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Development of a home based resistance exercise programme for muscle strength and function during weight loss

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A Doctoral Thesis

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Thesis abstract

Background

The prevalence of obesity continues to increase, representing a major public health concern across the globe. While dietary interventions can reduce body mass, the concurrent loss of fat free mass and muscle strength is a potentially deleterious consequence. Resistance exercise may help preserve muscle mass and function during weight loss, yet its implementation remains challenging. This thesis investigated the potential of home-based resistance exercise to attenuate these deleterious effects of weight loss through three research studies.

Methods

Study 1 included a systematic review and meta-analysis examining the effects of resistance exercise on body composition, muscle strength, and cardiometabolic health during dietary weight loss. Study 2 employed qualitative methods to explore experiences and perceptions of resistance exercise among people living with overweight or obesity (n=11), informing a theory of change for intervention development. Study 3 evaluated the effects of a 12-week home-based resistance exercise intervention, during dietary weight loss, through a randomised controlled pilot trial (n=48).

Results

The systematic review and meta-analysis (25 RCTs) demonstrated that supervised resistance exercise during dietary weight loss preserved fat free mass (SMD: 0.40, $p<0.001$), increased fat mass loss (SMD: -0.36, $p<0.001$), and improved muscle strength (SMD: 2.36, $p<0.001$) relative to a no exercise control. The qualitative study identified multiple barriers, including pandemic-related limits, access to facilities and financial constraints to traditional gym-based resistance exercise, and indicated strong preferences for home-based alternatives. The pilot trial showed that, during weight loss, home-based resistance training improved grip strength ($p=0.046$), knee extensor maximal voluntary contraction force ($p=0.019$) and sit-to-stand performance ($p<0.001$), but did not have any effects on body composition (body mass index, total body mass, fat mass, fat free mass, muscle thickness) compared to dietary weight loss alone.

Conclusions

The current thesis demonstrates that supervised resistance exercise enhances the benefits of diet induced weight loss by preserving muscle mass and improving muscle function. The development and evaluation of a home-based programme showed promising results for overcoming traditional barriers to resistance exercise participation and improving muscle strength and function, but not muscle mass. These findings support the implementation of accessible resistance exercise interventions during weight loss for people living with overweight or obesity.

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Publications

Peer-reviewed journal articles

Binmahfoz, A., Dighriri, A., Gray, C.M. and Gray, S. Effect of resistance exercise on body composition and cardiometabolic health during dietary weight loss in people living with overweight or obesity: A systematic review and meta-analysis. BMJ open sport & exercise medicine. Submitted on 31 Oct 2024.

Binmahfoz, A., Dunning, E., Johnston, L., Gray, C.M. and Gray, S. The effects of a home-based resistance training programme on body composition and muscle function during weight loss in people living with overweight or obesity: a randomised controlled pilot trial. Nutrition & Metabolism. Submitted on 09 Nov 2024.

Peer-reviewed conference abstracts and presentations

Binmahfoz, A., Dighriri, A., Gray, C.M. and Gray, S., 2024. The effects of resistance exercise on cardiometabolic health and body composition in people living with obesity or overweight undergoing dietary weight loss interventions: A systematic review and meta-analysis. Proceedings of the Nutrition Society, 83(OCE2), p.E238.

Binmahfoz, A., Dunning, E., Johnston, L., Gray, C.M. and Gray, S., 2024. The effects of a home-based resistance training programme on body composition and muscle function during weight loss in people living with overweight or obesity: a randomised controlled pilot trial. Abstracts from the 9th UK Congress on Obesity 2024. International Journal of Obesity, 48, 47-93.

Additional papers

Timraz, M., Binmahfoz, A., Quinn, T.J., Combet, E. and Gray, S.R., 2023. The effect of long chain n-3 fatty acid supplementation on muscle strength in older adults: a systematic review and meta-analysis. Nutrients, 15(16), p.3579.

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Author’s declaration

Unless otherwise stated by acknowledgment or reference to published literature, the presented work in this thesis is the author’s own, as approved by the Thesis committee and the Graduate Office and has not been submitted for a degree at another institution.

AHMAD BINMAHFOZ

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Abbreviations

1RM: One-repetition maximum

8RM: Eight-repetition maximum

BMI: Body mass index

CI: Confidence interval

CONSORT: Consolidated Standards of Reporting Trials Checklist

CVD: Cardiovascular disease

FFM: Fat free mass

FM: Fat mass

GLP-1: Glucagon-like peptide 1

GRADE: Grades of Recommendation, Assessment, Development and Evaluation assessment

HDL: High-density lipoprotein

HOMA-IR: Homeostatic model assessment insulin resistance

HR: Hazard ratios

LDL: Low density lipoprotein

MD: Mean difference

MVC: Maximum voluntary contraction

NIHR: The National Institute for Health and Care Research

OGTT: Oral glucose tolerance test

PAR-Q+: Physical Activity Readiness Questionnaire

PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses

PROSPERO: International Prospective Register of Systematic Reviews.

RCT: Randomised controlled trial

RPE: Rating of Perceived Exertion

RR: Relative risk

RT+WL: Diet induced weight loss plus home-based resistance training

SD: Standard deviations

SMD: Standardised mean difference

SMI: Skeletal muscle index

STS: 30-second sit-to-stand test

VO_{2max}: Maximum amount of oxygen consumption

VO_{2peak}: Highest amount of oxygen consumption

WHO: World Health Organization

WL: Diet induced weight loss

Chapter 1 Literature Review

1.1 Obesity prevalence

The World Health Organization (WHO) defines obesity as "abnormal or excessive fat accumulation that may impair health" (World Health Organization, 2021). Overweight and obesity are commonly categorised by Body Mass Index (BMI), where a BMI of 25–29.9 kg/m^2 refers to overweight and a BMI of ≥30 kg/m^2 refers to obesity (World Health Organization, 2021). Recent developments in the classification of obesity have, however, gone beyond these BMI categories. For example, The Lancet Commission on Obesity proposed an approach that distinguished between preclinical and clinical obesity (Rubino et al., 2025). According to the Commission, preclinical obesity is defined as "a state of excess adiposity with preserved function of other tissues and organs and a varying, but generally increased, risk of developing clinical obesity and several other non-communicable diseases (e.g., type 2 diabetes, cardiovascular disease, certain types of cancer, and mental disorders)." In contrast, clinical obesity is defined as "a chronic, systemic illness characterised by alterations in the function of tissues, organs, the entire individual or a combination thereof, due to excess adiposity," which "can lead to severe end-organ damage, causing life-altering and potentially life-threatening complications." As this new definition has not been widely adopted, as yet, and it was proposed after the current thesis was planned, the WHO definition will be used throughout this work. Obesity is a major public health concern globally, affecting both developed and developing countries. The prevalence of overweight and obesity has increased significantly in recent years around the world. In 1975, it was estimated that there were 105 million adults living with obesity worldwide (NCD Risk Factor Collaboration, 2016) and this number increased to over 650 million in 2016 (World Health Organization, 2021, NCD Risk Factor Collaboration, 2016). The recent COVID-19 pandemic contributed to this trend, with new research showing faster weight gain in many populations during lockdown periods (Bakaloudi et al., 2022). It is indicated that these numbers will rise in the future; with estimates that by 2035 more than 51% of the world's adult population will have overweight or obesity (World Obesity Federation, 2023).

The prevalence of obesity and overweight varies significantly across the world, with the highest levels observed in North America, Europe, and Oceania (Ng et al., 2014). In the United States and Canada in 2018, approximately 42% and 27% of adults, respectively, were classified as having obesity (Hales et al., 2020, Lytvyak et al., 2022). Across Europe, overweight prevalence ranges from approximately 45% to 75%, with obesity ranging from less than 10% in some countries to over 30% in others (Blundell et al., 2017, Gallus et al., 2015). According to the WHO European Regional Obesity Report 2022, 59% of adults in the region have overweight or obesity (World Health Organization, 2022). Specifically, as of 2020, Turkey (32.1%), Malta (28.8%) and Bosnia and Herzegovina (26.6%) have the highest prevalence of obesity in Europe, while Romania (9.4%), Switzerland (9.6%), and Italy (10.3%) have the lowest prevalence (World Health Organization, 2020b). There is a significant variation in the prevalence of overweight and obesity among different demographic groups, with higher prevalence of obesity observed among adults with lower levels of education and income (Hales et al., 2020, Lytvyak et al., 2022). The gender distribution of overweight and obesity also varies, with women generally showing a higher prevalence of obesity than men in many regions, particularly in low- and middle-income countries, while the prevalence of overweight tends to be higher among men in high-income countries (NCD Risk Factor Collaboration, 2016).

In the UK, obesity and overweight prevalence has increased significantly over the past few decades. According to the Health Survey for England 2019, 63% of adults were classified as having overweight or obesity (36% overweight and 28% obese)(NHS Digital, 2021, NHS Digital, 2020). This is a significant increase compared to 1993, when 53% of adults had overweight or obesity, (38% overweight and 15% obese) (NHS Digital, 2020). Gender differences are evident in these figures, with currently 68% of men and 60% of women having overweight or obesity, and the prevalence varies by age group, with higher prevalence typically seen in middle-aged (45-74 years) compared to younger adults (NHS Digital, 2020).

The prevalence of overweight and obesity in the UK is projected to rise, with estimates that 70% of adults will have overweight or obesity, with 36% having obesity, by 2040 (Payne et al., 2022). This increase would mean an estimated 21 million UK adults living with obesity by 2040. In Scotland, the prevalence of obesity and overweight is higher than the UK average, 66% of adults had overweight or obesity, with around 29% of adults having obesity in 2019 (Obesity Action Scotland, 2021, Scottish Government, 2020). The gender distribution shows that 69% of men and 63% of women in Scotland have overweight or obesity (Scottish Government, 2020). Over the past few decades, the prevalence of overweight and obesity has increased in Scotland since 1995 with around 52% having overweight or obesity, (16% having obesity). Additionally, the prevalence of overweight and obesity varies by age, rising from 40% in those aged 16 to 24 to a peak of 79% among people aged 65 to 74 (Scottish Government, 2020). The prevalence of obesity is expected to continue increasing in Scotland in the coming years, with projections indicating that, over 40% of Scottish adults will be classified as having obesity by 2030 (Donnelley et al., 2010). This would be one of the highest obesity rates in Europe, with major consequences for public health, economic costs and healthcare services.

1.2 Risks associated with obesity

Obesity is linked to many negative health consequences, raising the risk of morbidity and mortality. A comprehensive meta-analysis of 239 prospective studies, with a total of 10.6 million participants, found that an increase in BMI of 5 kg/m^2 above 25 kg/m^2 significantly increased the risk of all-cause mortality (hazard ratios (HR) 1.31, 95% CI: 1.29-1.33) (Di Angelantonio et al., 2016). This relationship between excess weight and mortality has been shown to follow a J-shaped curve (Figure 1-1) with the lowest risk observed in the BMI range of 20-25 kg/m^2 (Di Angelantonio et al., 2016).

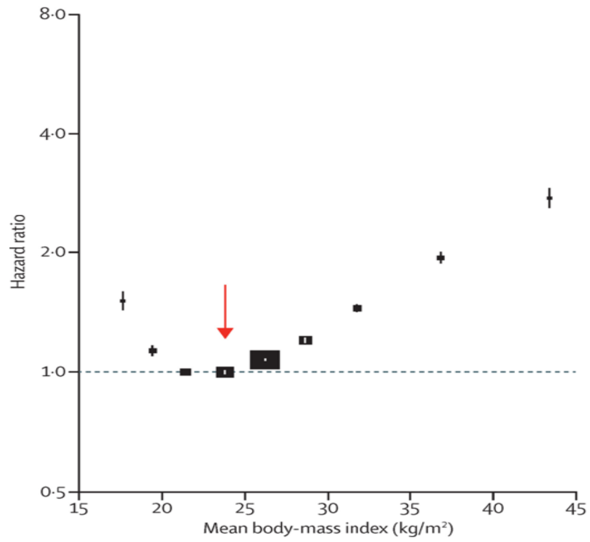


Figure 1-1 Data association of body-mass index with mortality adapted from Di Angelantonio et al. (2016).

Several specific health problems have been associated with obesity metabolically, non-metabolically and psychologically, including an increased risk of developing chronic diseases such as type 2 diabetes, cardiovascular disease, certain cancers, and musculoskeletal disorders (Haslam and James, 2005, Ng et al., 2014, World Health Organization, 2021). Indeed, a recent study concluded that people living with obesity (BMI ≥30.0 kg/m^2) had a higher risk of developing multimorbidity (two diseases - HR 5.17 (95% CI 4.84–5.53) and four or more diseases HR 12.39 (95% CI 9.26–16.58)) compared to those with healthy weight (BMI 18.5-24.9 kg/m^2) (Kivimäki et al., 2022). These conditions not only adversely affect individuals overall health, but also contribute to a higher incidence of disability and a reduction in functional capacity (Roth, 2018).

Metabolically, the risk of type 2 diabetes increases by 5-10 fold in people living with obesity compared to those of normal weight (Abdullah et al., 2010). The association between obesity and type 2 diabetes has also been well-documented and a recent umbrella review of meta-analyses of 86 studies showed a significant association between BMI and type 2 diabetes (RR = 6.88, 95% CI, 5.39-8.78, $p = 4.2 \times 10^{-54}$) (Bellou et al., 2018) highlighting that people living with obesity have a seven-fold higher risk of type 2 diabetes compared to those of normal weight (Bellou et al., 2018). Obesity also disrupts lipid metabolism, leading to dyslipidaemia characterised by high triglycerides, decreased HDL cholesterol, and increased LDL cholesterol (Klop et al., 2013).

Exploring this in further detail, it has been established that obesity increases the risk of cardiovascular diseases. The National Institute for Health and Care Research (NIHR) reported that people living with obesity have a 28% increased risk of heart disease compared to people of normal weight (National Institute for Health and Care Research, 2017). A systematic review and meta-analysis, involving more than 300,000 participants, examining the association of overweight and obesity with the risk of coronary heart disease, showed that overweight and obesity increases the risk of coronary heart disease with a relative risk (RR) of 1.32 (95% CI, 1.24-1.40) and 1.81 (95% CI, 1.56-2.10) respectively (Bogers et al., 2007). This is further supported by other research, which found that a 10 kg increase in body mass is associated with a 12% higher risk of coronary artery disease, as well as a 3 mmHg rise in systolic and a 2.3 mmHg rise in diastolic blood pressure (Koliaki et al., 2019, Csige et al., 2018).

Non-metabolically, a significant health consequence of obesity is an increased risk of musculoskeletal disorders. Excess weight on joints contributes to conditions such as low back pain, osteoarthritis, and reduced physical function (Thijssen et al., 2015, Chait and Den Hartigh, 2020). A recent systematic review and meta-analysis found significant associations of fat mass with musculoskeletal pain (standardised mean difference (SMD) 0.49, 95% CI 0.37–0.61, $p < 0.001$) (Walsh et al., 2018). Another systematic review and meta analysis found that for every 5 kg/m^2 higher BMI, the risk of knee osteoarthritis was 35% higher (Zheng and Chen, 2015). Furthermore, it has been shown that people living with overweight or obesity have 2.45 and 4.55 times higher risk of knee osteoarthritis compared to those with normal weight, respectively (Zheng and Chen, 2015).

On top of this, obesity significantly increases the risk of certain cancers. An umbrella review of meta-analyses of 204 studies, investigating the relationship between obesity and the risk of developing cancer, showed that every 5 kg/m^2 higher BMI raised the risk of cancer from 9% (RR = 1.09, 95% CI, 1.06 to 1.13) to 56% (RR = 1.56, 95% CI, 1.34 to 1.81) (Kyrgiou et al., 2017). In the UK, obesity is a major risk factor for cancer, ranking second only to smoking as the leading preventable cause (Brown et al., 2018). According to Cancer Research UK data, obesity and overweight are associated with an estimated 22,800 cases (6.3%) of cancer every year in the UK (Brown et al., 2018). In Scotland, obesity contributed the highest proportion of cancer cases 6.8% among the UK countries (compared to 6.3% in England, 5.4% in Wales and 6.2% in Northen Ireland) (Brown et al., 2018).

Psychologically, obesity and related diseases significantly impact psychological wellbeing, with individuals living with obesity showing higher risk of depression (odds ratio 1.55 (95% CI 1.22-1.98)) and anxiety (odds ratio 1.40 (95% CI 1.23-

1.57)) (Luppino et al., 2010, Gariepy et al., 2010). These health problems can also have a significant negative impact on quality of life, including stigmatisation and reduced self-esteem (Puhl and Heuer, 2009), and lead to increased healthcare costs and reduced life expectancy (Tremmel et al., 2017, Bray, 2004).

The mechanisms underlying obesity's health effects are closely tied to adipocyte biology and inflammatory processes. A key mechanism linking obesity to multiple health conditions is chronic low-grade inflammation. As adipocytes enlarge in obesity (hypertrophy), typically exceeding 150-200μm, they undergo pathological changes in function and experience mechanical stress, endoplasmic reticulum stress, and eventually hypoxia due to insufficient vascularization (Sun et al., 2011). These enlarged adipocytes become insulin resistant, leading to increased lipolysis and elevated free fatty acid release into circulation. Once adipocyte storage capacity is exceeded, lipids accumulate in ectopic sites such as liver, muscle, and pancreas, further impairing metabolic function (Virtue and Vidal-Puig, 2010). Additionally, hypertrophic adipocytes exhibit altered secretory profiles, with decreased production of beneficial adipokines, like adiponectin, and increased secretion of inflammatory adipokines (Ouchi et al., 2011). The resulting inflammatory environment harms blood vessels, interferes with insulin signalling, and results in adipose tissue dysfunction (Gregor and Hotamisligil, 2011). This adipocyte hypertrophy and inflammatory response independently contribute to the increased disease risk associated with obesity (Reilly and Saltiel, 2017). Beyond inflammation, this excess adipose tissue also causes endocrine disruptions, such as increased leptin synthesis, decreased adiponectin, and changed sex hormone levels particularly decreasing the levels of testosterone and increasing the production of oestrogen, all of which contribute to metabolic dysfunction

(Gregor and Hotamisligil, 2011). Several of these factors contribute to insulin resistance, which plays a key role in the development of type 2 diabetes (Hotamisligil, 2006). In addition, obesity negatively affects hormone levels, such as increasing levels of insulin-like growth factors, which may support the growth of some types of cancer cells (Renehan et al., 2008, Renehan et al., 2004).

The economic burden of obesity is also significant, with estimates suggesting that by 2050, obesity will cost more than £50 billion per year in the UK for direct and indirect costs (Public Health England, 2017). In 2017/18, approximately £600 million was spent by the NHS in Scotland on obesity-related health problems, and this cost is expected to increase to over £1 billion per year by 2030 (Scottish Government, 2018).

1.3 Association between obesity, body composition, metabolic health and muscle function

During the development of obesity there are increases in both fat mass and fat free mass, but fat mass increases at a greater rate resulting in a lower ratio of muscle to fat (Sizoo et al., 2021, Cava et al., 2017, Purnell, 2023). Fat free mass refers to all non-fat components of the human body, including skeletal muscle, bone, organs, water and connective tissues. Skeletal muscle accounts for approximately 40-50% of total fat free mass in healthy adults, with the remainder distributed among other tissues (Heymsfield et al., 2015). Indeed, a recent study found that for each 10% increase in total body mass, fat mass and fat free mass accounted for 8.5% and 1.5% of the increase, respectively (de França et al., 2020). In people living with obesity, increases in different types of body mass have different impacts on muscle strength and function. While a 10% increase in fat free mass is associated with a 6.9% increase in strength, a 10% increase in fat mass is associated by a 1.5% decrease in strength (de França et al., 2020). The overall effect of obesity on muscle strength differs by body region due to different levels of loading of each muscle group. For example, the weight-bearing muscles of the lower body and trunk experience chronic loading during activities of daily living and postural control, leading to increased strength of the legs and trunk, but not of the handgrip or arm muscles (Tomlinson et al., 2016). Indeed, it has been demonstrated in several studies that individuals living with obesity have higher absolute strength in leg and trunk muscles compared to individuals living without obesity, with improvements of 20-30% in maximum knee extensor strength, (Tomlinson et al., 2016, Morgan et al., 2020), with no difference ($P > 0.05$) in handgrip strength between people living with obesity (52.1 ± 1.2kg) and people living without obesity (52.2 ± 0.6kg) (Rolland et al., 2004). Beyond this, preserving muscle strength has important implications for longevity. A large prospective cohort study of 502,293 adults demonstrated that higher muscle strength is associated with lower risk of all-cause mortality, with each 5 kg higher grip strength associated with a lower risk of all-cause mortality in men and women, respectively, (HR 1.20, 95% CI 1.17 to 1.23, and 1.16, 1.15 to 1.17) (Celis-Morales et al., 2018).

While absolute strength may be greater in certain muscle groups, strength relative to body mass (a measure of muscle quality) is lower in people living with obesity. Indeed it has been shown that when normalised to body mass, knee extensor strength is 6-7% lower in adults living with obesity (Tomlinson et al., 2016). This reduced relative strength has important functional implications, particularly for tasks requiring movement or support of body weight. For example, in people living with overweight or obesity, research has demonstrated that higher BMIs are associated with poorer chair rise performance (-0.76% 95% CI -1.07, -0.44 and -1.04% 95% CI -1.19, -0.90) and slower walking pace (-0.76cm/s 95% CI -0.97, -0.56 and -0.92% 95% CI -1.19, -0.65) in both men and women, respectively (Hardy et al., 2013). These negative effects in functional capacity significantly impact quality of life and independence in performing daily activities (Gilleard, 2012, Tomlinson et al., 2016).

On top of this, body composition plays a vital role in a variety of diseases, including cardiovascular disease, diabetes and cancer as well as metabolic health. However, the relationship between body composition and metabolic health is complex and studies have shown inconsistent results. An investigation of the association between body composition, including lean body mass, skeletal muscle mass, body fat mass and body mass index (BMI), with metabolic health profiles, including blood pressure, fasting glucose, triglyceride and high-density lipoprotein cholesterol, in the general population (190,599 participants from The Korean National Health Insurance Service-National Health Screening) reported that in both men and women: 1) for each kilogram increase in skeletal muscle mass, systolic blood pressure decreased by 1.24-2.06 mmHg, triglycerides decreased by 9.26-10.28 mg/dL and HDL cholesterol increased by 1.00-1.29 mg/dL, 2) for each kilogram increase in lean mass, systolic blood pressure decreased by 0.66-0.82 mmHg, triglycerides decreased by 4.38-4.85 mg/dL and HDL cholesterol increased by 0.44-0.50 mg/dL and conversely, 3) for each kilogram increase in fat mass, systolic blood pressure increased by 0.67-0.85 mmHg, triglycerides increased by 4.58-4.65 mg/dL and HDL cholesterol decreased by 0.45-0.51 mg/dL (see Table 1-1) (Oh et al., 2021).

Table 1-1 Linear regression analysis for the predictors of metabolic profiles from Oh et al. (2021)

Variable	Δ systolic blood pressure β (95% CI)	Δ diastolic blood pressure β (95% CI)	Δ fasting glucose β (95% CI)	Δ Triglyceride β (95% CI)	Δ high-density lipoprotein cholesterol β (95% CI)
Men					
Δ lean body mass	−0.66 (−0.72, −0.61)	−0.40 (−0.44, −0.36)	−0.28 (−0.35, −0.21)	−4.85 (−5.11, −4.58)	0.50 (0.43, 0.57)
Δ skeletal muscle mass	−1.24 (−1.34, −1.13)	−0.75 (−0.83, −0.67)	−0.47 (−0.62, −0.32)	−9.26 (−9.81, −8.70)	1.00 (0.86–1.13)
Δ body fat mass	0.67 (0.62, 0.72)	0.40 (0.36, 0.43)	0.21 (0.14–0.28)	4.65 (4.39, 4.92)	−0.51 (−0.57, −0.44)
Δ body mass index	1.31 (1.22, 1.39)	0.76 (0.71, 0.82)	0.31 (0.20–0.42)	9.54 (9.12, 9.96)	−1.01 (−1.11, −0.91)
Women					
Δ lean body mass	−0.82 (−0.89, −0.75)	−0.40 (−0.45, −0.35)	−0.20 (−0.27, −0.12)	−4.38 (−4.67, −4.09)	0.44 (0.34, 0.53)
Δ skeletal muscle mass	−2.06 (−2.24, −1.88)	−0.93 (−1.05, −0.80)	−0.10 (−0.29, 0.08)	−10.28 (−11.01, −9.55)	1.29 (1.05–1.5)
Δ body fat mass	0.85 (0.77, 0.92)	0.41 (0.36, 0.46)	0.21 (0.14–0.29)	4.58 (4.28, 4.88)	−0.45 (−0.55, −0.35)
Δ body mass index	0.96 (0.88, 1.05)	0.49 (0.43, 0.55)	0.32 (0.24–0.41)	5.21 (4.88, 5.54)	−0.46 (−0.57, −0.35)

These relationships demonstrate the opposing effects of lean mass and fat mass on cardiometabolic health parameters. Particularly noteworthy is the observation that skeletal muscle mass shows the strongest beneficial associations with cardiometabolic health markers, especially in terms of blood pressure and lipid profiles. However, these relationships show some gender specificity, with women demonstrating different patterns, particularly where no association between skeletal muscle mass and fasting glucose was found (95% CI: -0.29, 0.08) (Oh et al., 2021). The combined impact of altered body composition on both metabolic and functional parameters creates a concerning cycle in people living with overweight or obesity. Reduced relative strength leads to increased perceived effort during movement, resulting in decreased physical activity levels. This can be particularly challenging in obesity, where higher body mass already places greater demands on the musculoskeletal system. Indeed, it has been shown that individuals living with obesity have to generate 60-70% greater knee extensor force compared to normal weight when performing the same functional activities, despite having only 20-30% higher absolute strength (Maffiuletti et al., 2007). This decrease in physical activity can further compound the negative effects of obesity on muscle strength by result in a decrease in muscle mass and strength. For example, lowering daily steps to 750-1500/day for two weeks resulted in a 2.8% loss of leg lean mass and reductions in knee extensor strength by about 6-9% (Oikawa et al., 2019). Hence, this can further compromise cardiometabolic health (Manini and Clark, 2012), as demonstrated that reduced daily physical activity led to a significant decrease in insulin sensitivity by approximately 39% (Stephens et al., 2011).

