compatible with a range of effects that represent a clinically meaningful reduction in WC.[86,87] However, high heterogeneity was present (Q [37] = 348, $p < 0.0001$ and $I^2 = 92.4\%$), with 62.7% of heterogeneity coming from within the study clusters (Level 2), and 29.5% from between the study clusters (Level 3).

3.7 | Moderator analysis

There was a significant moderating effect of change in VAT ($k = 36$, $\beta = 4.02$, 95% CI 1.37, 6.66, $p = 0.004$) (Figure S2B) and change in BW ($k = 37$, $\beta = 0.7$ kg, 95% CI 0.38, 1.04, $p = 0.0001$) (Figure S2A)

TABLE 2 Exercise intervention characteristics

Study	Intervention duration	Modality	Intensity	Frequency (days/week)	Session time (min)	Control	Exercise adherence (%)
Baria 2014	12 weeks	MOD[A]: Treadmill MOD[B]: At home, backyard, or street locations. Guidance from EP	MOD[A]: VT (~40%–60% VO_{2max}) MOD[B]: VT (~40%–60% VO_{2max}) Progressed monthly by EP	3 (alternate days)	MOD[A, B] WU: 5 Ex: 30 initially, ↑ by 10 every 4 weeks CD: 5	Complete no physical activity	NR
Blond 2019	6 months	MOD and VIG: Varied gym equipment	Weekly EE (all groups): 1600 kcal (F) 2100 kcal (M) MOD: 50% $VO_{2peak\text{-}reserve}$ VIG: 70% $VO_{2peak\text{-}reserve}$	2 initially, ↑ to 5	MOD and VIG: Varied on time to achieve daily EE: 320 kcal (F) 420 kcal (M)	Maintain sedentary lifestyle	0–3 months MOD: 100 VIG: 102 0–6 months MOD: 94 VIG: 92
Choi 2012	12 weeks	Walking	MOD: Moderate exercise capacity (3.6–6.0 METs)	5	MOD: 60	Maintain usual activities	NR
Cowan 2018	24 weeks	Treadmill: Walk and/or jog	MOD[C]: 50% VO_{2peak} 180 kcal (F); 300 kcal (M) MOD[D]: 50% VO_{2peak} 360 kcal (F); 600 kcal (M) VIG: 75% VO_{2peak} 360 kcal (F); 600 kcal (M)	5	All training groups: Time to reach EE goal	No exercise All groups: Maintain induction period energy intake	MOD[C]: 88.1 ± 17.8 MOD[D]: 95.1 ± 5.1 VIG: 92.3 ± 7.4
DiPietro 1998	4 months	MOD: Mini trampoline	MOD: Trampoline walking: Initially 55% HR_{max}, ↑ to 60% HR_{max} Trampoline running: 75% HR_{max} from Week 8 onward	4	MOD: WU: 5 Initially 20–30, ↑ to 40, then 50	Sessions of stretching, yoga, and stretch band exercises. Continue lifestyle habits	NR
Friedenreich 2011	1 year	VIG: Individualized: Facility-based (FB)/home-based (HB)	VIG: 50%–60% HRR (0–3 months), then ↑ 70%–80% HRR	5 (3FB/2HB days)	WU: 5 Ex: Initially 15–20, ↑ to 45 CD: 5–10	Maintain usual lifestyle All groups: Usual diet	NR
Heydari 2012	12 weeks	HIIT: Cycle ergometer	HIIT: 8-s work/12-s recovery Work: 80%–90% HR_{peak} @ 120–130 RPM Recovery: 40 RPM at same resistance	3	WU: 5 HIIT: 20 CD: 5	No exercise All groups: Usual eating habits	NR
Irving 2008	16 weeks	MOD and VIG: Walking/running	MOD: ≤LT (RPE ~ 10–12) VIG: <LT (2/7 days) RPE ~ 10–12; between LT and VO_{2peak} (3/7 days) RPE ~ 15–17	3, ↑ to 5 (Week 5)	MOD and VIG: All individualized. Weeks 1–2: 300 kcal per session (3/7 days) Weeks 3–4: 350 kcal per session (4/7 days)	Maintain current physical activity	MOD: 79.3 ± 3 VIG: 83 ± 3

