

Review article

# The Health and Functional Benefits of Eccentric versus Concentric Exercise Training: A Systematic Review and Meta-Analysis

Misha Ansari ✉, Sibella Hardcastle, Stephen Myers and Andrew D. Williams

School of Health Sciences, University of Tasmania, Launceston, Australia

## Abstract

This review compared the effects of eccentric versus concentric exercise training in healthy people and people with metabolic disease. A systematic search on Cochrane Central Register of Controlled Trials, MEDLINE, Embase, CINAHL, SPORTDiscus, Web of Science, SCOPUS and PubMed was conducted in February 2022. Randomised controlled trials conducted on sedentary healthy adults or those with an existing metabolic disease that compared eccentric versus concentric exercise training interventions of four weeks or longer that involved multiple joints and large muscle groups (e.g., walking, whole-body resistance training) were included in the review. The primary outcome was glucose handling, measured as HbA1c, HOMA, fasting glucose or insulin. Measures of cardiovascular health, muscle strength, and functional physical fitness were secondary outcomes. Nineteen trials involving 618 people were included. Results of meta-analyses showed that eccentric exercise had no benefit to glucose handling (HbA1c level; SMD - 0.99; 95% CI, -2.96 to 0.98;  $n = 74$ ;  $P = 0.32$ ) but resulted in significant increases in overall muscle strength (SMD 0.70; 95% CI 0.25 to 1.15;  $n = 224$ ;  $P = 0.003$ ) and decreases in blood pressure (Systolic Blood Pressure; MD - 6.84; 95% CI, -9.84 to -3.84;  $n = 47$ ,  $P = 0.00001$ , and Diastolic Blood Pressure; MD -6.39; 95% CI -9.62 to -3.15;  $n = 47$ ,  $P = 0.0001$ ). Eccentric exercise is effective for improving strength and some markers of cardiovascular health compared to traditional exercise modalities. Additional high-quality studies are necessary to validate these results. (PROSPERO registration: CRD42021232167).

**Key words:** Non-traditional exercise modalities, physical fitness, markers of health.

## Introduction

Since the mid-twentieth century, numerous research studies have investigated the advantages of exercise and physical activity in preventing and treating chronic health conditions, with results overwhelmingly supporting the role of physical activity as a lifestyle medication (Bull et al., 2020; Pedersen and Saltin, 2015). Research shows that exercise not only prevents the occurrence of diseases but is also helpful in treating established diseases (Pedersen and Saltin, 2015). Multiple reviews have highlighted the evidence for using exercise as primary and secondary prevention for various disorders related to metabolic syndrome (obesity, insulin resistance, type 2 diabetes mellitus (T2DM)); diseases of joints and bone (rheumatoid arthritis, fibromyalgia, osteoporosis); cancer, depression, and cardiovascular events (Sharman et al., 2015; Warburton et al., 2006).

Despite numerous benefits associated with regular exercise, compliance is less due to low motivation, the inability to fit exercise into a daily routine, lack of enjoyment and fatigue (Argent et al., 2018; Hassmén et al., 2000; Sharman et al., 2015). A potential solution to this problem of poor exercise adherence is to promote enjoyable activities that require less perceived effort and could be easily integrated into daily routines (Arlinghaus and Johnston, 2019; Huberty et al., 2008). When designing an exercise programme for people with lower motivation or energy levels, the emphasis should be placed on prescribing easy-to-perform exercises, which are perceived to be less demanding on the body. During exercise, the perceived effort relies on the type of muscular contraction. Muscle contractions are of two types: eccentric and concentric. During an eccentric contraction, muscle fibres elongate and lengthen while under load, whereas muscle fibres shorten under load in concentric contraction. Most movements involve a mixture of eccentric and concentric contractions of the muscles, but the proportions of each contraction type may vary. For example, walking uphill requires predominately concentric muscle contractions of the lower limbs, whereas walking downhill requires a greater focus on eccentric contractions of the lower limbs to decelerate force and control the movement. During eccentric muscle contractions, the cost of producing force in terms of energy is minimal compared to comparable concentric muscle contraction (Komi and Buskirk, 1972) and is perceived as being easier than concentric contractions (Raj et al., 2012; Stauber, 1989). Compared to concentric activity of the same volume, eccentric exercise reduces peak heart rates, systolic blood pressures, cardiac indices, and ventilation rates (Overend et al., 2000; Vallejo et al., 2006). As a direct result of this and due to perceived ease of performance, there have been reports of increased compliance with eccentric exercise training and eccentric modalities compared to concentric exercise (Marcus et al., 2008; Raj et al., 2012).

Chronic exercise training studies conducted on healthy individuals and those at risk of chronic disease have shown that eccentric exercise presents a suitable substitute, or adjunct, to concentric resistance exercise (Chen et al., 2017a; Chen et al., 2017b; Drexel et al., 2008; Zeppetzauser et al., 2013). In these studies, eccentric exercise improved health-related risk factors such as glucose handling and lipid profiles and reduced heart rate (HR) and blood pressure (BP) compared with concentric exercise. Clinical trials on healthy populations have shown that chronic eccentric training improved glucose handling (Chen et al., 2017a; Chen et al., 2017b; Drexel et al., 2008;

Zeppetzauser et al., 2013). The physiological reasons supporting the benefit of eccentric exercise in improving glucose handling are related to greater microdamage to muscle fibres during eccentric contractions and higher metabolic repair costs (Proske and Morgan, 2001). During eccentric exercise, due to repetitive lengthening contractions, muscle fibres sustain microdamage (Hody et al., 2019). Repairing damaged muscle requires significant energy, with as much as 20% of the resting metabolic rate (RMR) estimated to be needed for protein resynthesis (Welle and Nair, 1990). This higher energy demand for muscle healing and protein synthesis results in a prolonged elevation of the post-exercise RMR. Research studies have indicated that the resting metabolic rate can remain elevated for 48 hours following an acute resistance exercise involving eccentric muscle action overload (Dolezal et al., 2000).

Several systematic reviews have attempted to determine the advantages of eccentric exercise over concentric exercise and reported eccentric training to be safe (Ellis et al., 2015) and effective in improving body composition (Roig et al., 2009), musculoskeletal function (Čretnik et al., 2022; Ellis et al., 2015; Molinari et al., 2019; Roig et al., 2009; Roig et al., 2008), and balance (Kulkarni et al., 2022), in healthy individuals (Kulkarni et al., 2022; Molinari et al., 2019; Roig et al., 2009) and those with a range of chronic conditions (Čretnik et al., 2022; Ellis et al., 2015; Roig et al., 2008). However, these reviews (Molinari et al., 2019; Roig et al., 2008) also concluded that further studies are needed to establish the potential benefits of eccentric exercise. A limitation of these reviews is that they were conducted on a limited studies (Čretnik et al., 2022; Molinari et al., 2019), included smaller sample sizes (Kulkarni et al., 2022; Molinari et al., 2019), and have only investigated limited performance-related (strength and fitness) outcome measures (Čretnik et al., 2022; Ellis et al., 2015; Kulkarni et al., 2022; Roig et al., 2009; Roig et al., 2008). In addition, while the benefits of eccentric exercise have been well explained in older adults, other groups, such as people with metabolic disease, have received less attention. Furthermore, none of the previous reviews have investigated how eccentric exercise affects health risk variables like blood glucose, lipids and cardiovascular function. Thus, further analysis is needed to describe the effects of eccentric training and modalities compared to concentric/traditional exercise on glucose handling, cardiovascular function, strength, and functional fitness. The primary objective of this systematic review and meta-analysis was to evaluate and compare the impact of eccentric exercise and traditional/concentric exercise on glycaemic management. The secondary objective was to investigate the effect of these exercises on cardiovascular measures, functional physical fitness parameters and strength in healthy populations and people with a metabolic disease who were not previously involved in structured exercise training. The outcomes of this systematic review will offer healthcare providers up-to-date evidence on the effectiveness of eccentric versus concentric training and will assist exercise and health professionals (and participants) in making in-

formed decisions about appropriate exercise to meet their needs.

## Methods

This systematic review is reported following the Preferred Reporting Items for Systematic review and Meta-Analysis Protocols (PRISMA-P 2015) statement (Moher et al., 2015). The study was registered in the PROSPERO (CRD42021232167).

### Eligibility criteria

Our systematic review incorporated randomized controlled trials (RCTs) that underwent peer review and were published between 1999 and February 2022. RCTs, including chronic eccentric training involving multiple joints and large muscle groups (e.g., walking, running, full body resistance training) having a treatment period of at least four weeks or more, intervention delivered a minimum once a week, designed to compare eccentric vs concentric exercise or traditional exercise were included in the review. Controlled trials involving sedentary healthy adults or those with an existing metabolic disease as a primary medical condition not engaged in structured exercise training in the past six months were included in this review. Trials on individuals with neurological conditions preventing safe exercise performance or with a primary medical condition other than metabolic disease were excluded.

For our review, we defined eccentric exercise as exercises with high eccentric contractions, i.e., downhill walking, descending stairs and lowering weights. Concentric exercises are defined as those with high concentric contractions, i.e., uphill walking, lifting but not lowering the weights. Traditional exercises are defined as movements with relatively even proportions of concentric and eccentric contractions. The PICOS (participants, interventions, comparators, outcomes, and study designs) detailed eligibility criteria are given in Table 1. This review covered studies that included at minimum one outcome measure from the following measures.

### Primary outcomes

- Glycated Haemoglobin (HbA1c; defined as a haemoglobin molecule with a glucose molecule attached, which shows a person's mean blood glucose level over a period of two to three months preceding the test). HbA1c is measured by drawing a blood sample and analysing it in laboratory by mixing with a chemical solution in a technique called high-performance liquid chromatography Measurement unit: mmol/L or %
- Blood glucose (defined as glucose in the blood): Blood glucose measured by drawing blood sample from a vein or fingerpick and analysis in laboratory by apparatus called glucose meter. Measurement unit: mmol/L
- Insulin resistance (defined as reduced effectiveness of insulin in lowering blood glucose levels): The researcher measured with HOMA IR. Measurement unit: mmol/L or %

**Table 1. Eligibility criteria for inclusion of studies in the review**

	Inclusion	Exclusion
<b>Population</b>	Sedentary healthy individuals or those with an existing metabolic disease as a primary medical condition who are $\geq 18$ years of age and who are not performing structured exercise training in the previous six months are included in this review.	Individuals with neurological conditions preventing safe exercise performance or with a primary medical condition other than metabolic disease are excluded.
<b>Intervention</b>	All randomised controlled trials (RCT) with a treatment duration of four weeks or more, intervention delivered at least once a week, designed to compare eccentric vs concentric exercise or traditional exercise on treadmill/cycle ergometer or downhill vs uphill walking were included in this review. RCTs utilising Eccentric-focused exercise training involving multiple joints and large muscle groups (e.g., walking, running, cycling, whole-body resistance training) will be included. Eccentric-focused exercise compared with concentric-focused or combined movement exercise	Trials analysing cross-training effects (e.g., exercising one limb and assessing the effect from the other limb) Trials studying acute effects of exercise (single bout or less than four weeks duration) Trials involving non-exercise interventions, including diet or supplements, where exercise components cannot be isolated. Trials conducted on animals.
<b>Comparator</b>	Concentric training Combined movement exercise	No comparator group
<b>Outcomes</b>	Primary outcomes HbA1c Glucose Insulin resistance Secondary outcomes Muscle strength Lipids Functional Physical fitness: Six-minute walk test(6MWT), Time up and go test (TUG) Heart rate Brachial Blood pressure Central Blood pressure Arterial Stiffness	Studies that do not report at least one primary or secondary outcome.
<b>Study design</b>	1. Randomised controlled trials (blinded and open, parallel), including chronic Eccentric training (4 or more weeks) involving multiple joints and large muscle groups (e.g., walking, running, cycling, whole-body resistance training), will be included in this review. 2. Cross-over trials where pre-cross-over data is available from study authors.	Observational studies (case studies, case reports, cross-sectional studies, ecological studies, cross-sectional studies, and cohort studies) Qualitative research Narrative reviews Systematic reviews cross-over and single-arm trials Trials not reported in English.

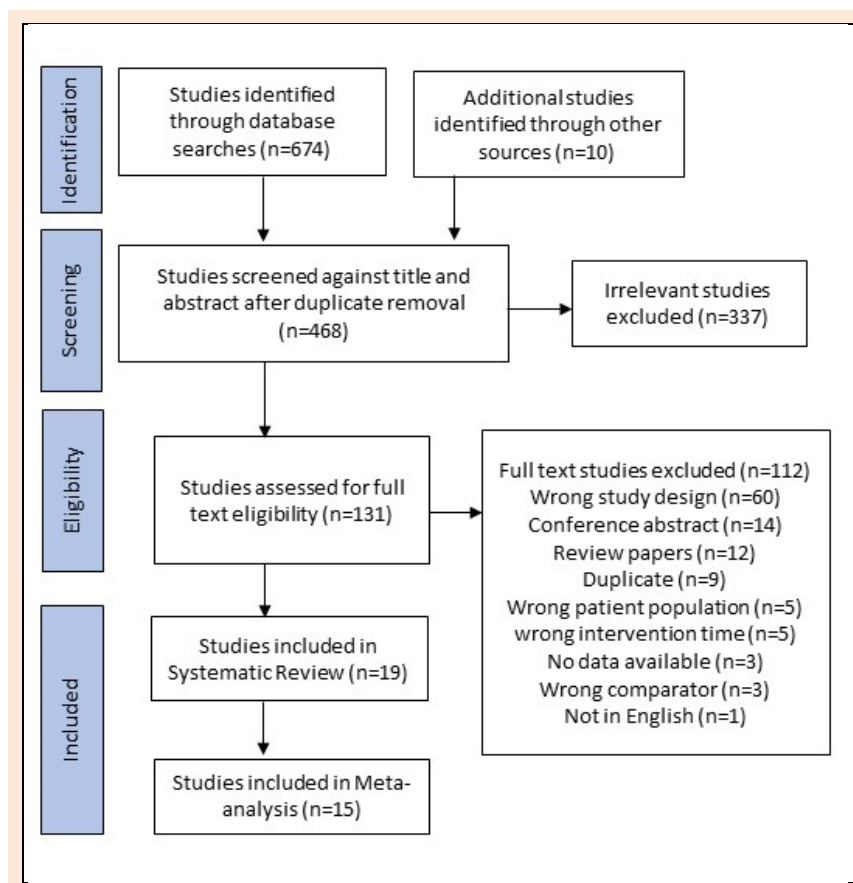
**Secondary outcomes**

- Muscle strength (defined as the ability of a muscle or group of muscles to generate force against a resistance): The researcher measured strength as Repetition Maximum testing or dynamometry. Measurement unit: Kg or Nm.
- Lipids (fats/lipids found in human blood, total cholesterol [TC], serum triacylglycerols [TG], low-density lipoprotein cholesterol [LDLC], and high-density lipoprotein cholesterol [HDLC]): The researcher measured with blood sampling and pathology analysis. Measurement unit: mmol/L
- Heart rate (defined as the number of times the heart beats within a specific time, usually a minute. Measurement unit: beats/min)
- Brachial Blood Pressure (defined as the pressure exerted by blood on brachial arteries): The researcher measured with manual or automatic equipment. Measurement unit: mmHg
- Central blood pressure (the pressure exerted by blood on the aorta): The researcher measured via invasive or non-invasive techniques. Measurement unit: mmHg

- Arterial stiffness (defined as the rigidity of the arterial walls): The researcher measured via invasive or non-invasive techniques. Measurement unit: m/s
- Functional Physical fitness: defined as a set amount of physical activity completed over a specified duration of time. The researcher measured through functional tests. The measurement unit will depend on the assessment method.