The evidence presented demonstrates that while obesity may lead to increases in absolute strength, the increase in fat mass relative to lean mass creates significant cardiometabolic and functional challenges. The reduced relative strength impairs performance in activities of daily living, while the altered body composition negatively impacts cardiometabolic health parameters. These findings emphasise the need for targeted interventions that can effectively modify body composition by reducing fat mass while preserving or enhancing lean mass. Weight loss interventions, therefore, need to be carefully designed to achieve this optimal balance.

1.4 Weight loss interventions

The increasing prevalence of obesity in recent years has led to the development and evaluation of various weight loss interventions. A meta-analysis comparing different weight loss interventions showed that bariatric surgery resulted in greater weight loss (mean difference (MD) -26 kg; 95% CI -31 to -21) compared to non-surgical interventions (Gloy et al., 2013). This analysis of 11 randomised controlled trials demonstrated consistent benefits in a variety of bariatric surgery techniques, with gastric banding achieving a mean weight loss of -22.6 kg (95% CI -28.4 to -16.7) and other bariatric techniques achieving -29.4 kg (95% CI -37.6 to -21.4) compared to non-surgical intervention (Gloy et al., 2013). Another recent systematic review and meta analysis comparing bariatric surgery to pharmacological interventions found that bariatric surgery resulted in greater weight loss (mean difference -22.05 kg, 95% CI -28.86 to -15.23 kg) (Pipek et al., 2024). On top of this, a recent meta analysis of 95 randomised controlled trials comparing exercise, diet, and pharmacological interventions demonstrated that diet combined with weight-lowering drugs resulted in the greatest reduction in BMI (mean difference -2.61 kg/m^2; 95% CI -3.04 to -2.19), followed by diet alone (−1.94 kg/m^2; 95% CI −2.30 to −1.57), and exercise + diet (−1.42 kg/m^2;, 95% CI −1.76 to −1.09) (Ruiz-González et al., 2024). Bariatric surgery, while most effective for weight loss, has significant issues. A systematic review and meta analysis of 164 studies showed that while gastric bypass or sleeve gastrectomy achieved 25-30% body mass reduction at 5 years (Chang et al., 2014), complications occurred in 10-17% of cases, with reoperation rates of 7-12% (O'Brien et al., 2019). Additionally, the cost per quality-adjusted life year (QALY) ranged from £5,000 to £15,000 (Picot et al., 2009), limiting its accessibility as a population-level intervention (National Institute for Health and Care Research, 2014).

Pharmacological interventions provide effectiveness in reducing body mass, with varying risk profiles. A recent meta-analysis of 28 randomised clinical trials evaluating US Food and Drug Administration (FDA)-approved medications showed that glucagon-like peptide 1 (GLP-1) receptor agonists achieved an average weight loss of 5.3 kg (~5-10% of body weight) at one year, while other medications like naltrexone-bupropion and phentermine-topiramate achieved 5-7% (Khera et al., 2016). In more recent work in a randomised double-blind trial with almost 2,000 participants it was shown that the GLP-1 receptor agonist semaglutide resulted in an average weight loss of 15% over 68 weeks, confirming the efficacy of GLP-1 agonists in achieving significant weight loss (Wilding et al., 2021). However, discontinuation rates due to side effects range from 5-20% (Rubino et al., 2021, Apovian et al., 2015), and medication costs (£150-400 per month) present significant barriers to long-term use (National Institute for Health and Care Research, 2014).

Dietary interventions currently remain the most widely implemented approach to weight loss, with several strategies available. A meta-analysis of 59 randomised trials with 7,286 participants comparing different dietary approaches revealed that all reduced-calorie diets resulted in weight loss and the differences between specific dietary interventions was minimal (Johnston et al., 2014). For example, low-carbohydrate (7.25 kg, 95% CI 5.33 to 9.25 kg) and low-fat (7.27 kg, 95% CI 5.26 to 9.34 kg) diets showed similar effectiveness at 12 months (Johnston et al., 2014). This is further supported by a recent systematic review and meta-analysis of 121 randomised controlled trials involving 21,942 adults with overweight or obesity which demonstrated that most different dietary approaches, such as low-carbohydrate, low-fat and Mediterranean, had a similar effect on weight loss an average of 4.7 kg, 4.4 kg and 4.1 kg at six months, respectively (Ge et al., 2020). The key determinant of success was adherence rather than macronutrient composition, with all approaches achieving similar results when a caloric deficit was maintained. However, the maintenance of weight loss presents a significant challenge and long-term follow-up studies indicate that approximately 50% of lost weight is regained within two years, regardless of the dietary approach (Hall and Kahan, 2018, Franz et al., 2007, Anderson et al., 2001). This has led to increased focus on strategies for maintaining weight loss, including ongoing support and monitoring.

Physical activity alone has shown limited effectiveness for weight loss. A systematic review and meta analysis of 14 randomised controlled trials, with 1,847 people living with overweight or obesity, demonstrated that exercise only interventions typically achieve modest weight loss of 1.6 kg, (95% CI 1.64 to 1.56 kg) at 6 months and 1.7 kg, (95% CI 2.29 to 1.11 kg) at 12 months (Thorogood et al., 2011). However, physical activity can play a crucial role in weight loss maintenance and provides important health benefits independent of weight loss (Wing and Phelan, 2005). Additionally, when combined with dietary interventions, physical activity enhances weight loss outcomes. Indeed, when combined with caloric restriction, exercise further improves body composition changes and metabolic adaptations beyond changes expected from the additional energy expenditure alone (Swift et al., 2018). The challenge lies in the substantial volume of exercise required for meaningful weight loss, approximately 60-90 minutes of moderate intensity physical activity is required daily to achieve a weight loss of 2-3 kg over 12 months without dietary modification (Donnelly et al., 2009).

Combining dietary and exercise interventions shows more promising results than either approach alone, particularly for long-term outcomes. Multiple systematic reviews and meta analyses found that combined interventions achieved greater weight loss by an average of 5.13 kg to 8.98 kg, compared to diet alone, over 6 - 12 months, with improved maintenance at 24 months (Johns et al., 2014, Wu et al., 2009). Due to this complementary effect, the American Heart Association, American College of Cardiology, and The Obesity Society (AHA/ACC/TOS) guidelines from 2013 emphasise that comprehensive lifestyle interventions—combining reduced calorie diets, increased physical activity, and behaviour therapy—should be considered the cornerstone of weight loss treatment (Jensen et al., 2014).

Summarising, the evidence demonstrates that while multiple approaches to weight loss exist, each has advantages and limitations. Bariatric surgery offers the most substantial weight loss (25-30%) but carries surgical risks and high costs. Pharmacological interventions provide effectiveness (5-15% weight loss) but are limited by side effects and ongoing costs. Dietary interventions, while showing more modest weight loss, remain the most accessible and widely implemented approach, though long-term maintenance remains challenging with 50% weight regain common within two years. Physical activity alone has limited impact on weight loss but provides crucial health benefits and improves long-term maintenance. Therefore, comprehensive approaches that can achieve meaningful weight loss, but it is prudent to look beyond simple body mass and investigate the effects of weight loss interventions on body composition, metabolic health and muscle function.

1.5 Effects of weight loss interventions on body composition, metabolic health and muscle function

Metabolic health is often improved early in weight loss interventions, even before significant weight loss occurs (Soll et al., 2022, Farhana and Rehman, 2021). Insulin sensitivity often increases with calorie restriction (Shah, 2019, dos Santos et al., 2024) and recent research found that after initial weight loss, HOMA-IR (a measure of insulin resistance) decreased by 1.60 on average, and glucose response after OGTT by 27.51 (mg dl^{-1} min^{-1}) indicating improved insulin sensitivity and glucose metabolism (Li et al., 2022), with this effect remaining for 18-24 months. Furthermore, greater weight loss can lead to greater metabolic improvements. For example, the Diabetes Remission Clinical Trial (DiRECT) illustrated that (~10kg) of weight loss resulted in full remission of type 2 diabetes in almost half of participants (Lean et al., 2018). Specifically, remission rates varied with weight loss, with 7% remission seen after losing <5 kg, and 86% remission after losing ≥15 kg (Lean et al., 2018).

Lipid profiles are also improved with weight loss, with increases in HDL cholesterol and decreases in triglycerides, LDL cholesterol, and total cholesterol (Arnett et al., 2019, Ma et al., 2017). A recent meta-analysis examining 73 randomised controlled trials (n=32,496 participants; mean age, 48.1 years; mean weight, 101.6 kg; and mean body mass index, 36.3 kg/m^2) revealed that for every kilogram of weight lost, triglycerides decreased by -4.0 mg/dL (95% CI, -5.24 to -2.77 mg/dL), LDL-C decreased by -1.28 mg/dL (95% CI, -2.19 to -0.37 mg/dL), and HDL-C increased by 0.46 mg/dL (95% CI, 0.20 to 0.71 mg/dL) (Hasan et al., 2020). Another important benefit of weight loss interventions is the improvement in blood pressure, and a meta-analysis of 25 randomised controlled trials with a total of 4,874 participants demonstrated that systolic blood pressure dropped by 1.05 mmHg and diastolic blood pressure by 0.92 mmHg for each kilogram of weight lost (Neter et al., 2003). In addition, a larger randomised clinical trial, the Look AHEAD study, with 5,145 adults with overweight or obesity and type 2 diabetes demonstrated that those achieving weight loss of 10% had a 21% lower risk of cardiovascular diseases (adjusted hazard ratio [HR] 0.79, 95% CI 0.64–0.98) (Gregg EW, 2016).

Whilst these benefits of weight loss are to be celebrated, there are some unintended consequences. For example, during weight loss, alongside the loss of fat mass there is a consistent loss of fat free mass, particularly skeletal muscle mass. The magnitude of fat free mass loss can vary greatly depending on the dietary approach adopted (Figure 1-2), ranging from 10% to 30% of total weight lost is fat free mass, which includes muscle tissue (Cava et al., 2017). The loss of muscle during weight loss can have negative impacts on overall health and long-term weight loss (McCarthy and Berg, 2021). For example, these losses of lean tissue can potentially impact strength and physical function, and have important implications for both short and long term outcomes. A systematic review and meta analysis of 27 randomised controlled trials investigating the impact of weight loss on muscle strength in people living with overweight or obesity found that diet--induced weight loss results in significant decreases in absolute muscle strength including knee extensor strength, -9.0 (95% CI: -13.8 to -4.1 N/m), and handgrip strength, -2.4% (95% CI: -4.8 to -0.0 kg), with an average of 7.5% and 4.6% reductions from baseline (Zibellini, 2015). On the other hand, while absolute strength decreases with weight loss, physical function often improves due to the reduced load on the musculoskeletal system. A study of 93 participants with obesity found that weight loss of >9% body mass led to significant improvements in physical performance measures in the range of 12% - 21% in the Physical Performance Test (a 9-item test including tasks such as lifting a book, putting on and removing a coat, picking up a penny, a 50-foot walk, standing up from a chair, climbing one flight of stairs, performing a progressive Romberg test, climbing up and down four flights of stairs, and performing a 360-degree turn) and gait speed in the range of 14% - 23% (Villareal et al., 2011).

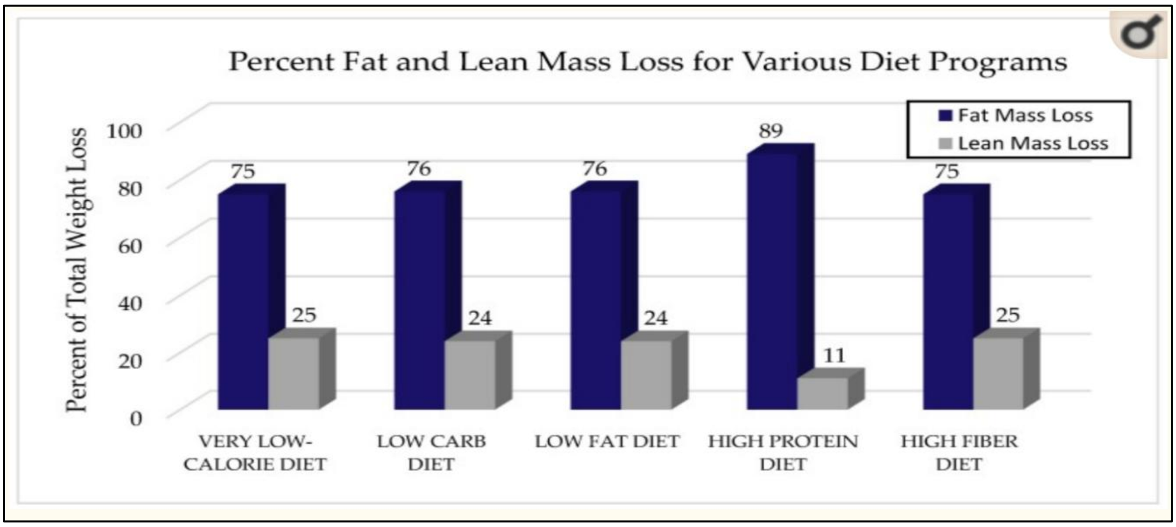


Figure 1-2 Changes in fat mass and fat free mass across different types of dietary weight loss interventions adapted from Willoughby et al. (2018)

The preservation and maintenance of muscle mass during weight loss is important due to muscle tissue's vital role in health and function (Wolfe, 2006). Skeletal muscle, comprising approximately 40% of total body mass in healthy adults, serves as more than just a mechanical apparatus for movement (Janssen et al., 2000). Skeletal muscle accounts for approximately 80% of insulin-stimulated glucose disposal, making it central to maintaining glucose homeostasis (Shulman, 2000, DeFronzo and Tripathy, 2009). For example, a cross-sectional analysis investigating whether higher muscle mass was associated with improved glucose found that for each 10% higher skeletal muscle index (SMI), there was an 11% lower HOMA-IR and a 12% lower prediabetes prevalence (Srikanthan and Karlamangla, 2011).

Importantly for weight loss and maintenance, the contribution of muscle tissue to resting energy expenditure is substantial and directly proportional to muscle mass. Several studies indicate that each kilogram of muscle tissue contributes approximately 13-15 kcal/day to resting metabolic rate (Wang et al., 2010) and muscle tissue accounts for 20-30% of total resting energy expenditure (Frampton et al., 2020). Losing muscle mass can reduce basal metabolic rate, making it more difficult to maintain weight loss over time (Stiegler and Cunliffe, 2006). On top of this, the preservation of muscle mass during weight loss can improve balance, mobility and overall quality of life (Villareal et al., 2017) and muscle strength shows strong associations with functional independence and mortality risk. For example, the Prospective Urban-Rural Epidemiology (PURE) study, involving over 140,000 participants across multiple countries, found that each 5kg decrease in grip strength increased all-cause mortality risk by 16% (Leong et al., 2015). Furthermore, a recent study investigating the associations between decreased handgrip strength and disabilities in each activity of daily living (ADL) showed that 5kg decrease in handgrip strength was associated with increased odds for the overall ADL limitations with an average 6%-20% (McGrath et al., 2018).

These findings highlight the need for weight loss strategies that can achieve the desired reduction in fat mass while preserving muscle mass and strength, to enhance its beneficial effects. The traditional focus on total weight loss may, therefore, need to shift toward an approach that considers more body composition changes and their long-term implications. This has led to increasing interest in specific intervention strategies, such as resistance exercise, that might help achieve more favourable body composition changes during weight loss while maintaining or enhancing the metabolic and functional benefits of muscle tissue.

The following section will, therefore, examine the effects of resistance exercise in people with overweight or obesity, and will briefly consider its potential to optimise body composition changes and enhance long term outcomes of weight loss.

1.6 Effects of resistance exercise on body composition, metabolic health and muscle function

Resistance exercise, defined as physical activity that involves voluntary muscle contractions against external resistance with the expectation to increase muscle strength/mass, physical function and/or endurance (Fleck and Kraemer, 2014), has become a key intervention for enhancing body composition, metabolic health and muscle function in people living with overweight or obesity (Strasser and Schobersberger, 2011). Resistance exercise can take many forms including weight training with machines or free weights, bodyweight exercises and resistance band exercises. The fundamental principle underlying resistance exercise is progressive overload, which gradually increases the stress placed on the body during training by modifying variables such as intensity (weight/resistance), volume (sets and repetitions), and frequency (training sessions per week) (American College of Sports, 2009). Unlike aerobic exercise, which focusses on cardiovascular endurance through continuous moderate-intensity activity, resistance exercise often consists of intermittent, higher-intensity efforts designed to stress specific muscle groups. In recent years, the effects of resistance exercise on body composition have been widely studied. A recent systematic review and meta-analysis of 56 randomised controlled trials, examining the effects of resistance exercise training in people living with overweight or obesity, demonstrated that resistance exercise significantly reduces body fat percentage by 1.6% and whole-body fat mass by 1.0 kg, compared to no exercise training controls (Lopez et al., 2022). Along with these improvements in body composition, resistance exercise was also found to be the most effective for increasing lean mass with a 0.8 kg gain compared to no exercise training controls (Lopez et al., 2022).

The benefits of resistance exercise in improving muscle function and strength outcomes is also well documented, with even minimal dose strategies (Nuzzo et al., 2024). A systematic review and meta-analysis examining 30 randomised controlled trials (n=1,416) in people living with overweight or obesity, reported that resistance exercise improved muscle strength (SMD 1.39, 95% CI 1.05 to 1.73), as well as physical function (SMD 0.67, 95% CI 0.25 to 1.08) compared to no exercise training control groups (Orange et al., 2020). A recent study examining the impact of resistance exercise on muscle strength and function in older women living with obesity or overweight reported that hand grip strength increased by 1.70 kg ($p < 0.01$), and lower body strength, assessed using the 30 second chair stand test, increased by 3.87 repetitions ($p < 0.001$), as well as increases in knee flexor peak torque muscle strength by 3.87 Nm ($p < 0.05$) (Kim et al., 2022). These findings are supported by a meta-analysis examining the impact of resistance exercise training on older adults, which reported significant effects of resistance exercise on handgrip strength (SMD = 0.83[0.43,1.23]) and knee extension strength (SMD = 0.90[0.50,1.30]) (Sun et al., 2024).

On top of these benefits to body composition and muscle strength, resistance exercise has been considered a fundamental tool for improving metabolic health in people living with overweight or obesity. Resistance exercise training has been shown to result in significant improvements in insulin sensitivity, and a recent meta-analysis examining 54 randomised controlled trials conducted without dietary intervention has shown that it reduced HOMA-IR (SMD = −0.34 [−0.49, −0.18], $p < 0.0001$) (Battista et al., 2021). In this same meta-analysis, resistance exercise also has been found to reduce systolic and diastolic blood pressure (MD = −2.95 mmHg [95% CI −4.22, −1.68], $p < 0.00001$, $I^2 = 63\%$ and MD = −1.93 mmHg [95% CI −2.73, −1.13], $p < 0.00001$, $I^2 = 54\%$,) (Battista et al., 2021). Lipid profiles are also improved by resistance exercise independently of dietary intervention, for example, a research study found that resistance exercise led to a 9% reduction in total cholesterol and a 14% reduction in LDL cholesterol (Prabhakaran et al., 1999). Further research comparing different forms of exercise without dietary intervention concluded that resistance exercise resulted in greater increases in HDL cholesterol levels 1.44 ± 0.08 mmol/L than aerobic exercise 1.28 ± 0.07 mmol/L (Ho et al., 2012). Beyond immediate metabolic improvements, resistance exercise provides wide-ranging health benefits for people living with overweight or obesity. Analysis of data from 11 population cohorts involving approximately 750,000 participants over a 10-year follow-up period examined the associations between strength-promoting exercise (gym based and own body weight strength activities) and all cause, cancer, and cardiovascular disease mortality and found that participating in any strength promoting exercise (meeting the guidelines of twice per week) was linked to a 31% decrease in cancer mortality and a 23% decrease in all cause mortality, although clearly such work cannot determine causality in these relationships (Stamatakis et al., 2018).

The mechanisms that link resistance training to better metabolic health are complex. For example, resistance exercise can improve glucose uptake via insulin-dependent and insulin-independent mechanisms. Muscle contraction stimulates GLUT4 glucose transporter translocation to the cell membrane, increasing glucose uptake, independently of insulin (Holten et al., 2004). Chronic resistance training increases GLUT4 protein expression, insulin receptor substrate (IRS) content, and improves insulin signalling pathway and thus insulin sensitivity (Ibañez et al., 2005). Furthermore, resistance exercise increases muscle mass, providing a greater reservoir for glucose disposal, and changes muscle fibre type to more insulin-sensitive phenotypes (Croymans et al., 2013). For blood pressure, resistance exercise enhances endothelial function by increasing nitric oxide synthesis, lowers arterial stiffness, and adjusts the autonomic nervous system towards greater parasympathetic tone (Cornelissen and Smart, 2013). The positive effects of resistance exercise on lipid profiles appear to be mediated by increased lipoprotein lipase activity, enhanced fatty acid oxidation, and lower inflammatory markers such as C-reactive protein, which collectively improve cholesterol transport and metabolism (Mann et al., 2014).

The role of resistance exercise during weight loss has recently received more attention, although the available research is limited. A systematic review and meta-analysis examined the combined effects of resistance exercise and caloric restriction in people living with overweight or obesity and demonstrated that the combination resulted in greater reductions in body fat percentage by 3.8% and whole-body fat mass by 5.3 kg, whereas importantly lean mass was maintained

(Lopez et al., 2022). However, the quality and heterogeneity of this evidence present several limitations such as the high risk of bias and different methods of body composition assessment. As well as fat mass and fat free mass improvements, there is also evidence that during weight loss, resistance exercise can increase muscle strength. Some research studies have shown that resistance exercise during weight loss resulted in a greater strength an average mean of 30-60 N, than weight loss only (Avila et al., 2010, Hunter et al., 2015), but this has not been explored in a systematic review and meta-analysis.

Despite the potential benefits, rates of participation in resistance exercise remain low. In a study of approximately 400,000 U.S adults (aged 18–80 years), only 30% met guidelines for muscle strengthening activities (two or more times/week), with rates even lower (22%) among people living with obesity (Bennie et al., 2018). Another population-level data analysis indicated that in the UK and Europe very few people perform resistance exercise, with only ~25% of adults meeting the guidelines to perform muscle strengthening exercises twice per week (Strain et al., 2016, Bennie et al., 2020). This is likely to be even lower in people undergoing weight loss, where it may have particular benefit. Indeed, it has been shown that people with higher BMI (>25 kg/m^2) are less likely to participate in resistance exercise which indicates some barriers to exercise (Rhodes et al., 2017).

Several research studies have reported multiple barriers that contribute to this low level of participation in resistance exercise. For example, recent systematic reviews have reported that barriers for older adults include safety, fear, fatigue, health concerns, pain, and lack of social support (Burton et al., 2017, Cavill and

Foster, 2018). Further research in college women have found that barriers to participation in resistance exercise included perceived lack of time, not feeling comfortable in the gym, as well as lack of knowledge regarding the use of free weights and other forms of resistance exercise (Hurley et al., 2018, Peters et al., 2019). More recent research, assessing barriers to exercise and gym preferences in approximately 400 adults living with overweight or obesity, found that 68% of adults with obesity reported difficulty accessing gym facilities and discomfort in public exercise settings (Schvey et al., 2017). It has also been recently demonstrated that the COVID-19 pandemic has further emphasised the need for accessible, home-based exercise options (Kaur et al., 2020, Nyenhuis et al., 2020). Thus far, the majority studies of resistance exercise interventions in people living with overweight or obesity have been primarily in supervised settings using traditional weight training machines or free weights, which can thus limit accessibility and thus scaling up.

One potential strategy to increase accessibility and overcome many barriers to participation is to develop interventions based on simple resistance exercises with minimal equipment that can be carried out at home. Home-based exercise interventions provide several benefits that may help overcome barriers to traditional gym-based resistance exercise. Some research studies reported advantages, and have identified that home-based approaches can be effective in reduced time and cost barriers associated with gym memberships and equipment, and enhanced convenience, privacy for individuals uncomfortable exercising in public and greater flexibility (Scott et al., 2019, Morgan et al., 2016). Furthermore, home-based programmes may promote increased autonomy and self-efficacy, which are essential psychological variables for long-term adherence

(Ricke et al., 2023). However, these interventions also have some challenges, including, limited equipment variety affecting exercise progression, potential safety concerns without direct supervision, difficulties in maintaining motivation without social interaction, and potential space constraints in the home environment as well as struggling with proper technique without immediate feedback, potentially reducing effectiveness or increasing injury risk (Argent et al., 2018, Olson et al., 2023).

The effectiveness of home-based resistance exercise on body weight/composition outcomes and markers of cardiometabolic health alongside increases in muscle strength, physical functioning and functional mobility has been shown, with studies primarily in older adults. For example, a recent systematic review and meta-analysis of 17 randomised controlled trials with approximately 1,500 healthy older adults, found that home based exercise programmes resulted in improvements in muscle strength (SMD = 0.30, 95% CI 0.12-0.48, $p < 0.01$) (Chaabene et al., 2021). A recent randomised controlled trial of 120 people with diabetes (BMI 31.1 (5.4) kg/m^2) evaluating the effects of pragmatic home based resistance exercise training, showed that home-based resistance exercise resulted in increases in arm lean mass (116 g, 95% CI: 6, 227) and leg lean mass (438 g, 95% CI 65, 810) and number of press ups, although other markers of physical function and strength were not improved (Al Ozairi et al., 2023). Moreover, a randomised controlled trial with a total of 48 adults with obesity and type 2 diabetes found that the home based resistance exercise resulted in increases in overall body strength (measured by a seated chest press and seated row for upper body strength and a leg press for lower body strength) with an average mean increase of 20–37% compared to controls (Plotnikoff et al., 2010). Focussing on body composition, a recent systematic review and meta-analysis of 18 randomised controlled trials with a total of 669 participants compared the effects of different resistance exercise types including bodyweight, resistance band and free weight exercises found that resistance band exercises were most effective for reducing body fat percentage with a reduction of SMD -0.79 (95% CI: -1.25 to -0.33), and bodyweight exercises were most effective for increasing skeletal muscle mass in people living with overweight or obesity with an increase of SMD 0.48 (95% CI: 0.04-0.92) (Liu et al., 2022). However, the impact of home-based resistance exercise specifically during weight loss in people living with overweight or obesity remains limited and has not yet been explored.

The evidence presented demonstrates both the potential value and current limitations of home-based resistance exercise interventions. While traditional resistance exercise shows clear benefits for body composition, metabolic health, and muscle function, the significant barriers to participation, particularly among people living with overweight or obesity, highlight the need for more accessible approaches. Home-based resistance exercise appears promising as a solution to overcome these barriers, offering improved accessibility and potentially better adherence. However, the current evidence base, particularly regarding its efficacy and implementation during weight loss, remains incomplete, making this an important area for investigation. a crucial research priority.