TABLE 2 (Continued)

Study	Intervention duration	Modality	Intensity	Frequency (days/week)	Session time (min)	Control	Exercise adherence (%)
					Weeks 5–16: 400 kcal (5/7 days)		
Irving 2009	16 weeks	MOD and VIG: Walking/running	MOD: ≤LT (RPE ~ 10–12) VIG: <LT (2/7 days) RPE ~ 10–12; between LT and VO_{2peak} (3/7 days) RPE ~ 15–17	3, ↑ to 5 (Week 5)	MOD and VIG: Weeks 1–2: 300 kcal per session (3/7 days) Weeks 3–4: 350 kcal per session (4/7 days) Weeks 5–16: 400 kcal (5/7 days)	Maintain current physical activity	MOD: 76 ± 3 VIG: 83 ± 3
Jung 2012	12 weeks	NR	MOD: 3.5–5.2 METs VIG: >5.3 METs	5	MOD: 60 VIG: 30	Did not participate in exercise program and education	NR
Jung 2014	12 weeks	MOD: Walking	MOD: 3.6–5.2 METs (~500 kcal/day)	3	MOD: 60	No exercise programs All groups: 1× dietary education program at start	NR
Karstoft 2013	4 months	MOD and HIIT: Walking	MOD: >55% EE_{peak} HIIT: ≥5× sets of 3-min fast walking @ >70% EE_{peak}/3-min slow walking @ <70% EE_{peak}	5	MOD: 60 HIIT: 60	Continue lifestyle habits	MOD: 94 ± 6 HIIT: 85 ± 4
Keating 2015	8 weeks	All: Cycle erg (C) + brisk walk (W)	MOD^E: 50% VO_{2peak} VIG: 60%–70% VO_{2peak} MOD^F: 50% VO_{2peak}	$3C/1W^E$ 2C/1W $2C/1W^F$	MOD^E: 45, ↑ to 60 (Week 3) VIG: 30, ↑ to 45 (Week 3) MOD^F: 30, ↑ to 45 (Week 3)	Stretching, massage, fit ball 1/14 supervised sessions (new exercises, 5-min cycling @ 30 W)	MOD^E: 90 VIG: 94 MOD^F: 96 CON: 82
Ku 2010	12 weeks	MOD: Walking	MOD: 3.6–5.2 METs	5	MOD: 60	Diabetes education. Maintain sedentary lifestyle	NR
Lee 2012	14 weeks	MOD and VIG: Running	MOD: 50% VO_{2max} VIG: 70% VO_{2max}	3, ↑5	Based on individual VO_{2max}, and EE: MOD and VIG: 13.5 METs/h/week (Weeks 1–4) 18 METs/h/week (Weeks 5–9) 22.5 METs/h/week (Weeks 10–14)	No exercise All groups: Maintain diet and lifestyle habits	NR
Lesser 2016	12 weeks	VIG: Treadmill, cycle	VIG: 55% HR_{max}, ↑ 10% every 3 weeks (max. 85% HR_{max})	3	WU: 10 Ex: 40 CD: 10	Maintain physical activity and diet	67 ± 25
	12 months	VIG:	VIG: 60%–85% HR_{max}	3FB + 3HB	VIG:		

(Continues)

TABLE 2 (Continued)