**Electronic searches**

To identify relevant studies, an extensive search was conducted using free text terms and Medical Subject Headings (MeSH) in several web-based databases, including Cochrane Central Register of Controlled Trials, the Cochrane Library, Embase, PubMed, CINAHL, SPORTDiscus, Web of Science, MEDLINE, and SCOPUS. Human studies were considered only. Ongoing trials were searched for in clinicaltrials.gov and the World Health Organization (WHO) International Clinical Trials Registry Platform (ICTRP) up to February 2022. Further studies were also identified by searching selected articles' reference lists. The complete search strategy is provided in



**Figure 1. PRISMA flowchart of study selection.**

Appendix 1. In case further information was needed, authors were contacted.

### Selection of studies

One reviewer (MA) identified published studies through an extensive literature search in seven major databases. According to individual databases, the search strategy was adapted. For a detailed search strategy, see Appendix 1. Covidence software (Covidence systematic review software, Veritas Health Innovation, Melbourne, Australia. Available at [www.covidence.org](http://www.covidence.org)) was used to screen and review articles. On the articles identified by the initial search, a pair of review authors (SM, SH, and MA) independently performed title and abstract screening. From the reviewed articles, duplicate references were removed, and conflicts were resolved by the fourth reviewer (AW). Studies included after the abstract screening were then full text reviewed by a pair of reviewers (MA, AW, SH, SM). From the full text, the authors assessed whether the studies met the inclusion criteria based on their methodology, participants, and interventions. In case of any disagreements, consensus meetings were held to resolve them.

The reasons for excluding articles after full-text review are outlined in the PRISMA flow chart (Figure 1), which shows the status of identified studies. The quality of included studies was assessed independently by two review authors (AW, MA) and data was extracted.

### Data extraction

Two reviewers (AW, MA) independently extracted and

cross-checked the data using a standardised data extraction form using Covidence software and the following criteria.

- Study characteristics: Title of study, author details, date of publication and publication status.
- Eligibility and procedure for the research: Type of study, details of included participants, no of training groups, length of training, total training visits, outcome measures, and techniques for assessing outcomes.
- Quality of research methodology: the process of sequence generation, randomization, allocation concealment, blinding of research participants and evaluators, follow-up/post-test, incomplete reporting, and adherence to formerly mentioned methodologies.
- Results: Participant number per group and the mean, standard deviation for continuous outcomes.

### Methodological quality and the overall evidence profile

A pair of review authors (MA and AW) independently assessed the risk of bias in each included study across seven domains, using the criteria established in the Cochrane Handbook for Systematic Reviews of Interventions (Higgins et al., 2022). Disputes were handled through debate in consensus meetings (Higgins et al., 2011). A 'Risk of Bias' table was prepared for each trial using the 'Risk of Bias' function in Review Manager 5 software (Review Manager (RevMan) [Computer program]. Version 5.4. The Cochrane Collaboration, 2020). Review Manager 5 was used to calculate the total risk of bias for each of the seven areas listed below.

- Random sequence generation (examination for bias in



selection). The process utilized to generate the sequence of participant allocation to groups was rated as a low risk of bias when it used a genuinely random processor and a high risk if there was a non-random component involved in sequence generation. If the methods for sequence generation were not stated clearly, it was rated as unclear.

- Allocation concealment (prevention of selection bias): The process performed to conceal the participants allocation to different intervention groups was assessed and categorised as low, high, or having unclear risks. If the participants were allocated to groups based on consecutive numbers in opaque envelopes or based on central randomization, they were considered low risk. If the investigator assigned participants in non-opaque envelopes or used an open random allocation, it was labelled high risk. If no information was provided about allocation, then it was labelled as unclear.
- Blinding of research participants and personnel: The process of blinding the research participants involved in the study about the intervention they received, and the personnel involved in delivering the treatment was assessed. It was categorised into three categories. Studies which were blinded and described the technique used for blinding participants were labelled as having a low risk. Studies which were not blinded or did not mention blinding were labelled as high risk. Studies which mentioned blinding but did not mention the process were labelled as unclear.
- Blinding of outcome assessors: The method by which outcome assessors were blinded was assessed for each study and labelled as low, high, or unclear risk. Studies which were blinded and described the technique utilized to blind outcome assessors were labelled as low risk. Studies that were not blinded and where the outcome assessors could influence the outcomes were labelled as high risk. Studies which did not mention blinding were labelled as unclear risk.
- Incomplete outcome data: Procedures were evaluated on how missing data in studies was treated. If no information was provided on how missing data were treated in the study, it was labelled as high risk. Low-risk studies used 'baseline observation carried forward' analysis or had less than 10% of participants withdraw from the study. Studies were labelled as having unclear risks if they had insufficient information on attrition.
- Selective outcome reporting: The protocol papers of the included studies were compared to the study data to identify whether all the specified outcomes/variables were reported. If the study's results contained all the suggested outcomes indicated in the protocol paper, they were labelled as low risk, unclear if protocol papers were unavailable, or high risk if the study does not report all proposed outcomes.
- Other potential sources of bias included any issues with study methods not considered elsewhere.

The GRADE (Grading of Recommendations Assessment, Development, and Evaluation) profiler Guideline Development Tool software (GRADEpro GDT 2015) and the guidelines provided in Chapter 12.2 of the Cochrane Hand-

book for Systematic Reviews of Interventions were used to assess the quality of the evidence for each study (Higgins et al., 2011). The GRADE method assesses the quality of the body of evidence for each outcome by taking five factors into account (study limitations, consistency of effect, imprecision, indirectness, and publication bias). For allocating a grade, the following criteria were used.

- High grade: It is highly unlikely that more research would alter our level of confidence in the effect estimate.
- Moderate grade: we are relatively certain that the genuine effect will be close to the estimated effect, but it is possible that it could be significantly different.
- Low grade: We have low faith in the estimate of the effect; the true effect may differ significantly from the estimate.
- Very low grade: we have very little confidence in the estimate of effect; the genuine effect is likely to differ significantly from the effect estimate.

The grade of evidence was downgraded once if:

- If there was a high risk of bias in any criteria for more than 25% of studies included in the review
- The value for  $I^2$  was more than 40%, and heterogeneity was statistically significant.
- methodological discrepancies were evident between studies, such as exercise modalities used, population variances, or evaluation instruments used (indirectness)
- If the number of participants were less than 400 for continuous data
- Significant evidence of biases was found in the publication.

### Statistical analysis and data management

Review Manager (RevMan) [Computer program]. Version 5.4. The Cochrane Collaboration, 2020. was used to perform meta-analyses on the following outcome measures: HbA1c, Glucose, Insulin, HOMA, LDLC, HDLC, 6 MWT, TUG, Strength. The outcomes of the intervention group (eccentric exercise) and the comparator intervention group (concentric or traditional exercise) were compared in each meta-analysis. Intervention group data were not compared with non-exercise control group data. To determine the effect size for continuous variables, the mean difference (MD) was computed using either fixed effects or random effects MD (depending on heterogeneity), along with 95% confidence intervals (CI). If outcome data were inconsistently reported or different units of measurement were used, standardised mean difference (SMD) was used to estimate effect size. To assess heterogeneity, the  $I^2$  statistic was used in all meta-analyses, and the degree of heterogeneity was interpreted based on Deeks and colleagues' recommendations (Deeks et al., 2011), with an  $I^2$  value greater than 30% indicating probable heterogeneity that needs further investigation.

For outcomes with low heterogeneity ( $P$  values higher than 0.1 and  $I^2$  statistic less than 30% or not available), we utilised a fixed effect meta-analysis. We utilised a random effects model to account for heterogeneity where there was significant variability. The Review Manager calculator (Review Manager) was used to

convert data reported as least-squares mean SE or 95% CI to SD. The analysis also included studies that offered mean change data. Where studies graphically published data, authors were contacted to obtain the specific mean and standard deviation figures. If summary information for averages, standard deviations, and the number of individuals assigned to each group were not available, they were excluded from the meta-analyses.

## Results

### Search Summary (study selection)

Several major databases were searched on 20<sup>th</sup> February 2022 for studies from the inception of that database to 15<sup>th</sup> February 2022. The PRISMA diagram (Figure 1) shows the record of studies in various steps. The literature search conducted initially yielded a total of 674 records, with an additional ten articles being identified through manual searching of reference lists of the screened articles. After identifying and eliminating 213 duplicate records, 468 studies were evaluated based on their title and abstract. Among these, 337 studies were excluded due to not meeting the selection criteria. For full-text eligibility, 131 studies were assessed, with 112 studies being rejected. Ultimately, 19 studies were included in this review. Reasons for exclusion are provided in Figure 1. The Covidence software, an online tool developed by Veritas Health Innovation Ltd located in VIC 3000, Australia, was used to screen and review the articles.

### Description of included studies

Table 2 presents the characteristics of the study participants, interventions, and results. This review includes 19 studies. Seventeen were conducted on healthy individuals (Chen et al., 2017a; Chen et al., 2017b; Drexel et al., 2008; Duncan et al., 1989; Franchi et al., 2014; Gault et al., 2012; Hortobagyi et al., 1996a; Hortobagyi et al., 1996b; Lewis et al., 2018; Miller et al., 2006; Nickols-Richardson et al., 2007; Pavone and Moffat, 1985; Raue et al., 2005; Regnersgaard et al., 2022; Rodio and Fattorini, 2014; Tomberlin et al., 1991; Zeppetzauser et al., 2013), and two included people with T2DM (Hajihassani et al., 2014; Kudiarasu et al., 2021). Included studies were RCTs with an exercise training intervention. The modes of performing eccentric exercise training differed in the trials. Out of the 19 studies, in nine studies, exercise training was performed on a dynamometer (Duncan et al., 1989; Hortobagyi et al., 1996a; Hortobagyi et al., 1996b; Kudiarasu et al., 2021; Miller et al., 2006; Nickols-Richardson et al., 2007; Pavone and Moffat, 1985; Raue et al., 2005; Tomberlin et al., 1991). In three studies, training was performed on a treadmill (Hajihassani et al., 2014; Gault et al., 2012; Rodio and Fattorini, 2014), hiking uphill and downhill in two studies (Drexel et al., 2008; Zeppetzauser et al., 2013), ascending and descending stairs in two studies (Chen et al., 2017a; Regnersgaard et al., 2022), two studies on leg press/extension

machine (Chen et al., 2017b; Franchi et al., 2014), and one study on a cycle ergometer (Lewis et al., 2018).

Each study included in this review investigated the impacts of eccentric exercise training in comparison to concentric exercise training, except one study, in which downhill treadmill walking (eccentric exercise) was compared with flat walking (Gault et al., 2012). One study compared eccentric and concentric exercises with isometric training (Pavone and Moffat, 1985). A control group was also included in five studies, which did not perform any exercise (Duncan et al., 1989; Hortobagyi et al., 1996a; Hortobagyi et al., 1996b; Raue et al., 2005; Tomberlin et al., 1991). One study compared eccentric and concentric training with an additional group performing eccentric exercises and carrying a heavy load (Regnersgaard et al., 2022). In another study, in addition to the uphill and downhill walking group, two more groups exercised by walking on flat and mixed gradients (Rodio and Fattorini, 2014). The overall length of training intervention was variable among trials; the average duration of intervention was nine weeks, ranging from four to 20 weeks. The frequency of exercise sessions per week was found to vary across the studies; the average was 2.8 sessions per week from the range of one to five sessions every week. Depending on the study, the overall repetitions performed per session also varied.

In terms of participant number, there was variation among studies, ranging from 12 to 70. Overall, there were 618 participants in all included studies after adjusting for dropouts. Of the 19 studies, seven studies were on females only (Chen et al., 2017a; Hortobagyi et al., 1996a; Hortobagyi et al., 1996b; Miller et al., 2006; Nickols-Richardson et al., 2007; Pavone and Moffat, 1985; Rodio and Fattorini, 2014), five were on males only (Chen et al., 2017b; Duncan et al., 1989; Franchi et al., 2014; Lewis et al., 2018; Raue et al., 2005) and seven included both males and females (Hajihassani et al., 2014; Drexel et al., 2008; Gault et al., 2012; Kudiarasu et al., 2021; Regnersgaard et al., 2022; Tomberlin et al., 1991; Zeppetzauser et al., 2013). The distribution of gender was not proportional in included studies; there were 319 women and 163 men. Gender information was not supplied for 136 participants across four studies.

The meta-analyses included fifteen studies. The outcomes of the studies were typically reported as mean and standard deviation (SD) or 95% confidence interval or as mean and standard deviation (SD) or 95% confidence interval or as mean change and SD. Four studies that presented data in graphical format were not included in the meta-analyses. These papers were omitted from the analysis because the authors were approached for findings but never responded. Meta-analyses were carried out in Revman (Review Manager (RevMan) [Computer program]. Version 5.4.1, The Cochrane Collaboration, 2020.)

**Table 2. Main characteristics of the studies.**

Study	Population	Intervention	Duration	Health related measures	Functional fitness measures	Results
Hajihassani et al. (2014)	Diabetes Type 2 (n = 28) mean age 51.79	<b>Intervention 1:</b> Eccentric Exercise (Running on treadmill with ramp slope controlled for $-4^\circ$ ) n= 14 <b>Intervention 2:</b> Concentric Exercise (Running on treadmill with ramp slope controlled for $+4^\circ$ ) n = 14	Eight weeks	N/A	6MWT, TUG	Eccentric and concentric exercises significantly decreased the result of TUG. There was a significant difference in 6MWT b/w concentric and eccentric groups ( $P = 0.036$ ), although, in both groups, the distance walked increased after the intervention.
Chen et al. (2017a)	Elderly Obese Women (n = 30) Mean age 66	<b>Intervention 1:</b> Descending stair walking. n = 15 <b>Intervention 2:</b> Ascending stair walking. n = 15	12 weeks (2 sessions x week)	HbA1C HOMA OGTT Lipids HR	6MWT, MVC <sub>iso</sub> , 30-s chair stand, 8-ft up-and-go, 2-min step, and 6-m Tandem walk	Decreases in serum triacylglycerols, total and low-density lipoprotein cholesterol, glucose, insulin, HOMA, HbA1c, and increases in high-density lipoprotein cholesterol were greater ( $P < 0.05$ ) after Descending Stair Walking (DSW) than Ascending Stair Walking (ASW). MVC <sub>iso</sub> increased greater for DSW (34%) than ASW (15%). Physical fitness improved for both groups; however, the 30-s chair stand and 6MWT showed greater improvement for DSW than ASW
Chen et al. (2017b)	Healthy Elderly Men (n = 26) Mean age 66	<b>Intervention 1:</b> Eccentric training on Leg extension machine, 30-60 contractions of knee extensors once a week, intensity progressively increased from 10 -100% of 1 RM. n = 13 <b>Intervention 2:</b> Concentric training of knee extensors on the same device with intensity increased from 50 – 100% of 1 RM. n = 13	12 weeks (1 session x week)	HbA1C HOMA OGTT Lipids	1 RM, MVC <sub>con</sub> , MVC <sub>iso</sub> , 6MWT, 30-s chair stand (CS), 2-m step (2MS), 8-foot up-and-go (8UG), one-leg stand with eyes open (OLST), 6-meter tandem walk (6-mTW)	Functional physical fitness (e.g., 30-s chair stand) and maximal concentric contraction strength of the knee extensors increased greater ( $P \leq 0.05$ ) after Eccentric training than concentric training. HOMA, OGTT and HbA1c showed improvement in insulin sensitivity only after eccentric training ( $P \leq 0.05$ ). Greater ( $P \leq 0.05$ ) decreases in fasting TG, TC, and LDLC were evident after eccentric training than concentric training, and HDLC increased only after eccentric training.
Regnersgaard et al. (2022)	Healthy men and women (n=21) Mean age 70	<b>Intervention 1:</b> Descending stair walking. N = 07 <b>Intervention 2:</b> Ascending stair walking. N = 07 <b>Intervention 3:</b> Descending stair walking with carrying additional weight. N = 07	3 weeks or 6 weeks (3 sessions x week)		Leg muscle mass (kg), Thigh muscle mass, calf muscle mass, calf circumference, 6MWT, Sit to stand test (Chair stand test), power-CST, relative power-CST (W/kg), leg press 3RM (kg), leg extension power (W)	Leg muscle mass increased more in eccentric + ( $+0.29 \pm 0.09$ kg) vs concentric ( $+0.08 \pm 0.05$ kg) ( $P < 0.05$ ) but not different from eccentric ( $+0.16 \pm 0.06$ kg). The 6MWT increased after 6 weeks more ( $P < 0.05$ ) in eccentric + ( $+85 \pm 23$ m) compared with eccentric ( $+37 \pm 13$ m) and concentric ( $+27 \pm 12$ m). Leg press (3 RM) was higher ( $P = 0.028$ ) after training with no possible distinction between training groups.

