Table 2. Continue….

Study	Population	Intervention	Duration	Health related measures	Functional fitness measures	Results
Raue (2005)	Healthy sedentary male (n = 15) Mean age 23	**Intervention 1:** Eccentric exercise training on knee extensor device Cybex (4 sets of 8 reps, Intensity = starting at 80% of 1 RM Con). n=06 **Intervention 2:** Concentric exercise training on the same device and parameters. n=06 **Control:** 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	**Intervention 1:** Level walking on a treadmill (30 min at 1 m/s). n=07 **Intervention 2:** Uphill walking on a treadmill (30 min, +20% incline, 0.75m/s). n=08 **Intervention 3:** Downhill walking on a treadmill (30 min, -20% decline, 1.36m/s). n=07 **Intervention 4:** 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	**Intervention 1:** Eccentric training on KIN-COM Dynamometer. n=21 **Intervention 2:** Concentric training on the same device. N=19 **Control:** 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.
Zeppetzauer et al. (2013)	healthy sedentary Men (n = 16) Women (n = 29) Mean age 48	**Intervention 1:** Hiking downwards (eccentric training) on 540 meters trial. n=22 **Intervention 2:** 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; Zeppetzauer 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; Zeppetzauer et al., 2013) reported about effects on lipids, six (Hajihasani 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; Zeppetzauer 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)

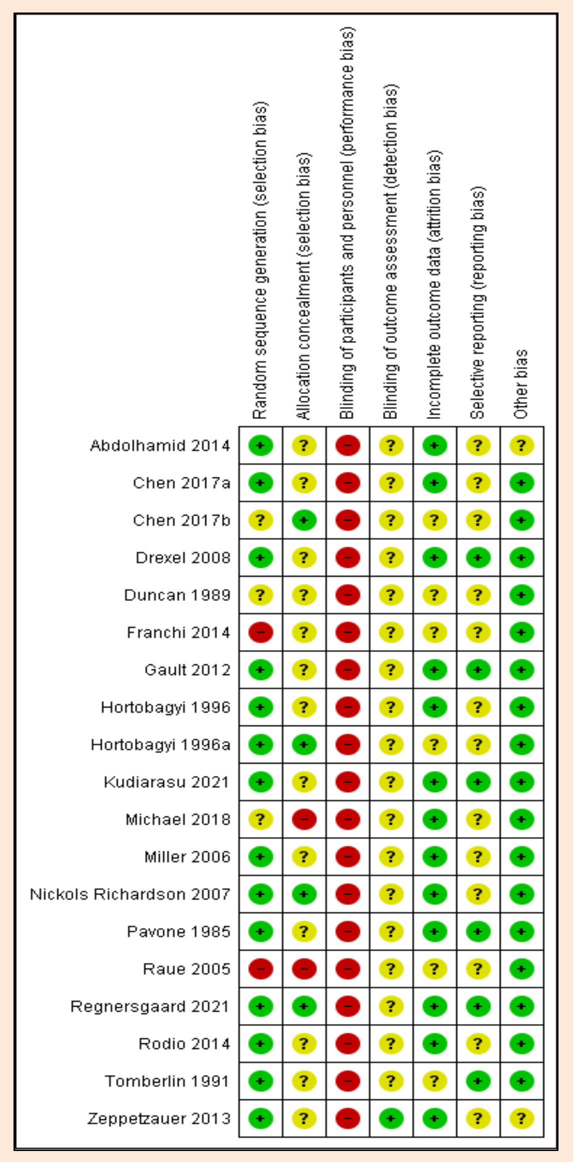
Figure 2 summarises the risk of bias assessment for each included study. Nineteen studies (Hajihasani et al., 2014; Chen et al., 2017a; Chen et al., 2017b; Drexel et al., 2008; Duncan et al., 1989; Franchi et al., 2014; Gault et al., 2012; Hortobagyi et al., 1996a; Hortobagyi et al., 1996b; Kudiarasu 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; Zeppetzauer 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; Zeppetzauer 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; Zeppetzauer 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; Zeppetzauer 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.