Study	Intervention duration	Modality	Intensity	Frequency (days/week)	Session time (min)	Control	Exercise adherence (%)
McTiernan 2007		Facility-based (FB): Treadmill, cycle, elliptical, rower Home-based (HB): NR			WU: 5–10 Ex: 60 CD: 5–10	Maintain exercise or diet habits	80% adherence + 360 min/week goal: 71%
Moghadasi 2012	12 weeks	VIG: Treadmill	VIG: HR corresponding to 75%–80% VO_{2max}	4	VIG: 45	Maintain normal diet and physical activity habits	NR
Pugh 2014	16 weeks	VIG: Treadmill and cycle ergometer	VIG: Weeks 1–4: 30% HRR Weeks 4–8: 45% HRR Weeks 8–12: 45% HRR Weeks 12–16: 60% HRR	3, ↑5 (Week 12)	VIG: Weeks 1–4: 30 Weeks 4–8: 30 Weeks 8–12: 45 Weeks 12–16: 45	Lifestyle advice from clinic nurse or hepatologist to modify lifestyle	92
Ross 2000	3 months	VIG: Walking or jogging	VIG: ≤70% VO_{2peak} (∼80% HR_{max})	7	VIG: Time to expend 700 kcal	Maintain bodyweight All exercise: Maintain baseline period energy intake	98
Ross 2004	14 weeks	VIG: Walking or light jogging (motorized treadmill)	VIG: ∼80% HR_{max}	7	VIG: Time to expend 500 kcal	Maintain bodyweight All groups: Maintain baseline period energy intake	96
Short 2003	16 weeks	VIG: Stationary bike	VIG: Initially 70% HR_{max}, ↑ to 80% HR_{max} (final month)	3, ↑4	VIG: Initially 20, ↑ to 40 (final month)	Flexibility exercises, maintain lifestyle All groups: Maintain bodyweight	Session and workload compliance: >90
Sigal 2007	22 weeks	MOD: Treadmills or bicycle ergometers	MOD: Initially 60% HR_{max}, ↑ 75% HR_{max}	3	MOD: Initially 15–20, ↑ 45	Asked to revert to pre-study activity levels	80 (interquartile range, 46% to 93%)
Zhang 2015	12 weeks	HIIT: Treadmill running (W)/walking (R) MOD: Treadmill running	HIIT: 4 min @ 85%–95% HR_{peak} 3 min @ 50%–60% HR_{peak} 7-min rest MOD: 60%–70% HR_{peak}	4	Both WU: 10 CD: 5 HIIT: 4× (W) 4 min/(R) 3 min MOD: ∼33	No training All groups: Maintain daily activity and diet habits	HIIT: 94 ± 3 MOD: 90 ± 2
Zhang 2016	12 months	MOD: Brisk walking VIG–MOD: Treadmill jogging	MOD: 45%–55% HR_{max} (3.0–6.0 METs) VIG–MOD: 1st 6 months @ 65%–80% HR_{max} (8.0–10.0 METs), then same as MOD group	5	MOD: 30 VIG–MOD: 30	Maintain physical activity habits All groups: Maintain diet habits	At least 80% adherence: MOD: 97.1 (6 months) 95.7 (12 months)

Abbreviations: CD, cool down; CON, control; EE, energy expenditure; F, female; HIIT, high-intensity interval training; HR_{max}, heart rate maximum; HR_{peak}, heart rate peak; HRR, heart rate reserve; LT, lactate threshold; M, male; METs, metabolic equivalents; MOD, moderate intensity; NR, not reported; R, rest; RPE, rate of perceived exertion; VIG, vigorous intensity; W, work; WU, warm up.