HOMA: Homeostasis model assessment, MVC<sub>con</sub>: maximal voluntary concentric contraction torque, MVC<sub>iso</sub>: maximal voluntary isometric contraction torque, 6MWT: Six-minute walk test, TUG: Timed up and go test, TC: total cholesterol, TG: serum triacylglycerols, LDLC: low-density lipoprotein cholesterol, HDLC: high-density lipoprotein cholesterol, RM: repetition maximum, HbA1c: glycosylated haemoglobin, 5-RSTS: five repetition sit-to-stand.

Table 2. Continue....

Study	Population	Intervention	Duration	Health related measures	Functional fitness measures	Results
Drexel et al. (2008)	Healthy sedentary people Men (n = 14) Women (n = 28) Mean age 48	<b>Intervention 1:</b> Eccentric training (Hiking Downwards) n=23 <b>Intervention 2:</b> Concentric training (Hiking upwards) n=22	8 weeks (3-5 sessions x week)	HOMA Lipids Glucose	N/A	Eccentric exercise significantly lowered insulin resistance, fasting serum insulin, and the HOMA index of insulin resistance. An improvement in glucose tolerance was seen after both eccentric and concentric exercise but only the difference obtained by eccentric exercise reached statistical significance. TC, apolipoprotein B, and the apo B/apo A1 ratio were decreased by both.
Duncan et al. (1989)	Healthy men (n = 48) Mean age 24	<b>Intervention 1:</b> Eccentric training on KIN-COM Dynamometer (10 reps x session, Intensity = MVC) n=16 <b>Intervention 2:</b> Concentric training on the same device (10 reps x session, Intensity = MVC) n=14 <b>Control:</b> No exercise performed. n=18	6 weeks (3 sessions x week)	N/A	Eccentric strength, concentric strength	Eccentric and concentric training improved eccentric and concentric strength respectively, and gains after eccentric training were more mode specific.
Franchi et al. (2014)	Young male (n = 12) Mean age 25	<b>Intervention 1:</b> Eccentric training on the leg press machine. (4 sets of 8-10 reps at 80% of eccentric 1RM) n=06 <b>Intervention 2:</b> Concentric training on the same device. (4 sets of 8-10 reps at 80% of CON 1RM) n=06	10 weeks (3 sessions x week)	N/A	MVCiso, 1-RM	Similar increases in muscle volume (+6% eccentric and +8% concentric) and in MVCiso (+11% eccentric and +9%) were found after training among both groups.
Gault et al. (2012)	Healthy adults (n = 24) Mean age 67	<b>Intervention 1:</b> Downhill walking on a treadmill (30 min, -10% decline, self-selected walking speed). N=13 <b>Intervention 2:</b> Level walking on a treadmill (30 min at self-selected walking speed). N=11	12 weeks (3 sessions x week)	N/A	Concentric strength, Eccentric strength, 5-RSTS, maximal walking speed (MWS), TUG, dynamic strength	Improvements in 5-RSTS, MWS and TUG was substantial and similar for both groups. 5-RSTS improved by 32 and 34% in LTW and DTW. TUG improved by 22% for both groups. Peak eccentric and concentric torque did not change.
Hortobagyi et al. (1996a)	Sedentary Women (n = 42) Mean age 21	<b>Intervention 1:</b> Eccentric training on KIN-CON dynamometer, (4 sets of 6-10 reps) n=14 <b>Intervention 2:</b> Concentric training on the same device and parameters n=14 <b>Control:</b> No exercise performed. n=14	6 weeks (4 sessions x week)	N/A	concentric strength, eccentric strength, Isometric strength	Eccentric training improved isometric strength significantly ( $P < 0.05$ ) more than concentric training. Eccentric training improved concentric strength by 14% ( $P > 0.05$ ) and increased eccentric strength significantly ( $P < 0.05$ ) more than concentric training increased concentric strength.

HOMA: Homeostasis model assessment, MVCcon: maximal voluntary concentric contraction torque, MVCiso: maximal voluntary isometric contraction torque, 6MWT: Six-minute walk test, TUG: Timed up and go test, TC: total cholesterol, TG: serum triacylglycerols, LDLC: low-density lipoprotein cholesterol, HDLC: high-density lipoprotein cholesterol, RM: repetition maximum, HbA1c: glycosylated haemoglobin, 5-RSTS: five repetition sit-to-stand.



Table 2. Continue....

Study	Population	Intervention	Duration	Health related measures	Functional fitness measures	Results
Hortobagyi et al. (1996b)	Sedentary Men (n = 21) Mean age 21	<b>Intervention 1:</b> Eccentric training on KIN-CON dynamometer (Almost 50 reps x session, Intensity = MVC) n=07 <b>Intervention 2:</b> Concentric training on the same device and parameters. n=08 <b>Control:</b> No exercise performed. n=06	12 weeks (3 sessions x week)		concentric strength, eccentric strength, Isometric strength	Eccentric training increased eccentric strength 3.5 times more (pre/post 46%, P < 0.05) than concentric training increased concentric strength (pre/post 13%). Eccentric training increased concentric strength and Concentric training increased eccentric strength by about the same magnitude (5 and 10%, respectively, P > 0.05).
Kudiarasu et al.(2021)	Adults with T2DM (n=18) Mean age	<b>Intervention 1:</b> Eccentric training on Cybex. Exercises included chest press, lateral pull-down, bicep curl, triceps extension, leg extension, leg curl, calf raise, abdominal crunch (2–3 sets of 10 eccentric-only for 5 s) n=09 <b>Intervention 2:</b> Concentric training on the same device (2–3 sets of 10 concentric-only (1-2 s). n=09	12 weeks (2 sessions x week)	plasma glucose, serum insulin, HbA1c, Lipids, HOMA	muscle strength, 6MWT, chair rise test, TUG	No significant changes in blood biomarkers were found for both groups. One-repetition maximal strength of each exercise increased (p < 0.05) for both eccentric (12–37%) and concentric (27–68%). Both groups improved (p < 0.05) 6MWT distance and chair rise time but only eccentric improved (p < 0.05) the TUG.
Lewis et al. (2018)	Middle-aged male (n=17) Mean age 42	<b>Intervention 1:</b> Eccentric cycling at 60% peak concentric workload. N= 09 <b>Intervention 2:</b> Concentric cycling. N=08	8 weeks (2 sessions x week)	N/A	6RM MVIC	Both groups significantly increased 6RM and MVIC relative to their baseline (P < 0.05). Therefore, improved leg strength was equivalent between concentric and eccentric groups.
Miller et al. (2006)	Healthy Women (n=38) Mean age 20	<b>Intervention 1:</b> Eccentric training on Iso-kinetic Dynamometer, Intensity=MVC. n= 17 <b>Intervention 2:</b> Concentric training on the same device and parameters. n=21	20 week (3 sessions x week)	N/A	Isokinetic Strength	Eccentric training increased eccentric knee extension and flexion peak torque more than concentric training.
Nickols-Richardson et al. (2007)	Healthy Women (n = 70) Mean age 20	<b>Intervention 1:</b> Eccentric training on Isokinetic Dynamometer (30 reps x session, Intensity = MVC). n=33 <b>Intervention 2:</b> Concentric training on the same device and parameters. n=37	20 weeks (3 sessions x week)	N/A	Concentric peak torque (Nm) Eccentric peak torque (Nm)	Muscular strength (peak torque) of the trained leg was significantly higher after training in both the concentric (18.6%) and eccentric (28.9%) training groups
Pavone and Moffat (1985)	Healthy Women (n = 27) Mean age 29	<b>Intervention 1:</b> Eccentric training on Cybex II Isokinetic Dynamometer, 30 reps x session, Intensity=% 1RM Eccentric. N=11 <b>Intervention 2:</b> Concentric training on the same device. 30 repetitions per session, Intensity=% 1RM Con. n=08 <b>Intervention 3:</b> Isometric training on the same device by holding the load at 60 of knee flexion. N=08	6 week (3 sessions x week)	N/A	MVCiso	Significant strength gain was achieved through concentric, eccentric, and isometric training. No one method of training is superior to other.

HOMA: Homeostasis model assessment, MVCcon: maximal voluntary concentric contraction torque, MVCiso: maximal voluntary isometric contraction torque, 6MWT: Six-minute walk test, TUG: Timed up and go test, TC: total cholesterol, TG: serum triacylglycerols, LDLC: low-density lipoprotein cholesterol, HDLC: high-density lipoprotein cholesterol, RM: repetition maximum, HbA1c: glycosylated haemoglobin, 5-RSTS: five repetition sit-to-stand.

Table 2. Continue....

Study	Population	Intervention	Duration	Health related measures	Functional fitness measures	Results
Raue (2005)	Healthy sedentary male (n = 15) Mean age 23	<b>Intervention 1:</b> Eccentric exercise training on knee extensor device Cybex (4 sets of 8 reps, Intensity = starting at 80% of 1 RM Con). n=06 <b>Intervention 2:</b> Concentric exercise training on the same device and parameters. n=06 <b>Control:</b> No exercise training. n=03	4 weeks (3 sessions x week)	N/A	Knee extensors strength	Concentric training increased knee extensor strength by 19% (p <0.05)—no difference in knee extensor strength pre to post-training for eccentric or Control group.
Rodio and Fattorini (2014)	Healthy young adults Women (n = 28) Mean age 26	<b>Intervention 1:</b> Level walking on a treadmill (30 min at 1 m/s). n=07 <b>Intervention 2:</b> Uphill walking on a treadmill (30 min, +20% incline, 0.75m/s). n=08 <b>Intervention 3:</b> Downhill walking on a treadmill (30 min, -20% decline, 1.36m/s). n=07 <b>Intervention 4:</b> Mixed walking on a treadmill (+20% incline, 0.75 m/s, 15 min and -20% decline, 1.36m/s, 15 min). n=06	6 weeks (3 sessions x week)	N/A	MVCiso	In all groups, strength values were increased from baseline to post-intervention but resulted in statistically different only in the Downhill walking group.
Tomberlin et al. (1991)	Healthy people Men (n = 31) Women (n = 32) Mean age 27	<b>Intervention 1:</b> Eccentric training on KIN-COM Dynamometer. n=21 <b>Intervention 2:</b> Concentric training on the same device. N=19 <b>Control:</b> no exercise performed. n=23	6 weeks (3 sessions x week)	N/A	Concentric peak torque (Nm) Eccentric peak torque (Nm)	Eccentric and concentric training increased eccentric and concentric strength respectively.
Zeppetzauser et al. (2013)	healthy sedentary Men (n = 16) Women (n = 29) Mean age 48	<b>Intervention 1:</b> Hiking downwards (eccentric training) on 540 meters trail. n=22 <b>Intervention 2:</b> Hiking upwards (Concentric exercise) on the same path. n=23	8 weeks (3-5 sessions x week)	Lipids Glucose Creatine kinase CRP Heart Rate	N/A	Eccentric training improved glucose tolerance (AUC) per unit of energy expenditure significantly more than concentric training. The decrease of LDLC per kilocalorie spent was significantly stronger with eccentric exercise.

HOMA: Homeostasis model assessment, MVCcon: maximal voluntary concentric contraction torque, MVCiso: maximal voluntary isometric contraction torque, 6MWT: Six-minute walk test, TUG: Timed up and go test, TC: total cholesterol, TG: serum triacylglycerols, LDLC: low-density lipoprotein cholesterol, HDLC: high-density lipoprotein cholesterol, RM: repetition maximum, HbA1c: glycosylated haemoglobin, 5-RSTS: five repetition sit-to-stand.

### Study outcomes

Six studies (Chen et al., 2017a; Chen et al., 2017b; Drexel et al., 2008; Kudiarasu et al., 2021; Regnersgaard et al., 2022; Zeppetzauser et al., 2013) provided information about the effects of eccentric exercise on glucose handling, five (Chen et al., 2017a; Chen et al., 2017b; Drexel et al., 2008; Kudiarasu et al., 2021; Zeppetzauser et al., 2013) reported about effects on lipids, six (Hajihassani et al., 2014; Chen et al., 2017a; Chen et al., 2017b; Gault et al., 2012; Kudiarasu et al., 2021; Regnersgaard et al., 2022) reported the effects on functional physical fitness, sixteen (Chen et al., 2017a; Chen et al., 2017b; Duncan et al., 1989; Franchi et al., 2014; Gault et al., 2012; Hortobagyi et al., 1996a; Hortobagyi et al., 1996b; Kudiarasu et al., 2021; Lewis et al., 2018; Miller et al., 2006; Nickols-Richardson et al., 2007; Pavone and Moffat, 1985; Raue et al., 2005; Regnersgaard et al., 2022; Rodio

and Fattorini, 2014; Tomberlin et al., 1991) studies reported the effects on muscle strength. Two papers (Drexel et al., 2008; Zeppetzauser et al., 2013) reported results from the same study. However, due to possible duplication, only one of these studies was included in the meta-analysis (Drexel et al., 2008).

### Methodological quality (Risk of Bias)

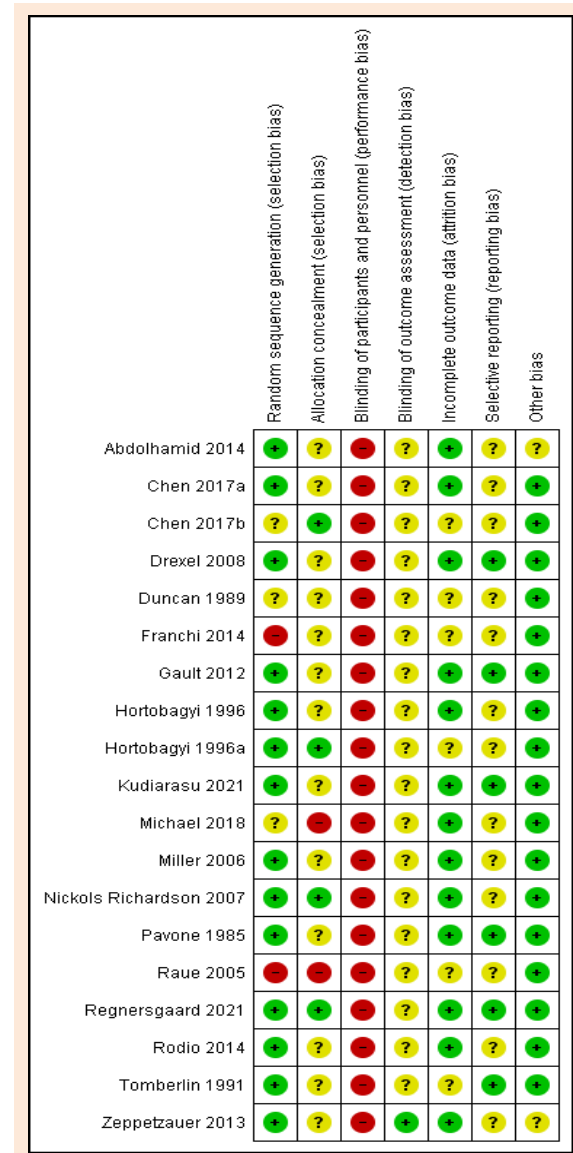
Figure 2 summarises the risk of bias assessment for each included study. Nineteen studies (Hajihassani et al., 2014; Chen et al., 2017a; Chen et al., 2017b; Drexel et al., 2008; Duncan et al., 1989; Franchi et al., 2014; Gault et al., 2012; Hortobagyi et al., 1996a; Hortobagyi et al., 1996b; Kudiarasu et al., 2021; Lewis et al., 2018; Miller et al., 2006; Nickols-Richardson et al., 2007; Pavone and Moffat, 1985; Raue et al., 2005; Regnersgaard et al.,

2022; Rodio and Fattorini, 2014; Tomberlin et al., 1991; Zeppetzauser et al., 2013) were at high risk of bias for blinding participants and personnel criteria as in these exercise studies participants were not blinded to the intervention they received. In one study (Raue et al., 2005), the risk of bias was high for random sequence generation and allocation concealment (selection bias). In one study (Franchi et al., 2014), the risk of bias was high for random sequence generation. In another study (Lewis et al., 2018) risk of bias was high for allocation concealment (selection bias). For other categories, the bias was often low or not clear. Figure 2 represents the results of the risk of bias assessment. Figure 3 shows the review authors' judgements about each risk of bias item for the review presented as percentages across included studies.