	Random sequence generation (selection bias)	Allocation concealment (selection bias)	Blinding of participants and personnel (performance bias)	Blinding of outcome assessment (detection bias)	Incomplete outcome data (attrition bias)	Selective reporting (reporting bias)	Other bias
Abdolhamid 2014	+	?	−	?	+	?	?
Chen 2017a	+	?	−	?	+	?	+
Chen 2017b	?	+	−	?	?	?	+
Drexel 2008	+	?	−	?	+	+	+
Duncan 1989	?	?	−	?	?	?	+
Franchi 2014	−	?	−	?	?	?	+
Gault 2012	+	?	−	?	+	+	+
Hortobagyi 1996	+	?	−	?	+	?	+
Hortobagyi 1996a	+	+	−	?	?	?	+
Kudiarasu 2021	+	?	−	?	+	+	+
Michael 2018	?	−	−	?	+	?	+
Miller 2006	+	?	−	?	+	?	+
Nickols Richardson 2007	+	+	−	?	+	?	+
Pavone 1985	+	?	−	?	+	+	+
Raue 2005	−	−	−	?	?	?	+
Regnersgaard 2021	+	+	−	?	+	+	+
Rodio 2014	+	?	−	?	+	?	+
Tomberlin 1991	+	?	−	?	?	+	+
Zeppetzauer 2013	+	?	−	+	+	?	?

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.

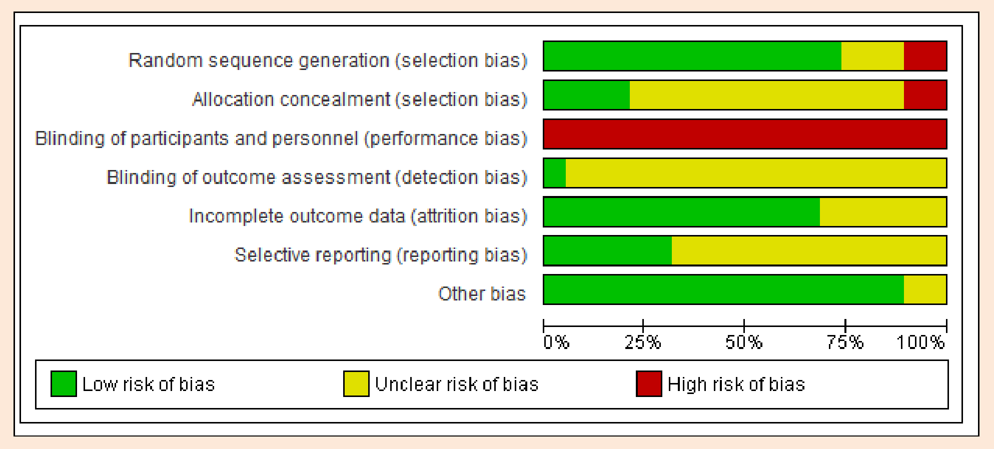


Figure 3. Overall Risk of Bias summary. Risk of bias summary: review authors' judgements about each risk of bias item for each included study. Green symbols represent a low risk of bias, yellow symbols represent an unclear risk, and red symbols represent a high risk of bias.

Received: 08 March 2023 / Accepted: 15 May 2023 / Published (online): 01 June 2023

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 blinding 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 (I2 = 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).