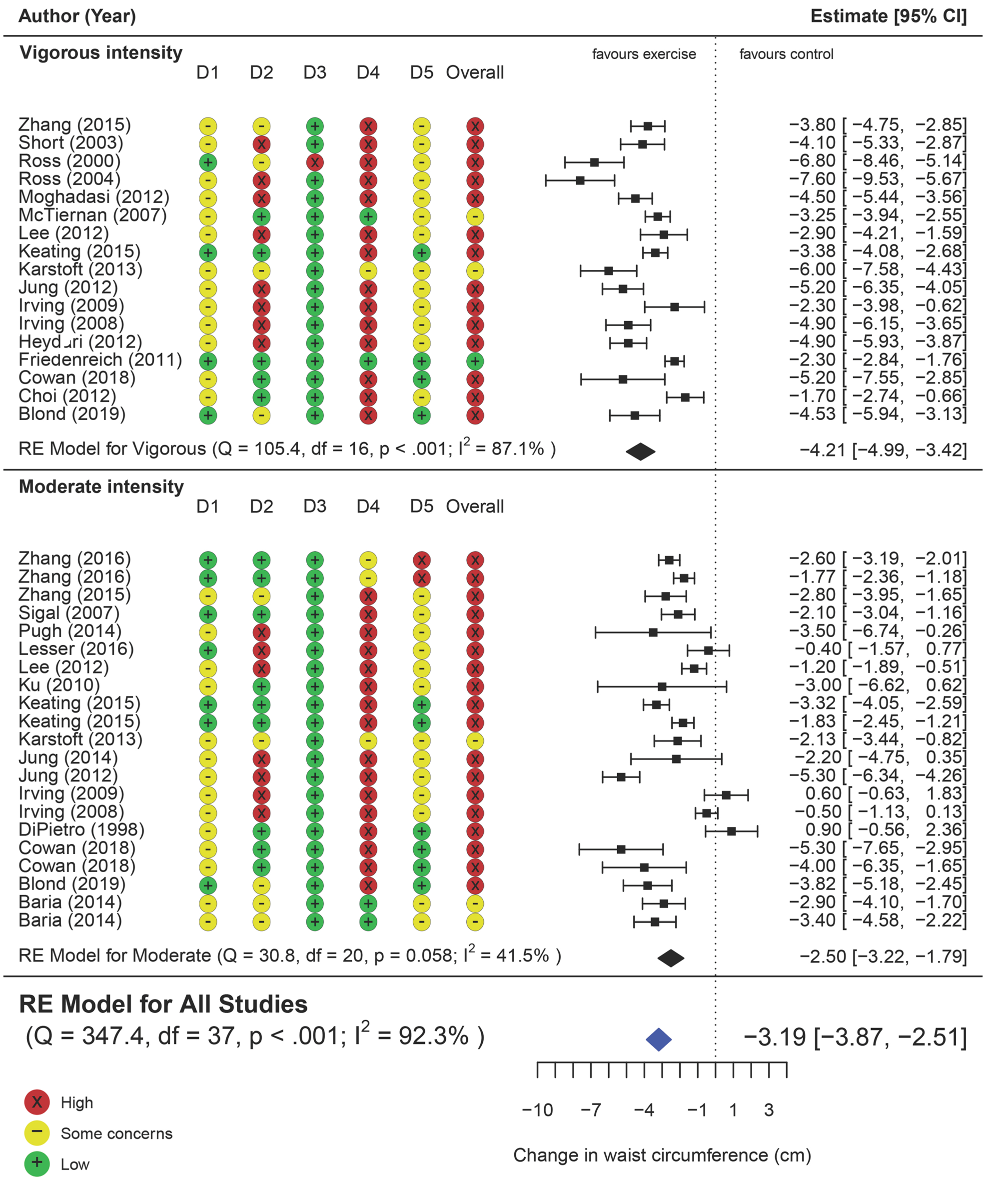

FIGURE 2 Forest plot of the pooled effect of AEx versus CON on WC, including subgroup analysis of moderate intensity versus control and vigorous intensity versus control; D1: Randomization, D2: Deviation for intended interventions, D3: Missing outcome data, D4: Measurement of the outcome, D5: Selection of reported result [Correction added on 3 June 2022, after first online publication: A new image for Figure 2 has been inserted earlier in the article and the caption originally published with Figure 1 is being used with this new Figure 2 image.]

on change in WC, whereby reductions in BW and VAT were associated with a reduction in WC.