1.7 Rationale

Developing and evaluating effective weight loss interventions for people living with overweight or obesity is a key public health priority (Department of Health and Social Care, 2020). Although dietary interventions result in significant weight loss (Ge et al., 2020), losing lean muscle at the same time is a significant problem (Cava et al., 2017) and attenuating this loss may enhance the benefits of weight loss. Resistance training exercise is the most effective way to improve muscle mass and strength, improving metabolic health and enhancing functional capacity (Westcott, 2012). Recent meta-analyses have demonstrated that resistance exercise significantly improves multiple health parameters in people living with obesity: increasing fat free mass by 0.8 kg (Lopez et al., 2022), enhancing muscle strength (SMD 1.39, 95% CI 1.05 to 1.73), improving physical function (SMD 0.67, 95% CI 0.25 to 1.08) (Orange et al., 2020), and provides significant metabolic benefits including reduced insulin resistance (SMD = −0.34) and improved blood pressure (Battista et al., 2021). These comprehensive benefits make resistance exercise a particularly valuable intervention tool for weight loss interventions

The current thesis addresses these research gaps through three related studies aimed at improving the understanding of the potential of resistance exercise during weight loss and developing more accessible interventions. The first study, a systematic review and meta-analysis, establishes the current state of the data by examining the effects of resistance exercise on body composition, muscle strength and cardiometabolic health during dietary weight loss. This systematic evidence synthesis provided a strong foundation for understanding the potential benefits and limitations of resistance exercise.

Building on this evidence synthesis, the second study uses qualitative methods to explore the experiences and perceptions of resistance training in people living with overweight or obesity who are trying to lose weight. The qualitative data were used to develop a theory of change for guiding intervention development. The theory of change provides a systematic way of mapping how an intervention leads to desired outcomes (Funnell and Rogers, 2011). Despite evidence suggesting that only approximately 25% of adults meet guidelines for muscle strengthening exercises (Strain et al., 2016, Bennie et al., 2020), there is limited understanding of the barriers and facilitators to resistance exercise participation in the population of interest of the current thesis. Conducting a qualitative investigation was therefore essential for understanding participants' experiences, motivations and barriers to undertaking home-based resistance exercises, to develop a theory of change that would inform the development of an acceptable, accessible and effective resistance exercise intervention.

The final study, a randomised controlled pilot trial of a home-based resistance training exercise programme during weight loss, an intervention with minimal equipment requirements, was designed to address implementation challenges and barriers identified in previous research, including gym access, time constraints, and discomfort in public exercise settings (Cavill and Foster, 2018).

Overall, this work addresses several key gaps in the current literature. While previous research has shown that resistance training is beneficial, there has been limited investigation of how to effectively implement such interventions in real-world settings, particularly for people living with overweight or obesity during weight loss. The development of accessible, home-based resistance exercise programmes is a potential approach to overcoming known barriers to participation while maintaining the potential benefits of resistance exercise.

1.8 Aims and hypotheses

The overall goal of this thesis is to investigate the potential impact of resistance exercise during weight loss in people living with overweight or obesity on associated health outcomes, particularly focusing on its ability to preserve muscle mass and strength. The specific aims and hypotheses of this research are as follows:

- Chapter 2: Effect of resistance exercise on body composition, muscle strength and cardiometabolic health during dietary weight loss in people living with overweight or obesity: A systematic review and meta-analysis

  Aim: To examine the effect of resistance exercise on body composition, muscle strength and cardiometabolic health in people living with overweight or obesity undergoing dietary weight loss interventions.

  Hypotheses:

  1. Resistance exercise during dietary weight loss will attenuate the loss of fat free mass compared to diet alone.
  2. Resistance exercise during dietary weight loss will result in greater improvements in muscle strength compared to diet alone.
  3. The addition of resistance exercise during dietary weight loss will enhance cardiometabolic health outcomes.

- Chapter 3: A qualitative study of the experiences and perceptions of resistance training in people living with overweight or obesity who are trying to lose weight

  Aim: To explore the experiences and perceptions of doing resistance exercise in people living with overweight or obesity and are trying to lose weight.

  Hypotheses:

  1. Participants will identify multiple barriers to traditional resistance exercise.
  2. Home-based options will be identified as an alternative way of resistance exercise to overcome several of these barriers.

- Chapter 4: The effects of a home-based resistance training programme on body composition and muscle function during weight loss in people living with overweight or obesity: A randomised controlled pilot trial

  Aim: To examine the effects of a home-based resistance exercise programmes on body composition and muscle function during weight loss in people living with overweight or obesity.

  Hypotheses:

  1. Home-based resistance exercise will preserve fat free mass during dietary weight loss.
  2. The intervention will improve muscle strength and physical function during dietary weight loss.

Chapter 2 Effect of resistance exercise on body composition, muscle strength and cardiometabolic health during dietary weight loss in people living with overweight or obesity: A systematic review and meta-analysis

2.1 Abstract

2.1.1 Background

The prevalence of obesity has tripled in over the past 35 years. Although caloric restriction reduces body fat, lean tissue is also lost. Resistance exercise may mitigate these effects. This review aims to assess the effects of resistance exercise on body composition, muscle strength and cardiometabolic health in adults living with overweight or obesity undergoing dietary weight loss.

2.1.2 Methods

A search was performed in PubMed, Embase, CINAHL, Scopus, Web of Science, and CENTRAL. Systematic searches yielded n=6,934 studies of which n=25 were included after screening for eligibility. Randomised controlled trials of adults (18-65 years, BMI≥25 kg/m^2) comparing dietary weight loss interventions including resistance exercise to either diet-only weight loss interventions or dietary weight loss intervention combined with other forms of exercise were included. The Cochrane Collaboration's risk of bias and Grades of Recommendation, Assessment, Development and Evaluation (GRADE) assessment tools used. Meta-analysis was performed including only studies that compared dietary weight loss plus resistance exercise interventions to diet-only weight loss interventions.

2.1.3 Results

Overall, resistance exercise during diet-induced weight-loss had no effect on body mass (mean between-group difference: -0.32kg, p=0.35) but did preserve fat free mass (between-group standardised mean difference (SMD): 0.40, p<0.001) and increase loss of fat mass (SMD: -0.36, p<0.001). Muscular strength was also significantly improved (SMD: 2.36, p<0.001) by the inclusion of resistance exercise.

No effects of resistance exercise were seen in any of the other cardiometabolic markers studied, including cardiorespiratory fitness, lipid profiles, blood pressure and glycaemic control.

2.1.4 Conclusions

In people living with obesity and overweight, the addition of resistance exercise to dietary restriction may enhance its beneficial effects on body composition changes and functional outcomes. Current evidence, therefore, supports the implementation of resistance exercise during weight loss to attenuate the loss of fat free mass, increase fat mass loss and improve muscle strength.

2.2 Introduction

Obesity is a major public health problem with serious consequences for morbidity, mortality, and health-care costs (Upadhyay et al., 2018). Obesity increases the risk of type 2 diabetes, hypertension, coronary heart disease, dyslipidaemia and certain cancers (An et al., 2018). Whilst the global prevalence continues to rise, the burden of obesity is greatest in adults aged 45 to 59 and in women (James et al., 2001, Siervo et al., 2014). Dietary interventions are a mainstay for the treatment of obesity and a recent systematic review and meta-analysis has shown they result in significant weight loss (around 4-5 kg), that is, at least partially, sustained up to 12 months (Ge et al., 2020). This level of weight loss is associated with improvements in cardiovascular risk factors such as blood pressure, low density lipoprotein (LDL) and high-density lipoprotein (HDL) cholesterol and glycaemic control (Ge et al., 2020). Greater weight loss (~10kg) has been shown to result in full remission of type 2 diabetes in almost half of participants (Lean et al., 2018).

One of the less desirable consequences of dietary interventions is that ~20-30% of weight lost is fat free mass, which includes the loss of muscle tissue (Enriquez Guerrero et al., 2021, Pellegrini et al., 2020, Cava et al., 2017). This is a concern as skeletal muscle has both functional and metabolic roles (McCarthy and Berg, 2021, Wolfe, 2006), and low muscle mass/strength is a contributing factor to cardiometabolic and other obesity-related diseases (Sajoux et al., 2019) and is associated with higher mortality and morbidity (Cava et al., 2017). Incorporating strategies to maintain fat free/muscle mass and muscle strength may improve the beneficial effects of dietary weight loss interventions.

Resistance exercise is the most effective method to maintain or increase muscle mass and strength (Westcott, 2012). It has also been shown to improve blood lipids, reduce blood pressure and glycemic control, increase cardiorespiratory fitness (Ashton et al., 2020, Cornelissen et al., 2011), and improve muscle strength, power, and endurance (Peterson et al., 2010). However, there is no consensus about whether resistance exercise can reduce fat free mass and muscle strength loss during dietary weight loss. The aim of the current systematic review was to examine the impact of resistance exercise on body weight/composition, including fat free mass loss, muscle strength and markers of cardiometabolic health, in people living with overweight or obesity undergoing dietary weight loss interventions.

2.3 Methods

A systematic review and meta-analysis of randomized controlled trials was conducted and reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2021 updated guidelines (Page et al., 2021) (see Appendix 2-A PRISMA checklist). The study was registered with PROSPERO (registration ID: CRD 42021266482).

Review questions

The review was designed to address the following questions with the Population, Intervention, Comparison, Outcomes, and Study Design (PICOS) detailed in Table 2-1.

1. Does the addition of resistance exercise to a dietary weight loss intervention impact changes in body weight/composition or markers of

cardiometabolic health in people living with overweight or obesity compared to dietary weight loss interventions?

2. Does the addition of resistance exercise to a dietary weight loss intervention impact changes in physical function and strength in people living with overweight or obesity compered to dietary weight loss interventions?

Table 2-1 PICOS

Review Questions	Inclusion criteria	Exclusion criteria
Population (P)	Adults (18-65 years of age) who are overweight/obese, overweight (BMI 25 to 29.9 kg/m^2) or obese (BMI ≥ or = 30). For the age criteria the mean age of the study sample ± 1SD for inclusion was used.	Anyone <18 years or >65 years with obesity, overweight; any population without, obesity or overweight
Intervention (I)	Dietary weight loss intervention (with no minimum caloric deficit required), including caloric restriction, meal replacements and VLCDs + all resistance exercise interventions (free weights, machines, resistance bands, body weight, gym, lab or home-based, mhealth/digitally delivered interventions)	No weight loss intervention
Comparator (C)	Dietary weight loss intervention + Any comparator including no intervention or non-resistance exercise interventions	Resistance exercise in all comparator arms
Outcomes (O)	Empirical evidence of measured changes in cardiometabolic health, body weight/composition and muscle strength due to any resistance exercises	Other outcomes
Study design (S)	Experimental studies: RCTs,	Systematic reviews and meta-analyses, quasi-experimental designs, Observational studies: Cross-sectional study; Single-case studies, case control studies, discussion articles, Non-randomised studies, documents for reviews, cohort studies,
Other	Published peer-reviewed articles in scientific journals, in an English language, human subjects	-

2.3.1 Search strategy and study selection

Systematic searches were conducted in the following databases: PubMed, Embase, CINAHL, Scopus, Web of Science and the Cochrane Central Register of Controlled Trials (CENTRAL). First, keyword and categorical searches were performed for (i) obesity or overweight, (ii) weight loss, (iii) resistance exercise or resistance training, (iv) body weight or body composition or metabolic syndrome or muscle function (see Appendix 2-B Keywords and search terms). The categories were then combined using 'and'. The search was restricted to humans and papers published in English, with no restriction on the publication period. Search dates were from July 2021 to September 2021 and searches were re-run before the final analysis from November 2022 to January 2023. A screening process was carried out by two independent reviewers (AB and AD) using Rayyan software (Ouzzani et al., 2016), with a third reviewer (SG) consulted to reach agreement when required.

2.3.2 Data extraction and risk of bias assessment

Data were independently extracted by AB and AD into a pre-designed data extraction form (see Appendix 2-C). Extracted information included bibliometric data (study title, funding), study characteristics (sample size, identified limitations of the study), participants (age, sex, BMI), intervention characteristics (type of exercise, frequency, intensity, dietary weight loss strategy), control characteristics (dietary weight loss strategy) and outcomes (body weight/composition - body mass, fat mass, fat free mass and muscle mass; cardiometabolic health - cardiorespiratory fitness, lipid profile, blood pressure and glycaemic control; and muscle strength and function). Where required, corresponding authors were contacted to request additional data.

Risk of bias was assessed by AB and AD using the Cochrane risk of bias tool (Cochrane Collaboration Glossary, 2010, Higgins JPT, 2011, Schünemann H, 2009, John, 2001). Each study was classified as high, low or unclear risk of bias based on the following five bias domains: (selection, performance, detection, attrition, and reporting). The results were entered into Review Manager (RevMan) software 5.4 (Cochrane Collaboration, 2014). Any disagreement during the review process was resolved through discussion.

In addition, the Grades of Recommendation, Assessment, Development and Evaluation (GRADE) assessment (with GRADE PRO software (https://gdt.gradepro.org)) was utilised to assess the quality of evidence for outcomes reported (Schünemann H, 2009, Guyatt et al., 2008). Because all included studies were RCTs, their GRADE scores started high, but were downgraded due to limitations regarding risk of bias, inconsistency, indirectness, imprecision or publication bias (Higgins JPT, 2011, Schünemann H, 2009).

2.3.3 Data synthesis

Given the potential benefits of resistance exercise in improving body composition, cardiometabolic health, and physical function in people living with overweight or obesity, this study aimed to specifically investigate the impact of adding resistance exercise to dietary weight loss interventions on body weight/composition (body mass, fat mass, fat free mass and muscle mass), muscle strength and function, and cardiometabolic health (cardiorespiratory fitness, lipid profile, blood pressure and glycaemic control). Therefore, it was decided to include only studies that compared resistance exercise plus dietary weight loss interventions to dietary weight loss only interventions in the meta-analysis, to allow for a more focused analysis of the effects of resistance exercise on these outcomes (American College of Sports, 2013).

For this review, eligible dietary interventions were those specifically designed for weight loss, including caloric restriction (with no minimum energy deficit required), meal replacements, and very low calorie diets (VLCDs). Resistance exercise interventions involving free weights, machines, resistance bands, body weight, gym, lab or home-based, mhealth/digitally delivered interventions were included. This allowed us to examine the specific effects of resistance exercise training during dietary weight loss interventions.

Meta-analyses were conducted in order to compare the effectiveness of intervention (resistance exercise plus diet and diet only) groups on these outcomes in Review Manager version 5.4 (Cochrane Collaboration, 2014). Sub-group analyses stratifying studies by the duration of interventions (short duration (≤ 5 months) or long duration (≥ 6 months)), and by BMI status (overweight vs obesity) were carried out for the primary body composition variables only, due to insufficient number of studies for other variables. Based on a random-effects analysis, the standardised mean difference (SMD) was calculated for fat mass, fat free mass, muscle strength and insulin sensitivity and mean difference (MD) for body mass and cardiometabolic health outcome measures between intervention groups. Mean changes (final − baseline) were utilised as well as standard deviations SDs. A request for data was made to the corresponding author where these were not available. Missing SDs were calculated and median to mean conversions conducted using established methods (Higgins JPT, 2008).

2.4 Results

As shown in Figure 2-1, the initial search yielded 6,934 unique results. After title, abstract and full text screening, 25 RCT studies met the inclusion criteria and were included in meta-analysis.

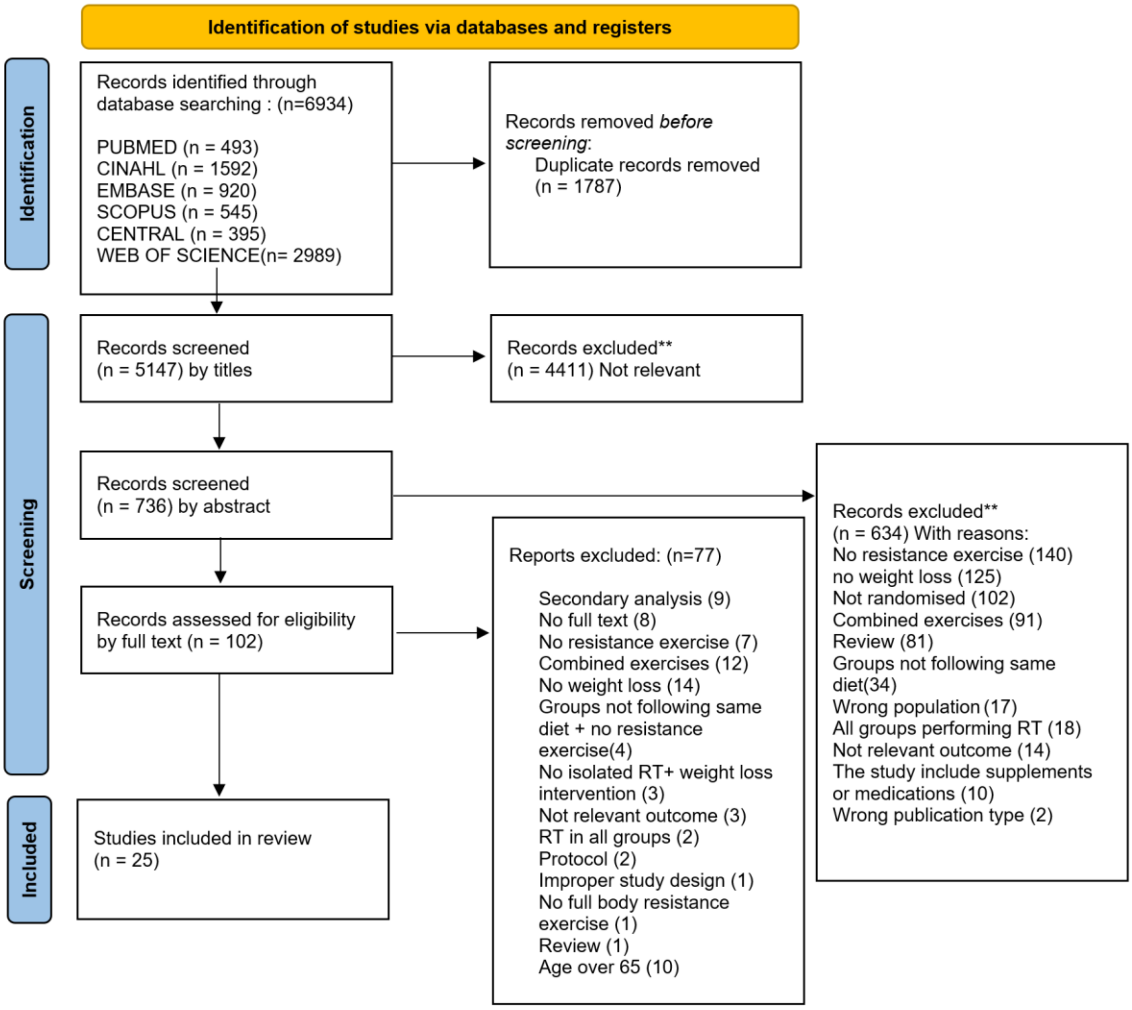


Figure 2-1 PRISMA flow diagram for study selection

2.4.1 Study characteristics

The characteristics of the 25 eligible studies are summarised in Appendix 2-D. They included 1,608 participants (Andersen et al., 1997, Avila et al., 2010, Ballor et al., 1988, Beavers et al., 2017, Benito et al., 2020b, Borges et al., 2019, Brochu et al., 2009, Bryner et al., 1999, Donnelly et al., 1991, Donnelly et al., 1993, Dunstan et al., 2002, Figueroa et al., 2013, Fisher et al., 2012, Geliebter et al., 2014, Herring et al., 2014, Hunter et al., 2015, Ibanez et al., 2010, Janssen et al., 2002, Joseph et al., 2001, Marks et al., 1995, Morencos et al., 2012, Nakata et al., 2008, Rojo-Tirado et al., 2021, Said et al., 2018, Sénéchal et al., 2012). Two studies included people with obesity and type 2 diabetes (Dunstan et al., 2002), CVD and/or metabolic syndrome (Beavers et al., 2017). One study included only student males (Said et al., 2018), 15 studies had only females (with 9/15 focusing on the pre- or post- menopausal period) (Andersen et al., 1997, Ballor et al., 1988, Borges et al., 2019, Brochu et al., 2009, Donnelly et al., 1991, Donnelly et al., 1993, Figueroa et al., 2013, Fisher et al., 2012, Hunter et al., 2015, Ibanez et al., 2010, Janssen et al., 2002, Joseph et al., 2001, Marks et al., 1995, Nakata et al., 2008, Sénéchal et al., 2012) and the remainder included both sexes (Avila et al., 2010, Beavers et al., 2017, Benito et al., 2020b, Bryner et al., 1999, Dunstan et al., 2002, Geliebter et al., 2014, Herring et al., 2014, Morencos et al., 2012, Rojo-Tirado et al., 2021). Eight studies had two experimental groups testing diet and resistance exercise against diet alone (Andersen et al., 1997, Avila et al., 2010, Brochu et al., 2009, Bryner et al., 1999, Donnelly et al., 1993, Dunstan et al., 2002, Joseph et al., 2001, Nakata et al., 2008). Ten studies had three experimental groups, eight of which tested diet and resistance exercise against diet and aerobic exercise or against diet alone (Beavers et al., 2017, Borges et al., 2019, Fisher et al., 2012, Geliebter et al., 2014, Herring et al., 2014, Hunter et al., 2015, Janssen et al., 2002, Said et al., 2018), and the remaining two limited comparison to diet and resistance exercise against diet alone or against a control group (Figueroa et al., 2013, Ibanez et al., 2010). Across the remaining seven studies, four to five experimental groups were included: resistance exercise + weight loss diet, aerobic exercise + weight loss diet, resistance plus aerobic exercise + weight loss diet, weight loss diet alone, or control (Ballor et al., 1988, Benito et al., 2020b, Donnelly et al., 1991, Marks et al., 1995, Morencos et al., 2012, Rojo-Tirado et al., 2021, Sénéchal et al., 2012). Eighteen studies were of interventions that were delivered for a shorter time period (2 months – 5 months) (Avila et al., 2010, Ballor et al., 1988, Benito et al., 2020b, Borges et al., 2019, Bryner et al., 1999, Donnelly et al., 1991, Donnelly et al., 1993, Figueroa et al., 2013, Geliebter et al., 2014, Herring et al., 2014, Hunter et al., 2015, Ibanez et al., 2010, Janssen et al., 2002, Joseph et al., 2001, Marks et al., 1995, Nakata et al., 2008, Said et al., 2018, Sénéchal et al., 2012). In seven studies, the interventions lasted for at least 6 months (6 months – 18 months), with some provided follow up to 3 years (Andersen et al., 1997, Beavers et al., 2017, Brochu et al., 2009, Dunstan et al., 2002, Fisher et al., 2012, Morencos et al., 2012, Rojo-Tirado et al., 2021). The majority of participants in thirteen of the included studies were living with obesity (Andersen et al., 1997, Ballor et al., 1988, Beavers et al., 2017, Bryner et al., 1999, Donnelly et al., 1991, Donnelly et al., 1993, Dunstan et al., 2002, Figueroa et al., 2013, Herring et al., 2014, Ibanez et al., 2010, Janssen et al., 2002, Said et al., 2018, Sénéchal et al., 2012), while six studies included those living with overweight (Benito et al., 2020b, Borges et al., 2019, Fisher et al., 2012, Hunter et al., 2015, Morencos et al., 2012, Nakata et al.

al., 2008) and six studies included people living with overweight and obesity (Avila et al., 2010, Brochu et al., 2009, Geliebter et al., 2014, Joseph et al., 2001, Marks et al., 1995, Rojo-Tirado et al., 2021)

2.4.1.1 Resistance exercise intervention characteristics

Most included (n=23) studies employed supervised resistance exercise sessions using traditional weight training machines or free weights (Andersen et al., 1997, Avila et al., 2010, Ballor et al., 1988, Beavers et al., 2017, Benito et al., 2020b, Borges et al., 2019, Brochu et al., 2009, Bryner et al., 1999, Donnelly et al., 1991, Donnelly et al., 1993, Dunstan et al., 2002, Figueroa et al., 2013, Fisher et al., 2012, Geliebter et al., 2014, Herring et al., 2014, Hunter et al., 2015, Ibanez et al., 2010, Janssen et al., 2002, Morencos et al., 2012, Nakata et al., 2008, Rojo-Tirado et al., 2021, Said et al., 2018, Sénéchal et al., 2012). Resistance exercise was most often performed three times per week, with some studies using two (Ibanez et al., 2010) or four (Donnelly et al., 1991, Beavers et al., 2017) sessions weekly. Sessions duration lasted between 30 and 60 minutes on average, involving 8-10 exercises targeting major muscle groups and including leg extension, leg press, chest press, shoulder press, lateral pull-down, and arm exercises.