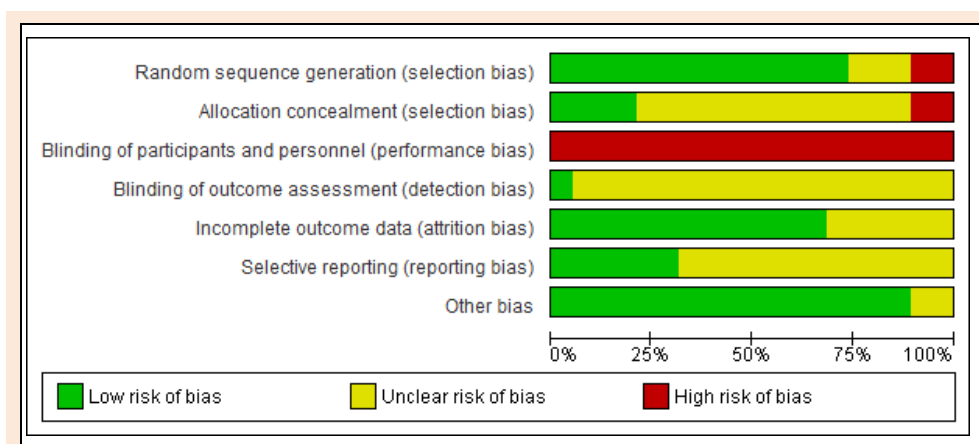
**Description of Results & Meta-Analysis**  
**Effect of eccentric exercise on glycaemic control**

Six studies reported the effectiveness of eccentric exercise intervention on glycaemic control. Five studies were conducted on healthy people (Chen et al., 2017a; Chen et al., 2017b; Drexel et al., 2008; Regnersgaard et al., 2022; Zeppetzauser et al., 2013), and one was on people with T2DM (Kudiarasu et al., 2021). The modality of training used in these studies was a leg extension machine (Chen et al., 2017b), hiking upwards and downwards (Drexel et al., 2008; Zeppetzauser et al., 2013), resistance exercises (bicep curl, chest press, latissimus dorsi, triceps extension, leg extension, leg curl, calf raise, abdominal crunch) (Kudiarasu et al., 2021), and descending and ascending stairs (Chen et al., 2017a; Regnersgaard et al., 2022).

In two studies (Chen et al., 2017a; Chen et al., 2017b), glycaemic control was measured through fasting glucose, insulin, HOMA, HbA1C, and Oral glucose tolerance test (OGTT). Two studies (Drexel et al., 2008; Zeppetzauser et al., 2013) measured HOMA, Serum fasting insulin and glucose area under the curve in response to an OGTT. In one study (Regnersgaard et al., 2022), only fasting blood glucose was measured. In one study on people with T2DM (Kudiarasu et al., 2021), glycaemic control was measured through fasting plasma glucose, serum insulin, HbA1c and HOMA.



**Figure 2. Risk of Bias summary.** Risk of bias summary: review authors' judgements about each risk of bias item for each included study. Green symbols represent a low risk of bias, yellow symbols represent an unclear risk, and red symbols represent a high risk of bias.



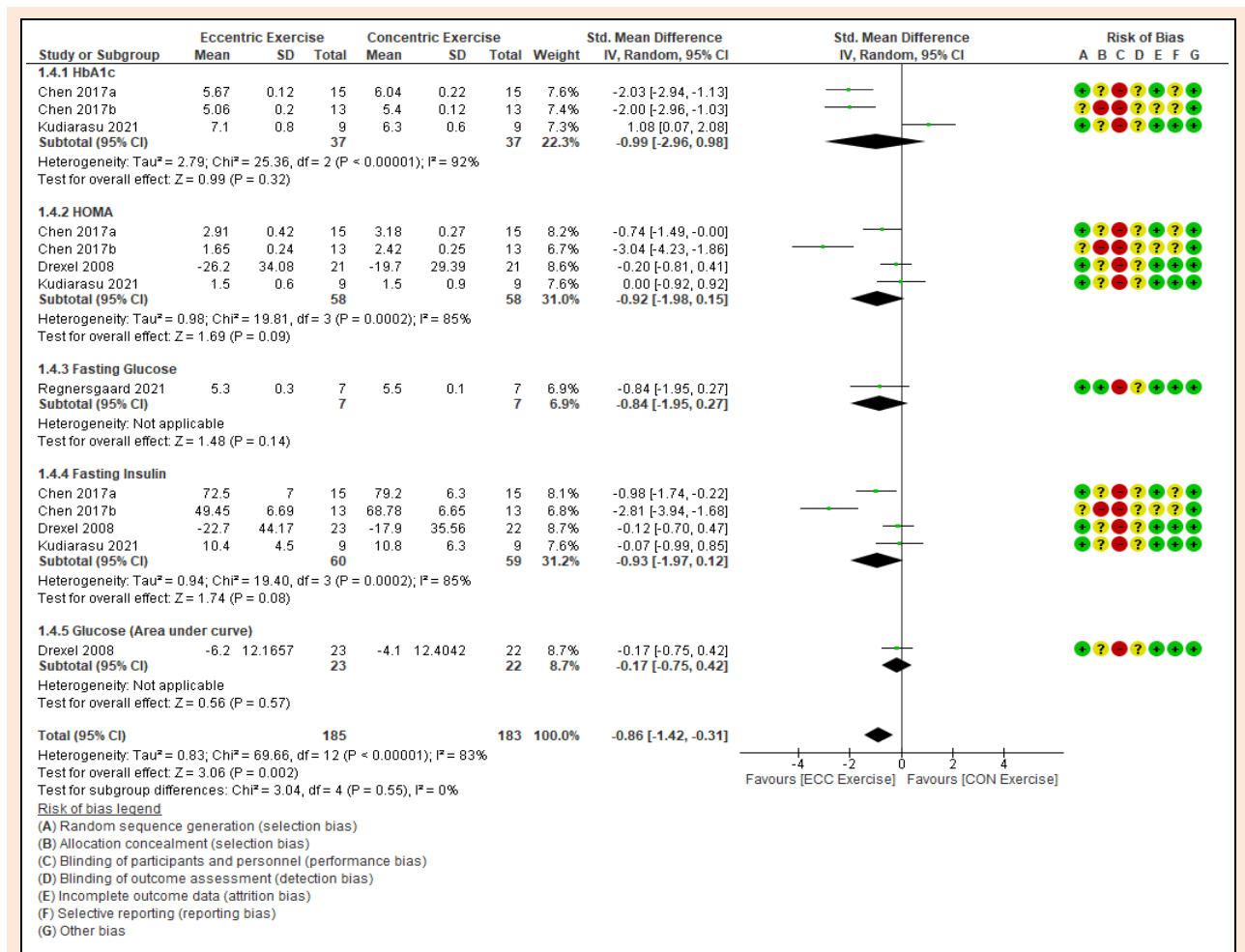
**Figure 3. Overall Risk of Bias summary.** Risk of bias summary: review authors' judgements about each risk of bias item for each included study. Green symbols represent a low risk of bias, yellow symbols represent an unclear risk, and red symbols represent a high risk of bias.

In four studies (Chen et al., 2017a; Chen et al., 2017b; Drexel et al., 2008; Zeppetzauer et al., 2013), the HOMA index of insulin resistance and fasting serum insulin were lowered by eccentric exercise. In one study (Drexel et al., 2008), a decrease in the area under the glucose curve after a standardised oral glucose load was seen after performing both concentric and eccentric exercise training; however, only the difference acquired through eccentric exercise was statistically significant. In one study (Kudiarasu et al., 2021), HbA1c decreased significantly ( $p < 0.05$ ) after twelve weeks of concentric training only and not after eccentric training. In another study, no statistically significant difference was observed in glucose after intervention in any group (Regnersgaard et al., 2022).

HbA1c was measured in three studies (Chen et al., 2017a; Chen et al., 2017b; Kudiarasu et al., 2021) (74 participants). All studies reported results as mean and SD. A random effects meta-analysis using SMD showed eccentric exercise led to non-significant decreases in HbA1c level (SMD - 0.99; 95% CI, -2.96 to 0.98;  $n = 74$ ;  $P = 0.32$ ; Figure 4) across all studies in the meta-analysis with high and significant ( $I^2 = 92\%$ ,  $p = 0.00001$ ) heterogeneity observed. The evidence for eccentric exercise to decrease HbA1c as compared to concentric exercise was graded as very low. The quality of evidence was downgraded thrice; once for the high risk of bias in included studies due to lack of blind-

ing for participants and assessors; once for small sample size, and once due to more than 40% heterogeneity. HOMA was measured in four studies (116 participants). A random-effects meta-analysis using SMD showed eccentric exercise led to non-significant decreases in HOMA (SMD -0.92; 95% CI, -1.98 to 0.15;  $n = 116$ ;  $P = 0.09$ ; Figure 4) across all studies in the meta-analysis with high and significant ( $I^2 = 85\%$ ,  $p = 0.0002$ ) heterogeneity observed. These findings represent an approximate decrease of 0.42 in HOMA (95% CI -0.90 to 0.07). The quality of evidence for eccentric exercise to decrease HOMA was graded as very low. The quality of evidence was downgraded thrice, once for the high risk of bias in the included studies due to lack of blinding for participants and assessors, once for a small sample size, and once due to more than 40% heterogeneity.

Glucose was measured as fasting serum glucose (Chen et al., 2017a; Chen et al., 2017b; Kudiarasu et al., 2021; Regnersgaard et al., 2022) and as Glucose (Area under the curve) in OGTT (Drexel et al., 2008). Fasting glucose was measured in four studies (Chen et al., 2017a; Chen et al., 2017b; Kudiarasu et al., 2021; Regnersgaard et al., 2022) (88 participants). A random-effects meta-analysis using SMD showed eccentric exercise led to non-significant decreases in fasting glucose level (SMD - 0.84; 95% CI, -1.95 to 0.27;  $n = 14$ ;  $P = 0.14$ ; Figure 4).



**Figure 4. Forest plot of eccentric vs concentric exercise on glycaemic management.** Risk of bias summary: review authors' judgements about each risk of bias item for each included study. Green symbols represent a low risk of bias, yellow symbols represent an unclear risk, and red symbols represent a high risk of bias.



The quality of evidence for eccentric exercise to decrease fasting glucose was graded as low. The quality of the evidence was rated as low because of the high risk of bias due to a lack of blinding for participants and assessors and once due to the small sample size.

Serum insulin was measured in four studies (119 participants) as fasting serum insulin (Chen et al., 2017a; Chen et al., 2017b; Drexel et al., 2008; Kudiarasu et al., 2021). A random-effects meta-analysis using SMD showed eccentric exercise led to non-significant decreases in insulin (SMD -0.93; 95% CI, -1.97 to 0.12; n = 119; P = 0.08; Figure 4) across all studies in the meta-analysis with high and significant ( $I^2 = 85\%$ ,  $p = 0.0002$ ) heterogeneity observed. This represents an approximate decrease of 17.98 pmol/L in insulin (95% CI -38.1 to 2.32). The quality of evidence for eccentric exercise to decrease insulin was graded as very low. The quality of evidence was downgraded thrice; once for the high risk of bias in the included studies due to lack of blinding for participants and assessors; once for a small sample size, and once due to more than 40% heterogeneity.

**Effect of eccentric exercise on lipids**

Five studies have reported the effects of eccentric exercise on lipids (Chen et al., 2017a; Chen et al., 2017b; Drexel et al., 2008; Kudiarasu et al., 2021; Zeppetzauser et al., 2013). Four studies were conducted on Healthy sedentary people (Chen et al., 2017a; Chen et al., 2017b; Drexel et al., 2008; Zeppetzauser et al., 2013) and one on people with T2DM(Kudiarasu et al., 2021). Exercise training was performed by hiking uphill and downhill (Drexel et al., 2008; Zeppetzauser et al., 2013), ascending and descending stair walking(Chen et al., 2017a), using a leg extension machine(Chen et al., 2017b) and Cybex dynamometer(Kudiarasu et al., 2021). TG, TC, LDLC, and HDLC were measured in all studies. In one paper Apolipoprotein B and apolipoprotein B/apolipoprotein A1 (apo B/apo A1), the ratio was also calculated (Drexel et al., 2008).

In two studies (Chen et al., 2017a; Chen et al., 2017b), TC, TG, and LDLC decreased significantly after eccentric and concentric training. However, the eccentric group's lowered magnitude was substantially greater than the concentric groups. In HDLC, a significant increase after only eccentric exercise was observed. In other studies, (Drexel et al., 2008; Zeppetzauser et al., 2013), HDLC,

LDLC, TC, and apo B/apo A1 ratio were reduced in both eccentric and concentric groups, but only the difference for LDLC was statistically significant. There were no significant changes in the lipid profile for either group from pre- to post-intervention in the study on people with T2DM (Kudiarasu et al., 2021).

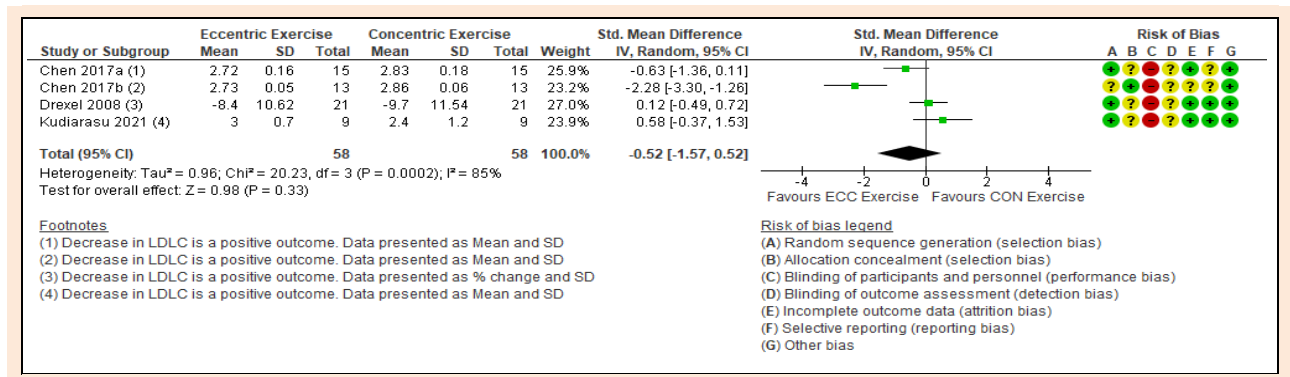
A meta-analysis was performed on the results of four studies (Chen et al., 2017a; Chen et al., 2017b; Drexel et al., 2008; Kudiarasu et al., 2021; Regnersgaard et al., 2022) as two papers reported the same study and had similar results (Drexel et al., 2008; Zeppetzauser et al., 2013), so data from only one study (Drexel et al., 2008) was included. The results show eccentric exercise is associated with non-significant LDLC reduction (SMD -0.52; 95% CI, -1.57 to 0.52; n = 116, P = 0.33; Figure 5) with high and significant ( $I^2 = 85\%$ ,  $P = 0.0002$ ) heterogeneity observed and increased HDLC (SMD 0.74; 95% CI, -0.29 to 1.76; n = 116; P = 0.16; Figure 6) with high and significant ( $I^2 = 84\%$ ,  $P = 0.0003$ ) heterogeneity observed as compared with concentric exercise. This represents an approximate decrease of 0.25 mmol/L (95% CI -0.77 to 0.25) in LDLC and an increase of 0.22 mmol/L (95% CI -0.09 to 0.52) in HDLC. The quality of evidence for eccentric exercise to decrease LDLC and increase HDLC was graded as very low. The quality of evidence was downgraded thrice; once for the high risk of bias in the included studies due to lack of blinding for participants and assessors; once for a small sample size, and once due to more than 40% heterogeneity.