Exercise intensity was a significant moderator for WC change, where vigorous intensity interventions led to greater reduction in WC compared with moderate intensity ($k = 38$, $\beta = -1.86$ cm, 95% CI −2.73, −1.00, F [1, 36] = 19.10, $p = 0.0001$). Exercise frequency also had a moderating effect on WC ($k = 38$, $\beta = -0.68$ cm, 95% CI −1.30, −0.06, $p = 0.03$), whereby every extra day of exercise per week was associated with a 0.68-cm greater reduction in WC. However, there was no moderating effect on WC from weekly exercise volume ($k = 25$, $\beta = -0.002$ cm, 95% CI −0.012, 0.006, $p = 0.586$) or intervention duration ($k = 38$, $\beta = 0.01$ cm, 95% CI −0.04, 0.06, $p = 0.60$).

Age had a moderating effect on change in WC ($k = 36$, $\beta = 0.06$, 95% CI −0.0002, 0.12, $p = 0.05$), such that for every 10 years of age older is associated with an attenuated response (0.6 cm). Similarly, baseline CRF also had a moderating effect on change in WC ($k = 26$, $\beta = -0.1$, 95% CI −0.21, 0.0005, $p = 0.04$), where for every 10 ml/kg, there is a difference of 1 cm. However, baseline BMI ($k = 36$, $\beta = -0.0004$, 95% CI −0.004, 0.003, $p = 0.86$), sex ($k = 14$, $\beta = -1.5$, 95% CI −3.78, 0.69, $p = 0.16$), and baseline WC ($k = 36$, $\beta = 0.28$, 95% CI −0.46, 1.03, $p = 0.44$) did not moderate change in WC.

3.8 | Subgroup analysis

Only seven studies (nine comparisons) allowed for a direct comparison between vigorous and moderate intensities, where there was a modest, yet significant reduction in WC favoring vigorous intensity (−1.49 cm, 95% CI −2.82, −0.16, $t = -2.59$, $p = 0.03$), with high heterogeneity (Q [8] = 55.3, $p \leq 0.0001$ and $I^2 = 86.73\%$) (Figure 3). [Correction added on 3 June 2022, after first online publication: The figure number citation in the preceding sentence was updated from '2' to '3'.]