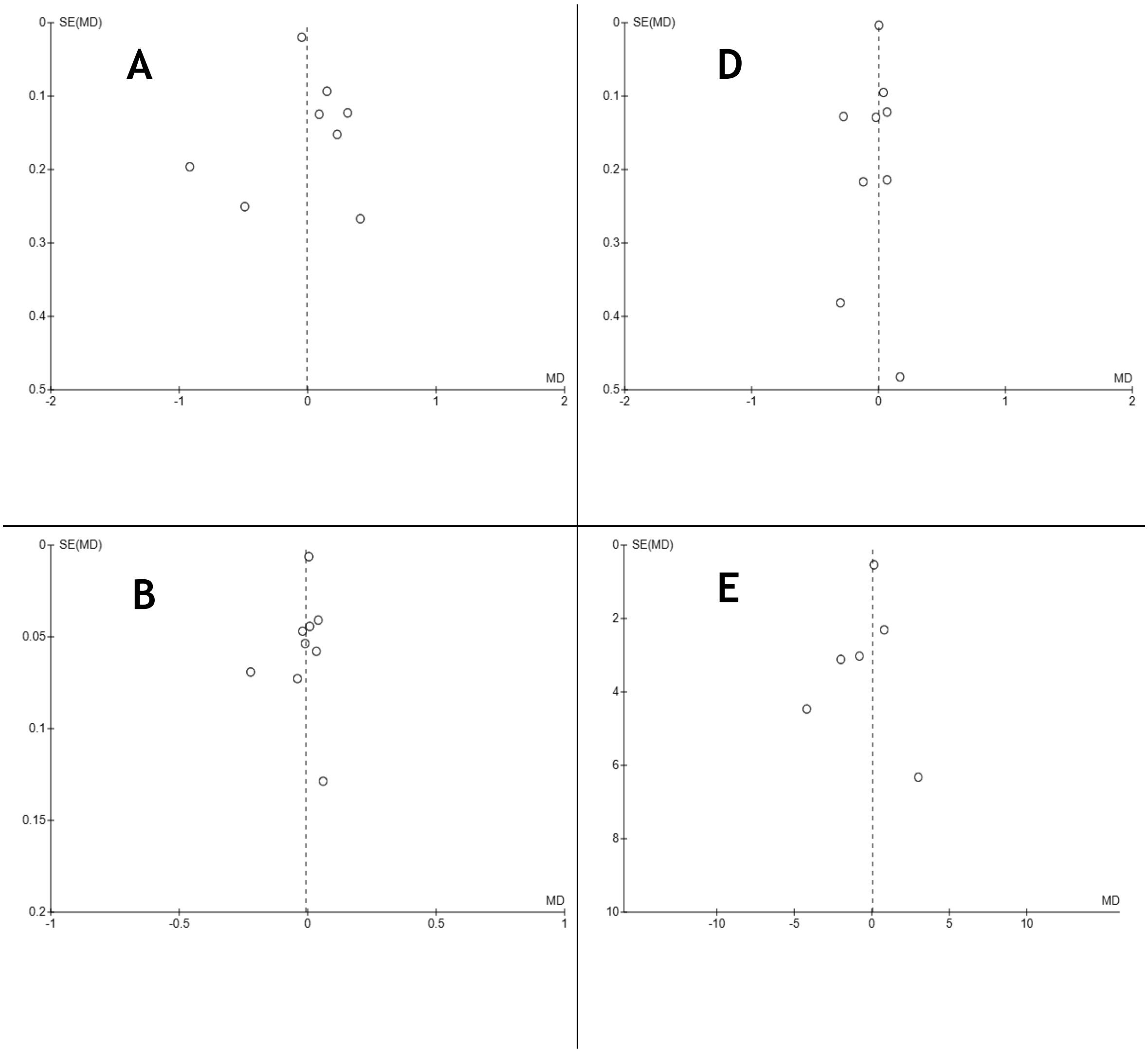
2.4.1.2 Dietary weight loss intervention characteristics

Included studies employed various dietary weight loss approaches, with caloric restriction being the common element. Most studies (n=15) utilised a moderate caloric restriction of 500-1200 kcal/day below estimated requirements (Avila et al., 2010, Ballor et al., 1988, Benito et al., 2020b, Brochu et al., 2009, Dunstan et al., 2002, Figueroa et al., 2013, Herring et al., 2014, Ibanez et al., 2010, Janssen et al., 2002, Joseph et al., 2001, Morencos et al., 2012, Nakata et al., 2008, Rojo-

Tirado et al., 2021, Said et al., 2018, Sénéchal et al., 2012), while others (n=10) implemented very low calorie diets (Andersen et al., 1997, Beavers et al., 2017, Borges et al., 2019, Bryner et al., 1999, Donnelly et al., 1991, Donnelly et al., 1993, Fisher et al., 2012, Geliebter et al., 2014, Hunter et al., 2015, Marks et al., 1995). Macronutrient distribution generally followed standard guidelines, with most diets providing 50-60% of calories from carbohydrates, 20-30% from fat, and 15-25% from protein. Several studies (n=8) used liquid meal replacements, either exclusively or partially, particularly those implementing very low calorie interventions (Andersen et al., 1997, Bryner et al., 1999, Donnelly et al., 1991, Donnelly et al., 1993, Fisher et al., 2012, Geliebter et al., 2014, Hunter et al., 2015, Nakata et al., 2008).

2.4.2 Study quality and risk of bias

As shown in Appendix 2-E, all studies had low risk of selection bias, as they provided information on the method of random sequence generation. Allocation concealment was reported in only one study, with a low risk of bias for this domain (Herring et al., 2014). All studies were at high risk of performance bias, due to the inability to blind investigators/participants to exercise participation. One study had low detection bias, meaning that there was a possibility of bias in the assessment of the outcomes (Dunstan et al., 2002). In all other studies, the risk of bias in blinding of outcome assessment was unclear. Most longer duration interventions studies had a high risk of attrition bias, with high dropout rates (>25%), not stating how they handled missing data from these dropouts and lacking of intention-to-treat analysis (Beavers et al., 2017, Brochu et al., 2009, Fisher et al., 2012, Morencos et al., 2012, Rojo-Tirado et al., 2021). All studies had a low risk of reporting and other bias. Since many of the included studies (n=24) did not report concealment of allocations or blinding of assessment of outcomes, there is a lack of clarity regarding their potential bias. For the GRADE quality of evidence, the overall certainty of the evidence for each outcome shown in Appendix 2-F was moderate. The main reasons for downgrading evidence quality were inconsistency because of heterogeneity and imprecision because of the small number of trials evaluating resistance exercise during weight loss. There was no clear evidence of publication bias, except for blood lipids and blood pressure, with funnel plots demonstrating an asymmetric distribution (Figure 2-2).



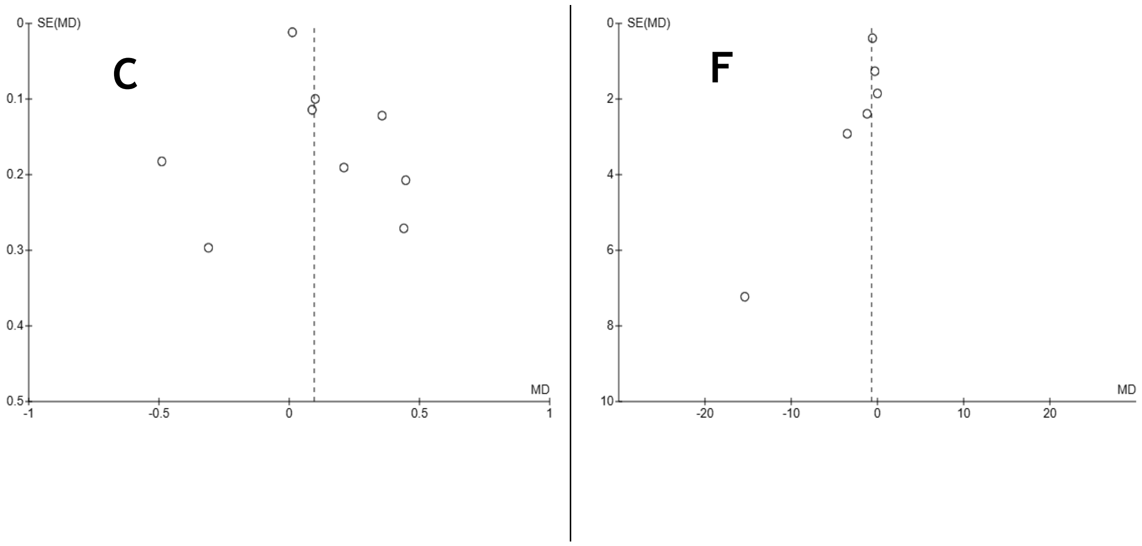
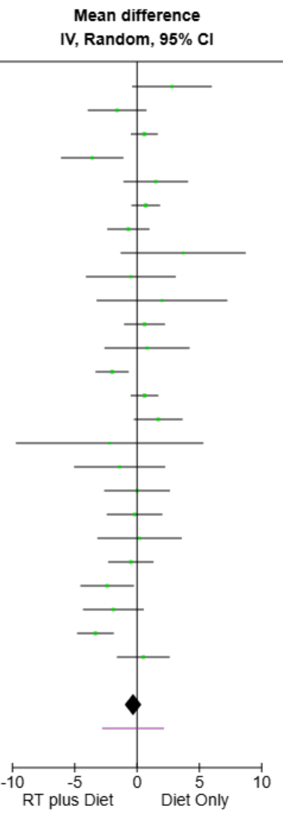


Figure 2-2 Funnel plots for: A) Total cholesterol; B) HDL cholesterol; C) LDL cholesterol; D) Triglycerides; E) Systolic; F) Diastolic.

2.4.3 Effect of resistance exercise interventions on body weight/composition

Twenty-five studies reported changes in body mass. As shown in Figure 2-3, the meta-analysis revealed no significant differences in change in body mass between diet plus resistance exercise and diet only (mean difference: -0.32kg, 95% confidence interval [CI] -1.00kg to 0.35kg; p=0.35, I^2= 60%). Similar findings were found for both short (≤ 5 months) (mean difference: -0.07kg, 95% confidence interval [CI] -0.86kg to 0.73kg; p=0.87, I^2= 55%) and long (≥ 6 months) (mean difference: -0.87kg, 95% confidence interval [CI] -2.09kg to 0.35kg; p=0.16, I^2= 63%) duration interventions (Appendix 2-G, Appendix 2-H). Similar findings were also found, when stratified by weight status, in people with overweight (mean difference: -0.35kg, 95% confidence interval [CI] -1.53kg to 0.83kg; p=0.56, I^2= 71%) or obesity (mean difference: -0.20kg, 95% confidence interval [CI] -1.42kg to 1.02kg; p=0.75, I^2= 66%) (Appendix 2-I, Appendix 2-J).

Study or Subgroup	RT plus Diet Mean	RT plus Diet SD	RT plus Diet Total	Diet Only Mean	Diet Only SD	Diet Only Total	Weight	Mean difference IV, Random, 95% CI
Andersen et al, 1997	-16.6	4.3	12	-19.4	3.18	9	2.8%	2.80 [-0.40 , 6.00]
Avila et al, 2010	-3.3	3.0984	15	-1.7	3.1177	12	4.0%	-1.60 [-3.96 , 0.76]
Ballor, et al, 1988	-3.89	1.0119	10	-4.47	1.423	10	6.6%	0.58 [-0.50 , 1.66]
Beavers , et al, 2017	-8.9	8.1404	81	-5.3	8.1921	82	3.8%	-3.60 [-6.11 , -1.09]
Benito, et al, 2020	-4.6	4.5	30	-6.1	5.6	29	3.6%	1.50 [-1.10 , 4.10]
Borges JH, et al, 2019	-11.8	2.69	52	-12.5	2.44	29	6.4%	0.70 [-0.45 , 1.85]
Brochu et al, 2009	-5.8	4.9	48	-5.1	4.7	89	5.3%	-0.70 [-2.40 , 1.00]
Bryner et al, 1999	-14.46	5.27	10	-18.16	6.15	10	1.5%	3.70 [-1.32 , 8.72]
Donnelly et al, 1993	-20.9	6.2	18	-20.4	5.7	26	2.4%	-0.50 [-4.11 , 3.11]
Donnelly, et al, 1991	-15.1	4.7	7	-17.1	5.3	7	1.4%	2.00 [-3.25 , 7.25]
Dunstan et al, 2002	-2.5	2.9	19	-3.1	2.1	17	5.4%	0.60 [-1.04 , 2.24]
Figueroa A, et al, 2013	-4.8	3.31	14	-5.6	5.42	13	2.6%	0.80 [-2.62 , 4.22]
Fisher, et al, 2012	-9	2.65	41	-7	2.65	24	6.0%	-2.00 [-3.33 , -0.67]
Gary, et al, 2016	-11.6	2.3	47	-12.2	3.1	46	6.5%	0.60 [-0.51 , 1.71]
Geliebter, et al, 2014	-7.5	4	27	-9.2	3.3	27	4.7%	1.70 [-0.26 , 3.66]
Herring LY, et al, 2014	-2.9	7.46	11	-0.7	9.84	10	0.7%	-2.20 [-9.73 , 5.33]
Ibáñez, et al, 2010	-7.1	4.29	13	-5.7	4.98	12	2.4%	-1.40 [-5.06 , 2.26]
Janssen, et al, 2002	-10	3	14	-10	3.9	13	3.6%	0.00 [-2.64 , 2.64]
Joseph et al, 2001	-3.2	2.39	11	-3	2.93	11	4.2%	-0.20 [-2.43 , 2.03]
Marks, et al, 1995	-3.5	3.4	11	-3.7	4.4	10	2.6%	0.20 [-3.19 , 3.59]
Morencos E, et al, 2012	-6.4	3.93	30	-5.9	3.2	29	5.0%	-0.50 [-2.33 , 1.33]
Nakata et al, 2008	-8.6	3.6	21	-6.2	3.5	21	4.4%	-2.40 [-4.55 , -0.25]
Rojo-Tirado, et al, 2021	-3.2	6.92	60	-1.3	6.66	59	3.9%	-1.90 [-4.34 , 0.54]
Said MA, et al, 2018	-9.37	1.99	23	-6.03	2.08	11	5.7%	-3.34 [-4.81 , -1.87]
Sénéchal, et al, 2012	-3.8	1.8	9	-4.3	2.7	9	4.4%	0.50 [-1.62 , 2.62]
Total (Wald[a])			**634**			**615**	**100.0%**	**-0.32 [-1.00 , 0.35]**
95% prediction interval								[-2.81 , 2.16]



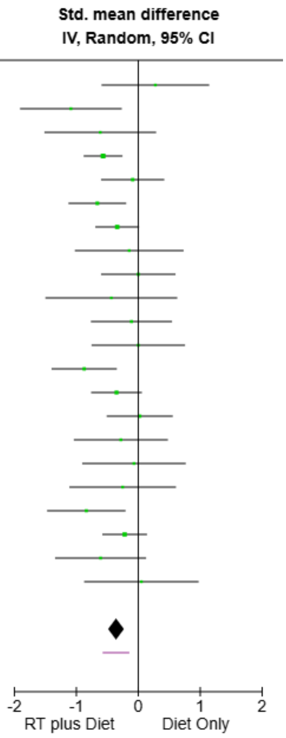
Test for overall effect: Z = 0.94 (P = 0.35)
Test for subgroup differences: Not applicable
Heterogeneity: Tau² (DL[b]) = 1.49; Chi² = 59.42, df = 24 (P < 0.0001); I² = 60%

Footnotes
[a]CI calculated by Wald-type method.
[b]Tau² calculated by DerSimonian and Laird method.

Figure 2-3 Effect of dietary weight loss plus resistance exercise vs. diet-only weight loss on body mass in people living with overweight or obesity

Figure 2-4 with twenty-two studies included, shows a significantly greater reduction in fat mass for diet plus resistance exercise groups, compared to diet-only groups (SMD: -0.36, 95% confidence interval [CI] -0.49 to -0.23; p< 0.00001, I^2= 9%). Similar improvements were demonstrated in both short (≤ 5 months) (SMD: -0.33, 95% confidence interval [CI] -0.50 to -0.17; p< 0.0001, I^2= 0%) and long (≥ 6 months) (SMD: -0.38, 95% confidence interval [CI] -0.62 to -0.14; p=0.002, I^2= 40%) duration interventions (Appendix 2-K, Appendix 2-L). In addition, similar improvements were found in people living with overweight (SMD: -0.54, 95% confidence interval [CI] -0.82 to -0.25; p=0.0002, I^2= 38%) or obesity (SMD: -0.32, 95% confidence interval [CI] -0.52 to -0.13; p=0.001, I^2= 0%) (Appendix 2-M, Appendix 2-N)

Study or Subgroup	RT plus Diet Mean	RT plus Diet SD	RT plus Diet Total	Diet Only Mean	Diet Only SD	Diet Only Total	Weight	Std. mean difference IV, Random, 95% CI
Andersen et al, 1997	-15.3	4.64	12	-16.6	4.36	9	2.1%	0.28 [-0.59 , 1.15]
Avila et al, 2010	-4.1	3.4857	15	-0.2	3.4641	12	2.3%	-1.09 [-1.91 , -0.27]
Ballor, et al, 1988	-4.32	1.2017	10	-3.56	1.17	10	1.9%	-0.61 [-1.52 , 0.29]
Beavers , et al, 2017	-7.9	5.8792	81	-4.4	6.3716	82	12.7%	-0.57 [-0.88 , -0.25]
Benito, et al, 2020	-4.24	2.02	30	-3.94	4.18	29	5.6%	-0.09 [-0.60 , 0.42]
Borges JH, et al, 2019	-10.8	1.89	52	-9.5	2.05	29	6.6%	-0.66 [-1.13 , -0.19]
Brochu et al, 2009	-5.3	4.3	48	-4	3.5	89	10.5%	-0.34 [-0.69 , 0.01]
Bryner et al, 1999	-14.5	15.19	10	-12.8	4.09	10	2.0%	-0.15 [-1.02 , 0.73]
Donnelly et al, 1993	-16.1	4.1	18	-16.1	5.1	26	4.2%	0.00 [-0.60 , 0.60]
Donnelly, et al, 1991	-6.1	2.2	7	-5.1	2.1	7	1.4%	-0.44 [-1.50 , 0.63]
Dunstan et al, 2002	-2.4	2.8	19	-2.1	2.5	17	3.6%	-0.11 [-0.77 , 0.54]
Figueroa A, et al, 2013	-4.4	3.06	14	-4.4	4.48	13	2.7%	0.00 [-0.75 , 0.75]
Fisher, et al, 2012	-6	2.08	41	-4	2.55	24	5.3%	-0.87 [-1.40 , -0.35]
Gary, et al, 2016	-12	2.4	47	-11.2	2.1	46	8.2%	-0.35 [-0.76 , 0.06]
Geliebter, et al, 2014	-5.8	5	27	-5.9	3.2	27	5.2%	0.02 [-0.51 , 0.56]
Janssen, et al, 2002	-8.6	2.4	14	-7.8	3.1	13	2.7%	-0.28 [-1.04 , 0.48]
Joseph et al, 2001	-3.2	2.58	11	-3	2.93	11	2.2%	-0.07 [-0.91 , 0.77]
Marks, et al, 1995	-4.2	2.3	11	-3.4	3.7	10	2.1%	-0.25 [-1.11 , 0.61]
Nakata et al, 2008	-6.9	3	21	-4.5	2.6	21	3.8%	-0.84 [-1.47 , -0.21]
Rojo-Tirado, et al, 2021	-2.4	6.81	60	-0.9	6.75	59	10.2%	-0.22 [-0.58 , 0.14]
Said MA, et al, 2018	-5	1.27	23	-4.22	1.21	11	2.9%	-0.61 [-1.34 , 0.13]
Sénéchal, et al, 2012	-3.1	1.8	9	-3.2	2	9	1.8%	0.05 [-0.87 , 0.97]
Total (Wald[a])			**580**			**564**	**100.0%**	**-0.36 [-0.49 , -0.23]**
95% prediction interval								[-0.58 , -0.14]



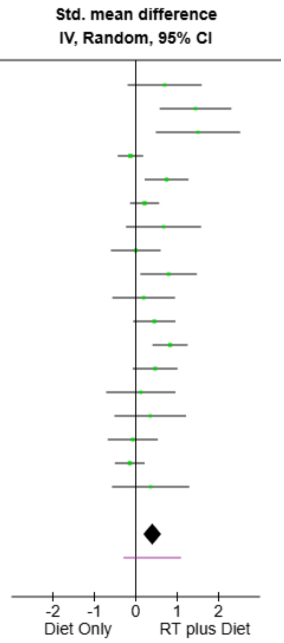
Test for overall effect: Z = 5.52 (P < 0.00001)
Test for subgroup differences: Not applicable
Heterogeneity: Tau² (DL[b]) = 0.01; Chi² = 22.97, df = 21 (P = 0.35); I² = 9%

Footnotes
[a] CI calculated by Wald-type method.
[b] Tau² calculated by DerSimonian and Laird method.

Figure 2-4 Effect of dietary weight loss plus resistance exercise vs. diet-only weight loss on fat mass in people living with overweight or obesity.

Figure 2-5 shows with eighteen studies reported a significantly lower reduction in fat free mass for diet plus resistance exercise groups, compared to diet-only groups (SMD: 0.40, 95% confidence interval [CI] 0.18 to 0.61; p=0.0003, I^2= 59%). Improvement was found for short duration interventions (≤ 5 months) (SMD: 0.52, 95% confidence interval [CI] 0.25 to 0.78; p=0.0001, I^2= 43%), as well in people with overweight (SMD: 0.52, 95% confidence interval [CI] 0.15 to 0.90; p=0.006, I^2= 53%) or obesity (SMD: 0.41, 95% confidence interval [CI] 0.03 to 0.78; p=0.03, I^2= 57%) (Appendix 2-O, Appendix 2-P, Appendix 2-Q). However, no improvement was seen in long duration interventions (≥ 6 months) (SMD: 0.20, 95% confidence interval [CI] -0.09 to 0.48; p=0.17, I^2= 57%) (Appendix 2-R).

Study or Subgroup	RT plus Diet Mean	RT plus Diet SD	RT plus Diet Total	Diet Only Mean	Diet Only SD	Diet Only Total	Weight	Std. mean difference IV, Random, 95% CI
Andersen et al, 1997	-1.3	2.01	12	-2.8	2.14	9	3.8%	0.70 [-0.20 , 1.59]
Avila et al, 2010	0.8	1.5492	15	-1.4	1.3856	12	3.9%	1.44 [0.58 , 2.31]
Ballor, et al, 1988	0.43	0.8222	10	-0.91	0.8854	10	3.2%	1.50 [0.48 , 2.52]
Beavers , et al, 2017	-1.2	1.809	81	-0.9	2.7307	82	8.8%	-0.13 [-0.44 , 0.18]
Benito, et al, 2020	0.03	0.9	30	-0.94	1.59	29	6.5%	0.74 [0.22 , 1.27]
Brochu et al, 2009	-0.4	2.2	48	-0.9	2.4	89	8.3%	0.21 [-0.14 , 0.57]
Bryner et al, 1999	-0.8	4	10	-4.1	5.33	10	3.7%	0.67 [-0.24 , 1.58]
Donnelly, et al, 1991	-4.7	4.6	18	-4.7	4.3	26	5.8%	0.00 [-0.60 , 0.60]
Dunstan et al, 2002	0.5	1.2	19	-0.4	1	17	5.2%	0.79 [0.11 , 1.48]
Figueroa A, et al, 2013	-0.8	2.16	14	-1.3	2.88	13	4.6%	0.19 [-0.57 , 0.95]
Fisher, et al, 2012	0.2	2.11	41	-0.7	1.74	24	6.7%	0.45 [-0.06 , 0.96]
Gary, et al, 2016	0.3	1.4	47	-1	1.7	46	7.6%	0.83 [0.40 , 1.25]
Geliebter, et al, 2014	-2.9	3.4	27	-4.4	2.9	27	6.4%	0.47 [-0.07 , 1.01]
Joseph et al, 2001	0.1	1.03	11	-0.1	1.97	11	4.1%	0.12 [-0.71 , 0.96]
Marks, et al, 1995	0.7	3	11	-0.2	1.7	10	3.9%	0.35 [-0.51 , 1.21]
Nakata et al, 2008	-1.8	1.2	21	-1.7	1.5	21	5.8%	-0.07 [-0.68 , 0.53]
Rojo-Tirado, et al, 2021	-1	4.13	60	-0.4	4.1	59	8.2%	-0.14 [-0.50 , 0.21]
Sénéchal, et al, 2012	-0.4	0.9	9	-0.8	1.2	9	3.6%	0.36 [-0.57 , 1.29]
Total (Wald[a])			**484**			**504**	**100.0%**	**0.40 [0.18 , 0.61]**
95% prediction interval								[-0.30 , 1.09]



Test for overall effect: Z = 3.61 (P = 0.0003)
Test for subgroup differences: Not applicable
Heterogeneity: Tau² (DL[b]) = 0.11; Chi² = 41.06, df = 17 (P = 0.0009); I² = 59%

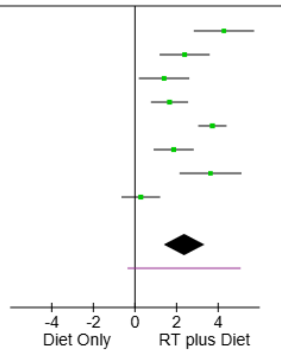
Footnotes
[a]CI calculated by Wald-type method.
[b]Tau² calculated by DerSimonian and Laird method.

Figure 2-5 Effect of dietary weight loss plus resistance exercise vs. diet-only weight loss on fat free mass in people living with overweight or obesity.

2.4.4 Effects of resistance exercise interventions on markers of cardiometabolic health and physical function

Cardiometabolic health and physical function outcomes studied included muscle strength, cardiorespiratory fitness, blood glucose, insulin levels/sensitivity, lipid profile, blood pressure and glycaemic control. As shown in Figure 2-6 with eight studies reported, improvements in muscle strength were greater in diet plus resistance exercise compared to diet-only groups (SMD= 2.36 95% confidence interval [CI] 1.38 to 3.34; p=0.00001, I^2= 86%).

Study or Subgroup	RT plus Diet Mean	RT plus Diet SD	RT plus Diet Total	Diet Only Mean	Diet Only SD	Diet Only Total	Weight	Std. mean difference IV, Random, 95% CI
Avila et al, 2010	60	18	15	-5	9	12	11.2%	4.28 [2.83 , 5.73]
Ballor, et al, 1988	5.31	2.846	10	-0.69	1.8657	10	12.2%	2.39 [1.18 , 3.59]
Donnelly et al, 1993	20	11	7	5.3	8.5	7	12.1%	1.40 [0.19 , 2.61]
Figueroa A, et al, 2013	25	14.49	14	-7	22.33	13	13.3%	1.66 [0.77 , 2.56]
Gary, et al, 2016	31	12	47	-22	16	46	13.9%	3.72 [3.04 , 4.40]
Ibáñez, et al, 2010	107.7	53.62	13	16.3	39.69	12	13.0%	1.86 [0.90 , 2.83]
Marks, et al, 1995	6	2.8	11	-3	1.8	10	11.1%	3.63 [2.14 , 5.12]
Sénéchal, et al, 2012	-11.2	17.9	9	-17.6	24.9	9	13.1%	0.28 [-0.65 , 1.21]
Total (Wald[a])			**126**			**119**	**100.0%**	**2.36 [1.38 , 3.34]**
95% prediction interval								[-0.36 , 5.08]



Test for overall effect: Z = 4.73 (P < 0.00001)
Test for subgroup differences: Not applicable
Heterogeneity: Tau² (DL[b]) = 1.68; Chi² = 49.87, df = 7 (P < 0.00001); I² = 86%

Footnotes
[a]CI calculated by Wald-type method.
[b]Tau² calculated by DerSimonian and Laird method.

Figure 2-6 Effect of dietary weight loss plus resistance exercise vs. diet-only weight loss on muscular strength in people living with overweight or obesity.