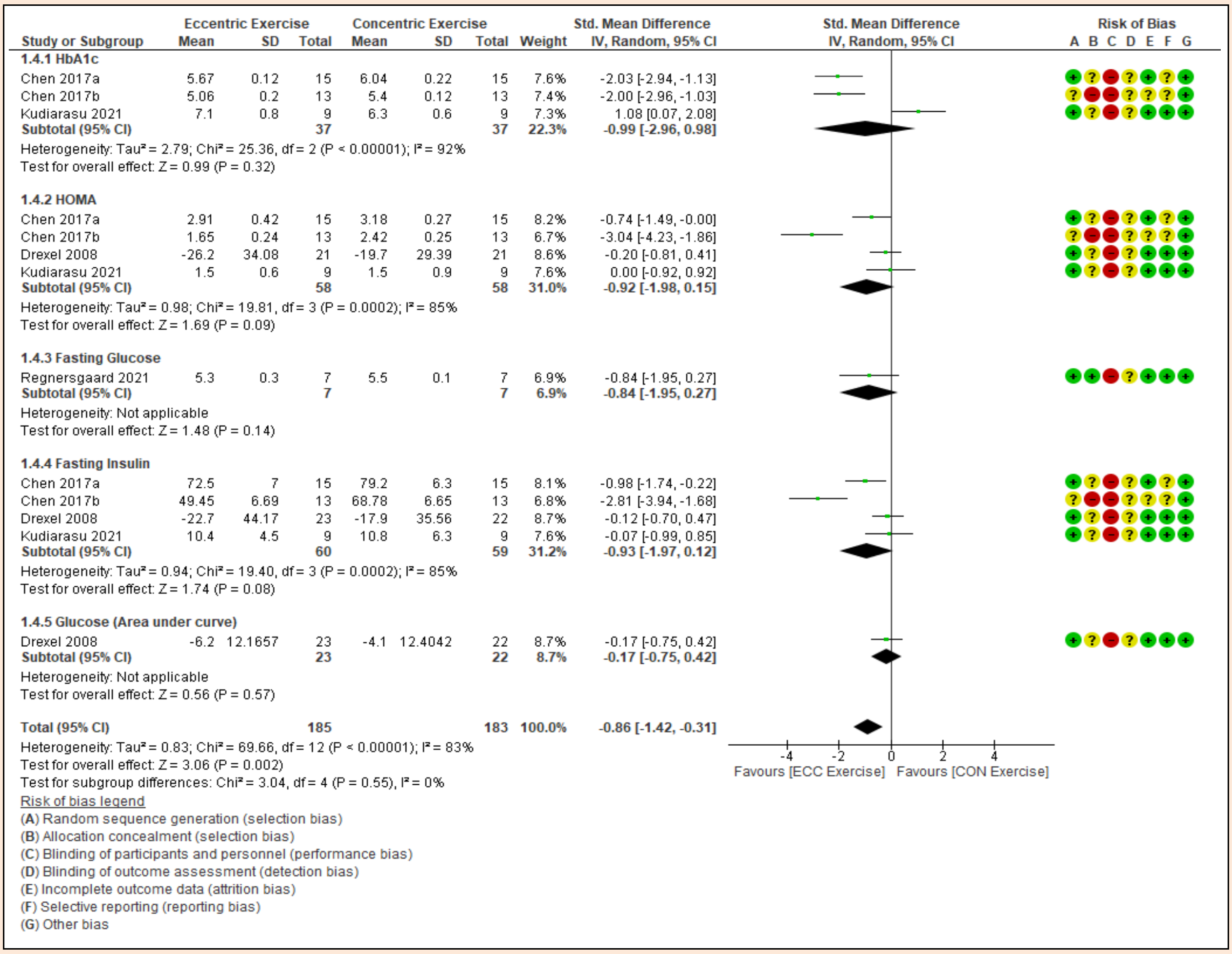


Figure 4. Forest plot of eccentric vs concentric exercise on glycaemic management. Risk of bias summary: review authors' judgements about each risk of bias item for each included study. Green symbols represent a low risk of bias, yellow symbols represent an unclear risk, and red symbols represent a high 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 (I2 = 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; Zeppetzauer et al., 2013). Four studies were conducted on Healthy sedentary people (Chen et al., 2017a; Chen et al., 2017b; Drexel et al., 2008; Zeppetzauer 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; Zeppetzauer 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; Zeppetzauer 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).

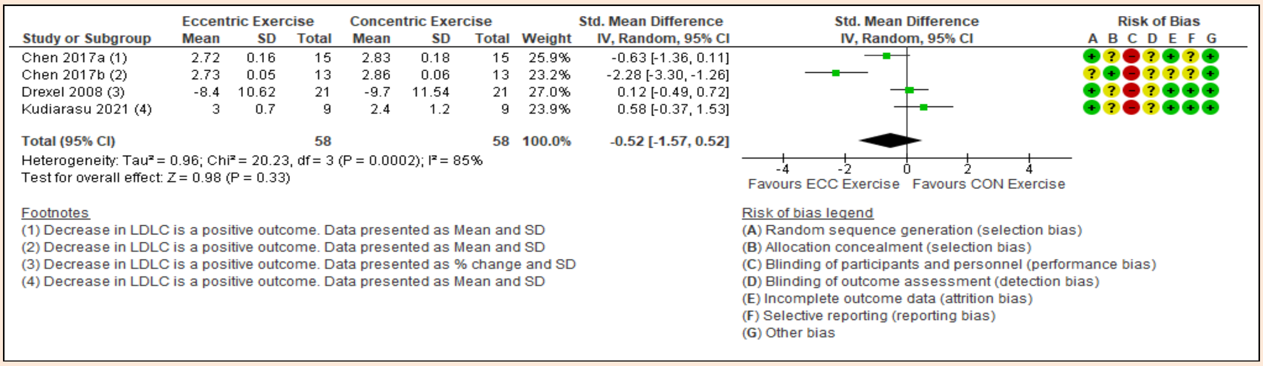
A meta-analysis was performed on the results of four studies (Chen et al., 2017a; Chen et al., 2017b; Drexel et al., 2008; Kudiarasu et al., 2021; Regnersgaard et al., 2022) as two papers reported the same study and had similar results (Drexel et al., 2008; Zeppetzauer et al., 2013), so data from only 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