**Cardiovascular parameters**

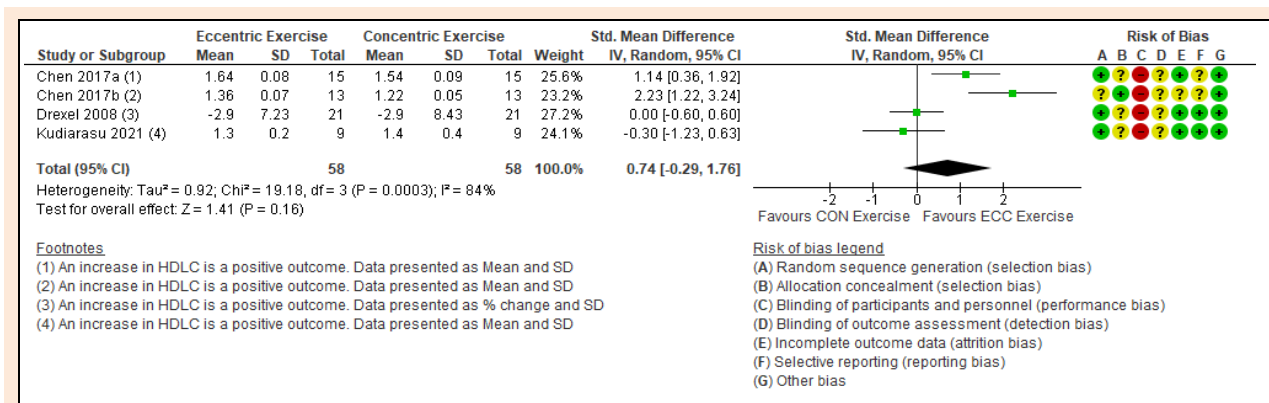
Two studies (Chen et al., 2017a; Lewis et al., 2018) reported the effect of chronic eccentric exercise training compared to concentric training on cardiovascular outcome measures. Both these studies reported the effect of chronic eccentric training on resting brachial blood pressure, and only one (Chen et al., 2017a) reported an effect on resting heart rate. None of the studies measured central (aortic) blood pressure or arterial health.

**Brachial blood pressure**

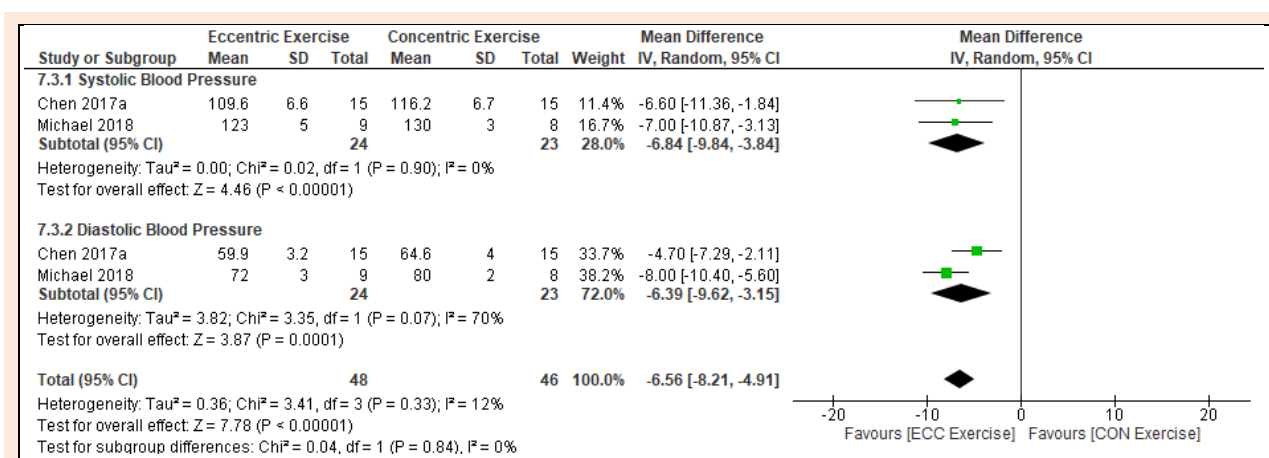
Two studies on healthy participants measured brachial systolic and diastolic blood pressure (SBP and DBP) (Chen et al., 2017a; Lewis et al., 2018). The results of one study



**Figure 5. Forest plot of eccentric vs concentric exercise on LDLC.** Risk of bias summary: review authors' judgements about each risk of bias item for each included study. Green symbols represent a low risk of bias, yellow symbols represent an unclear risk, and red symbols represent a high risk of bias.



**Figure 6. Forest plot of eccentric vs concentric exercise on HDLC.** Risk of bias summary: review authors' judgements about each risk of bias item for each included study. Green symbols represent a low risk of bias, yellow symbols represent an unclear risk, and red symbols represent a high risk of bias.



**Figure 7. Forest plot of meta-analyses showing a comparison of eccentric versus concentric training on systolic and diastolic blood pressure.**

(Chen et al., 2017a) in which the training modality was walking up and down stairs showed SBP decreased more after eccentric exercise (-9%) than after concentric exercise (-4%). In the case of DBP, significant decreases were found in both groups following the training intervention, with no substantial differences between them. Another study (Lewis et al., 2018) showed a non-significant decrease in SBP and DBP among both training groups after training. At baseline, there was no difference in resting blood pressure between the groups, and this remained the same following training.

A random-effects meta-analysis using MD showed eccentric exercise led to significant decreases in SBP (MD -6.84; 95% CI, -9.84 to -3.84; P = 0.00001 n = 47; Figure 7) with no (I<sup>2</sup> = 0%; P = 0.90) heterogeneity observed. The quality of evidence for eccentric exercise to decrease SBP was graded as low. The quality of evidence was downgraded twice, once for the high risk of bias in the included studies due to lack of blinding for participants and assessors and once for a small sample size.

A random-effects meta-analysis using MD performed on the results of two studies showed eccentric exercise led to a significant decrease in DBP (MD -6.39; 95% CI -9.62 to -3.15; P = 0.0001, n = 47; figure 7) with high and non-significant (I<sup>2</sup> = 70%; P = 0.07) heterogeneity observed. The quality of evidence for eccentric exercise to

decrease DBP was graded as very low. The quality of evidence was downgraded thrice; once for the high risk of bias in the included studies due to lack of blinding for participants and assessors; once for a small sample size, and once due to more than 40% heterogeneity.

**Resting heart rate**

One study (Chen et al., 2017a) on a healthy population reported the effects of concentric and eccentric exercise training on resting heart rate. Results showed that resting heart rate was significantly decreased after eccentric exercise (-9.8 + 4.3%) compared to concentric exercise (-4.0% + 3.7%) after a 12-week intervention.

**Effect of exercise on functional physical fitness**

Six studies have reported the effects of eccentric exercise on functional physical fitness. Four studies (Chen et al., 2017a; Chen et al., 2017b; Gault et al., 2012; Regnersgaard et al., 2022) were conducted on a healthy population and two studies (Hajihassani et al., 2014; Kudiarasu et al., 2021) on people with T2DM. The training was performed by walking on a treadmill (Hajihassani et al., 2014; Gault et al., 2012), ascending and descending stairs (Chen et al., 2017a; Regnersgaard et al., 2022), using a leg extension machine (Chen et al., 2017b) and a Cybex dynamometer (Kudiarasu et al., 2021). The studies included in our review assessed a

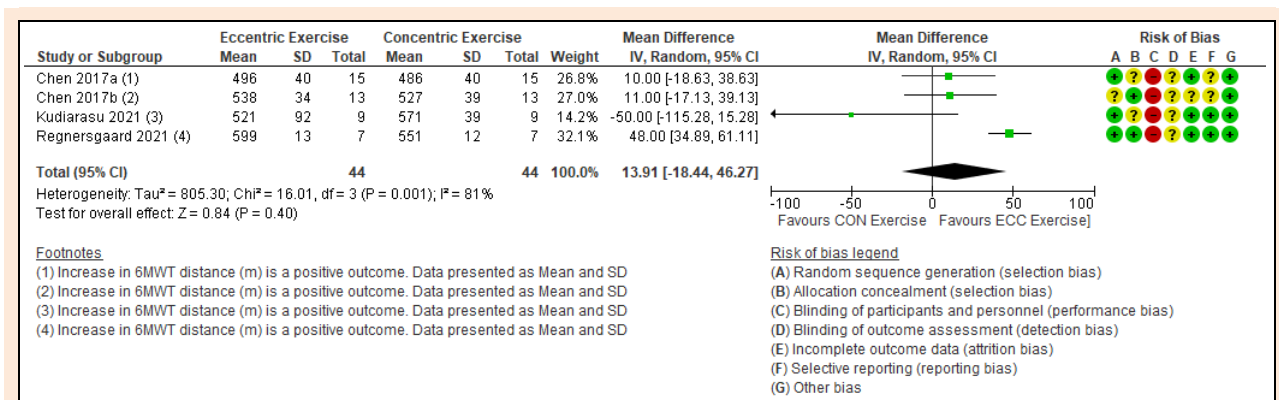
range of functional fitness tests, including tests for aerobic fitness/endurance (6MWT) and tests for mobility/flexibility, balance, and strength such as (TUG, 30-sec chair stand, 8 foot up and go, 6 m tandem walk, 2 min- step test). All but one study assessed functional fitness through 6MWT (Hajihassani et al., 2014; Chen et al., 2017a; Chen et al., 2017b; Kudiarasu et al., 2021; Regnersgaard et al., 2022). The remaining study (Gault et al., 2012) assessed functional physical fitness through TUG, and five repetitions sit to stand test. TUG was also performed in two other studies (Hajihassani et al., 2014; Kudiarasu et al., 2021). Two studies (Chen et al., 2017a; Chen et al., 2017b) performed other measures of functional physical fitness in addition to 6MWT, such as 30 seconds sit-to-stand test (30STS), 2 min- step test, 8 foot up and go test, and 6 m tandem walk test.

In the three studies which measured functional physical fitness through TUG, two studies (Hajihassani et al., 2014; Kudiarasu et al., 2021) compared eccentric exercise to concentric exercise, whereas one compared eccentric exercise (downhill walking) with traditional exercise (flat-level walking) (Gault et al., 2012). Results of two studies (Hajihassani et al., 2014; Gault et al., 2012) indicated that both types of exercise training decreased TUG time (sec) pre- to post-training significantly; however, in between group analysis, there was no significant difference observed. The third study showed that only eccentric training decreased time (sec) after training for TUG significantly (Kudiarasu et al., 2021). Meta-analysis was not performed on results because, in two studies, data was graphically presented (Hajihassani et al., 2014; Gault et al., 2012).

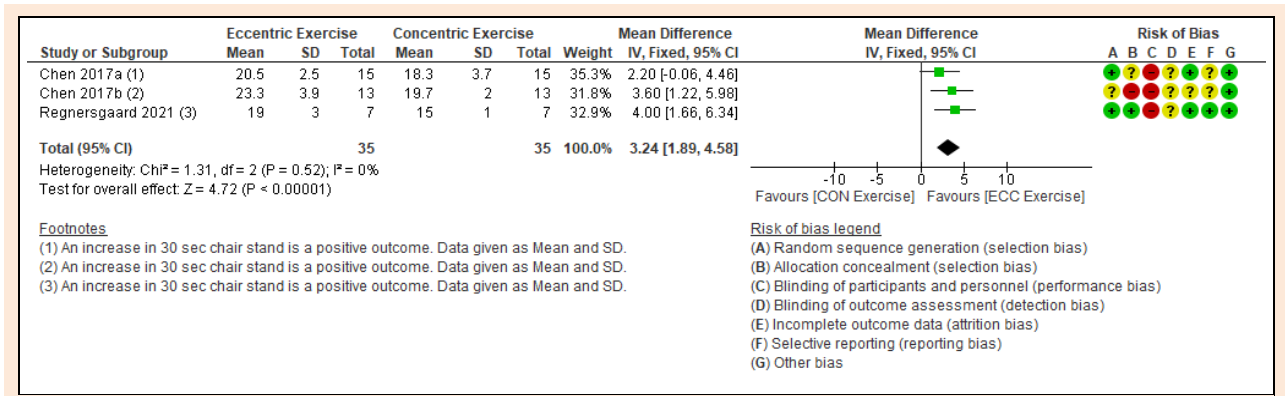
Among five studies that performed 6MWT, distance walked in 6 minutes increased post-training intervention in both groups. In two studies (Hajihassani et al., 2014; Chen et al., 2017a), the increase in 6MWT distance was significantly more for the eccentric training group than the concentric training group. Three studies (Chen et al., 2017b; Kudiarasu et al., 2021; Regnersgaard et al., 2022) reported no significant difference between groups, functional physical fitness increased in both groups because of training. A random effects meta-analysis using MD was performed on the results of four studies, as data was graph-

ically presented in one paper (Hajihassani et al., 2014). The distance walked post-intervention was greater in both intervention groups in all studies. Results showed a non-significant increase in distance walked in meters in 6MWT following the eccentric versus concentric intervention (MD 13.91; 95%CI -18.44 to 46.27;  $p = 0.40$ ; Figure 8) across all studies in the meta-analysis with a high and significant level of heterogeneity ( $I^2 = 81%$ ,  $p = 0.001$ ). The evidence for eccentric exercise to increase the distance walked in 6MWT was graded as very low. The quality of evidence was downgraded thrice; once for the high risk of bias in the included studies due to lack of blinding for participants and assessors; once for a small sample size, and once due to more than 40% heterogeneity.

Results from one (Chen et al., 2017a) of the two studies (Chen et al., 2017a; Chen et al., 2017b), which performed a 30-s chair stand, 8 foot up and go, 2 min- step test, and 6 m tandem walk, showed significant improvement in all these functional physical fitness parameters. However, the 30-s chair stand test and 6 m tandem walk showed more remarkable improvement for the eccentric than the concentric group. In the other study (Chen et al., 2017b), 8-foot up-and-go and 30-s chair stand test results were significantly better ( $P < 0.05$ ) for the eccentric training group than concentric training group, but no significant differences were found for other tests. Another study (Regnersgaard et al., 2022) also performed a 30-sec chair-stand test; results showed that the number of stands increased significantly after both types of exercise. A fixed-effects meta-analysis using MD was performed on the results of all studies. Results showed a significantly increased number of stands in the 30-sec chair-stand-test following the eccentric versus concentric intervention (MD 3.24; 95%CI -1.89 to 4.58;  $n = 70$ ;  $p = 0.00001$ ; Figure 9) across all studies in the meta-analysis with no heterogeneity observed ( $I^2 = 0%$ ,  $p = 0.52$ ). The evidence for eccentric exercise to increase the number of stands in the 30-sec chair-stand test was graded as low. The quality of evidence was downgraded twice, once for study limitations due to the high risk of bias due to lack of blinding for participants and assessors and once due to small sample size.



**Figure 8. Forest Plot of meta-analyses showing a comparison of eccentric versus concentric training on Functional Physical Fitness measured as distance covered in meters in 6 Minute walk test.** Risk of bias summary: review authors' judgements about each risk of bias item for each included study. Green symbols represent a low risk of bias, yellow symbols represent an unclear risk, and red symbols represent a high risk of bias.