Eight studies reported cardiorespiratory fitness (VO_{2max} or VO_{2peak}), blood glucose and insulin levels, and six studies reported insulin sensitivity. No between-group differences were observed in cardiorespiratory fitness (VO_{2max} or VO_{2peak}) (mean difference= 0.46ml/kg/min, 95% confidence interval [CI] -0.05ml/kg/min to 0.96ml/kg/min, I^2= 0%) (Appendix 2-S), blood glucose (mean difference= -0.01mmol/l, 95% confidence interval [CI] -0.05mmol/l to 0.04mmol/l, I2= 0%) (Appendix 2-T), insulin (mean difference= -0.28mU/l, 95% confidence interval [CI] -1.18mU/l to 0.62mU/l, I^2= 0%) levels (Appendix 2-U) or insulin sensitivity (SMD -0.18, 95% confidence interval [CI] -0.44 to 0.09, I^2= 0%) (Appendix 2-V).

There were no differences in blood lipids in the nine studies which compared these between the diet plus resistance exercise and diet-only weight loss groups: total cholesterol: (mean difference= -0.01mmol/l, 95% confidence interval [CI] -0.20mmol/l to 0.19mmol/l, I^2= 84%); HDL cholesterol: (mean difference= -

0.01mmol/l, 95% confidence interval [CI] -0.04mmol/l to 0.03mmol/l, I^2= 37%); LDL cholesterol: (mean difference= 0.10mmol/l, 95% confidence interval [CI] -0.05mmol/l to 0.24mmol/l, I^2= 69%); triglycerides: (mean difference= 0.00mmol/l, 95% confidence interval [CI] -0.00mmol/l to 0.01mmol/l, I^2= 0%) (Appendix 2-W, Appendix 2-X, Appendix 2-Y, Appendix 2-Z). Similarly, there were no differences in blood pressure with six studies reporting this (systolic: mean difference= 0.05mm Hg, 95% confidence interval [CI] -0.94mm Hg to 1.04mm Hg, I^2= 0%; diastolic: (mean difference= -0.68mm Hg, 95% confidence interval [CI] -1.64mm Hg to 0.28mm Hg, I^2= 7%) (Appendix 2-AA, Appendix 2-BB).

Studies measuring physical function such as walking tests, chair stands, balance and flexibility were also included in the systematic review. Although no meta-analyses were performed due to limited data, these functional outcomes are important as they demonstrate the practical benefits of maintaining muscle mass/strength during weight loss. Walking performance yielded varied results. Two studies found no effects of resistance exercise during weight loss on 6 min walk test distance (Said et al., 2018, Sénéchal et al., 2012). However, one study found that physical function, measured by shuttle walk test, was greater in the resistance exercise group (Δ 165.0 ± 183.30 m, 53.7%, p= 0.06) compared to the diet only group (Δ −14.3 ± 38.7 m, −9.7%) (Herring et al., 2014). For other functional measures, one study reported no impact of resistance exercise during weight loss on physical function, assessed by the 5-chair stand and 400-m walk (Avila et al., 2010). In one study, balance, as measured by one leg stand test, was greater after the weight loss intervention in the resistance exercise, relative to the diet only group (Sénéchal et al., 2012). Additionally, one study reported improvements in 1-min sit up test and reach flexibility test in the resistance exercise group compared to a diet only group ($p < 0.05$) (Said et al., 2018).

2.5 Discussion

The current systematic review and meta-analysis examined the impact of resistance exercise on body weight/composition, muscle strength and cardiometabolic markers in people living with overweight or obesity taking part in dietary weight loss interventions. The addition of resistance exercise had no effect on changes in body mass but resulted in a greater loss of fat mass, preservation of fat free mass and improved muscle strength. The sub-group analyses indicate that the effects on fat mass were similar regardless of intervention duration or BMI status but the effects on fat free mass were not seen in longer duration interventions. There was no evidence of effects on cardiometabolic markers, although there was less certainty in this data due to the limited number of studies/participants that contributed to the comparisons.

Dietary weight loss results in loss of both fat free mass and fat mass, and some studies have indicated that the addition of resistance exercise may have a role in preserving (or possibly increasing) fat free mass (Hunter et al., 2015, Miller et al., 2018). The current systematic review presents the first evidence synthesis on this subject, providing a level of evidence not shown before. To date, there is only one previous systematic review and meta-analysis which demonstrated that resistance exercise and caloric restriction was effective for decreasing fat mass and improving fat free mass in people living with overweight or obesity (Lopez et al., 2022). However, this review included children and adolescents, along with adults and older adults. On top of this, some of the included studies in the meta-analysis involved combined resistance and aerobic exercise and did not examine muscle strength/function, or cardiometabolic health measures. The current systematic review and meta-analysis is, therefore, the first to specifically examine resistance exercise during dietary weight loss in adults living with overweight or obesity across a broad range of outcomes. The analysis showed that resistance exercise decreases the loss of fat free mass during weight loss, although this effect was not seen when the duration of intervention was greater than 5 months which may reflect difficulties in maintaining adherence to resistance exercise in the long term. Indeed, data from longer durations studies (≥ 6 months) revealed significant dropout rates ranging from 25% to 49% (Beavers et al., 2017, Brochu et al., 2009, Fisher et al., 2012, Morencos et al., 2012, Rojo-Tirado et al., 2021), with generally poor adherence level among completers – although this was not well reported. For example, one study stated that during the six-month intervention period, only 33% of the resistance exercise plus diet group attended ≥90% of training sessions (Brochu et al., 2009).

Fat free mass preservation was only present in shorter duration interventions (<5 months). While declining adherence over time may contribute to this finding, other factors are also likely involved. For example, longer interventions may have featured less intensive supervision as they progressed, potentially reducing exercise quality and intensity, although reporting on this was generally poor. Additionally, physiological adaptations occur over time, with the adaptations plateauing after several months of the intervention, with progressive overload required to stimulate further adaptations. One study reported a clear progression protocol including regular one-repetition maximum (1RM) reassessments to adjust training loads, maintaining and intensity of 75-85% 1RM during the intervention (Dunstan et al., 2002). Other studies, however, provided limited details on progression only stating initial intensity. Furthermore, dietary factors such as protein intake and overall caloric deficit, which may influence findings, are easier to control in shorter interventions – although again this was poorly reported. Future research is required to investigate the longer-term role of resistance exercise during weight loss.

Alongside changes in fat free mass, the current review demonstrated that resistance exercise during dietary weight loss results in greater muscle strength. The link between changes in fat free mass and muscle strength is complex and not always directly proportional. Although meta-analyses of resistance exercise in healthy adults clearly demonstrate that resistance exercise significantly increases muscle mass (Benito et al., 2020a), there is evidence that resistance training exercise partially increases strength independently of changes in mass. This occurs via neural adaptations, such as increased recruitment of motor units, increased firing frequency and improved coordination movements between muscles (Folland and Williams, 2007, Škarabot et al., 2021). The findings of the current study indicate that resistance exercise during dietary weight loss enhances strength (SMD 2.36) while also preserving fat free mass to a lesser extent (SMD 0.40), suggesting that changes in strength are occurring both dependently and independently of changes in mass. On top of this, the current review suggests that including resistance exercise in weight loss interventions may be beneficial in maximising fat loss, and importantly minimising the potential negative consequences of weight loss, such as loss of lean muscle mass.

The mechanisms behind the increased fat mass loss with resistance exercise during dietary restriction are likely complex. Resistance exercise increases resting energy expenditure through increased muscle mass, which has higher metabolic activity than fat mass, by about 5–7% over several months (Aristizabal et al., 2015, Westcott, 2012, Hunter et al., 2008). Additionally, resistance exercise creates a substantial post-exercise oxygen consumption effect (EPOC), elevating metabolic rate by approximately 20% for 24-48 hours after training (Schuenke et al., 2002, Williamson and Kirwan, 1997). At the molecular level, resistance exercise enhances fat oxidation capacity through increased mitochondrial density and function (Porter et al., 2015), while also improving insulin sensitivity and glucose metabolism, which may further promote fat utilisation (Croymans et al., 2013). These physiological changes contribute to the larger loss of fat mass observed when resistance exercise is combined with dietary restriction.

Despite fat free mass and muscle strength being associated with a variety of health outcomes (Ashton et al., 2020), and resistance exercise resulting in improvement in cardiometabolic health markers (Cornelissen et al., 2011), no impact was found of the addition of resistance exercise to a weight loss intervention to markers of cardiometabolic health. Instead of simply reflecting the importance of weight loss itself in changes in these outcomes, this may indicate several possibilities. The level of caloric restriction in weight loss interventions may mask the cardiometabolic benefits of resistance exercise that are seen in non-caloric-restricted settings. It is also possible that the prescribed resistance exercise training volume, intensity or progression in these combination interventions was not sufficient to produce further cardiometabolic benefits over and above those from weight loss alone. Additionally, the timing of outcome assessments may not have captured the whole adaptive response, especially if metabolic benefits from resistance training follow time frames that are distinct from the metabolic benefits of dietary restriction. It is crucial to emphasize that there is strong evidence supporting resistance exercise alone as an effective intervention for improving cardiometabolic outcomes, frequently with few or no changes in body weight (Ashton et al., 2020, Paluch et al., 2024).. Alternatively, there were far fewer studies and greater uncertainty in the analysis of these outcomes, and it would be suggested that further work, including larger randomised controlled trials with carefully designed protocols and appropriate assessments, is needed on this topic.

The UK physical activity guidelines recommend performing muscle strengthening exercises twice a week (Department of Health & Social Care, 2019) and it has been shown that resistance exercise training can help with the preservation of fat free mass during weight loss. Unfortunately, it is known that participation in resistance exercise is generally very low (17-30%) (Bennie et al., 2020, Strain et al., 2016) and so to achieve any of the benefits of resistance exercise, strategies to increase its uptake are needed (Al-Ozairi et al., 2021). This can be particularly challenging as the majority of the studies included (n=23/25) in this review employed supervised resistance exercise at specialist facilities. Resistance exercise training traditionally involves specialised equipment, which may not be accessible to many people due to barriers generally associated with any physical activity, such as work, time, vacations, weather, boredom, tiredness, injury/illness, and family commitments (Tulloch et al., 2013, Trost et al., 2002, Burton et al., 2017), which can further limit participation. However, it is important to highlight that just making resistance exercise training more accessible without maintaining adequate intensity and progression may limit effectiveness, as shown in some large trials using simpler, non-supervised approaches (Bischoff-Ferrari et al., 2020). Despite this challenge, there are interventions that balance accessibility with effectiveness, which include progressive bodyweight exercise training (American College of Sports, 2009, Fyfe et al., 2022), programmes utilising resistance bands with systematic progression protocols (Kraemer and Ratamess, 2004) and home based programmes that use household objects while emphasising appropriate technique and progressive overload (World Health Organization, 2020a). It could be argued, therefore, that developing pragmatic resistance exercises that are simple, easy to use and effective in preserving fat free mass during weight loss are needed. These might include home-based programmes requiring minimal equipment which could be widely implemented for individuals living with overweight or obesity who are trying to lose weight.

To the authors knowledge, this is the first systematic review and meta-analysis assessing the effect of resistance exercise on body weight/composition, muscle strength and cardiometabolic markers in people living with overweight or obesity taking part in weight loss interventions. All the studies included were randomised controlled trials of high quality. For the meta-analysis, resistance exercise was the only exercise performed by the participants, since studies that had only aerobic exercise or balance training were excluded to allow for a more focused analysis of the effects of resistance exercise during dietary weight loss interventions compared to dietary weight loss alone. The current research indicates that resistance training improves fat free mass, fat mass, muscle strength and can be a useful strategy to employ during weight loss.

The current review has a number of limitations. First, most included studies (n=24) failed to report the concealment of allocations, the blinding of assessment of outcomes and missing data. As a result, many studies were rated as having an unclear risk of bias, which may have influenced the heterogeneity of the data. Second, only a few studies reported cardiometabolic health outcomes, and available evidence was limited for each outcome. The quality of evidence for these outcomes was therefore either low or moderate, and their effect estimates may lack accuracy. Third, over half of the included studies (n=15) recruited only women, with the others mixed sex studies, which may limit the generalisability of the findings to men. In order to make these findings more applicable and to gain a more comprehensive understanding of how resistance exercise during dietary weight loss may be more effective, future research should aim to include more representative samples. Fourth, most included studies (n=23) employed supervised resistance exercise at specialist facilities, with very few examining unsupervised or home-based interventions. This prevented us from conducting sub-group analysis comparing the effectiveness of supervised versus unsupervised resistance training during weight loss. Given that supervision may influence adherence, exercise intensity, and technique—all factors that could affect outcomes—this limitation highlights the need for more research on accessible, pragmatic approaches to resistance training that do not require extensive supervision. Fifth, only seven of the studies included in this meta-analysis were of at least six months duration, which has two important limitations: 1) the small sample size reduces statistical power for the sub group analyses, increasing the uncertainty around the estimate, and 2) the inconsistent reporting of exercise adherence across these studies prevented us from conducting meta-regression analyses to assess whether declining adherence explains the decreased effects seen in longer interventions. Finally, the current review only included peer-reviewed papers and included English language publications, and thus may have missed relevant studies published in the grey literature and other languages.

In conclusion, the current study highlights the potential benefits of resistance exercise, including increasing fat mass loss, reducing the loss of fat free mass and improving muscle strength for people taking part in dietary weight loss interventions. However, it is important to recognise the limitations that have been identified, such as the need for further research to investigate the cardiometabolic effects of resistance exercise during weight loss. There is also a need to develop and evaluate more pragmatic resistance exercise interventions that can be implemented. Including resistance exercise into dietary weight loss interventions is important to improve outcomes and inform evidence-based practice.

Chapter 3 A qualitative study of the experiences and perceptions of resistance training in people living with overweight or obesity who are trying to lose weight

3.1 Abstract

3.1.1 Background

Although resistance exercise is recommended, in people living with overweight or obesity who are trying to lose weight, little is known about the experiences and perceptions of resistance exercise training. This study aimed to understand the experiences and perceptions of resistance training in people living with overweight or obesity seeking to lose weight. Specifically, it used qualitative interviews to explore the barriers, preferences and changes in experiences and perceptions following participation in a short-term resistance exercise programme.

3.1.2 Methods

Face to face semi-structured interviews with participants (n=11) were conducted before and after undertaking four weeks of home-based resistance exercise. Interviews explored participants' views on physical activity, including resistance exercise, and weight loss, perceived barriers and facilitators of resistance exercise and their perceptions of changes as they performed resistance exercises over a short period of time. Thematic coding framework was used to analyse data.

3.1.3 Results

Participants reported a number of barriers to physical activity and resistance exercise, including financial constraints, access to facilities and pandemic-related limits. The home-based resistance programme was positively received due its accessibility and convenience. Both men and women adapted well to the exercises, although gender differences were noted in confidence and ability to perform particular exercises. Male participants appeared confident about trying

the different exercises, while female participants reported difficulties or challenges when initially trying exercises. Both men and women self-reported improvements in strength, body tone and mental well-being, with many expressing the intention to continue resistance exercise training after the programme. Throughout the programme, participants also became more aware of nutrition and changed their eating habits. These results informed a theory of change highlighting the importance of enjoyable, accessible, and supportive resistance exercise training programmes.

3.1.4 Conclusions

The study provides valuable insights into the experiences and perceptions of resistance exercise training in people living with overweight or obesity seeking to lose weight. The findings highlight the potential of home-based resistance training programmes to overcome common barriers to exercise participation.

3.2 Introduction

Obesity is a significant global health challenge (Upadhyay et al., 2018). Obesity increases the risk of a variety of chronic diseases, including hypertension, type 2 diabetes, coronary heart disease, dyslipidaemia and certain cancers (An et al., 2018). In the UK, obesity is defined as having a BMI higher than 30 kg/m^2 (NHS, 2019), with excess energy intake and lack of physical activity considered to be the main causes (WHO, 2009). Obesity affects 1 in 4 adults in the UK (NHS, 2019). Its prevalence has increased significantly over the past few decades (NHS Digital, 2021). In Scotland, obesity is a major public issue, with over 65% of the adult population overweight, and 28% having obesity, which is broadly in line with the rest of the UK (Scotland, 2021).

Dietary interventions are the primary treatment for obesity, producing significant weight loss, with body mass reductions between 4 and 5 kg over 12 months and associated with improvements in cardiovascular risk factors (Ge et al., 2020). Although significant weight loss and improvements in cardiovascular risk factors are positive outcomes of dietary interventions, one of the consequences of weight loss is the loss of lean tissue (muscle mass). Indeed during weight loss approximately 20-30% of the weight lost is muscle tissue (Cava et al., 2017, Enriquez Guerrero et al., 2021). For example, in a typical dietary intervention achieving about 5 kg of total weight loss, this results in the loss of approximately 1.3 kg muscle mass (Pellegrini et al., 2020). Lean tissue, including muscle, plays a key role in metabolic functions (Wolfe, 2006), and its reduction is a risk factor to cardiometabolic and other obesity-related diseases (Sajoux et al., 2019). Low muscle mass and function are also associated with increasing mortality and morbidity (Cava et al., 2017), and strategies to maintain muscle mass and function during weight loss may improve the beneficial effects of weight loss. Such strategies, however, remain understudied.

The most effective method to increase or maintain muscle mass and function is resistance exercise (Westcott, 2012), which has also been shown to improve blood lipids and glycaemic control in different populations (Ashton et al., 2020, Cornelissen et al., 2011). However, in the UK and Europe very few people perform resistance exercise, with only ~25% of adults meeting the guidelines to perform muscle strengthening exercises twice per week (Bennie et al., 2020, Strain et al., 2016). This is likely to be even lower in people undergoing weight loss, where it may have particular benefit. There is often limited awareness about the potential benefits of muscle preservation during weight loss, and possible lack of knowledge around performing resistance exercise. Indeed, it has been shown that people with higher BMI (>25 kg/m^2) are less likely to participant in resistance exercise which indicates some barriers to exercise (Rhodes et al., 2017). As shown in the systematic review and meta-analysis presented in Chapter 2 of this thesis adding resistance exercises during weight loss can significantly help preserve lean mass as well as improve muscle quality and strength.

Understanding these barriers along with the reasons people do not perform resistance exercise remain to be established. Studies of female college students found that barriers included perceived lack of time, not feeling comfortable in the gym, and lack of knowledge regarding free weights and other forms of resistance exercise (Hurley et al., 2018, Peters et al., 2019). A systematic review reported that barriers to participation in resistance exercise for older adults included safety, fear, fatigue, health concerns, pain, and lack of social support (Burton et al., 2017). It has been suggested that qualitative research would be helpful in order to inform interventions to overcome these barriers and increase participation in resistance exercise (Hurley et al., 2018). The development of effective resistance exercise interventions requires systematic application to understand how change occurs. Theory of change help understand how and why desired changes may occur (Funnell and Rogers, 2011). Therefore, it is important to conduct a qualitative study to inform the development of a straightforward, simple and easy resistance exercise programme for people living with overweight or obesity (Phillips and Winett, 2010).

Aim and objectives

The overall aim of this study is to understand the experiences and perceptions of resistance training in people living with overweight or obesity who are trying to lose weight. This will be achieved through addressing the following objectives: (i) To explore the experiences and perceptions of physical activity and resistance exercise along with barriers in people living with overweight or obesity, (ii) To identify the preferences of people living with overweight or obesity in relation to resistance exercise (iii) To examine changes in the experiences and perceptions of people living with overweight or obesity following participation in a four week resistance exercise programme.

3.3 Methods

3.3.1 Study design

This qualitative study involved face to face semi-structured interviews before and after undertaking four weeks of resistance exercise. The study was approved by the College of Medical Veterinary and Life Sciences Ethics Committee at the University of Glasgow (Project No: 200210108) and all participants provided written informed consent.

3.3.2 Participants

Participants were recruited via posters and/or flyers at venues in University of Glasgow and on social media platforms (Facebook and X). Inclusion criteria were people living in Glasgow who were aged 18 - 65 years, with overweight or obesity (BMI >25 kg/m^2) and currently trying to lose weight. Participants were excluded if they did not meet these criteria. In addition, participants were required to complete the Physical Activity Readiness Questionnaire (PAR-Q+). Those who answered 'No' to all questions were cleared for participation. Individuals who answered 'Yes' to any question were required to obtain written approval from their healthcare provider before participating in the study. This approval needed to state that the healthcare provider was aware of the study's resistance training component and deemed it safe for the individual to participate.

3.3.3 Data collection and interviews

Two interview topic guides (see Appendix 3-A & Appendix 3-B) were developed by the principal researcher (AB) and research supervisors (CG & SG) to explore participants' views on physical activity, including resistance exercise, and weight loss pre- and post-intervention (i.e., after four weeks of resistance exercises). These guides focused on participants' experiences, knowledge, perceived barriers and facilitators of resistance exercise and their perceptions of changes as they performed resistance exercises over a short period of time.

To minimise potential interviewer bias, several strategies were employed. First, the entire research team went through the interview topic guides to identify and edit any potentially leading questions. Second, the principal researcher (AB) received training in qualitative interviewing techniques, with emphasis on asking open-ended, non-judgmental questions and using neutral prompts to encourage elaboration. During interviews, the interviewer took care to use participants' own terminology when asking follow-up questions rather than introduce the interviewer's language or assumptions.

Prior to the first interview, participants completed a brief demographic survey which included questions about their gender, age and history of weight loss attempts, and their height and weight measures were taken. Two in-person semi-structured interviews with each participant were conducted at the University of Glasgow between June and September 2022. Each interview lasted approximately 10 to 20 minutes and was audio-recorded and transcribed verbatim.

The initial (pre-intervention) interview (see Appendix 3-A) explored participants' preferences for physical activity, including resistance exercise, and their views on the relationship between physical activity and weight loss. During the interview, the resistance training exercises were demonstrated and the participants tried them. Their initial views of these exercises were then sought. Participants were given a resistance exercise handout with instructions, pictures, and links to videos of the exercises (see Appendix 3-C).

The resistance exercise programme was designed to be simple, accessible and target major muscle groups while being suitable for home-based training with minimal equipment. Exercises were selected from a collection of previously resistance exercises that had been successfully implemented, and chosen based on their effectiveness for improving strength and muscle mass (Westcott, 2012). The selection criteria focused on: 1) exercises requiring minimal equipment to reduce barriers to participation, 2) movements that could be safely performed at home without supervision, and 3) exercises targeting major muscle groups for maximum benefit. This let to the selection of six exercises, including press-ups, band lateral raises, band seated low row, squat, lunge and calf raise. The resistance exercise programme was structured to promote gradual progression, with participants were asked to perform the resistance exercises twice a week for four weeks, completing three sets of each exercise. In order to build up intensity slowly, participants were asked to target a lower Rating of Perceived Exertion (RPE) of 4-6 during the first week, progressing with the goal of reaching a RPE of between 8-10 (on a scale of 1-10, where 10 represents maximal effort) for each set in the following weeks (Lagally and Robertson, 2006).

Although participants were told to undertake resistance exercises twice weekly for four weeks, no adherence tracking was used in this qualitative study. During the post-intervention interviews, participants were asked to describe their engagement with the programme, including frequency of exercise completion, but no objective measures of adherence were used.

After the four-week period, a follow-up interview focusing on participants' thoughts, experiences, perceptions and preferences about the resistance exercises they had performed was conducted (see Appendix 3-B).

3.3.4 Data analysis

A thematic coding framework approach (Braun and Clarke, 2013, Gale et al., 2013) was used to analyse the data, with the intention of developing a theory of change to inform future resistance exercise interventions (Funnell and Rogers, 2011). This involved exploring participants' experiences and perceptions before and after the programme. To ensure robustness, the analysis process involved several steps:

3.3.4.1 Initial coding & Framework development

AB and CG independently read two transcripts line by line to identify keywords and preliminary codes. AB and CG then met to compare Initial codes and discuss any differences. Through this discussion, AB and CG agreed a coding framework (a detailed description of each code is provided in Appendix 3-D).

3.3.4.2 Framework application

AB applied the agreed coding framework to all transcripts using NVivo V.12 software to organise the data. To ensure accuracy and consistency, the coding was reviewed by CG and SG, and any disagreements resolved through discussion.

3.3.4.3 Theme development

AB, CG and SG then read through the broad codes carefully to identify sub-codes. After that, AB produced a detailed narrative account of each code and sub-code using Microsoft Excel software to compare similarities and differences in accounts between men and women (Ritchie et al., 2013). Four main themes emerged as follow, each supported by specific codes:

1. Knowledge, barriers and motivations to physical activity and resistance exercise training: this theme described participants' current and previous physical activity, barriers, their physical activity identity and the reasons for joining the programme and for doing physical activity, including resistance exercise. It emerged from the following five codes: 1) Physical activity and weight loss or diet; 2) Physical activity previous and current; 3) Physical activity identity, 4) Reasons for joining the study; 5) Reasons for doing/not doing physical activity.
2. Perceptions, preferences and anticipations of resistance exercise training: this theme identified participants' preferences, prior experience and intentions about resistance exercise training before starting the programme. It emerged from the following five codes: 1) Resistance training exercises needs; 2) Resistance training exercises and weight loss or diet; 3) Initial response to resistance training exercises; 4) Prior resistance training exercises experiences; 5) Intentions and expectations of the resistance training programme.
3. Engagement and experiences of resistance exercise training: this theme described participants' experiences during and after the programme. It emerged from the following two codes: 1) When, where and how; 2) Experience of resistance training exercises during the programme.
4. Overall impact of the resistance exercise programme: this theme described the overall effects on participants including physical changes and benefits as a result of taking part in the programme. It emerged from the following

two codes: 1) Impact of resistance training exercises; 2) Post-programme maintenance of resistance exercises.

To ensure transparency, each quote in the findings is accompanied by a participant ID that includes the participant number, gender (male/female), age group (30-40 years or over 50 years, and whether the quote is from the pre-intervention or post-intervention interview. For example, *(P.05, Female, Over 50, Pre-interview)* indicates the quote is from participant 5, who is a female over the age of 50, and was collected during the pre-intervention interview. Similarly, *(P.11, Female, 30-40, Pre-interview)*, *(P.04, Male, 30-40, Post-interview)*, and *(P.07, Male, Over 50, Post-interview)* provide the corresponding participant details. A thematic 'map' is provided below in Figure **3-1** to help facilitate the understanding of the development of the four main themes (Braun and Clarke, 2013), and also detailed descriptions of each code, sub-code and theme development supported by participant quotes are provided in Appendix 3-E.