Study or Subgroup	Eccentric Exercise Mean	SD	Total	Concentric Exercise Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI	A	B	C	D	E	F	G
Chen 2017a (1)	2.72	0.16	15	2.83	0.18	15	25.9%	-0.63 [-1.36, 0.11]	+	?	−	?	+	?	+
Chen 2017b (2)	2.73	0.05	13	2.86	0.06	13	23.2%	-2.28 [-3.30, -1.26]	?	+	−	?	?	?	+
Drexel 2008 (3)	-8.4	10.62	21	-9.7	11.54	21	27.0%	0.12 [-0.49, 0.72]	+	?	−	?	+	+	+
Kudiarasu 2021 (4)	3	0.7	9	2.4	1.2	9	23.9%	0.58 [-0.37, 1.53]	+	?	−	?	+	+	+
Total (95% CI)			**58**			**58**	**100.0%**	**-0.52 [-1.57, 0.52]**							

Heterogeneity: Tau² = 0.96; Chi² = 20.23, df = 3 (P = 0.0002); I² = 85%
Test for overall effect: Z = 0.98 (P = 0.33)

Footnotes
(1) Decrease in LDLC is a positive outcome. Data presented as Mean and SD
(2) Decrease in LDLC is a positive outcome. Data presented as Mean and SD
(3) Decrease in LDLC is a positive outcome. Data presented as % change and SD
(4) Decrease in LDLC is a positive outcome. Data presented as Mean and SD

Risk of bias legend
(A) Random sequence generation (selection bias)
(B) Allocation concealment (selection bias)
(C) Blinding of participants and personnel (performance bias)
(D) Blinding of outcome assessment (detection bias)
(E) Incomplete outcome data (attrition bias)
(F) Selective reporting (reporting bias)
(G) Other bias

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.

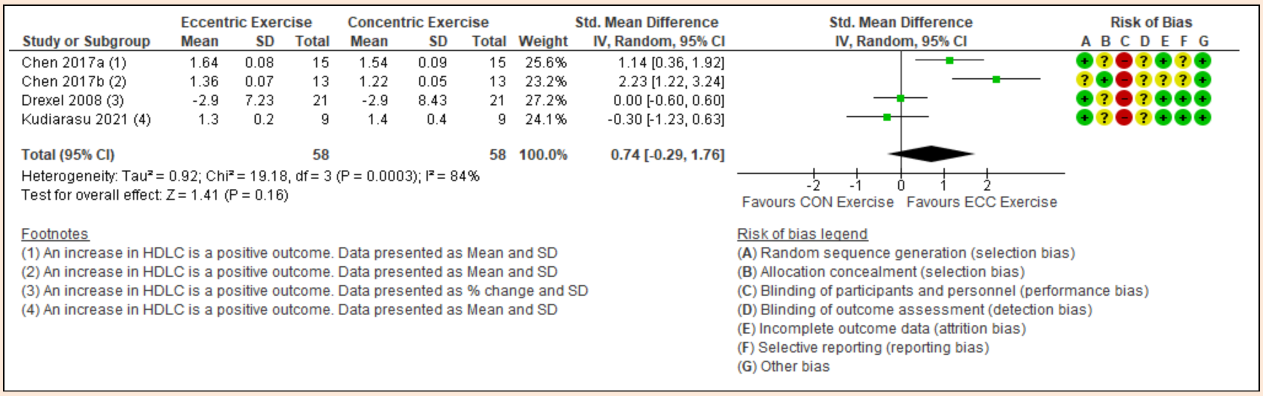


Figure 6. Forest plot of eccentric vs concentric exercise on HDLC. Risk of bias summary: review authors' judgements about each risk of bias item for each included study. Green symbols represent a low risk of bias, yellow symbols represent an unclear risk, and red symbols represent a high risk of bias.