**Figure 9. Forest Plot of meta-analyses showing a comparison of eccentric versus concentric training on Functional Physical Fitness measured as a 30-sec Chair stand test.** Risk of bias summary: review authors' judgements about each risk of bias item for each included study. Green symbols represent a low risk of bias, yellow symbols represent an unclear risk, and red symbols represent a high risk of bias.

**Effect of exercise on strength**

Sixteen studies reported the effects of eccentric exercise training on muscle strength (Chen et al., 2017a; Chen et al., 2017b; Duncan et al., 1989; Franchi et al., 2014; Gault et al., 2012; Hortobagyi et al., 1996a; Hortobagyi et al., 1996b; Kudiarasu et al., 2021; Lewis et al., 2018; Miller et al., 2006; Nickols-Richardson et al., 2007; Pavone and Moffat, 1985; Raue et al., 2005; Regnersgaard et al., 2022; Rodio and Fattorini, 2014; Tomberlin et al., 1991). Among these, 15 studies were conducted on healthy people, and one included people with T2DM (Kudiarasu et al., 2021). Fifteen studies compared eccentric exercise with concentric exercise (Chen et al., 2017a; Chen et al., 2017b; Duncan et al., 1989; Franchi et al., 2014; Hortobagyi et al., 1996a; Hortobagyi et al., 1996b; Kudiarasu et al., 2021; Lewis et al., 2018; Miller et al., 2006; Nickols-Richardson et al., 2007; Pavone and Moffat, 1985; Raue et al., 2005; Regnersgaard et al., 2022; Rodio and Fattorini, 2014; Tomberlin et al., 1991) and one study (Gault et al., 2012) compared eccentric exercise with mixed training. Five studies also included a non-exercise control group (Duncan et al., 2016; Hortobagyi et al., 1996a; Hortobagyi et al., 1996b; Raue et al., 2005; Tomberlin et al., 1991). One study (Rodio and Fattorini, 2014) included two additional comparison groups (level and mixed walking group), while another study (Pavone and Moffat, 1985) included an isometric training comparison group. A single study included two eccentric training groups (downhill walking and downhill walking while carrying additional weight in a backpack) (Regnersgaard et al., 2022). In nine studies, training was performed on an isokinetic dynamometer (Duncan et al., 1989; Hortobagyi et al., 1996a; Hortobagyi et al., 1996b; Kudiarasu et al., 2021; Miller et al., 2006; Nickols-Richardson et al., 2007; Pavone and Moffat, 1985; Raue et al., 2005; Tomberlin et al., 1991), two studies involved climbing or descending stairs (Chen et al., 2017a; Regnersgaard et al., 2022), two studies used a leg extension machine (Chen et al., 2017b; Franchi et al., 2014), two included treadmill walking (Gault et al., 2012; Rodio and Fattorini, 2014) and one study involved training on a cycle ergometer (Lewis et al., 2018). Strength was measured through an isokinetic dynamometer (Chen et al., 2017b; Duncan et al., 1989; Franchi et al., 2014; Gault et al., 2012; Hortobagyi et al., 1996a; Hortobagyi et al., 1996b; Lewis

et al., 2018; Miller et al., 2006; Nickols-Richardson et al., 2007; Pavone and Moffat, 1985; Raue et al., 2005; Tomberlin et al., 1991), leg extension device (Chen et al., 2017a), force plate (Regnersgaard et al., 2022), using free weights (Kudiarasu et al., 2021), and an experimental strength measurement device based on a load cell (Rodio and Fattorini, 2014). Strength was measured as one repetition maximum (RM) (Chen et al., 2017b; Franchi et al., 2014; Kudiarasu et al., 2021; Raue et al., 2005), 3 RM (Regnersgaard et al., 2022), 6 RM (Lewis et al., 2018), Maximum voluntary isometric contraction (MVC-Iso) (Chen et al., 2017a; Chen et al., 2017b; Hortobagyi et al., 1996a; Hortobagyi et al., 1996b; Lewis et al., 2018; Pavone and Moffat, 1985; Rodio and Fattorini, 2014), concentric isokinetic torque (Duncan et al., 1989; Gault et al., 2012; Hortobagyi et al., 1996a; Hortobagyi et al., 1996b; Miller et al., 2006; Nickols-Richardson et al., 2007; Tomberlin et al., 1991) and eccentric isokinetic torque (Duncan et al., 1989; Gault et al., 2012; Hortobagyi et al., 1996a; Hortobagyi et al., 1996b; Miller et al., 2006; Nickols-Richardson et al., 2007; Tomberlin et al., 1991).

Eccentric training increased isometric (Chen et al., 2017a; Chen et al., 2017b; Franchi et al., 2014; Hortobagyi et al., 1996a; Hortobagyi et al., 1996b; Lewis et al., 2018; Rodio and Fattorini, 2014), concentric (Chen et al., 2017b; Franchi et al., 2014; Kudiarasu et al., 2021; Miller et al., 2006; Nickols-Richardson et al., 2007; Pavone and Moffat, 1985) and eccentric strength (Duncan et al., 1989; Gordon et al., 2019; Hortobagyi et al., 1996b; Miller et al., 2006; Nickols-Richardson et al., 2007; Tomberlin et al., 1991). Concentric training also increased isometric (Franchi et al., 2014; Hortobagyi et al., 1996b; Lewis et al., 2018), concentric (Duncan et al., 1989; Franchi et al., 2014; Hortobagyi et al., 1996b; Kudiarasu et al., 2021; Miller et al., 2006; Nickols-Richardson et al., 2007; Raue et al., 2005; Regnersgaard et al., 2022; Tomberlin et al., 1991) and eccentric strength (Hortobagyi et al., 1996a; Miller et al., 2006; Nickols-Richardson et al., 2007; Tomberlin et al., 1991). A single study reported no change in eccentric and concentric strength after downhill and flat-level Walking (Gault et al., 2012).

**Isometric strength**

A random effects meta-analysis using SMD performed on



the results of five studies showed eccentric exercise led to a significant increase in isometric strength (SMD 0.84; 95% CI 0.03 to 1.65; n=120; P = 0.04, figure 10) with significant and high ( $I^2 = 76\%$ ;  $P=0.002$ ) heterogeneity observed. This represents an approximate 7.8 Nm increase in isometric strength (95% CI 0.27 to 15.25). The quality of evidence for eccentric exercise to increase isometric strength was graded as very low. The quality of evidence was downgraded thrice, once due to the high risk of bias in included studies due to lack of blinding for participants and assessors, once for small sample size and once for more than 40% heterogeneity.

**Concentric strength**

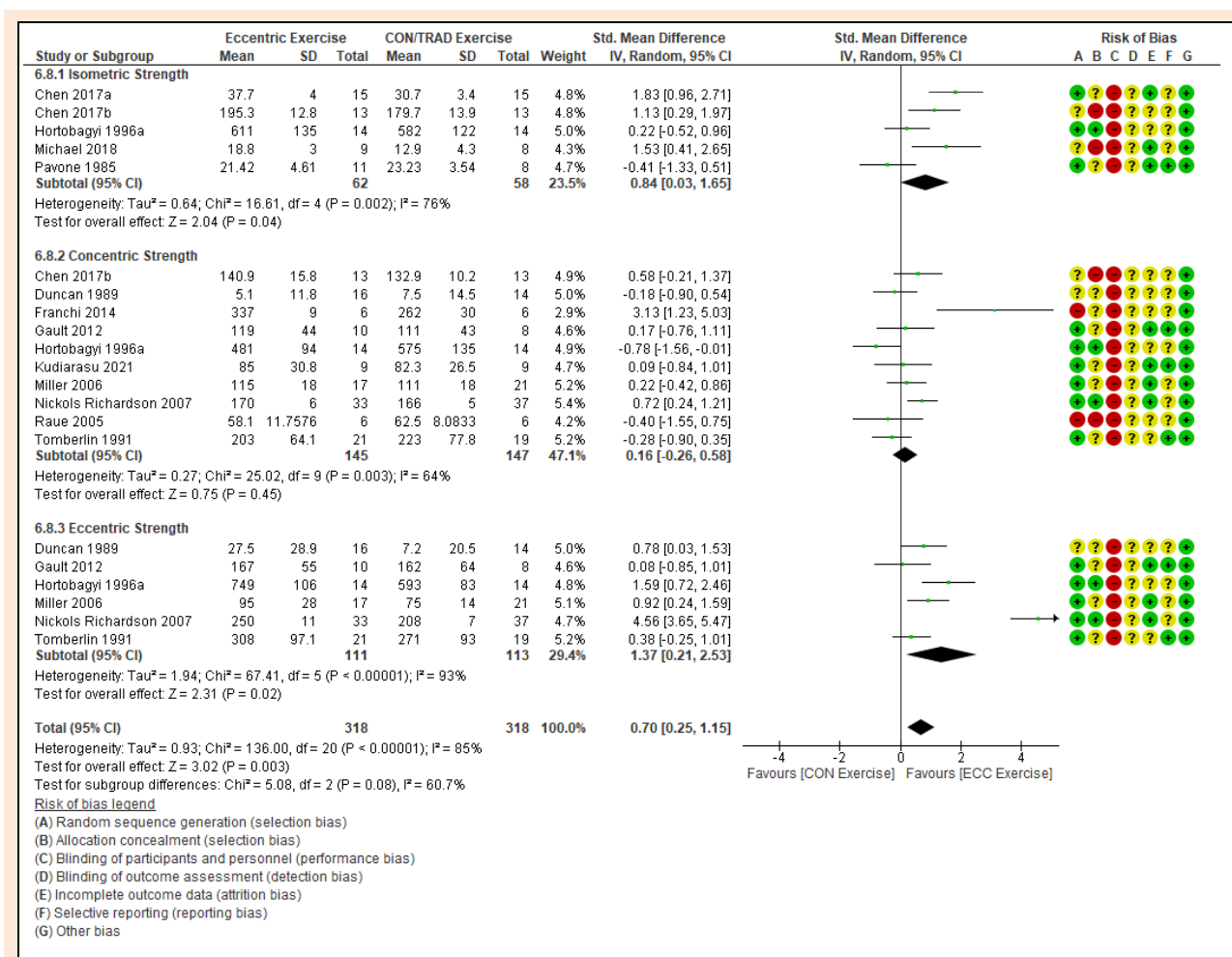
Meta-analysis was performed on the results of ten studies as data were presented graphically in one study (Hortobagyi et al., 1996b). A random effects meta-analysis using SMD showed concentric exercise led to a non-significant increase in concentric strength (SMD 0.16; 95% CI -0.26 to 0.58; n = 292; P = 0.45, figure 10) with high and significant ( $I^2 = 64\%$ ;  $P = 0.003$ ) heterogeneity observed. This represents an approximate 5.8 Nm increase in concentric strength (95% CI -9.43 to 21.04). The quality of evidence for eccentric exercise to increase concentric strength was graded as very low. The quality of evidence was down-

graded thrice, once due to the high risk of bias in included studies due to lack of blinding for participants and assessors, once for a small sample size and once for more than 40% heterogeneity.

**Eccentric strength**

Meta-analysis was performed on the results of six studies as results were in graphical form in one study(Hortobagyi et al., 1996b). A random effects meta-analysis using SMD performed on the results of six studies showed eccentric exercise led to a significant increase in eccentric strength (SMD 1.37; 95% CI 0.21 to 2.53; n = 224; P = 0.02, figure 10) with high and significant ( $I^2 = 93\%$ ;  $P = 0.00001$ ) heterogeneity observed. This represents an approximate 70.82 Nm increase in eccentric strength (95% CI 10.85 to 130.79). The quality of evidence for eccentric exercise to increase eccentric strength was graded as very low. The quality of evidence was downgraded thrice, once due to the high risk of bias in included studies due to lack of blinding for participants and assessors, once for a small sample size and once for more than 40% heterogeneity.

Each of these analyses shows a trend towards greater strength gains among those who exercise eccentrically versus concentrically.



**Figure 10.** Forest Plot of meta-analyses showing a comparison of eccentric versus concentric training on strength. Risk of bias summary: review authors' judgements about each risk of bias item for each included study. Green symbols represent a low risk of bias, yellow symbols represent an unclear risk, and red symbols represent a high risk of bias.

## Discussion

This systematic review summarises the latest evidence about the efficacy of eccentric exercise training in comparison to concentric/traditional exercise training interventions on health risk factors and physical function in healthy populations and people with metabolic disease not previously involved in structured exercise training. The main findings are: (a) eccentric exercise leads to significant gains in isometric, eccentric and overall strength, (b) eccentric exercise training leads to significant decreases in SBP and DBP, and (c) none of the included studies analysed central blood pressure or any measures of arterial health.

### Health risk factors

The health-related risk factors explored in this review included glucose handling, lipids, and blood pressure. Only six RCTs compared the effects of eccentric exercise to concentric exercise on glucose handling. Results indicated that eccentric exercise led to similar or better glucose handling by decreasing HbA1c, HOMA, fasting glucose and insulin compared to concentric exercise. The mechanism related to better glucose handling during eccentric exercise is based on the type of contractions. During lengthening eccentric contractions, there is greater microdamage sustained by muscle fibres. Hence, more energy is required to repair the damaged muscle fibres, which leads to better blood glucose handling (Proske and Morgan, 2001). Although the overall effect size favoured eccentric exercise over concentric exercise, but there were very few studies, and significant heterogeneity was observed across studies; consequently, these findings require further investigation.

Similarly, limited research studies have investigated the effects of eccentric exercise training on lipids, and none of the previous reviews has examined these effects. Among the 19 studies, five examined the effects of eccentric exercise training on lipid levels. LDLC levels are directly and HDLC levels are inversely related to the risk of cardiovascular disorders. Meta-analyses performed on the results of four studies in our review represent a non-significant decrease in LDLC and an increase in HDLC after eccentric exercise training. A possible explanation is that oxidation of fatty acid increases after eccentric contractions (Peñailillo et al., 2014). Reduction in LDLC that occurred following eccentric resistance training may be caused by the flow of cholesterol into the muscle from plasma. This provides a platform for synthesising new cell membranes (Paschalis et al., 2011). The rise in HDLC that occurs after eccentric exercise may be attributable to an increase in lipoprotein lipase activity, an enzyme which accelerates the breakdown of TG derived from very low-density lipoproteins (VLDL) and reduces the size of lipoprotein particles. Consequently, an excess of shell lipids are produced, the majority of which are transferred to HDLC (Fraysn et al., 2003; Paschalis et al., 2010). Two studies analysed the effects of eccentric exercise training on HR and BP. Results showed that eccentric exercise significantly lowered both SBP and DBP.

Based on our findings, eccentric exercise is as or more effective than concentric exercise for the manage-

ment of health-related risk factors. Furthermore, our review indicates the trend of eccentric exercise towards better glucose handling than traditional or concentric exercise. This finding has important potential implications linked to the effective management of conditions involving impaired glucose handling, such as T2DM. Obesity and a sedentary lifestyle are key risk factors for developing T2DM (Qin et al., 2010). In sedentary individuals at risk of metabolic disease, adopting eccentric exercises could delay the development of metabolic disease and may be more attractive due to lower cardiovascular demand and reduced perceived effort associated with the exercise (Lewis et al., 2018). Nevertheless, additional high-quality studies with minimal risk of bias are necessary to validate these results.