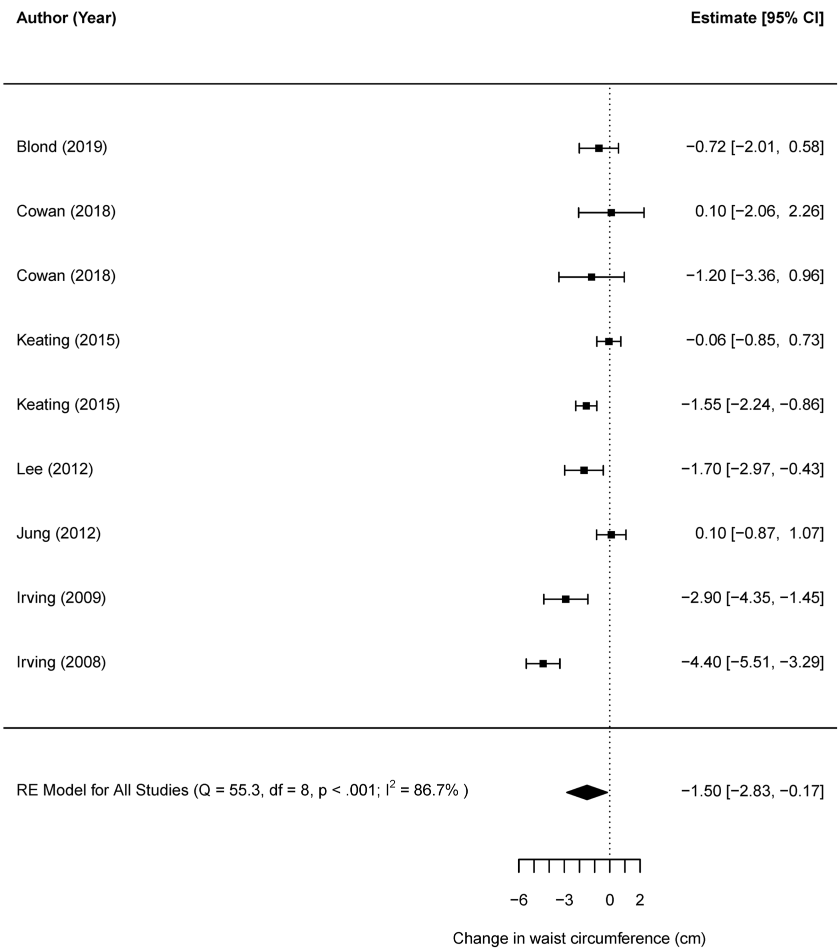

FIGURE 3 Direct comparison of vigorous versus moderate aerobic exercise on WC [Correction added on 3 June 2022, after first online publication: The preceding figure was renumbered from Figure 2 to Figure 3 in this version.]

4 | DISCUSSION

The purpose of this systematic review and meta-analysis was to provide clear evidence on the effect of regular AEx on WC and the associated change in VAT, in order to inform practice of health professionals managing adults with overweight or obesity. The findings from the 25 available RCTs clearly demonstrate that compared with non-exercise control, regular AEx reduces WC, with an average effect of 3.2 cm. Furthermore, change in WC is associated with statistically significant change in VAT but not significant weight loss. Despite the emphasis on achieving high weekly AEx volume and frequency for weight loss in current exercise recommendations,[29,30] there was no clear association between AEx volume and frequency on WC reduction. Rather, the current evidence suggests that exercise intensity may be a significant determinant of WC reduction in adults undertaking AEx programs, where vigorous intensity may lead to superior WC reduction compared with moderate intensity programs.

It is now widely acknowledged that excess visceral adiposity is associated with significant risk of cardiometabolic disease, independently of BW. However, in routine clinical practice, measurement of risk associated with obesity has historically relied on determination of BMI, although WC is increasingly advocated.[88–90] Importantly, in this study, we have demonstrated that change in WC from serial measurement is associated with change in visceral adiposity levels even when BW change is negligible and that beneficial reduction in WC (and VAT) can be achieved with regular AEx. Moreover, the current data suggest a modest benefit even with the limitations of WC measurement,[91] and uncertainty, with the upper limit 95% CI of WC reduction of 2.5 cm. Our findings on WC reduction are generally consistent with those of previous reviews that have reported average reductions between 2 and 3 cm.[42,44,92–94] However, it is important to recognize that although these findings demonstrate that change in waist may provide some insight into change in VAT, it should not be considered a perfect proxy for this purpose.[73,90,95,96] Further, the findings of previous studies were limited by the small number of studies they included measuring AEx and WC. Moreover, none of the above studies used gold standard measures of VAT (CT and MRI) to substantiate the change in WC with a change in VAT. Previous findings from a large meta-regression found that a 1-cm increase of WC is associated with an approximately 2% increased risk of cardiovascular disease (CVD).[97] Moreover, data from Cerhan et al.[87] suggest that each increase of 5 cm in WC was associated with increase in mortality risk of 7% and 9%, for men and women, respectively. Inference from both studies could be made that the reverse is true, such that the observed current reduction of 3.2 cm (95% CI −3.86, −2.51) with aerobic interventions could be associated with a mean CVD risk reduction of 6% (ranging 7%–4%) and a reduced mortality risk of ~4.5% in men and ~5.7% in women.