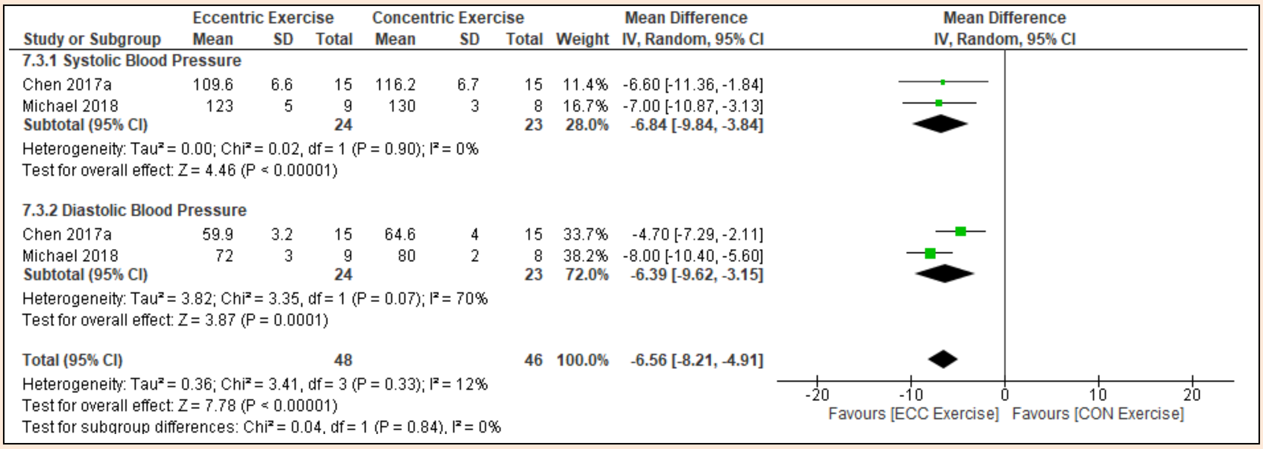


Figure 7. Forest plot of meta-analyses showing a comparison of eccentric versus concentric training on systolic and diastolic blood pressure.

(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 ($I^2 = 0\%$; 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 ($I^2 = 70\%$; 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.

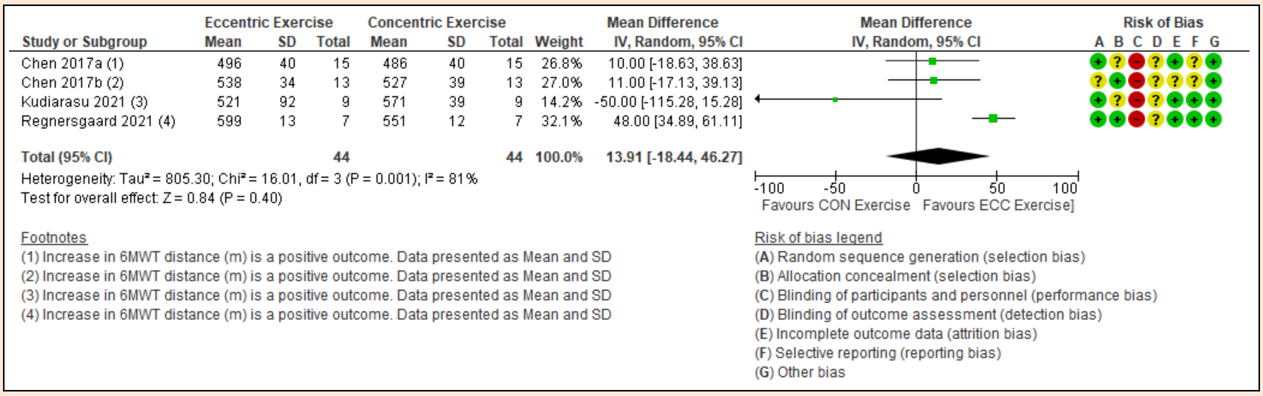
Effect of exercise on functional physical fitness

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 (Hajihasani et al., 2014; Kudiarasu et al., 2021) on people with T2DM. The training was performed by walking on a treadmill (Hajihasani 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 (Hajihasani 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 (Hajihasani 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 (Hajihasani 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 (Hajihasani 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 (Hajihasani 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 (Hajihasani 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 graphically presented in one paper (Hajihasani 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 (I2 = 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.