### Functional physical fitness

The capability to perform one's daily living (ADL) activities without undue fatigue or difficulty is typically considered an indicator of functional fitness. Functional fitness assessment tests are carried out to determine the individual's mobility, strength, flexibility and endurance (Rikli and Jones, 2013). As individuals age, functional fitness decreases. A low level of fitness in elderly is linked to excessive lean muscle loss, an abnormal metabolic profile, increases in blood pressure, poor balance and reduced muscle strength, all of which lead to increased dependence on others, which negatively impacts the quality of life and leads to increased risk of morbidity and mortality (Jae et al., 2010; Koster et al., 2010; Sui et al., 2012). Maintaining functional physical fitness from a young age is essential to delay mortality and dependency associated with ageing. Studies included in this review had a mix of young and older adult populations. Various tests, including 6MWT, assessed functional fitness. The ability to walk as far as possible in a given time reflects individuals' functionality and quality of life (Enright et al., 2003). Meta-analysis showed eccentric exercise led to a non-significant increase of 14 m in 6 MWT compared to concentric exercise. A previous review has shown that a change of 14.0 to 30.5m in 6MWT distance is clinically meaningful across multiple chronic disease groups (Bohannon and Crouch, 2017); this indicates that the increase reported in this review may represent a meaningful improvement in physical fitness. However, given that changes were not statistically significant, further research is required to support this contention. TUG and 30STS tests frequently assess fall risk and overall function (Bennell et al., 2011). All three studies that analysed the effects of eccentric exercise on TUG showed improvement after eccentric exercise training compared to pre-training scores (Hajjhasani et al., 2014; Gault et al., 2012; Kudiarasu et al., 2021). There was a significant improvement in 30STS after eccentric exercise training compared to traditional or concentric exercise. The conclusions of this review align with a recent review (Čretnik et al., 2022) conducted on older healthy adults (greater than 55 years) and patients with metabolic and cardiovascular diseases, which reported eccentric exercise elicited more significant improvements in TUG, 2-min sit-stand test and 30STS, but not significantly in 6MWT. Our findings build on this previous review by including a more diverse age group and additional studies.

## Strength

With age, people experience a simultaneous deterioration in their strength and the quality of their muscles, both of which lead to lower exercise tolerance and an increased risk of impairment, significantly decreasing their life quality (Hughes et al., 2001; Manini et al., 2007). The cardiovascular function also declines with age (Gault and Willems, 2013). Less cardiovascular stress is caused by eccentric actions (Vallejo et al., 2006) and the perceived exertion is also low (Hollander et al., 2003). Our review confirms that eccentric exercise training significantly increases isometric and eccentric strength more than traditional/concentric exercise. Eccentric exercise training also indicated a trend towards greater gains in concentric strength than concentric exercise, even though the difference was not statistically significant. In conclusion, this systematic review suggests that eccentric exercise may be more beneficial for people with lower exercise tolerance due to greater improvements in strength with lower perceived effort compared to concentric exercise (Vallejo et al., 2006). The meta-analyses conducted on strength showed a positive finding for heterogeneity. This variation could be due to disparities in training modalities, training duration and intensity, methods used for testing strength, and participant characteristics. Our results align with a previous review (Roig et al., 2009), showing increased strength with eccentric exercise. In contrast to our results, a systematic review of older people demonstrated that isometric strength gains were greater following eccentric training than concentric/traditional training. Although the overall effect favoured the eccentric group, it was not statistically significant (Čretnik et al., 2022). The difference between the previous and our review is due to the difference in studies included in both reviews. The previous review encompassed studies involving older individuals (greater than 55 years) only, whereas this review included studies conducted on both young and ageing populations. As eccentric contractions can enhance muscle strength and mass without imposing undue stress on the cardiopulmonary system, they merit exploration as a potential exercise option for individuals with low exercise tolerance, including frail elderly individuals or those with chronic illnesses (Roig et al., 2008; Vallejo et al., 2006).

## Strengths and limitations of review

There are several strengths of this review. Before conducting the searches, the decisions related to the selection of studies, data extraction and analyses were made, and the study protocol was registered on Prospero. We used certified tools like Covidence and Grade Pro to screen studies and grade the evidence quality and adhered to the PRISMA-P guidelines. Data were extracted by two reviewers independently in Covidence. Two reviewers conducted an independent risk of bias assessment, and the findings were utilized to evaluate the quality of the evidence. Since RCTs are part of the review, it is considered to have the highest possible level of evidence. Another important strength is that the included studies were not limited to a specific population but included diverse populations, so the findings of this review are widely applicable.

However, we recognise that this review has some

limitations. Few studies have been conducted to examine the chronic effects of eccentric exercise programmes in contrast to concentric/traditional exercise on health risk factors such as glucose handling, lipids, heart rate, blood pressure and arterial health. Furthermore, limited studies were conducted on people with metabolic disease, so meta-analyses were conducted on these limited studies, and subgroup analyses were not possible. Most of these studies received a "low" rating in methodological quality due to their failure to implement blinding procedures for participants, evaluators, and therapists responsible for delivering training in the study. It is vital to consider that blinding participants and therapists in exercise training type studies is difficult.

There was heterogeneity in exercise type and data measurement methods, for example, strength was measured using a range of equipment, making it difficult to compare outcomes. In some studies, participants engaged in aerobic training (i.e., walking or cycling); while in others, they engaged in resistance-type protocols (i.e., isokinetic). Because there were few studies, it was impossible to categorise them based on the sort of training technique used. In future studies, it may be possible to eliminate these disparities by utilizing more exact descriptors to characterise each mode of training.

## Conclusion

This review found that eccentric exercises significantly improve strength and decrease brachial blood pressure compared to traditional/ concentric exercises. The limited number of studies that observed the effects of eccentric exercise training on health-related parameters such as glucose handling, lipids, and cardiovascular function found that eccentric exercise was comparable to or even more effective than concentric/traditional exercise in managing these health-related risk factors.

Since eccentric exercise requires less perceived effort than traditional/concentric exercise, it may be a more appealing option for people, particularly those with low exercise tolerance. Individuals with low exercise capacity or comorbidities may be able to safely engage in this type of exercise. Given the improvement in test outcomes for mobility, flexibility, balance and strength from eccentric exercise training, healthcare professionals can confidently prescribe eccentric exercises to patients with reduced exercise tolerance having balance and mobility issues.

Eccentric exercises are cheap and easy to perform. These can be performed without needing specialised equipment while carrying out daily activities to emphasise eccentric contractions (e.g., while sitting down, descending slowly in the chair). Descending stairs or walking downhill has emerged as a useful eccentric exercise for older people (Chen et al., 2017a; Regnersgaard et al., 2022). This technique is feasible where an escalator or other means of assisting the person to ascend is available and requires no special equipment. Eccentric exercise can also be performed on specialised treadmills and cycle ergometers, so including such devices in gyms and rehabilitation centres will provide an attractive option to traditional ergometers. Although promising, eccentric training must be explored



further to understand the underlying physiology. This knowledge will assist health care professionals in understanding the mechanisms of benefit and thereby increase the prescription of eccentric training modalities for beneficial outcomes in clients with reduced exercise tolerance or balance and mobility issues and healthy younger individuals.

### Acknowledgements

The datasets generated and analyzed during the current study are not publicly available, but are available from the corresponding author who was an organizer of the study.

### References

- Argent, R., Daly, A. and Caulfield, B. (2018) Patient Involvement With Home-Based Exercise Programs: Can Connected Health Interventions Influence Adherence? *Journal of Medical Internet Research, Mhealth Uhealth* **6**, e47. <https://doi.org/10.2196/mhealth.8518>
- Arlinghaus, K.R. and Johnston, C.A. (2019) The Importance of Creating Habits and Routine. *American Journal of Lifestyle Medicine* **13**, 142-144. <https://doi.org/10.1177/1559827618818044>
- Bennell, K., Dobson, F. and Hinman, R. (2011) Measures of physical performance assessments: Self-Paced Walk Test (SPWT), Stair Climb Test (SCT), Six-Minute Walk Test (6MWT), Chair Stand Test (CST), Timed Up & Go (TUG), Sock Test, Lift and Carry Test (LCT), and Car Task. *Arthritis Care & Research* **63**, 350-370. <https://doi.org/10.1002/acr.20538>
- Bohannon, R.W. and Crouch, R. (2017) Minimal clinically important difference for change in 6-minute walk test distance of adults with pathology: a systematic review. *Journal of Evaluation in Clinical Practice* **23**, 377-381. <https://doi.org/10.1111/jep.12629>
- Bull, F.C., Al-Ansari, S.S., Biddle, S., Borodulin, K., Buman, M.P., Cardon, G., Carty, C., Chaput, J.-P., Chastin, S., Chou, R., Dempsey, P.C., DiPietro, L., Ekelund, U., Firth, J., Friedenreich, C.M., Garcia, L., Gichu, M., Jago, R., Katzmarzyk, P.T., Lambert, E., Leitzmann, M., Milton, K., Ortega, F.B., Ranasinghe, C., Stamatakis, E., Tiedemann, A., Troiano, R.P., van der Ploeg, H.P., Wari, V. and Willumsen, J.F. (2020) World Health Organization 2020 guidelines on physical activity and sedentary behaviour. *British Journal of Sports Medicine* **54**, 1451. <https://doi.org/10.1136/bjsports-2020-102955>
- Chen, T.C., Chung-Chan, H., Kuo-Wei, T., Chih-Chiao, H. and Kazunori, N. (2017a) Effects of Descending Stair Walking on Health and Fitness of Elderly Obese Women. *Medicine & Science in Sports & Exercise* **49**, 1614-1622. <https://doi.org/10.1249/MSS.0000000000001267>
- Chen, T.C., Tseng, W.C., Huang, G.L., Chen, H.L., Tseng, K.W. and Nosaka, K. (2017b) Superior Effects of Eccentric to Concentric Knee Extensor Resistance Training on Physical Fitness, Insulin Sensitivity and Lipid Profiles of Elderly Men. *Frontiers in Physiology* **8**, 209. <https://doi.org/10.3389/fphys.2017.00209>
- Čretnik, K., Pleša, J., Kozinc, Ž., Löfler, S. and Šarabon, N. (2022) The Effect of Eccentric vs. Traditional Resistance Exercise on Muscle Strength, Body Composition, and Functional Performance in Older Adults: A Systematic Review With Meta-Analysis. *Frontiers in Sports and Active Living* **4**. <https://doi.org/10.3389/fspor.2022.873718>
- Deeks, J.J., Higgins, J. and Altman D.G. (2011) Chapter 9: Analysing data and undertaking meta-analyses. In: Higgins JP, Green S, editors(s) *Cochrane Handbook for Systematic Reviews of Interventions* Version 5.1.0
- Dolezal, B.A., Potteiger, J.A., Jacobsen, D.J. and Benedict, S.H. (2000) Muscle damage and resting metabolic rate after acute resistance exercise with an eccentric overload. *Medicine & Science in Sports & Exercise* **32**, 1202-1207. <https://doi.org/10.1097/00005768-200007000-00003>
- Drexel, H., Saelly, C.H., Langer, P., Lourenser, G., Marte, T., Risch, L., Hoefle, G. and Aezel, S. (2008) Metabolic and anti-inflammatory benefits of eccentric endurance exercise - a pilot study. *European Journal Of Clinical Investigation* **38**, 218-226. <https://doi.org/10.1111/j.1365-2362.2008.01937.x>
- Duncan, M.J., Vandelanotte, C., Trost, S.G., Rebar, A.L., Rogers, N., Burton, N.W., Murawski, B., Rayward, A., Fenton, S. and Brown, W.J. (2016) Balanced: a randomised trial examining the efficacy of two self-monitoring methods for an app-based multi-behaviour intervention to improve physical activity, sitting and sleep in adults. *BMC Public Health* **16**, 670. <https://doi.org/10.1186/s12889-016-3256-x>
- Duncan, P.W., Chandler, J.M., Cavanaugh, D.K., Johnson, K.R. and Buehler, A.G. (1989) Mode and speed specificity of eccentric and concentric exercise training. *Journal of Orthopaedic & Sports Physical Therapy* **11**, 70-75. <https://doi.org/10.2519/jospt.1989.11.2.70>
- Ellis, R., Shields, N., Lim, K. and Dodd, K.J. (2015) Eccentric exercise in adults with cardiorespiratory disease: a systematic review. *Clinical Rehabilitation* **29**, 1178-1197. <https://doi.org/10.1177/0269215515574783>
- Enright, P.L., McBurnie, M.A., Bittner, V., Tracy, R.P., McNamara, R., Arnold, A. and Newman, A.B. (2003) The 6-min walk test: a quick measure of functional status in elderly adults. *Chest* **123**, 387-398. <https://doi.org/10.1378/chest.123.2.387>
- Franchi, M.V., Atherton, P.J., Reeves, N.D., Flück, M., Williams, J., Mitchell, W.K., Selby, A., Beltran Valls, R.M. and Narici, M.V. (2014) Architectural, functional and molecular responses to concentric and eccentric loading in human skeletal muscle. *Acta Physiologica* **210**, 642-654. <https://doi.org/10.1111/apha.12225>
- Frayn, K.N., Karpe, F., Fielding, B.A., Macdonald, I.A. and Coppack, S.W. (2003) Integrative physiology of human adipose tissue. *International journal of obesity and related metabolic disorders* **27**, 875-888. <https://doi.org/10.1038/sj.jjo.0802326>
- Gault, M.L., Clements, R.E. and Willems, M.E. (2012) Functional mobility of older adults after concentric and eccentric endurance exercise. *European Journal of Applied Physiology* **112**, 3699-3707. <https://doi.org/10.1007/s00421-012-2338-4>
- Gault, M.L. and Willems, M.E. (2013) Aging, functional capacity and eccentric exercise training. *Aging and Disease* **4**, 351-363. <https://doi.org/10.14336/AD.2013.0400351>
- Gordon, J.P., Thompson, B.J., Crane, J.S., Bressel, E. and Wagner, D.R. (2019) Effects of isokinetic eccentric versus traditional lower body resistance training on muscle function: examining a multiple-joint short-term training model. *Applied Physiology, Nutrition, and Metabolism* **44**, 118-126. <https://doi.org/10.1139/apnm-2018-0333>
- Hajihassani, A., Bahrpeyma, F. and Bakhtiyari, A.H. (2014) Effects of Eccentric and Concentric Exercises on Some Functional Activity Indexes of Patients With Diabetes Type 2. *Middle East Journal of Rehabilitation and Health Studies*. **1**, e20839. <https://doi.org/10.17795/mejrh-20839>
- Hassmén, P., Koivula, N. and Utela, A. (2000) Physical Exercise and Psychological Well-Being: A Population Study in Finland. *Preventive Medicine* **30**, 17-25. <https://doi.org/10.1006/pmed.1999.0597>
- Higgins JPT, Green S (editors). *Cochrane Handbook for Systematic Reviews of Interventions* Version 5.1.0 [updated March 2011]. The Cochrane Collaboration, 2011. Available from [www.handbook.cochrane.org](http://www.handbook.cochrane.org).
- Higgins, J.P.T., Thomas, J., Chandler, J., Cumpston, M., Li, T., Page, M.J. and Welch V.A. (2022) *Cochrane Handbook for Systematic Reviews of Interventions*
- Hody, S., Croisier, J.L., Bury, T., Rogister, B. and Leprince, P. (2019) Eccentric Muscle Contractions: Risks and Benefits. *Frontiers in Physiology* **10**, 536. <https://doi.org/10.3389/fphys.2019.00536>
- Hollander, D.B., Durand, R.J., Trynicki, J.L., Larock, D., Castracane, V.D., Hebert, E.P. and Kraemer, R.R. (2003) RPE, pain, and physiological adjustment to concentric and eccentric contractions. *Medicine & Science in Sports & Exercise* **35**, 1017-1025. <https://doi.org/10.1249/01.MSS.0000069749.13258.4E>
- Hortobagyi, T., Barrier, J., Beard, D., Braspeninx, J., Koens, P., Devita, P., Dempsey, L. and Lambert, J. (1996a) Greater initial adaptations to submaximal muscle lengthening than maximal shortening. *Journal of Applied Physiology* **81**, 1677-1682. <https://doi.org/10.1152/jappl.1996.81.4.1677>
- Hortobagyi, T., Hill, J.P., Houmar, J.A., Fraser, D.D., Lambert, N.J. and Israel, R.G. (1996b) Adaptive responses to muscle lengthening and shortening in humans. *Journal of Applied Physiology* (1985) **80**, 765-772. <https://doi.org/10.1152/jappl.1996.80.3.765>
- Huberty, J.L., Ransdell, L.B., Sidman, C., Flohr, J.A., Shultz, B., Grosshans, O. and Durrant, L. (2008) Explaining Long-Term Exercise Adherence in Women Who Complete a Structured