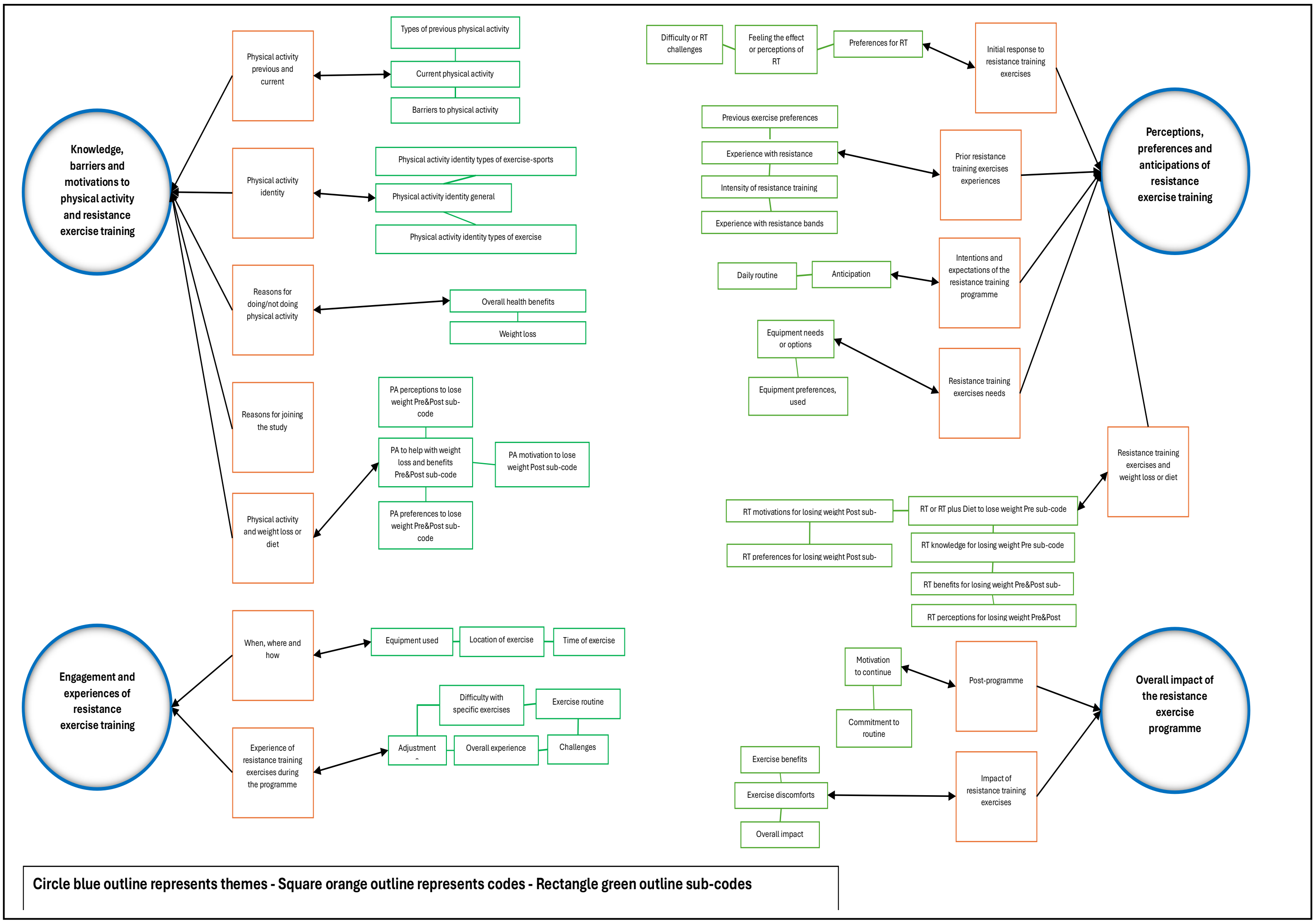


Figure 3-1 Thematic map

3.4 Results

As shown in Table 3-1, of the 11 participants (4 male, 7 female) recruited, 10 completed both interviews, and one (female) provided a pre-interview but then withdrew from the study because of health reasons not related to the study. Participants' educational background varied, with the majority holding postgraduate degrees. Almost two-thirds of the participants were married. The mean age of the participants was 47.2 years (SD 9.4), ranging from 35 to 59 years.

The average BMI was 29.5 kg/m^2 (SD 3.3), with slightly more than half of the participants classified as obese (BMI ≥ 30 kg/m^2).

Table 3-1 Participant characteristics.

Age (years)	47.2 (9.4)		
Sex	Male	(n=4)	(36.4%)
	Female	(n=7)	(63.6%)
Highest degree	High School	(n=3)	(27.3%)
	Bachelor's Degree	(n=1)	(9.1%)
	Master's Degree	(n=4)	(36.4%)
	Ph.D. or higher	(n=3)	(27.3%)
Marital status	Single	(n=3)	(27.3%)
	Married	(n=7)	(63.6%)
	In a relationship	(n=1)	(9.1%)
[a]BMI (kg/m^2)	29.5 (3.3)		
Fat mass (kg)	29.2 (10.7)		
Fat free mass (kg)	53.7 (9.6)		

Data are presented as mean (SD) or n= number of participants (%)

a. BMI: Body mass index

3.4.1 Knowledge, barriers and motivations to physical activity and resistance exercise training

This theme explores participants' current and previous physical activity, barriers, their motivations and reasons for joining the programme and for doing physical activity, including resistance exercise.

3.4.1.1 Previous and current physical activity

Prior to taking part in the programme, all participants demonstrated a wide range of knowledge and experiences of physical activity. For example, one participant reported *"in the past I've done yoga and I've done some gym exercises. And recently this year, I started going to a Pilates class (P.01, Female, Over 50, Pre-Interview)"* while another reported *"I play football every Friday (P.04, Male, 30-40, Pre-Interview)".*

Both men and women reported doing a range of physical activities, including cycling *"Yeah. I'm usually cycling (P.4, Male, 30-40, Pre-Interview)"*, regular walking *"I walk at least once or twice a week as well (P.05, Female, Over 50, Pre-Interview)"*, and gym workouts:

"I go to the gym maybe three times a week and I use an exercise bike or a cross trainer for 30 minutes and I use weights machines for 30 minutes (P.07, Male, Over 50, Pre-Interview)".

However, some participants reported doing little or no physical activity at all:

"I don't do anything just now other than a bit of walking (P.11, Female, 30-40, Pre-Interview)".

3.4.1.2 Barriers to physical activity and resistance exercise

Participants reported a range of barriers to doing physical activity and resistance exercise training. For example, as a result of the pandemic, access to facilities and regular exercise routines were challenging, both men and women reported being more home-based, one participant stating that *"when the pandemic hit, the gyms closed and I tried to do some in the house but just didn't really work out (P.11, Female, 30-40, Pre-Interview)"*, and another mentioning that *"I have been a member of the University of Glasgow gym and I would go there maybe twice a* *week. That kind of stopped, obviously because of the COVID lockdown and we couldn't go (P.07, Male, Over 50, Pre-Interview)"*. Additionally, financial constraints affected their ability to afford gym memberships and personal training, as reported by one participant *"So I stopped working with them, just through finances (P.03, Male, 30-40, Pre-Interview)"*.

3.4.1.3 Overall health benefits motivations

Most participants reported overall health benefits were the main reasons for doing physical activity. Participants highlighted several health benefits both physically and psychologically well-being, as including *"keep myself supple (P.01, Female, Over 50, Pre-Interview)", "keep fit and to keep active (P.07, Male, Over 50, Pre-Interview) "good for my health (P.03, Male, 30-40, Pre-Interview)" and "make myself healthier and get myself fitter and better and a bit more confident (P.11, Female, 30-40, Pre-Interview)"*

There are others reasons for doing exercise mentioned, specifically with resistance exercise that it helped maintain strength, with one person stating, *"I did it because I felt strong afterwards, I enjoyed doing it (P.02, Male, 30-40, Pre-Interview)"*, and prevent diseases, with another person mentioning, *"I think I know that resistance exercises help you with some diseases like osteoporosis, things like that, so that's why I've built those exercises into my routine. (P.05, Female, Over 50, Pre-Interview)"*.

3.4.1.4 Weight loss motivations

Many participants reported different physical activity types to help with weight loss as *"walking (P.03, Male, 30-40, Pre-Interview)" "playing football (P.04, Male, 30-40, Pre-Interview)"* and *"cycling (P.05, Female, over 50, Pre-Interview)"*. However, one woman spoke specifically about frustration with certain type of physical activity for losing weight stating that *"The aerobics frustrating, because I can't tell my left from my right (P.10, Female, 30-40, Pre-Interview)"*.

Overall, the participants demonstrated a range of reasons for engaging in physical activity and resistance training exercises. A common reason was weight loss:

"I know that you can use resistance training to help with weight loss in terms of converting fat to muscle and various other bits like that. So, you might not lose mass, but you can lose body fat (P.02, Male, 30-40, Pre-Interview)"

"So my aim is to try and get rid of the weight obviously (P.06, Female, 30-40, Pre-Interview)".

3.4.1.5 Reasons for joining the resistance exerices study

Participants also reported a number of reasons to join the study. One person reported being motivated for the structured research to try resistance exercise *"I'm willing to try resistance exercises, I think because it was part of a study, I was motivated to do it (P.01, Female, Over 50, Pre-Interview)"*.

Another participant reported limited knowledge and uncertainty, and seeking guidance about the resistance exercises which made her want to join up *"Because I think I don't quite know the right exercises that I need, and that's why I want to do your study (P.05, Female, Over 50, Pre-Interview)"*.

Others talked about the fact that they had a realisation that joining the study and the resistance exercise programme might help with weight loss as well as wanting building strength:

"I've been actively trying to lose the weight that I've put on. And now what I need to do…now that I've kind of got the eating under control, I now need to look at

exercise and I now need to try and do a wee bit more exercise to try and kind of marry the two in together (P.11, Female, 30-40, Pre-Interview)".

"I'm just wanting to build myself back up again (P.09, Female, Over 50, Pre-Interview)".

3.4.1.6 Physical activity identity

Before starting the programme, many participants had a relatively positive physical activity identity and described themselves in ways that indicated an active lifestyle. For example, some participants identified themselves as *"fit and healthy (P.09, Female, Over 50, Pre-Interview)",* However, some participants, particularly women, spoke specifically about hesitancy towards the gym:

"I'm not a fan of the gym… I do a little bit of walking, I don't mind (P.01, Female, Over 50, Pre-Interview)"

3.4.2 Perceptions, preferences and anticipations of resistance exercise training

This theme explores participants' preferences, prior experience and intentions about resistance exercise training before starting the programme.

3.4.2.1 Perceived benefits of resistance exercise

Participants (both men and women), reported perceptions about resistance exercise and its specific benefits on physical improvements and body changes. Many participants pointed out the need of building muscle strength for enhanced flexibility and prevent injuries:

"To build up the muscle.. I want the muscles, but also I believe it can prevent, what's that thing called, loose skin.. I think that it might help my flexibility and prevent injuries (P.10, Female, 30-40, Pre-Interview)"

Other participants noted the body toning benefit:

"What I've noticed is, it's not so much the weight loss with the resistance training, I would say it's better tone and things like that (P.09, Female, Over 50, Pre-Interview)".

3.4.2.2 Understanding the relationship between resistance exercise and diet

Many participants recognised the importance of combining resistance exercises with a healthy diet for losing weight:

"I don't think it's good enough on its own. I think, any time I've lost weight, you have to do the diet as well. So they both go hand in hand (P.03, Male, 30-40, Post-Interview)"

3.4.2.3 Preferences and accessibility of resistance exercise

Most participants reported preferences with resistance exercises:

" I eventually moved to the kind of free weights, I was doing, like, dead lifts, and presses, so that's been great. So I was doing, kind of, free weights at home, and doing some kind of body weight exercises. I've been doing, kind of push-ups and lats (P.03, Male, 30-40, Pre-Interview)"

Before starting the programme, many participants also talked about various equipment options they use for performing resistance exercise training as *"I've used dumb-bells, yeah (P.03, Male, 30-40, Pre-Interview)", "I have two weights, dumbbells (P.10, Female, 30-40, Pre-Interview)".*

3.4.2.4 Initial responses to the resistance exercise programme

After the resistance exercises were initially demonstrated to them, both men and women participants assessed the exercises programme positively stating that *"Yeah, they're fine, they're all simple, achievable, yeah (P.02, Male, 30-40, Pre-Interview)"* and reported feeling the effects of trying out the different exercises themselves:

"It's a different exercise. Oh, yeah. Feel that, actually. Yeah, I can feel that actually (P.06, Female, 30-40, Pre-Interview)"

However, gender differences were noticed in participants' confidence level of the resistance exercises. Male participants appeared confident about trying the exercises with greater self-efficacy. For example, one man stated that *"I can do one, yeah. I can do a press up (P.07, Male, Over 50, Pre-Interview)"* when exercises demonstrated. Female participants on the other hand reported difficulties or challenges when initially trying exercises:

"Probably do the wall one in case I fall and bash my teeth or something in the kitchen (P.06, Female, 30-40, Pre-Interview)"

3.4.2.5 Intentions and expectations of the resistance training programme

Despite some initial challenges, most participants showed a positive anticipation regarding starting the home-based resistance exercise training programme:

"Excellent, I'm looking forward to starting. No questions at all, that'll be good, and I'm eager to get started, so I'll start tomorrow morning (P.01, Female, Over 50, Pre-Interview)"

Indeed, men and women expressed that how they would incorporate the exercises into their daily routines:

"I think that'll fit into my normal morning routine very well, and they look quite fun, so I'd be happy to do even twice during the week and at the weekend (P.01, Female, Over 50, Pre-Interview)"

3.4.3 Engagement and experiences of resistance exercise training

This theme describes how participants engaged with the resistance exercise programme, including when and where they exercised, the challenges they had, and their overall experience during the home-based programme.

3.4.3.1 Exercise engagement

During the programme, all participants did their resistance exercises at different times and different locations. Timing of exercises varied among participants based on their schedule:

"I would do them either…they would be quite random. If I got up early and I had time, I would do them. If I didn't have time, I would do them at night (P.09, Female, Over 50, Post-Interview)"

After completing the home-based programme, many participants reported how the exercises easily fitted within daily routine and performing the resistance exercises as part of their activities:

"I have been doing them during my morning routine when I get up in the morning. I've been doing them Monday to Friday when I get up to go to work (P.01, Female, Over 50, Post-Interview)".

Some participants exceeded the recommended frequency:

"I think I did more than I was supposed to on. Yeah, it's good (P.07, Male, Over 50, Post-Interview)".

In terms of exercise location, all participants did the resistance exercises at home in different spaces. Men mainly chose to exercise in spaces like garages or offices: *"Actually in my garage at home mostly (P.07, Male, Over 50, Post-Interview)"*. On the other hand women commonly used living areas: *" In my living room in the morning, basically because it's away from…our bedrooms are upstairs (P.01, Female, Over 50, Post-Interview).*

3.4.3.2 Challenges

Many participants (both men and women) described difficulties with some specific exercises. For example, push ups were most challenging:

"Yeah, the push-up is most…harder (P.04, Male, 30-40, Post-Interview)"

Also, the lunges were an issue for some:

"Yeah, I really hate lunges. Because they're so sore. the lunges were horrible (P.11, Female, 30-40, Post-Interview)"

Both men and women reported general challenges that were not related to particular exercises. They found that motivation was a major concern:

"What's really hard is the motivation to do them. I was quite often forgetting to do them, because if you've got a really busy day you then just go, right I've finished my day now, and then you kind of forget (P.02, Male, 30-40, Post-Interview)".

They found also that selecting the best option or type of the bands for the exercises was difficult:

"the only thing was just trying to get what band was suitable for what exercise (P.11, Female, 30-40, Post-Interview)".

3.4.3.3 Adjustment and adaptations

Although with these challenges, both men and women reported some adjustments and found ways to continue performing the exercises:

"I had to figure out some of my own exercises for some physiotherapy for my hip, I have a chronic hip problem, and I used the bands to do that. So they were useful for other exercises as well (P.07, Male, Over 50, Post-Interview)".

3.4.3.4 Convenience and accessibility

Most participants expressed satisfaction with convenience of the resistance exercises showing the ability to exercise at home with minimal equipment:

"I liked the fact it didn't take up much space. I could do it in my jeans and t-shirt as opposed to getting into sports gear (P.02, Male, 30-40, Post-Interview)"

Although couple of female participants used their own weights or even household objects instead of the bands *"I didn't use the bands. I found I could do better with cans (P.08, Female, Over 50, Post-Interview)"*, overall most participants highlighted the positive effect of using the bands as an accessible alternative for doing the home-based resistance exercise programme:

"Yeah, I think the bands are good instruments, they're good at what they do (P.02, Male, 30-40, Post-Interview)"

3.4.4 Overall impact of the resistance exercise programme

This theme describes the overall effects of the resistance exercise programme on participants, including physical, psychological and lifestyle changes, as well as the benefits and barriers as a result of taking part in the programme.

3.4.4.1 Benefits of resistance exercise

3.4.4.1.1 Physical benefits

Most participants reported a beneficial impact from doing the resistance exercise programme. For example, some participants reported gaining strength and physical changes as primary benefits:

"Well, I do feel as if I've gained a little bit of strength, and I do feel as if I've trimmed a little bit (P.01, Female, Over 50, Post-Interview)"

One woman highlighted how resistance exercises could specifically improve body shape stating that *"I think my body shape will change a lot more doing these as well rather than the aerobics is obviously all cardio but I think I'll end up…I think by doing these resistance I'll have a…I'll tone up a lot more (P.10, Female, 30-40, Post-Interview)"*.

Overall, both men and women felt resistance exercises were a valuable tool and may promote positive changes beyond weight loss, including metabolic and long-term health:

"I mean good resistance exercises, it's fine for obviously muscles in terms of having muscle tone, muscle strength, that it's good for long-term sort of metabolic reasons (P.02, Male, 30-40, Post-Interview)

3.4.4.1.2 Psychological benefits

Beyond physical changes, participants described how the programme influenced their lifestyles, enhanced positive feelings and sense of accomplishment:

"I enjoyed the feeling after, and the feeling of accomplishment when you've actually finished it… good, a positive feeling, yeah. And the only reason I say that is because I've stopped drinking since…since starting this (P.03, Male, 30-40, Post-Interview)"

3.4.4.1.3 Lifestyle benefits

A noteworthy finding was how the resistance exercise programme facilitated broader lifestyle modifications. Some participants reported that doing the exercises has encouraged them to change their diet and prompted dietary improvements:

"It's been good for me because it's focused my mind a little bit more, and like I say, I've associated the resistance for weight loss with diet as well, so it's made me implement a little change there. I think doing the resistance exercise, it's also made me more aware of my diet, because it's resistance for weight loss, and I've been more attuned to my diet (P.01, Female, Over 50, Post-Interview)"

"I've also noticed that it's made me eat better, because I know that a better diet helps with exercise (P.03, Male, 30-40, Post-Interview)"

3.4.4.1.4 Practical benefits

Participants valued the accessibility and convenience of the home-based programme:

"I like it, I personally like it because it's quick and easy, and you don't need to go to the gym (P.09, Female, Over 50, Post-Interview)"

3.4.4.2 Barriers to resistance exercise

3.4.4.2.1 Physical discomfort

However, some participants felt physical discomfort when doing the exercises, but it eased over time for both men and women:

"Obviously the first week or so that I did them, my body was sore because it's not used to doing it, and then it kind of eased off a bit, yeah, so (P.05, Female, Over 50, Post-Interview)".

3.4.4.2.2 Motivational and environmental barriers

One man spoke specifically about requiring external motivation to carry on the resistance exercises stating that *"sticking with it would be doing it with other people and having a structured time or somewhere you go to do it (P.02, Male, 30-40, Post-Interview)"*, and another woman reported some challenges, such as work stress, to keep going with the exercises stating that *"A bit more willpower, to be honest, I think… Oh, less stress at work. So in other words, a lot of factors I can't control (P.10, Female, 30-40, Post-Interview)"*

3.4.4.3 Continuing resistance exercise

By the end of the programme, many participants, despite the identified barriers, stated a clear intention and motivation to keep their resistance exercise routines:

"this has motivated me to keep doing it, even after the study. I'll still do the routine in the morning, because I think it's going to help me, I think I'll still do it every morning. I think the Monday to Friday will stick with me (P.01, Female, Over 50, Post-Interview)"

Some participants even planned to increase their exercise frequency:

"I think I will increase the times of the number of exercise per week. I will go to maybe three times a week (P.04, Male, 30-40, Post-Interview)"

Other participants reported that seeing benefits as weight loss results motivated them to continue with the home-based resistance exercises programme:

"I'm surprised, they're very good, I'll keep using them, yeah, I like them. it's easy to do, as I say, and also I'm seeing results in the weight loss, so it's motivating me to do it (P.05, Female, Over 50, Post-Interview)"

3.4.5 Changes in attitudes towards resistance exercise

An important finding of this study was the shift in participants' attitudes toward resistance exercise from pre- to post-intervention. The data revealed several aspects of attitude change throughout the programme.

3.4.5.1 Pre- and post programme perceptions

Before the intervention, there was an uncertainty, particularly among female participants, when describing the resistance exercises and gym machines. Some struggled to name the exercises despite having done them previously:

"using that machine where you pull down or you pull up, you know, I don't know what it's called (P.05, Female, Over 50, Pre-Interview)"

This uncertainty contrasted with their post-intervention confidence and familiarity:

"I used mostly the bands. I used to go to the gym, with the pull down machine or pull up machine, but I think the bands are similar to that machine, and cheaper and obviously easier to use, I would say it was even harder than the level that I

would use on that machine. I'm surprised, they're very good, I'll keep using them, yeah, I like them (P.05, Female, Over 50, Post-Interview)".

3.4.5.2 From fear to confidence

Pre-intervention, women in particular showed concern about their ability to perform certain exercises:

"A full push up, I know I can do them on my knees, not a full push up. I struggled (P.01, Female, Over 50, Pre-Interview)"

By the end of the programme, while some exercises remained challenging, participants demonstrated increased confidence in their overall ability to engage with resistance exercise training:

"it was good. It was good. And it increased my ability to do more exercises. Yeah. I'm trying to reduce actually, not my whole body weight, but I'm trying to reduce the tummy, you know, But it was good. It was good (P.04, Male, 30-40, Post-Interview)".

3.4.5.3 From anticipation to satisfaction

Before beginning the programme, all participants were optimistic about the potential benefits:

"I'm so excited to do them, I'm excited to see the difference… I'm more excited about seeing the progression. Yeah, I'm up for this. I'm ready to get started (P.11, Female, 30-40, Pre-Interview)"

After completing the programme, this anticipation turned into experienced satisfaction with actual effects:

"I think just from going from doing no exercise at all to starting to do exercise and then the kind of motivation kicked in a little bit, and then you start to look

forward to it a bit because you realise how good you feel afterwards (P.11, Female, 30-40, Post-Interview)"

3.4.6 Theory of change for future resistance exercise interventions

The study indicates the importance of enjoyment, accessibility, and the inclusion of resistance exercises with dietary changes to achieve overall health improvements. Many barriers were identified to resistance exercises, particularly concerns about gym and financial constraints, highlighting the importance of designing alternative programmes that are inclusive, supportive, and adaptable. The home-based resistance exercise programme demonstrated that simple and easy approaches can address these barriers to participation. It was noted that all participants, regardless of gender, demonstrated engagement with the home-based resistance exercise programme due to its multiple benefits including strength gains, weight loss, and toning and improved body shape. The combination of these physical improvements and the convenience of the home-based exercises reported by participants, particularly using resistance bands, appeared to be important factors for adherence, indicating that future interventions should focus on convenience, limited equipment, and flexibility. The programme's impact extended beyond physical changes, with participants reporting intentions to continue resistance training after the programme's completion and greater motivation to maintain regular physical activity. It is therefore necessary for future interventions to focus on developing accessible, enjoyable, and supportive resistance exercise training programme that emphasise the overall benefits of resistance exercises. By using this approach, weight loss interventions involving simple and easy resistance exercise may be motivating, and ultimately effective for people living with overweight or obesity (see Figure **3-2** below theory of change diagram for future resistance exercise interventions).

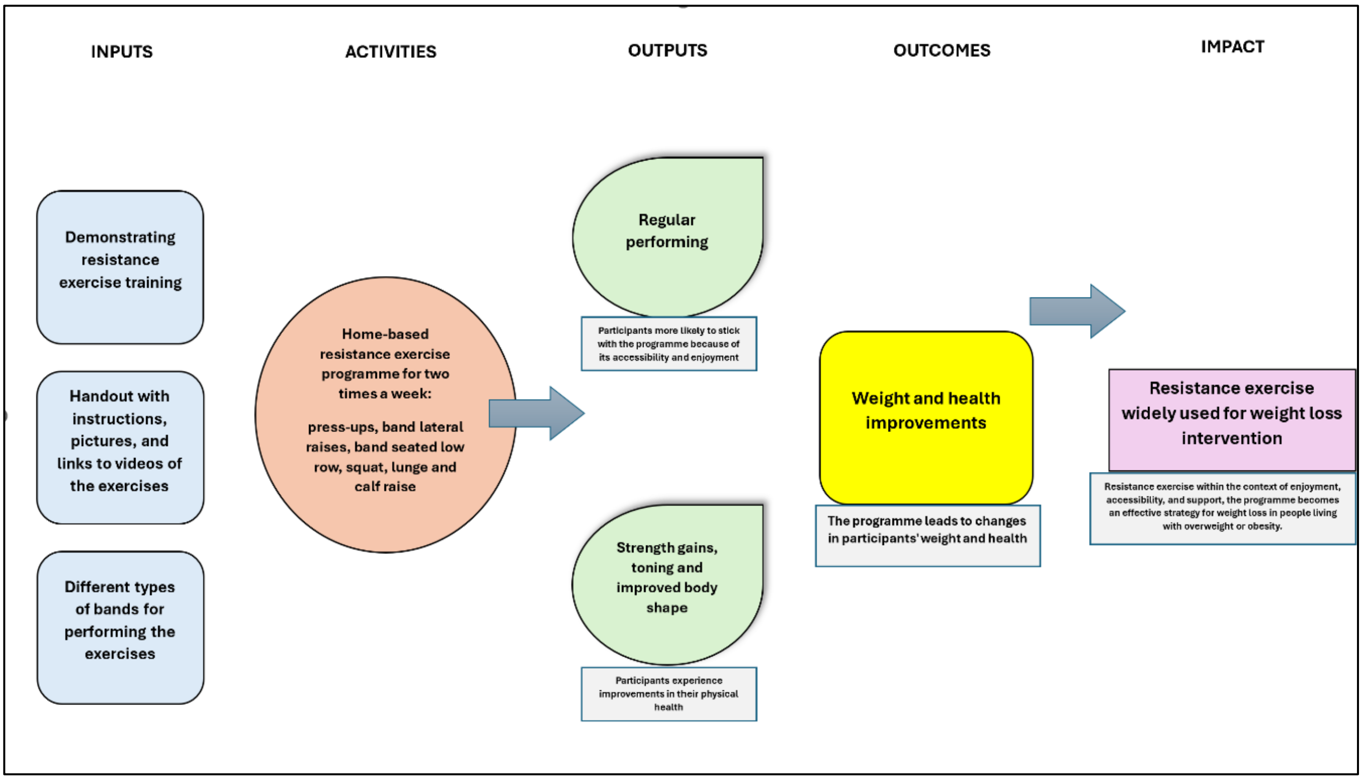


Figure 3-2 Theory of change for future resistance exercise interventions

3.5 Discussion

This qualitative study explored the perceptions and experiences of resistance training in people living with overweight or obesity and trying to lose weight. Participants reported engaging in a range of physical activities before the beginning of the programme, influenced by barriers such as financial constraints, limited access to facilities and the pandemic. There were also several reasons why participants joined the programme, including weight loss, health benefits, and the appeal of trying resistance exercises within a structured research study. Changes in attitudes towards resistance exercise were demonstrated, which can inform future interventions.