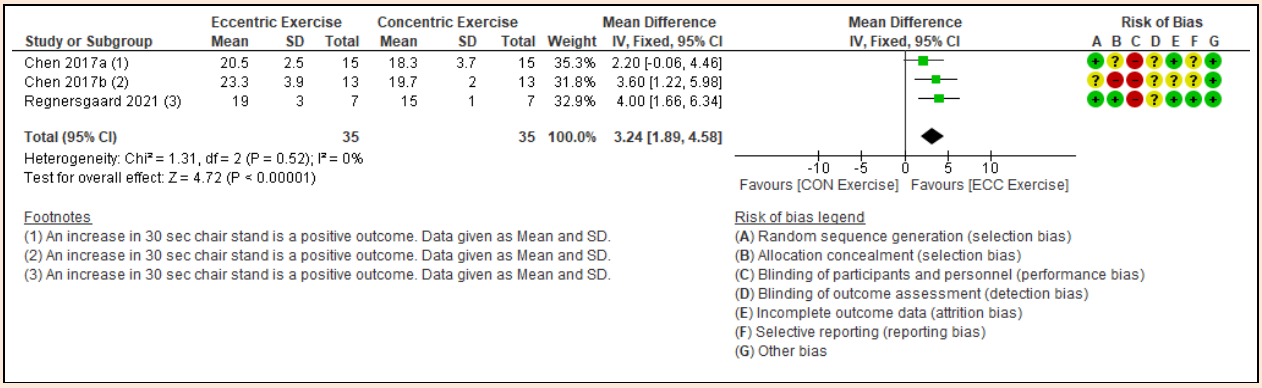
	Eccentric Exercise			Concentric Exercise				Mean Difference	Risk of Bias						
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI	A	B	C	D	E	F	G
Chen 2017a (1)	496	40	15	486	40	15	26.8%	10.00 [-18.63, 38.63]	+	?	−	?	+	?	+
Chen 2017b (2)	538	34	13	527	39	13	27.0%	11.00 [-17.13, 39.13]	?	+	−	?	?	?	+
Kudiarasu 2021 (3)	521	92	9	571	39	9	14.2%	-50.00 [-115.28, 15.28]	+	?	−	?	+	+	+
Regnersgaard 2021 (4)	599	13	7	551	12	7	32.1%	48.00 [34.89, 61.11]	+	+	−	?	+	+	+
Total (95% CI)			**44**			**44**	**100.0%**	**13.91 [-18.44, 46.27]**							

Heterogeneity: Tau² = 805.30; Chi² = 16.01, df = 3 (P = 0.001); I² = 81%
Test for overall effect: Z = 0.84 (P = 0.40)

Footnotes
(1) Increase in 6MWT distance (m) is a positive outcome. Data presented as Mean and SD
(2) Increase in 6MWT distance (m) is a positive outcome. Data presented as Mean and SD
(3) Increase in 6MWT distance (m) is a positive outcome. Data presented as Mean and SD
(4) Increase in 6MWT distance (m) is a positive outcome. Data presented as Mean and SD

Risk of bias legend
(A) Random sequence generation (selection bias)
(B) Allocation concealment (selection bias)
(C) Blinding of participants and personnel (performance bias)
(D) Blinding of outcome assessment (detection bias)
(E) Incomplete outcome data (attrition bias)
(F) Selective reporting (reporting bias)
(G) Other bias

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.



Study or Subgroup	Eccentric Exercise Mean	SD	Total	Concentric Exercise Mean	SD	Total	Weight	Mean Difference IV, Fixed, 95% CI	Risk of Bias A	B	C	D	E	F	G
Chen 2017a (1)	20.5	2.5	15	18.3	3.7	15	35.3%	2.20 [-0.06, 4.46]	+	?	-	?	+	?	+
Chen 2017b (2)	23.3	3.9	13	19.7	2	13	31.8%	3.60 [1.22, 5.98]	?	-	-	?	?	?	+
Regnersgaard 2021 (3)	19	3	7	15	1	7	32.9%	4.00 [1.66, 6.34]	+	+	-	?	+	+	+
Total (95% CI)			35			35	100.0%	3.24 [1.89, 4.58]							

Heterogeneity: Chi² = 1.31, df = 2 (P = 0.52); I² = 0%
Test for overall effect: Z = 4.72 (P < 0.00001)

Footnotes
(1) An increase in 30 sec chair stand is a positive outcome. Data given as Mean and SD.
(2) An increase in 30 sec chair stand is a positive outcome. Data given as Mean and SD.
(3) An increase in 30 sec chair stand is a positive outcome. Data given as Mean and SD.

Risk of bias legend
(A) Random sequence generation (selection bias)
(B) Allocation concealment (selection bias)
(C) Blinding of participants and personnel (performance bias)
(D) Blinding of outcome assessment (detection bias)
(E) Incomplete outcome data (attrition bias)
(F) Selective reporting (reporting bias)
(G) Other 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.