There is uncertainty around the components of exercise prescription that influence the change in WC with exercise interventions and consequentially a lack of clear direction for exercise professionals aiming to improve abdominal adiposity. Data from our moderator analysis and indirect subgroup analysis suggest a superior benefit on WC with AEx of a "vigorous" intensity, compared with "moderate" intensity training. However, where direct comparisons were available, there was insufficient evidence. These collective data are similar to recent findings by O'Donoghue and colleagues,[42] who found vigorous AEx to offer greater benefits than moderate when both were separately compared with control, although their review was limited by fewer studies that used AEx and measured WC. By contrast, Wewege et al.[44] directly compared AEx based on moderate intensity (MICT) and HIIT and observed no difference in WC improvement, with a mean reduction of ~3 cm with each. However, that analysis only included a relatively small number of studies that measured WC ($n = 5$). Similarly, findings from Ross et al.[98] found no difference between energy-matched high-volume high-intensity, high-volume low-intensity, and low-volume low-intensity training groups. Unlike Ross and colleagues,[98] only a handful of the included studies within the current review and in Wewege et al. (2017)[44] were matched for energy expenditure. Moreover, we were limited in the number of studies that directly compared moderate to vigorous AEx ($k = 7$). As such, it is difficult to determine whether the reductions in WC are influenced by intensity when energy expenditure is similar (or whether the superiority of high intensity partly reflects higher energy expenditure). Data from the current review did not find a clear influence of exercise volume on change in WC. This is in contrast to weight loss outcomes in current exercise guidelines to manage overweight/obesity, which recommend participating in as much as 250–300 min[28,29] to 300–420 min.[30] Although the findings from the current data are promising, there remains uncertainty around which components of AEx prescription are most influential in changing WC.

There are some limitations within the current review and, as such, the authors advise caution with interpretation of the findings. Firstly, the number of individual included studies with small sample sizes, limiting the strength of GRADE assessment, and reducing the ability to validly explore other practical considerations such as sex-specific effects of exercise on WC, and relationships between exercise dose and WC. Moreover, this review has limited scope in which to distinguish the contribution of change in VAT, from subcutaneous adipose tissue[99,100] change, which may partially account for some of the variance with associated WC reductions.[90] Secondly, although exercise interventions are known to be difficult to blind,[101] future exercise trials should, where possible, employ placebo/sham control groups and use intervention groups that meet the current guidelines.[29,30] Importantly, as identified in the RoB2, there are limitations arising from the lack of assessor blinding to group allocation of the primary outcome. In light of the established error in measurement and potential assessor bias,[91] future studies using WC as an outcome should employ blinding of assessors to treatment allocation and use a standardized method of measurement.[102] Similarly, the application of our primary finding of a modest reduction in WC (~3.2 cm) may be somewhat limited, as this magnitude of change falls within the typical error of measurement for WC.[91] However, the addition of "gold standard" measures (CT and MRI) add strength to the validity of the observed reduction of WC and VAT. We acknowledge that although this approach adds important biological evidence corroborating the benefit of AEx on abdominal adiposity, a limitation of this approach is that it does not capture the full published evidence on exercise and WC per se. Whereas there appeared to be no benefit of volume on moderator analysis, there were few studies that used volumes consistent with current recommendations for obesity management.[29,30] Given the apparent importance of exercise volume (and energy expenditure) in weight loss outcomes,[30] yet the apparent independent influence of exercise intensity on WC improvement, studies are needed which aim to clearly delineate the effects of intensity and volume/energy expenditure, for example, via energy-matched but intensity contrasted groups, and vice versa. Despite the current findings suggesting a superior benefit of higher intensity exercise for reducing WC, this review lacks power to support these conclusions with longer term exercise interventions. Moreover, the lack of longer duration studies included in this review are not able to accurately discern long-term changes in WC from regular exercise or inactivity. Some reports were not able to be retrieved ($n = 171$) using the university catalogue, and publicly available domain during the search process, and therefore may have impacted the final number of included studies. Lastly, to further improve quality of future research, studies should include the use of an intention-to-treat analysis, provide details around the randomization process, and report adherence for both supervised and unsupervised interventions.

This systematic review and meta-analysis provides evidence that participation in regular AEx may induce a modest reduction in WC (and VAT) in adults with overweight or obesity, and this can occur with negligible weight loss. Additionally, AEx programs performed at a vigorous intensity may offer superior benefit to moderate intensity exercise. Although these findings are promising, further research is needed to corroborate these data for practitioners working with clients with weight management problems.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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