- Exercise Program. *Research Quarterly for Exercise and Sport* **79**, 374-384. <https://doi.org/10.1080/02701367.2008.10599501>
- Hughes, V.A., Frontera, W.R., Wood, M., Evans, W.J., Dallal, G.E., Roubenoff, R. and Singh, M.A.F. (2001) Longitudinal Muscle Strength Changes in Older Adults: Influence of Muscle Mass, Physical Activity, and Health. *The Journals of Gerontology: Series A* **56**, 209-217. <https://doi.org/10.1093/gerona/56.5.B209>
- Jae, S.Y., Heffernan, K.S., Fernhall, B., Oh, Y.S., Park, W.H., Lee, M.K. and Choi, Y.H. (2010) Association between cardiorespiratory fitness and arterial stiffness in men with the metabolic syndrome. *Diabetes Research and Clinical Practice* **90**, 326-332. <https://doi.org/10.1016/j.diabres.2010.08.025>
- Komi, P.V. and Buskirk, E.R. (1972) Effect of Eccentric and Concentric Muscle Conditioning on Tension and Electrical Activity of Human Muscle. *Ergonomics* **15**, 417-434. <https://doi.org/10.1080/00140137208924444>
- Koster, A., Visser, M., Simonsick, E.M., Yu, B., Allison, D.B., Newman, A.B., van Eijk, J.T., Schwartz, A.V., Satterfield, S. and Harris, T.B. (2010) Association between fitness and changes in body composition and muscle strength. *Journal of the American Geriatrics Society* **58**, 219-226. <https://doi.org/10.1111/j.1532-5415.2009.02681.x>
- Kudiarasu, C., Rohadhia, W., Katsura, Y., Koeda, T., Singh, F. and Nosaka, K. (2021) Eccentric-only versus concentric-only resistance training effects on biochemical and physiological parameters in patients with type 2 diabetes. *BMC Sports Science, Medicine and Rehabilitation* **13**, 162. <https://doi.org/10.1186/s13102-021-00384-z>
- Kulkarni, D., Gregory, S. and Evans, M. (2022) Effectiveness of eccentric-biased exercise interventions in reducing the incidence of falls and improving functional performance in older adults: a systematic review. *European Geriatric Medicine* **13**, 367-380. <https://doi.org/10.1007/s41999-021-00571-8>
- Lewis, M.C., Peoples, G.E., Groeller, H. and Brown, M.A. (2018) Eccentric cycling emphasising a low cardiopulmonary demand increases leg strength equivalent to workload matched concentric cycling in middle age sedentary males. *Journal of Science and Medicine in Sport* **21**, 1238-1243. <https://doi.org/10.1016/j.jsams.2018.05.009>
- Manini, T.M., Visser, M., Won-Park, S., Patel, K.V., Strotmeyer, E.S., Chen, H., Goodpaster, B., De Rekeneire, N., Newman, A.B., Simonsick, E.M., Kritchevsky, S.B., Ryder, K., Schwartz, A.V. and Harris, T.B. (2007) Knee extension strength cutpoints for maintaining mobility. *Journal of the American Geriatrics Society* **55**, 451-457. <https://doi.org/10.1111/j.1532-5415.2007.01087.x>
- Marcus, R.L., Smith, S., Morrell, G., Addison, O., Dibble, L.E., Wahoff-Stice, D. and Lastayo, P.C. (2008) Comparison of combined aerobic and high-force eccentric resistance exercise with aerobic exercise only for people with type 2 diabetes mellitus. *Physical Therapy* **88**, 1345-1354. <https://doi.org/10.2522/ptj.20080124>
- Miller, L.E., Pierson, L.M., Nickols-Richardson, S.M., Wootten, D.F., Selmon, S.E., Ramp, W.K. and Herbert, W.G. (2006) Knee extensor and flexor torque development with concentric and eccentric isokinetic training. *Research Quarterly for Exercise and Sport* **77**, 58-63. <https://doi.org/10.1080/02701367.2006.10599332>
- Moher, D., Shamseer, L., Clarke, M., Ghersi, D., Liberati, A., Petticrew, M., Shekelle, P., Stewart, L.A. and Group, P.-P. (2015) Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. *Systematic Reviews* **4**, 1. <https://doi.org/10.1186/2046-4053-4-1>
- Molinari, T., Steffens, T., Roncada, C., Rodrigues, R. and Dias, C.P. (2019) Effects of Eccentric-Focused Versus Conventional Training on Lower Limb Muscular Strength in Older People: A Systematic Review With Meta-Analysis. *Journal of Aging and Physical Activity* **27**, 823-830. <https://doi.org/10.1123/japa.2018-0294>
- Nickols-Richardson, S.M., Miller, L.E., Wootten, D.F., Ramp, W.K. and Herbert, W.G. (2007) Concentric and eccentric isokinetic resistance training similarly increases muscular strength, fat-free soft tissue mass, and specific bone mineral measurements in young women. *Osteoporosis International* **18**, 789-796. <https://doi.org/10.1007/s00198-006-0305-9>
- Overend, T.J., Versteegh, T.H., Thompson, E., Birmingham, T.B. and Vandervoort, A.A. (2000) Cardiovascular Stress Associated With Concentric and Eccentric Isokinetic Exercise in Young and Older Adults. *The Journals of Gerontology: Series A* **55**, 177-182. <https://doi.org/10.1093/gerona/55.4.B177>
- Paschalis, V., Nikolaidis, M.G., Giakas, G., Theodorou, A.A., Sakellariou, G.K., Fatouros, I.G., Koutedakis, Y. and Jamurtas, A.Z. (2010) Beneficial changes in energy expenditure and lipid profile after eccentric exercise in overweight and lean women. *Scandinavian Journal of Medicine & Science in Sports* **20**, 103-111. <https://doi.org/10.1111/j.1600-0838.2009.00920.x>
- Paschalis, V., Nikolaidis, M.G., Theodorou, A.A., Panayiotou, G., Fatouros, I.G., Koutedakis, Y. and Jamurtas, A.Z. (2011) A weekly bout of eccentric exercise is sufficient to induce health-promoting effects. *Medicine and Science in Sports and Exercise* **43**, 64-73. <https://doi.org/10.1249/MSS.0b013e3181e91d90>
- Pavone, E. and Moffat, M. (1985) Isometric torque of the quadriceps femoris after concentric, eccentric and isometric training. *Archives of Physical Medicine and Rehabilitation* **66**, 168-170.
- Pedersen, B.K. and Saltin, B. (2015) Exercise as medicine - evidence for prescribing exercise as therapy in 26 different chronic diseases. *Scandinavian Journal of Medicine & Science in Sports* **25** Suppl 3, 1-72. <https://doi.org/10.1111/sms.12581>
- Peñailillo, L., Blazevich, A. and Nosaka, K. (2014) Energy expenditure and substrate oxidation during and after eccentric cycling. *European Journal of Applied Physiology* **114**, 805-814. <https://doi.org/10.1007/s00421-013-2816-3>
- Proske, U. and Morgan, D.L. (2001) Muscle damage from eccentric exercise: mechanism, mechanical signs, adaptation and clinical applications. *The Journal of Physiology* **537**, 333-345. <https://doi.org/10.1111/j.1469-7793.2001.00333.x>
- Qin, L., Knol, M.J., Corpeleijn, E. and Stolk, R.P. (2010) Does physical activity modify the risk of obesity for type 2 diabetes: a review of epidemiological data. *European Journal of Epidemiology* **25**, 5-12. <https://doi.org/10.1007/s10654-009-9395-y>
- Raj, I.S., Bird, S.R., Westfold, B.A. and Shield, A.J. (2012) Effects of eccentrically biased versus conventional weight training in older adults. *Medicine & Science in Sports & Exercise* **44**, 1167-1176. <https://doi.org/10.1249/MSS.0b013e3182442ecd>
- Raue, U., Terpstra, B., Williamson, D.L., Gallagher, P.M. and Trappe, S.W. (2005) Effects of short-term concentric vs. eccentric resistance training on single muscle fiber MHC distribution in humans. *International Journal of Sports Medicine* **26**, 339-343. <https://doi.org/10.1055/s-2004-821041>
- Regnersgaard, S., Knudsen, A.K., Lindskov, F.O., Mratinkovic, M., Pressel, E., Ingensen, A. and Dela, F. (2022) Down stair walking: A simple method to increase muscle mass and performance in 65+ year healthy people. *European Journal of Sport Science* **22**, 279-288. <https://doi.org/10.1080/17461391.2020.1856936>
- Rikli, R.E. and Jones, C.J. (2013) Development and validation of criterion-referenced clinically relevant fitness standards for maintaining physical independence in later years. *Gerontologist* **53**, 255-267. <https://doi.org/10.1093/geront/gns071>
- Rodio, A. and Fattorini, L. (2014) Downhill walking to improve lower limb strength in healthy young adults. *European Journal of Sport Science* **14**, 806-812. <https://doi.org/10.1080/17461391.2014.908958>
- Roig, M., O'Brien, K., Kirk, G., Murray, R., McKinnon, P., Shadgan, B. and Reid, W.D. (2009) The effects of eccentric versus concentric resistance training on muscle strength and mass in healthy adults: a systematic review with meta-analysis. *British Journal of Sports Medicine* **43**, 556-568. <https://doi.org/10.1136/bjism.2008.051417>
- Roig, M., Shadgan, B. and Reid, W.D. (2008) Eccentric exercise in patients with chronic health conditions: a systematic review. *Physiotherapy Canada* **60**, 146-160. <https://doi.org/10.3138/physio.60.2.146>
- Sharman, J.E., La Gerche, A. and Coombes, J.S. (2015) Exercise and cardiovascular risk in patients with hypertension. *American Journal of Hypertension* **28**, 147-158. <https://doi.org/10.1093/ajh/hpu191>
- Stauber, W.T. (1989) Eccentric action of muscles: physiology, injury, and adaptation. *Exercise and Sport Sciences Reviews* **17**, 157-185. <https://doi.org/10.1249/00003677-198900170-00008>
- Sui, X., Jackson, A.S., Church, T.S., Lee, D.C., O'Connor, D.P., Liu, J. and Blair, S.N. (2012) Effects of cardiorespiratory fitness on aging: glucose trajectory in a cohort of healthy men. *Annals of Epidemiology* **22**, 617-622. <https://doi.org/10.1016/j.annepidem.2012.05.005>

- Tomberlin, J.P., Basford, J.R., Schwen, E.E., Orte, P.A., Scott, S.C., Laughman, R.K. and Ilstrup, D.M. (1991) Comparative study of isokinetic eccentric and concentric quadriceps training. *Journal of Orthopaedic & Sports Physical Therapy* **14**, 31-36. <https://doi.org/10.2519/jospt.1991.14.1.31>
- Vallejo, A.F., Schroeder, E.T., Zheng, L., Jensky, N.E. and Sattler, F.R. (2006) Cardiopulmonary responses to eccentric and concentric resistance exercise in older adults. *Age Ageing* **35**, 291-297. <https://doi.org/10.1093/ageing/afj082>
- Warburton, D.E., Nicol, C.W. and Bredin, S.S. (2006) Health benefits of physical activity: the evidence. *Canadian Medical Association Journal* **174**, 801-809. <https://doi.org/10.1503/cmaj.051351>
- Welle, S. and Nair, K.S. (1990) Relationship of resting metabolic rate to body composition and protein turnover. *American journal of physiology* **258**, 990-998. <https://doi.org/10.1152/ajpendo.1990.258.6.E990>
- Zeppetzauer, M., Drexel, H., Vonbank, A., Rein, P., Aczel, S. and Saely, C.H. (2013) Eccentric endurance exercise economically improves metabolic and inflammatory risk factors. *European Journal Of Preventive Cardiology* **20**, 577-584. <https://doi.org/10.1177/2047487312444236>

### Key points

- Eccentric exercise (e.g., downhill walking) is widely perceived as easier to perform than traditional exercise (e.g., flat or uphill walking).
- Eccentric exercise may have more significant benefits for muscle strength and some markers of health than traditional exercise.
- Eccentric exercise may be an attractive alternative to traditional exercise in encouraging sedentary people to become more active.

## Appendix 1

### SEARCH TERMS

"Eccentric training" OR "Eccentric exercise" OR "Downhill walking" OR "Muscle lengthening"

AND "cardiovascular function" OR "Arterial Health" OR "Blood pressure" OR Glucose OR HbA1c OR metabolism OR lipids OR physiol\* OR \*health OR "glycosylated haemoglobin" OR glycol\* OR AGE\* OR insulin OR "quality of life" OR "glycosylated hemoglobin" OR "Physical fitness" OR "Physical function" OR "exercise tolerance" OR \*strength OR "exercise capacity" OR \*fitness OR flexibility OR balance OR falls\*

AND Metabolic\* OR diab\* OR T2DM OR T2D OR obes\* OR MetS OR \*diab\* OR Impaired glucose\* OR CVD OR CHF OR cardiovasc\* OR Seden\* OR "physical inact\*"

Search terms were "Eccentric training" OR "Eccentric exercise" OR "Downhill walking" OR "Muscle lengthening"

AND "cardiovascular function" OR "Arterial Health" OR "Blood pressure" OR Glucose OR HbA1c OR metabolism OR lipids OR physiol\* OR \*health OR "glycosylated haemoglobin" OR glycol\* OR AGE\* OR insulin OR "quality of life" OR "glycosylated hemoglobin" OR "Physical fitness" OR "Physical function" OR "exercise tolerance" OR \*strength OR "exercise capacity" OR \*fitness OR flexibility OR balance OR falls\* AND Metabolic\* OR diab\* OR T2DM OR T2D OR obes\* OR MetS OR \*diab\* OR Impaired glucose\* OR CVD OR CHF OR cardiovasc\* OR Seden\* OR "physical inact\*".

AND "HUMAN"

## AUTHOR BIOGRAPHY



### Misha ANSARI

#### Employment

PhD student at the School of Health Sciences, College of Health and Medicine, The University of Tasmania.

#### Degree

BSPT, PPDPT

#### Research interests

Exercise for the management of chronic diseases.

**E-mail:** [misha.ansari@utas.edu.au](mailto:misha.ansari@utas.edu.au)



### Sibella HARDCASTLE

#### Employment

Lecturer in Clinical Exercise Physiology, School of Health Sciences, College of Health and Medicine, University of Tasmania.

#### Degree

BHumMov(Ex&SpSci) (Hons), ESSAM, AEP, PhD,

#### Research interests

Using exercise to manage and prevent chronic health conditions.

**E-mail:** [sibella.hardcastle@utas.edu.au](mailto:sibella.hardcastle@utas.edu.au)



### Stephen MYERS

#### Employment

Senior Lecturer in Laboratory Medicine and Nutrition Sciences, School of Health Sciences, College of Health and Medicine, University of Tasmania.

#### Degree

Bachelor of Applied Sciences with first class honours; Master's in environmental management; PhD in Molecular Sciences

#### Research interests

Genetics of metabolic disease

**E-mail:** [stephen.myers@utas.edu.au](mailto:stephen.myers@utas.edu.au)



### Andrew D. WILLIAMS

#### Employment

Associate Professor in Clinical Exercise Science, Associate Head (Learning and Teaching), School of Health Sciences, College of Health and Medicine, University of Tasmania.

#### Degree

BAppSc(ExSportSc), BSc (Hons), PhD, GradCert ULT, AEP, FESSA, MRFF

TRIP Fellow

#### Research interests

Exercise for the prevention and management of chronic conditions, Exercise as Medicine

**E-mail:** [andrew.williams@utas.edu.au](mailto:andrew.williams@utas.edu.au)

### ✉ Misha Ansari

School of Health Sciences, University of Tasmania, Launceston, Australia