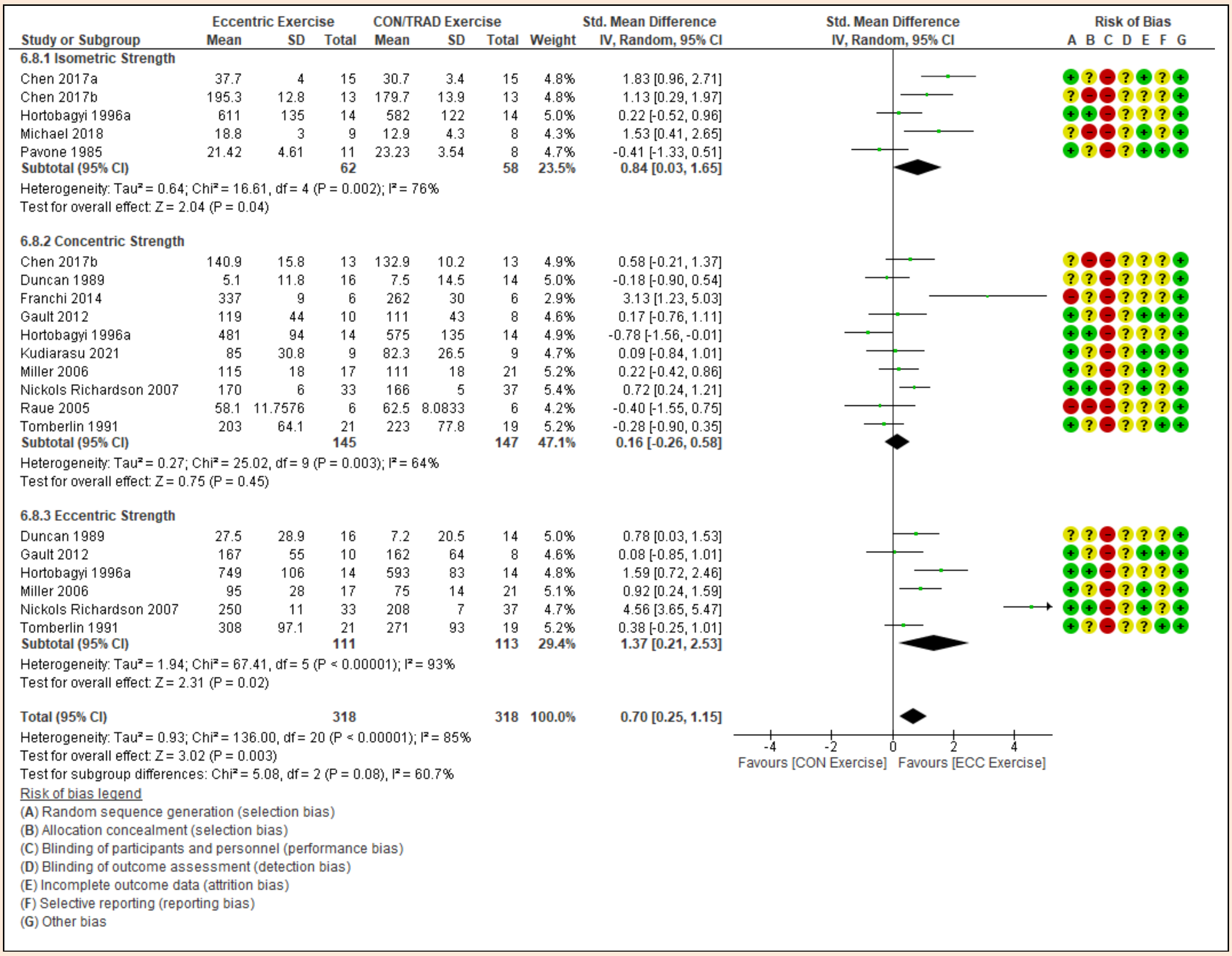
Concentric strength

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 eccentric 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 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.

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.