Participants reported a number of barriers to physical activity and resistance training, including access to facilities and financial constraints. Although these results are consistent with previous research that has highlighted factors that may limit exercise participation among people living with overweight or obesity (Trost et al., 2002), studies exploring barriers to resistance exercise during weight loss is limited. Previous research have investigated barriers to resistance exercise training in the general population (Burton et al., 2017), but few have focused on the challenges that people have through resistance exercise and seeking to lose weight. During the COVID-19 pandemic, limited access to exercise facilities emphasised these barriers, causing a decrease in physical activity levels and leading to an increase in sedentary behaviour (Stockwell et al., 2021). Financial constraints also considered a significant barrier, with participants highlighting the expenses associated with gym memberships and exercise equipment, in line with similar findings in previous study research exploring exercise barriers among people living with overweight or obesity (Lim et al., 2019, Zevin et al., 2019). Therefore, the findings contribute to understanding these challenges of implementing resistance exercise training programmes during weight loss in people living with overweight or obesity.

Prior to the programme, participants reported they had a positive identity regarding physical activity, seeing themselves as healthy, fit, or interested in fitness. Although participants had difficulties at the beginning of the programme with some exercises, they had a positive physical activity attitude towards doing resistance exercises. This positive self-perception can be vital to exercise adherence and behavioural changes in the long term (André et al., 2024, Oyserman et al., 2007). However, some participants stated discomfort in gym environments emphasising the need for alternative exercise settings such as home-based programmes. This preference for home-based is consistent with previous research on exercise preferences in people living with overweight or obesity (Oppert et al., 2021, Guess, 2012).

Many participants reported several reasons for joining the study, including weight loss, health benefits, and interest in resistance exercises. These motivations are in line with the Health Belief Model, which states that people are more likely to engage in health behaviours when they perceive potential benefits (Rosenstock et al., 1988). It is also possible that the structured nature of the study programme served as an additional motivator, providing participants a straightforward, simple and easy resistance exercises. Resistance exercise training has been shown to have a positive impact on metabolism and body composition and strength (Westcott, 2012). The participants' acknowledged these benefits, particularly in terms of weight loss, muscle strength, and body tone changes, demonstrated their understanding of the role of resistance training in weight management. The benefits reported beyond weight loss by participants, including mood and lifestyle changes, are in line with growing evidence on the psychological benefits of resistance training (Gordon et al., 2018). These improvements appeared to contribute to participants' overall positive experience with the programme.

Participants' understanding of the importance of combining exercise with a healthy diet reflects current evidence-based guidelines for weight management (Jensen et al., 2014). Throughout the programme, participants became more aware of nutrition and changed their eating habits, which illustrates the potential benefits that can be achieved by combining resistance exercise training with dietary interventions. In the study, both men and women were able to adapt well to the programme exercise routine, finding the ease of exercising without specialised equipment or specific exercise areas. This positive response to the home-based resistance training programme is encouraging, as it addresses common barriers to resistance exercise and may increase long-term adherence (Burton et al., 2017). Using resistance bands during the programme also provides flexibility and convenience, suggesting that they could be an effective component of future weight loss interventions for people living with overweight or obesity.

There were gender differences in confidence and ability to perform particular exercises. Male participants appeared confident about trying the exercises, while female participants reported difficulties or challenges when initially trying them. This is in line with previous research which found women expressed greater concerns about correct techniques when beginning resistance exercise training (Hurley et al., 2018). It is essential that future resistance exercise training programmes be adapted to individual needs and preferences, as well as addressing gender-specific barriers and concerns (Salvatore and Marecek, 2010). Participants' desire to continue performing resistance exercise following the programme completion indicates successful behaviour change. Participants stated plans to continue performing resistance exercise were often linked to their positive experiences and perceived benefits during the programme. If this stated intention is followed through in practice, this would be a very positive outcome as continuous engagement is important for long-term weight management and health improvements (MacLean et al., 2015).

The findings suggest that future resistance training interventions should focus on convenience and accessibility. Home-based resistance exercises programmes, using minimal equipment like resistance bands, appear to be well-received and may overcome barriers to participation. It is also worth noting the enjoyable aspects of resistance training, highlighting the ease of the programme as well as positive experiences may enhance long-term adherence (Rhodes and Kates, 2015). Designing supportive and adaptable programmes that emphasise the overall benefits of resistance exercise, weight loss and overall health increase motivation and adherence for participants and lead to successful weight management outcomes (Teixeira et al., 2015). Furthermore, future resistance exercise programmes for weight loss should focus on integrating resistance training with dietary guidance, which can maximise weight loss and health benefits (Clark, 2015). Indeed, research has shown that multi-component interventions are more effective for weight loss and maintenance than single-component interventions (Johns et al., 2014).

This study has several limitations that should be addressed in future research. A limitation of this study was the lack of formal adherence monitoring for the resistance exercise programme. While participants self-reported their engagement with the exercises during post-intervention interviews, no objective measures were used to verify compliance. Future research combining qualitative explorations with more rigorous adherence monitoring would strengthen the ability to connect participants' experiences with their actual engagement levels. Demand characteristics could have influenced the results of this study (Orne, 2017). Participants were aware that they were taking part in a research study examining resistance exercise training, which may have led them to report more positive experiences or greater adherence than occurred. This is a common challenge in interview-based research, particularly when participants interact with the same researcher who delivered the intervention and conducted the interviews. Despite efforts to create a receptive interview environment and ask open-ended questions, participants may have felt pressured to provide positive responses about the programme. Future research could address this limitation by conducting interviews with fieldworkers/independent researchers who had not been involved in delivery of the intervention.

Although the small sample size was suitable for qualitative analysis, it should be highlighted that the interviews were brief (10-20 minutes). Despite interviews being shorter than typical qualitative interviews, the analysis can still be considered rigorous for several reasons: 1) the focus of the study questions, 2) using a structured thematic analysis framework, 3) the pre- and post-intervention design giving comparison data points and 4) multiple researchers engaged in the coding process. Nevertheless, the short duration limited the depth of analysis possible for each topic, and future research would benefit from longer interviews that allowed for a more detailed investigation of participants' experiences. The sample in this study was relatively homogeneous, with a majority of participants having a high education level (63.7% with postgraduate degrees) and most being married (63.6%). This homogeneity is essential to acknowledge because several participants mentioned financial constraints as barriers, suggesting that socioeconomic factors may influence resistance exercise participation. Furthermore, there were gender differences in confidence levels and exercise preferences, indicating that demographic factors influence resistance exercise experiences. Future studies therefore should incorporate participants from a variety of demographic and socioeconomic backgrounds to examine how these factors may impact barriers, adherence and preferences to resistance training programmes, to provide a more comprehensive understanding of resistance training experiences in people living with overweight or obesity. Additionally, long-term follow-up studies are needed to assess the sustainability of health improvements observed during the short-term intervention. Investigating the optimal duration, frequency, and intensity of resistance training programmes for this population would also be valuable in informing evidence-based guidelines.

In conclusion, this qualitative study provides valuable insights into the experiences and perceptions of resistance training among people living with overweight or obesity seeking to lose weight. The findings highlight the potential of home-based resistance training programmes to overcome common barriers to exercise participation. Future interventions should focus on creating accessible, enjoyable, and supportive resistance exercise programmes that emphasise the overall benefits of resistance training while addressing individual needs and preferences. Incorporating these suggestions in weight loss interventions involving resistance exercise may be more motivating and effective for people living with overweight or obesity, ultimately contributing to improved health outcomes and quality of life.

These findings informed the development of a randomised controlled pilot trial, presented in the next chapter, which examines the effects of a home-based resistance training programme on body composition and muscle function during weight loss in people living with overweight or obesity.

Chapter 4 The effects of a home-based resistance training programme on body composition and muscle function during weight loss in people living with overweight or obesity: a randomised controlled pilot trial

4.1 Abstract

4.1.1 Background

Dietary interventions can be effective at reducing body mass and improving cardiovascular risk factors, but they also result in undesirable losses of lean tissue, highlighting the need for strategies that preserve muscle mass during weight loss. The aim of this randomised controlled trial was to investigate the effects of a home-based resistance training exercise programme on body composition and muscle function in people living with overweight or obesity undergoing dietary weight loss.

4.1.2 Methods

Participants (n=48, age=39 (11) years, BMI=30.1 (5.5) kg/m^2, body mass=86.7 (17.5) kg) from Glasgow were randomly assigned to either a diet-induced weight loss group (WL) or a diet plus home-based resistance training exercise group (RT+WL) for 12-weeks. Both groups were following the same dietary weight loss programme while participants in the RT+WL group included performing a home-based resistance exercise programme. Measures of body composition, muscle strength, and physical function were assessed at baseline and post-intervention.

4.1.3 Results

There was no effect of the resistance exercise training programme (all $p > .05$) on body composition (body mass index, total body mass, fat mass, fat free mass, muscle thickness) during weight loss. However, the resistance training group showed improvements in muscle and physical function, compared to the diet-induced weight loss group. These included higher grip strength (RT+WL: Δ2.65, 95% CI: 0.44, 4.86; WL: Δ-0.26, 95% CI: -2.04, 1.51:p=0.046), maximal voluntary

contraction force (RT+WL:Δ23.61, 95% CI: 3.39, 43.84 WL: Δ-11.95, 95% CI: -35.37, 11.48;$p=0.019$), and sit-to-stand test scores (RT+WL:Δ5.9, 95% CI: 4.27, 7.53 WL: Δ1.47, 95% CI: 0.13, 2.82; $p<0.001$).

4.1.4 Conclusions

These findings suggest that incorporating home-based resistance training into weight loss programmes can preserve, or even enhance, muscle function without negatively impacting the effectiveness of dietary weight loss interventions highlighting its potential to mitigate muscle function losses during weight loss in people living with overweight or obesity.

4.1.5 Trial registration

Name of the registry: ClinicalTrials.gov

The registration number: NCT05702840.

Date of Registry: 18/01/2023.

The registration title: EXerCise wEight Loss (EXCEL).

4.2 Introduction

Obesity continues to grow as a public health concern and is associated with an increased risk of morbidity and mortality, and greater health and social care costs (Upadhyay et al., 2018). For example, obesity increases the risk of a range of chronic diseases, such as hypertension, type 2 diabetes, coronary heart disease, dyslipidaemia and certain cancers (An et al., 2018). The prevalence of obesity continues to rise across regions the world especially in the Middle East, Central and Eastern Europe and North America, with the global burden highest in adults (between 45 to 59 years of age) and women (James et al., 2001, Siervo et al., 2014). Dietary interventions are a mainstay of the treatment of obesity, and a recent systematic review and meta analysis has shown they result in significant weight loss of around 4-5 kg on average (Ge et al., 2020). This level of weight loss results in improvements in cardiovascular risk factors such as blood pressure, LDL and HDL cholesterol and glycaemic control (Ge et al., 2020). Furthermore, larger levels of weight loss (~10kg) via more intense dietary intervention, have been shown to result in remission of diabetes in almost half of participants (Lean et al., 2018).

Whilst these benefits are a major positive, one of the less desirable consequences of weight loss is the concomitant loss of lean tissue (which is a marker of muscle mass). Indeed around ~20-30% of the weight lost is fat free mass, with a recent meta-analysis showing that weight loss is associated with a loss of fat free mass of ~1.3 kg on average (Cava et al., 2017, Enriquez Guerrero et al., 2021, Pellegrini et al., 2020). This is important as skeletal muscle has both functional and metabolic roles (Wolfe, 2006), with low muscle mass/strength recognised as a contributing factor to cardiometabolic and other obesity-related diseases (Sajoux et al., 2019) and being associated with higher mortality and morbidity (Cava et al., 2017). Although muscle mass and strength are generally higher in people with overweight/obesity (Tomlinson et al., 2016), to maximise the benefits of weight loss it is optimal to retain muscle mass and strength as much as possible, and effective strategies are needed.

The most effective lifestyle method to increase or maintain muscle mass is resistance exercise (Westcott, 2012) which has been shown to be effective in not only increasing muscle mass and strength but also improving blood lipids and glycaemic control, reducing blood pressure and increasing cardiorespiratory fitness in a variety of populations (Ashton et al., 2020, Cornelissen et al., 2011). As demonstrated in the systematic review and meta analysis presented in Chapter 2 of this thesis, there is also evidence that during weight loss resistance exercise can attenuate the decline in fat free mass, augment fat loss and increase muscle strength. Thus far, studies of resistance exercise interventions have been primarily in supervised settings using traditional weight training machines or free weights, which can limit accessibility and thus scaling up. The number of people regularly taking part in resistance exercise is low (Strain et al., 2016) and several studies have reported barriers. For example, research with college women found that barriers included perceived lack of time, not feeling comfortable in the gym, as well as lack of knowledge regarding the use of free weights and other forms of resistance exercise (Hurley et al., 2018, Peters et al., 2019). A systematic review reported that barriers to participation in resistance exercise for older adults include safety, fear, fatigue, health concerns, pain, and lack of social support (Burton et al., 2017, Cavill and Foster, 2018). Another recent study found that 68%

of adults with obesity reported difficulty accessing gym facilities and discomfort in public exercise settings (Schvey et al., 2017). It has also been recently demonstrated that the COVID-19 pandemic has further emphasised the need for accessible, home-based exercise options (Nyenhuis et al., 2020, Kaur et al., 2020).

One potential strategy to increase accessibility is to develop interventions based on simple resistance exercises with minimal equipment that can be carried out at home. As shown in Chapter 3 of this thesis, the qualitative analysis revealed that home-based resistance exercise training is acceptable and feasible for people living with overweight or obesity, with participants highlighting the convenience and comfort of exercising from home. To date, such interventions have not been investigated in adults living with overweight or obesity during a weight loss programme, and so the aim of the current study, therefore, is to investigate the effects of home-based resistance exercise programme on body composition and muscle function during weight loss in people living with overweight or obesity.

4.3 Methods

This study is reported following the Consolidated Standards of Reporting Trials (CONSORT) Checklist (Schulz et al., 2010) (see Appendix 4-A) and registered on ClinicalTrials.gov (registration number: NCT05702840, date of registration January 18, 2023).

4.3.1 Study design

This study was a 12-week, parallel group pilot randomised controlled trial with participants randomly assigned (1:1) to either 1) diet induced weight loss (WL) or 2) diet induced weight loss plus home-based resistance training (RT+WL). The study was approved by the College of Medical Veterinary and Life Sciences Ethics Committee at the University of Glasgow (Project No: 200220112) and all participants provided written informed consent.

4.3.2 Sample size

The current study is a pilot study and so no formal sample size calculation was carried out. The aim was to recruit 50 participants, which is within the recommended range of sample size for pilot studies (Whitehead et al., 2016) and would allow us to detect a 0.8 SD difference in outcomes (power 80%, alpha = 0.05). Based on the systematic review and meta-analysis presented in Chapter 2, this effect size is broadly consistent with the observed effects of resistance exercise during weight loss, where fat free mass showed an SMD of 0.40 and fat mass showed an SMD of -0.36. Although pilot studies are primarily designed to assess feasibility rather than definitively examine efficacy, this sample size has enough power to detect effect sizes comparable to those reported, although smaller effect sizes may be expected in the current study due to the nature of the resistance exercise.

4.3.3 Participants

Participants were recruited from in and around Glasgow by leaving posters and/or flyers at various public places and advertising the study online on social media platforms, such as Facebook and X, from February 2023 to December 2023. Inclusion criteria were: Body mass index (BMI) ≥ 25kg/m^2; aged 18-65 years; and passing the Physical Activity Readiness Questionnaire (PAR-Q+) (Warburton et al., 2011). Exclusion criteria were: currently taking part in more than 1.5 hours of structured exercise per week; having recently (<6 months) taken part in any resistance exercise training; taking any medications known to affect weight loss; being actively engaged in a weight loss programme; having lost more than 2kg weight in the last 6 months; and any other reason that would limit ability to perform the exercises and outcome measurements safely. As this study focused was on structured exercise participation, general physical activity levels (such walking for transportation or occupational activity) were not considered as exclusion criteria.

4.3.4 Randomisation

Randomisation was conducted upon completion of baseline measurements by an independent researcher using opaque envelopes that were numbered and sealed

(Friedman et al., 2015), with participants randomised to either the RT+WL group or WL group.

4.3.5 Interventions

4.3.5.1 Weight loss

All participants were provided access to the Weight Watchers weight loss programme for a 12-week period. Weight Watchers is a commercially available programme (Gudzune et al., 2015) that uses a science-based Points system to create a calorie deficit for weight loss. The programme assigns points to foods and beverages depending on their nutritional content, including calories, saturated fat, sugar and protein content (Johnston et al., 2014). Each participant is given a personalised daily Points budget depending on their individual characteristics (age, gender, height, weight and activity level), with the goal of creating an energy deficit to achieve weight loss of 0.5-0.9 kg per week (Johnston et al., 2014). Over 300 ZeroPoint foods, including fruits, vegetables, lean proteins and whole grains are available to Weight Watchers participants without the need to measure their intake (Gudzune et al., 2015). In addition, participants gain weekly bonus Points for flexibility. Rather than providing specific meals, the programme allows participants to select their own foods within their Points allocation, encouraging long-term dietary behaviour changes (Gudzune et al., 2015). Participants set an initial goal to lose 5kg of body mass over the 12 weeks. This approach was chosen to provide participants an achievable, clear goal that could easily understand and work towards, in accordance with clinical guidelines recommending weight loss for health benefits (Jensen et al., 2014). If 5kg weight loss was achieved, then the participant could choose further weight loss goals depending on their circumstances and preferences. The Weight Watchers programme provides a mobile app that allows participants to track their daily Points consumption, although formal adherence monitoring was not implemented in this study. The programme's effectiveness is supported by several research studies, with clinical trials showing Weight Watchers to be effective for weight loss (Tate et al., 2020, Ahern et al., 2011) .

4.3.5.2 Home based resistance training

Participants in the RT+WL group also received a resistance exercise booklet containing instructions for exercises and links to demonstration videos (see Appendix 4-B). A demonstration and explanation of the exercises were given face to face at the beginning of the intervention, alongside a discussion of the principles of the programme including starting level and progression. We asked participants to perform the resistance exercises three times a week throughout the 12-week period. This frequency was increased from the twice-weekly protocol used in the qualitative study (Chapter 3) based on established resistance training exercise guidelines recommending two to three times per week in an attempt to maximise strength and muscle mass adaptations (American College of Sports, 2009), and to align with the longer intervention duration (12 weeks vs 4 weeks) which could accommodate a higher training frequency. Participants were asked to perform three sets of each exercise, with the goal of reaching a Rating of Perceived Exertion (RPE) of between 8-10 (on a scale of 1-10, where 10 represents maximal effort) for each set. In order to build up intensity slowly, participants were asked to target a lower RPE of 4-6 during the first week (Lagally and Robertson, 2006). The exercises included were press-ups, band lateral raises, band seated low rows, squats, lunges and calf raises, with different levels depending on participants' baseline abilities and to allow progression. No formal adherence monitoring was implemented for the home-based resistance exercise intervention.

4.3.6 Outcomes Measures

Prior to the start of the intervention, height, blood pressure and heart rate were measured. At baseline and after the 12-week intervention period, the following outcomes were measured: body mass, body composition, muscle strength and physical function. Participants were asked to avoid strenuous exercise prior to the measurements, which were performed at the same time of day at each timepoint.

4.3.6.1 Body mass and composition

Body mass index (BMI) and composition were measured using scales and a Tanita TBF-300 bioelectrical impedance device to quantify fat mass and fat free mass (National Institutes of Health. Office of Medical Applications of Research, 1994). Participants were asked to remove all metal objects and shoes before measurement. However, other standardisation protocols, such as fasting requirements, hydration status control and measurement time were not adopted (Kyle et al., 2004). Vastus lateralis muscle thickness was also measured, as a measure of muscle size, using ultrasound as previously described (Ismail et al., 2019).

4.3.6.2 Muscle strength

Knee extensor maximal torque during a maximum voluntary contraction (MVC) was measured with participants strapped in a chair with their legs at a 90-degree angle. A strap was placed around the right ankle which was connected to a force transducer. Participants were asked to contract maximally with the leg fixed in position for 10 seconds. Participants performed three contractions, with 60 seconds rest between contractions, and if the 3rd contraction was >10% of the 2nd contraction, then a 4th contraction was performed. The highest value was used in the analysis. Grip strength was measured using a Jamar dynamometer, with participants asked to perform three maximal contractions in each hand. The highest value was used in the analysis.

4.3.6.3 Physical function

A 30-second sit-to-stand test (STS) was used to assess physical function. Participants were asked to sit in a chair with their hands crossed across their shoulders, rise to a full standing position, then sit back down again and repeat this for 30 seconds as quickly as they could. The number of full repetitions was recorded and used for analysis.

4.3.7 Statistical Analysis

Descriptive baseline characteristics of groups are presented as means and standard deviations (SD). Using SPSS 29.0.1.0, differences between the groups in 12-week outcomes were assessed using analysis of covariance (one-way ANCOVA) with baseline outcome included as a covariate. The outcome variable in the ANCOVA was the post-intervention (12-week) values for each measured outcome. Additional analyses were conducted including sex as a covariate to examine potential sex-related differences. Prior to analysis, tests of normality by Kolmogorov-Smirnov and assumptions for conducting one-way ANCOVA were assessed, with data meeting all necessary assumptions (Huitema, 2011). A comprehensive approach to normality testing was employed, using Kolmogorov-Smirnov for normality assessment of the data and Shapiro-Wilk for testing the standardised residuals from the ANCOVA. A p value of <0.05 was used to accept statistical significance. These assumptions include: (a) the covariate is linearly related to the dependent variable at each level of the independent variable, as assessed by visual inspection of a scatterplot; (b) there is homogeneity of regression slopes, as assessed by looking at the significancy interaction between the covariate and the independent variable; (c) the standardised residuals are normally distributed for each group of the independent variable, as assessed by the Shapiro-Wilk's test ($p > .05$); (d) there is homoscedasticity, as assessed by visual inspection of the standardised residuals plotted against the predicted values; (e) there is homogeneity of variance, as assessed by Levene's test ($p > .05$); and (f) there are no outliers, as assessed by no cases with standardised residuals greater than ±3 standard deviations.

A sub-group analysis was conducted to examine participants who achieved weight loss (≥5% of initial body weight), as recommended for weight loss interventions (Jensen et al., 2014). Descriptive statistics (means and standard deviations) were calculated for outcome measures in this sub-group, stratified by intervention group, due to the small sample size preventing formal statistical testing.

4.4 Results

From February to December 2023, a total of 48 participants were recruited and randomised. Of these, 39 individuals successfully completed the study (26 males and 13 females) (Figure 4-1).

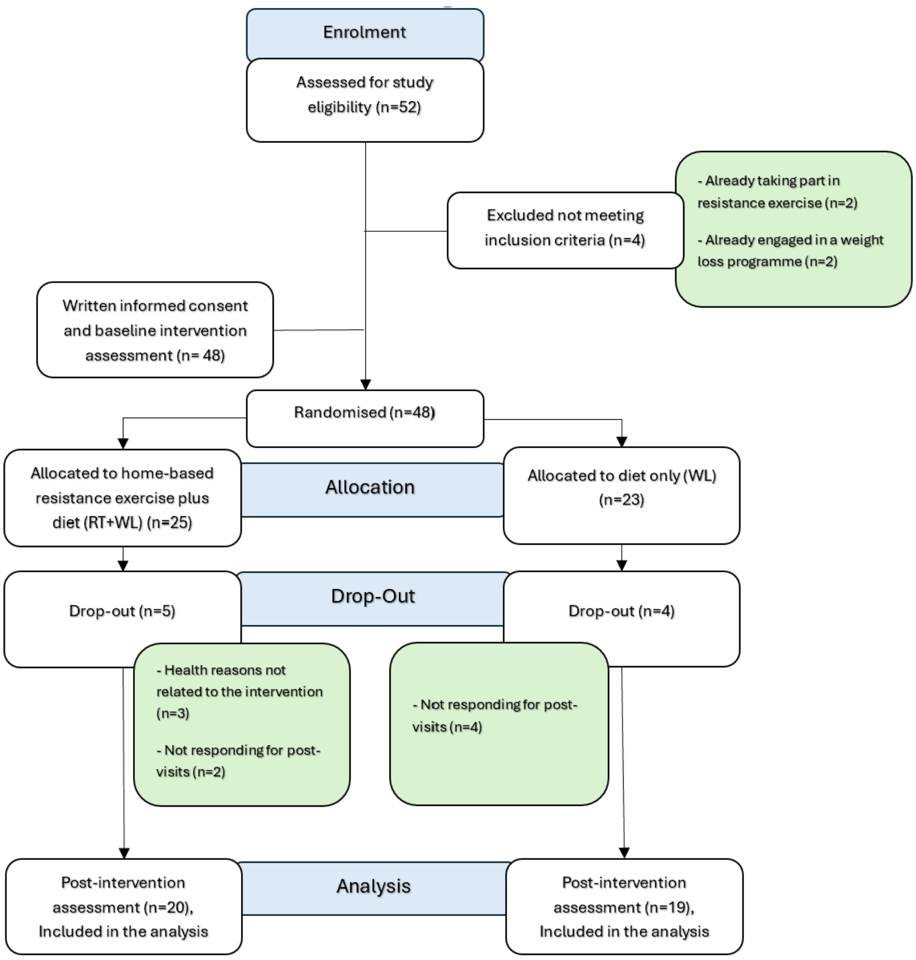


Figure 4-1 CONSORT diagram

Table 4-1 provides baseline demographics characteristics for all participants, completers and non-completers. There were no major differences between the groups, although the WL group were slightly younger and had a slightly higher proportion of female participants. The majority of participants were classified as overweight (BMI 25-29.9 kg/m^2), with 13 participants in both the RT+WL and WL groups. The remaining participants were classified as obese (BMI ≥30 kg/m^2): 7 participants in the RT+WL group and 6 participants in the WL group. Comparing completers and non-completers the majority of non-completers were female. Tests of normality and assumptions for conducting one-way ANCOVA are presented in Appendix 4-C. Briefly, all outcomes measured were normally distributed using Kolmogorov-Smirnov test ($p > .05$), and met all necessary assumptions provided in Appendix 4-C. No outliers were identified in the data, as assessed by standardised residuals not exceeding ±3 standard deviations.