	Eccentric Exercise			CON/TRAD Exercise				Std. Mean Difference	Risk of Bias						
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI	A	B	C	D	E	F	G
6.8.1 Isometric Strength															
Chen 2017a	37.7	4	15	30.7	3.4	15	4.8%	1.83 [0.96, 2.71]	+	?	−	?	+	?	+
Chen 2017b	195.3	12.8	13	179.7	13.9	13	4.8%	1.13 [0.29, 1.97]	?	−	−	?	?	?	+
Hortobagyi 1996a	611	135	14	582	122	14	5.0%	0.22 [-0.52, 0.96]	+	+	−	?	?	?	+
Michael 2018	18.8	3	9	12.9	4.3	8	4.3%	1.53 [0.41, 2.65]	?	−	−	?	+	?	+
Pavone 1985	21.42	4.61	11	23.23	3.54	8	4.7%	-0.41 [-1.33, 0.51]	+	?	−	?	+	+	+
Subtotal (95% CI)			**62**			**58**	**23.5%**	**0.84 [0.03, 1.65]**							
Heterogeneity: Tau² = 0.64; Chi² = 16.61, df = 4 (P = 0.002); I² = 76%															
Test for overall effect: Z = 2.04 (P = 0.04)															
6.8.2 Concentric Strength															
Chen 2017b	140.9	15.8	13	132.9	10.2	13	4.9%	0.58 [-0.21, 1.37]	?	−	−	?	?	?	+
Duncan 1989	5.1	11.8	16	7.5	14.5	14	5.0%	-0.18 [-0.90, 0.54]	?	?	−	?	?	?	+
Franchi 2014	337	9	6	262	30	6	2.9%	3.13 [1.23, 5.03]	−	?	−	?	?	?	+
Gault 2012	119	44	10	111	43	8	4.6%	0.17 [-0.76, 1.11]	+	?	−	?	+	+	+
Hortobagyi 1996a	481	94	14	575	135	14	4.9%	-0.78 [-1.56, -0.01]	+	+	−	?	?	?	+
Kudiarasu 2021	85	30.8	9	82.3	26.5	9	4.7%	0.09 [-0.84, 1.01]	+	?	−	?	+	+	+
Miller 2006	115	18	17	111	18	21	5.2%	0.22 [-0.42, 0.86]	+	?	−	?	+	?	+
Nickols Richardson 2007	170	6	33	166	5	37	5.4%	0.72 [0.24, 1.21]	+	+	−	?	+	?	+
Raue 2005	58.1	11.7576	6	62.5	8.0833	6	4.2%	-0.40 [-1.55, 0.75]	−	−	−	?	?	?	+
Tomberlin 1991	203	64.1	21	223	77.8	19	5.2%	-0.28 [-0.90, 0.35]	+	?	−	?	?	+	+
Subtotal (95% CI)			**145**			**147**	**47.1%**	**0.16 [-0.26, 0.58]**							
Heterogeneity: Tau² = 0.27; Chi² = 25.02, df = 9 (P = 0.003); I² = 64%															
Test for overall effect: Z = 0.75 (P = 0.45)															
6.8.3 Eccentric Strength															
Duncan 1989	27.5	28.9	16	7.2	20.5	14	5.0%	0.78 [0.03, 1.53]	?	?	−	?	?	?	+
Gault 2012	167	55	10	162	64	8	4.6%	0.08 [-0.85, 1.01]	+	?	−	?	+	+	+
Hortobagyi 1996a	749	106	14	593	83	14	4.8%	1.59 [0.72, 2.46]	+	+	−	?	?	?	+
Miller 2006	95	28	17	75	14	21	5.1%	0.92 [0.24, 1.59]	+	?	−	?	+	?	+
Nickols Richardson 2007	250	11	33	208	7	37	4.7%	4.56 [3.65, 5.47]	+	+	−	?	+	?	+
Tomberlin 1991	308	97.1	21	271	93	19	5.2%	0.38 [-0.25, 1.01]	+	?	−	?	?	+	+
Subtotal (95% CI)			**111**			**113**	**29.4%**	**1.37 [0.21, 2.53]**							
Heterogeneity: Tau² = 1.94; Chi² = 67.41, df = 5 (P < 0.00001); I² = 93%															
Test for overall effect: Z = 2.31 (P = 0.02)															
Total (95% CI)			**318**			**318**	**100.0%**	**0.70 [0.25, 1.15]**							

Heterogeneity: Tau² = 0.93; Chi² = 136.00, df = 20 (P < 0.00001); I² = 85%
Test for overall effect: Z = 3.02 (P = 0.003)
Test for subgroup differences: Chi² = 5.08, df = 2 (P = 0.08), I² = 60.7%

Risk of bias legend
(**A**) Random sequence generation (selection bias)
(**B**) Allocation concealment (selection bias)
(**C**) Blinding of participants and personnel (performance bias)
(**D**) Blinding of outcome assessment (detection bias)
(**E**) Incomplete outcome data (attrition bias)
(**F**) Selective reporting (reporting bias)
(**G**) Other bias

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 intervenetions 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 (Frayn 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 management 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 (Hajihasani 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., Saely, C.H., Langer, P., Loruenser, G., Marte, T., Risch, L., Hoefle, G. and Aczel, 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.ijo.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

Hajihasani, A., Bahrpeyma, F. and Bakhtiary, 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 Uutela, 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.

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., Braspennincx, 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., Houmard, 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., Ingersen, 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/bjsm.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

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

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

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

BApplSc(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

✉ **Misha Ansari**
School of Health Sciences, University of Tasmania, Launceston, Australia