Table 4-1 Baseline demographics characteristics.

	RT+WL group (n=20) completers	RT+WL group (n=5) non-completers	RT+WL group (n=25) all participants	WL group (n=19) completers	WL group (n=4) non-completers	WL group (n=23) all participants
Age	42 (11.76)	32 (12.55)	40 (12.15)	37 (8.74)	36 (16.47)	37 (9.99)
Sex	Male n=15 (75%)	Male n=1 (20%)	Male n=16 (64%)	Male n=11 (58%)	Male n=0 (0%)	Male n=11 (48%)
	Female n=5 (25%)	Female n=4 (80%)	Female n=9 (36%)	Female n=8 (42%)	Female n=4 (100%)	Female n=12 (52%)
Height (cm)	169 (8.14)	171 (12.07)	169 (8.79)	170 (10.13)	165 (5.59)	170 (9.65)
Systolic blood pressure (mmHg)	125 (13.83)	135 (15.42)	127 (14.57)	129 (16.04)	122 (16.87)	128 (16.03)
Diastolic blood pressure (mmHg)	77 (8.96)	87 (6.06)	79 (9.39)	79 (9.88)	81 (8.69)	80 (9.53)
Heart rate	77 (15.64)	85 (10.26)	79 (14.77)	77 (13.74)	86 (17.27)	79 (14.34)

Weight (kg)	85.2 (17.5)	96.3 (29.1)	87 (20.1)	86.9 (14.5)	77 (13.1)	85.2 (14.5)
[a]BMI (kg/m^2)	29.9 (6.2)	33.1 (9.9)	30.5 (6.9)	29.8 (3.6)	28.1 (2.9)	29.5 (3.5)
Fat mass (kg)	25.4 (13.4)	39.8 (23.7)	28.3 (16.4)	28.7 (9.6)	28.1 (10.1)	28.6 (9.4)
Fat percentage (%)	29 (10.2)	39 (11.9)	31 (11.1)	32.9 (9)	35.8 (6.9)	33.5 (8.6)
Fat free mass (kg)	59.8 (10.8)	56.6 (9.6)	59.2 (10.4)	58.2 (12.5)	48.9 (5.8)	56.6 (12)
Muscle thickness (mm)	24.4 (3.4)	23.9 (2.6)	24.4 (3.2)	25.7 (2.9)	27.2 (4.9)	25.9 (3.3)
Knee extensor maximal torque (N)	491.3 (79.8)	454.4 (82.6)	480.1(80.9)	492.8(75.1)	436.6 (107.4)	483 (81.7)
Grip strength (kg)	37 (8.8)	36.8 (13.3)	36.7 (9.4)	38.2 (9)	25.5 (9.6)	35.9 (10.1)
[b] STS (reps)	15.9 (3.9)	17 (4.2)	16 (3.9)	16 (2.7)	16.8 (2.2)	16.1 (2.6)

Continuous data are presented as mean (SD). Categorical data are presented as n= number of participants and percentage (%)

a. BMI: Body mass index
b. STS: 30-second sit-to-stand test.

4.4.1 Between-group differences in post-intervention outcomes

After the 12-week intervention period, there was no difference in BMI (p=0.642), body mass (p=0.822), fat mass (p=0.729), fat percentage (p=0.797), fat free mass (p=0.739) or muscle thickness (p=0.598) between the RT+WL and WL groups (Table 4-2). The ANCOVA revealed a significant difference in grip strength between the RT+WL and WL groups (p=.046), with a higher grip strength in the RT+WL compared to the WL group at 12 weeks. Resistance exercise training during weight loss also resulted in a higher knee extensor maximal torque in the RT+WL, compared to the WL, group at 12 weeks ($p=0.019$). Similarly at 12 weeks, there was a higher STS in the RT+WL, compared to the WL group ($p<0.001$). Muscle function and strength data are shown in Table 4-3. In additional analysis including sex as a covariate in the ANCOVA, there was no significant Group × Sex interaction ($p \geq 0.05$) for any outcome measure (Table 4-2 & Table 4-3), indicating that the resistance exercise intervention had similar effects in both men and women.

Sub-group analysis examined participants who achieved weight loss (≥5% of initial body weight). Only 7 participants (3 from RT+WL group, 4 from WL group) achieved ≥5% weight loss. These participants achieved similar weight loss (RT+WL: -7.6 ± 2.3 kg vs WL: -7.9 ± 3.8 kg). Descriptively comparing outcomes between groups, data shows that the RT+WL group have more favourable responses, compared to the WL group, in muscle thickness (+3.7 ± 3.5 mm vs -1.6 ± 1.7 mm), grip strength (+3.7 ± 10.0 kg vs -1.3 ± 4.2 kg), knee extensor maximal torque (-7.2 ± 49.0 N vs -27.4 ± 54.3 N) and STS (+6.3 ± 3.2 reps vs +1.5 ± 2.6 reps). However, no differences were found in other outcomes including BMI, body mass, fat mass, fat percentage and fat free mass.

Table 4-2 Differences in body mass and composition between groups before and after 12 weeks. Data are presented as mean (SD).

Outcome Variable	RT+WL group (n=20)			WL group (n=19)			[a]Post intervention mean difference (95% CI)	[b]P value	[c]Group x Sex
	Pre	Post	*Change (95% CI)	Pre	Post	*Change (95% CI)	RT+WL vs WL (ANCOVA)	(ANCOVA)	P value
[d]BMI (kg/m^2)	29.9 (6.2)	29 (5.6)	-0.9 (-1.33, -0.41)	29.8 (3.6)	28.8 (3.1)	-1 (-1.61, -0.39)	.14 (-.47, .75)	.642	.313
Body mass (kg)	85.2 (17.5)	82.8 (15.8)	-2.4 (-3.77, -1.13)	86.9 (14.5)	84.1 (13.9)	-2.8 (-4.63, -1.03)	.22 (-1.71, 2.15)	.822	.303
Fat mass (kg)	25.4 (13.4)	24.2 (12.4)	-1.2 (-2.48, 0.02)	28.7 (9.6)	26.8 (8.3)	-1.9 (-3.59, -0.29)	.31 (-1.49, 2.11)	.729	.256
Fat percentage (%)	29 (10.2)	28.4 (9.8)	-0.6 (-1.87, 0.68)	33 (9)	31.8 (8.4)	-1.2 (-2.44, 0.11)	.22 (-1.49, 1.94)	.797	.525
Fat free mass (kg)	59.8 (10.8)	58.6 (9.6)	-1.2 (-2.41, -0.03)	58.2 (12.5)	57.3 (11.9)	-0.9 (-1.62, -0.14)	-.21 (-1.45, 1.04)	.739	.918
Muscle thickness (mm)	24.4 (3.4)	24.3 (3.2)	-0.1 (-1.3, 1.15)	25.7 (2.9)	25 (3.7)	-0.7 (-1.75, 0.27)	.41 (-1.14, 1.95)	.598	.092

*Change data are presented as mean (95%) CI (lower, upper).

a. Adjusted mean differences for the post-outcome variable when controlling the pre outcome variable.
b. Significant difference for the ANCOVA test.
c. Not significant: The intervention works similarly for both sexes.
d. BMI: Body mass index.

Table 4-3 Differences in muscle function and strength between groups before and after 12 weeks. Data are presented as mean (SD).

Outcome Variable	RT+WL group (n=20)			WL group (n=19)			[a]Post intervention mean difference (95% CI)	[b]P value	[c]Group x Sex
	Pre	Post	*Change (95%CI)	Pre	Post	*Change (95%CI)	RT+WL vs WL (ANCOVA)	(ANCOVA)	P value
Knee extensor maximal torque (N)	491.3 (79.8)	514.9 (72.2)	23.6 (3.39, 43.84)	492.8 (75.1)	480.8 (86.9)	-12 (-35.37, 11.48)	35.35 (6.05, 64.65)	.019	.732
Grip strength (kg)	37 (8.8)	39.7 (9.5)	2.7 (0.44, 4.86)	38.1 (9)	37.9 (8.8)	-0.2 (-2.04, 1.51)	2.82 (.05, 5.58)	.046	.052
[d]STS (reps)	15.9 (3.9)	21.8 (4.9)	5.9 (4.27, 7.53)	16 (2.7)	17.5 (3.9)	1.5 (0.13, 2.82)	4.42 (2.35, 6.49)	<.001	.528

*Change data are presented as mean (95%) CI (lower, upper).

a. Adjusted mean differences for the post-outcome variable when controlling the pre outcome variable.
b. Significant difference for the ANCOVA test.
c. Not significant: The intervention works similarly for both sexes.
d. 30-second sit-to-stand test.

4.5 Discussion

The current study aimed to investigate the effects of a home-based resistance exercise training programme on body composition, and muscle function and strength during weight loss in adults living with overweight or obesity. The study found that home-based resistance exercise during weight loss had no effect on body composition, including body mass index, body mass, fat mass, fat free mass, or muscle thickness, but did lead to improvements in muscle strength and function, including grip strength, knee extensor maximal torque and sit-to-stand performance. The relatively small changes observed in body mass (RT+WL: -2.4 kg, WL: -2.8 kg) and fat mass (RT+WL: -1.2 kg, WL: -1.9 kg) over 12 weeks were less than expected, indicating participants did not achieve the substantial energy deficit required for weight loss, with 5-10% body weight loss anticipated. Indeed, in the sub-group analysis, data revealed that only 18% of participants achieved significant weight loss (≥5% of initial body weight), indicating relatively poor adherence to the Weight Watchers dietary protocol across both groups.

Currently, there is limited evidence available on the effects of home-based resistance exercise training during weight loss in adults living with overweight or obesity. Although the data indicates that this is not sufficient to preserve the loss of fat free mass, these losses were relatively small in the current pilot study where overall weight loss was also relatively low. This may have limited the ability to detect any effect of home-based resistance exercise on fat free mass or muscle thickness. Further work applying this intervention during more extreme loss of fat free mass, for example with the use of total diet replacement or weight loss medications such as the glucagon-like peptide 1 (GLP-1) agonists are, therefore, warranted. In addition, bioelectrical impedance analysis to measure fat free mass and ultrasound to measure vastus lateral thickness were employed, which are not the gold standard methods for assessment of fat free and muscle mass. Moreover, the relatively low sample size in this pilot work, it is likely that there was insufficient sensitivity or statistical power to detect differences in either fat free mass or muscle thickness.

It is also possible that there was no effects seen on body composition with the current intervention due to the resistance exercises being home-based and unsupervised. Previous research of supervised resistance exercise during weight loss demonstrated increases in fat free mass (Avila et al., 2010, Campbell et al., 2009), decreases in fat mass (Miller et al., 2018, Straight et al., 2012) and improved muscle strength (Avila et al., 2010, Straight et al., 2012). As indicated in the systematic review and meta analysis in Chapter 2, supervised resistance exercise training during weight loss has been shown to attenuate the loss of fat free mass and effectively lower body fat mass in people living with overweight or obesity. Specifically, the review found that resistance training attenuated the loss of fat free mass (standardised mean difference (SMD): 0.40, 95% confidence interval [CI] 0.18 to 0.61; p=0.0003,) and was effective for lowering body fat mass (SMD: -0.36, 95% confidence interval [CI] -0.49 to -0.23; p< 0.00001) during weight loss. As mentioned, these studies involved supervised, facility-based exercise interventions, and this may have provided a higher training stimulus compared to the home-based programme for the retention of fat free mass (Coleman et al., 2023, Hunter et al., 2008, Fisher et al., 2022, Hurst et al., 2022). There is, to date, only one relevant previous study of home-based resistance exercise, although this was in the weight maintenance phase which, similar to the current study, found that such exercise had no effect on fat free mass (Dunstan et al., 2005).

Although the current study did not find any effect of the intervention on measures of body composition, increases in measures of muscle function, including grip strength, knee extensor maximal torque and sit-to-stand performance were found, indicative of an increase in muscle quality. These results are consistent with previous studies of gym based, supervised resistance exercise training during weight loss which found that muscle strength was increased. For example, the systematic review and meta-analysis presented in Chapter 2 found that supervised resistance exercise can improve muscle strength (SMD= 2.36 95% confidence interval [CI] 1.38 to 3.34; p=0.00001) during weight loss in people living with obesity or overweight. Further research also observed improvements in strength with resistance exercise during weight loss, including handgrip strength (+1.2±2.5 kg, P<.001) and knee extensor torque (+7.9±19.1 N-m, P<.001) (Straight et al., 2012). Other studies reported that including supervised resistance exercise during dietary weight loss can help maintain muscle function (Orange et al., 2020) as assessed by a 4-minute walk test, a 6-minute walk test and STS performance, and strength measured one-repetition maximum (1RM) (Avila et al., 2010). Furthermore, despite using different methods for assessing muscle strength such as eight-repetition maximum (8RM) (Figueroa et al., 2013) or one-repetition maximum (1RM) (Hintze et al., 2018), studies in postmenopausal women living with overweight or obesity have shown that supervised resistance exercise training has a positive impact on muscle strength during weight loss. Overall therefore, existing evidence supports the assertion that resistance exercise during weight loss can be beneficial in enhancing and improving overall muscle strength and physical function, with the current study demonstrating that this can be achieved by a home-based simple and pragmatic intervention.

The observed improvements in muscular strength and function, despite no changes in body composition in the current study, could be due to several reasons including neural adaptations and improved neuromuscular function that occur with resistance training. There is evidence that resistance training exercise induces neural adaptations, such as increased recruitment of motor units, firing frequency, and coordinated movements between muscles, which can enhance force production and increase strength independent of hypertrophic or body composition changes (Folland and Williams, 2007, Škarabot et al., 2021). There is also, during weight loss, research which has shown that a negative energy balance can impair the muscle protein synthesis response to resistance exercise, limiting hypertrophic but not necessarily strength adaptations (Cava et al., 2017, Hector et al., 2015, Murphy and Koehler, 2020). This negative energy balance will have less of an impact on the neural adaptations related to strength improvements (Murlasits and Reed, 2020, Sale, 1988).

Data indicate that the lack of effect on body composition outcomes reflect genuinely small intervention effects rather than inadequate statistical power (Cohen, 2013). Effect sizes (partial eta squared) for body composition measures were very small (η^2 = 0.001-0.008), indicating that the home-based resistance exercise intervention has minimal impact on these outcomes, during weight loss, regardless of sample size. This pattern is consistent with previous research on resistance band training, in the absence of wight loss, which has demonstrated minimal to no effects on body composition measures in various populations (Colado and Triplett, 2008, Jakobsen et al., 2015). In contrast, strength and functional outcomes demonstrated medium to large effect sizes (grip strength η^2 = 0.106, knee extensor torque η^2 = 0.143 and STS η^2 = 0.342), confirming that the home based resistance exercise intervention results in significant improvements in muscle function during weight loss. These robust effects on strength align with established evidence showing that resistance band training effectively improves muscle strength and functional capacity, in the absence of weight loss, across diverse populations (Colado and Triplett, 2008, La Scala Teixeira et al., 2017, Liao et al., 2018). These findings suggest that a larger sample size would be unlikely to change the conclusions regarding body composition, although there remains some level of uncertainty in this regard, but confirms the robust effects on strength and physical function outcomes.

Among the key strengths of the current study is using a randomised controlled design, which is considered the gold standard. Also, a home-based resistance training programme was employed to raise the ecological validity and real-world applicability of the findings. The study therefore illustrates the feasibility and impacts of an accessible exercise intervention that may be applied more widely. This needs to be tested in a larger scale, appropriately powered, randomised controlled trial. However, before moving on with a larger scale trial, further investigation is needed to better replicate the benefits reported in supervised resistance training interventions within a home-based programme. It is also important to note the limitations of the current study. The investigation was carried out using a small sample size which may mean that there was insufficient statistical power to detect potential changes in all outcome measures. A limitation of this study was the lack of formal adherence monitoring for both the Weight Watchers dietary intervention and the home-based resistance exercise programme. Although participants were asked to follow a dietary weight loss programme, dietary intake was not strictly controlled or monitored. Similarly, participants in the resistance exercise group received exercise materials and instructions but were not required to maintain exercise logs, and no objective measures were used to verify exercise completion, frequency or intensity throughout the 12-week period. This limits the ability to assess the relationship between intervention adherence and study outcomes and may affect the interpretation of results. Future research should consider incorporating systematic adherence monitoring for both dietary and resistance exercise interventions to better understand the relationship between intervention compliance and health outcomes , particularly in terms of body composition changes. The lack of comprehensive standardisation protocols for bioelectrical impedance measurements (such as fasting requirements, hydration status control or timing restrictions) may have introduced measurement variability and should be considered when interpreting body composition results. Although participants were asked to remove metal objects and shoes, other factors (e.g. hydration status) that can influence bioelectrical impedance measurements were not controlled. Physical activity levels, detailed dietary intake and comprehensive attrition analysis were not measured due to the pilot study design and resource constraints. Future larger scale trials should incorporate comprehensive physical activity tracking, dietary assessment and attrition analysis to better understand intervention mechanisms and participant retention patterns.

The improvements in muscular strength and physical function observed with resistance exercise training during weight loss have important clinical and functional implications (Khodadad Kashi et al., 2023, Orange et al., 2020). Preserving or increasing muscle strength and functional capacity can improve quality of life (Shaughnessy et al., 2020) and independence in everyday tasks, and lower the risk of falls and disabilities (Billot et al., 2020, Hillsdon and Foster, 2018). Resistance exercise training has also been found to have major metabolic health benefits, such as enhanced insulin sensitivity and better glucose management, which are vital for avoiding and controlling type 2 diabetes and other metabolic disorders (Abou Sawan et al., 2023, Strasser and Schobersberger, 2011, Pesta et al., 2017). Although weight loss can decrease muscle strength due to the reduction in body mass (Cava et al., 2017), it often improves physical function due to the lower mechanical load on the body (Santanasto et al., 2011). Regardless, the further enhancement of muscle strength and physical function observed with resistance exercise training is still a positive outcome for long-term health. Therefore, combining it with a home-based resistance training programme seems to have further benefits for overall health and may be an effective way for people living with overweight or obesity to engage in an exercise intervention that is more accessible and more likely to be adhered to, although this remains to be tested.

In conclusion, this pilot randomised controlled trial found that a home-based resistance training programme during weight loss in people living with overweight or obesity had no impact body composition measures such as BMI, body mass, fat mass, or fat free mass. However, the limited weight loss observed suggests poor dietary adherence, which may have prevented detection of resistance exercise benefits on body composition. Among participants who achieved significant weight loss (≥5%), resistance exercise provided beneficial effects on muscle thickness and functional outcomes. Improvements were found in grip strength, knee extensor maximal torque and sit-to-stand performance among all participants. Overall, this study highlights the potential value of incorporating home-based resistance training into weight loss programmes for adults living with overweight or obesity, as it can assist in maintaining strength and physical capability.

Chapter 5 General Discussion

The current thesis investigated the potential utility of resistance exercise during weight loss, in people living with overweight or obesity, beginning with evidence synthesis, progressing to intervention development and pilot testing. The thesis consisted of three studies: 1) a systematic review and meta-analysis that examines the effects of resistance exercise on body composition, muscle strength and cardiometabolic health during dietary weight loss; 2) a qualitative study of experiences and perceptions of resistance training in people living with overweight or obesity; and 3) a pilot randomised controlled trial evaluating the effects of a home-based resistance training exercise programme of body composition and muscle function. Taken together, these studies address a significant gap in the literature regarding the implementation of accessible and effective resistance exercise interventions during weight loss.

Summarising the results of this body of work, firstly, the systematic review and meta-analysis provided the evidence base demonstrating the beneficial effects of resistance exercise during dietary weight loss, increasing fat mass loss, preserving fat free mass and increasing muscle strength. It was noted that amongst the studies included in this review that the resistance exercise applied was primarily supervised gym-based exercise, which can limit uptake and adherence. Based on these findings, it was concluded that more pragmatic interventions were needed to translate these benefits into practice. In the qualitative study that followed, key insights were obtained into barriers and facilitators to resistance exercise among people living with overweight or obesity. These findings were used to develop a theory of change for intervention development ensuring exercise enjoyment and confidence, and accessibility. These results directly guided the development of a home-based resistance exercise training programme, to be applied during dietary weight loss, which was assessed in the pilot randomised controlled trial. Although the intervention had no effect on body composition measurements, improvements in grip strength, knee extensor maximal torque, and sit to stand performance were noted which indicates that home-based resistance training exercise may preserve or improve physical function during weight loss. Overall, this thesis has highlighted the potential for a home-based resistance exercise intervention to be of benefit during weight loss, with a pragmatic design to improve uptake and adherence, although further work is needed.

Dietary weight loss results in the loss of both fat free mass and fat mass, and some studies have indicated that the addition of resistance exercise may have a role in preserving (or possibly increasing) fat free mass (Hunter et al., 2015, Miller et al., 2018). Our systematic review and meta-analysis confirm these findings demonstrating that resistance exercise during dietary weight loss can enhance outcomes by increasing fat mass loss, decreasing fat free mass loss, and improving muscle strength. These results, while perhaps not surprising, align with previous research in healthy adults without dietary weight loss. Indeed a meta-analysis of studies of resistance exercise in healthy adults who were not specifically trying to lose weight demonstrated that resistance exercise training significantly increased muscle mass (fat free mass = 1.56kg, lean muscle mass = 1.65kg, skeletal muscle mass = 1.11 kg) (range, 0 to 7.2 kg) (Benito et al., 2020a). Another systematic review found that resistance exercise leads to an average reduction of 1.4% in percentage body fat or 0.55kg in fat mass (Wewege et al., 2022).

Unfortunately, in spite of its benefits, it is also known that participation in resistance exercise is generally very low (17-30%) (Bennie et al., 2020, Strain et al., 2016) and so to achieve any of the benefits of resistance exercise, strategies to increase its uptake are needed (Al-Ozairi et al., 2021). The level of participation is likely to be even lower in people undergoing weight loss, where the current thesis has shown its benefit. Indeed, it has been shown that people with higher BMI (>25 kg/m2) are less likely to participant in resistance exercise compared to people with a lower BMI (Rhodes et al., 2017). Participation in resistance exercise can be particularly challenging as it has traditionally involved specialised equipment, in addition to other barriers generally associated with any physical activity such as work, time, vacations, weather, boredom, tiredness, injury/illness, and family commitments (Burton et al., 2017, Tulloch et al., 2013). The COVID-19 pandemic has further emphasised the need for accessible, home based exercise options (Kaur et al., 2020).

Prior to the current thesis there had been no qualitative study of the barriers and facilitators to resistance exercise in people living with overweight or obesity considering losing weight. Participants in the current qualitative research, reported a number of barriers to physical activity and specifically to resistance training. Key barriers included 1) limited access to gyms during COVID-19 lockdown as one participant noted: *"when the pandemic hit, the gyms closed and I tried to do some in the house but just didn't really work out (P.11, Female, 30-40, Pre-Interview)"*, and 2) expenses and costs related to exercising, reported by one participant: *"So I stopped working with them, just through finances (P.03, Male, 30-40, Pre-Interview)"*. Additionally, gender differences in confidence with resistance exercise were identified, particularly for women: *"A full push up, I know I can do* *them on my knees, not a full push up. I struggled (P.01, Female, Over 50, Pre-Interview)"*. Women also showed uncertainty about resistance exercise terminology despite having done them: *"using that machine where you pull down or you pull up, you know, I don't know what it's called (P.05, Female, Over 50, Pre-Interview)"*. However, several important facilitators were also identified. Participants identified a preference and valued the convenience and accessibility of home based exercise training: *"I like it, I personally like it because it's quick and easy, and you don't need to go to the gym (P.09, Female, Over 50, Post-Interview)"*, which aligns with recent trends in exercise delivery (Nyenhuis et al., 2020). Although these results are consistent with previous research (Trost et al., 2002) studies exploring barriers to resistance exercise training during weight loss are limited. Previous research has investigated barriers to resistance exercise training in the general population (Burton et al., 2017), but few have focused on the challenges that people have through resistance exercise and seeking to lose weight. In the current thesis (Chapter 3), both men and women were able to adapt well to the home based resistance exercise routine, finding the ease of exercising without specialised equipment or specific exercise areas: *"I liked the fact it didn't take up much space. I could do it in my jeans and t-shirt as opposed to getting into sports gear (P.02, Male, 30-40, Post-Interview)"*.

This positive response to the home-based resistance training programme confirmed that the intervention design was appropriate. The qualitative feedback supported the intervention components, such as the use of resistance bands and flexibility in exercise location and timing. However, one modification was made to the intervention frequency, increasing from twice weekly (as tested in the qualitative study) to three times weekly in the pilot trial, based on established resistance training guidelines recommending 2-3 sessions per week in an attempt to maximise strength and muscle mass adaptations (American College of Sports, 2009). This confirmation of the intervention approach is encouraging, as it addresses common barriers to resistance exercise and may increase long-term adherence. Indeed, many participants demonstrated increased self-efficacy and emphasised their desire to continue performing resistance exercise following the programme completion: *"this has motivated me to keep doing it, even after the study. I'll still do the routine in the morning, because I think it's going to help me, I think I'll still do it every morning. I think the Monday to Friday will stick with me (P.01, Female, Over 50, $_{Post-Interview}$)"*. The programme also facilitated broader lifestyle changes: *"I've also noticed that it's made me eat better, because I know that a better diet helps with exercise (P.03, Male, 30-40, $_{Post-Interview}$)"*.

Following this positive qualitative work, the pilot trial did not find any effect of the intervention on measures of body composition, but did find increases in measures of muscle function, including grip strength, knee extensor maximal torque and sit-to-stand performance. These muscle function results are consistent with previous studies of supervised resistance exercise training during weight loss which found that muscle strength was increased. For example, in Chapter 2 it was demonstrated that supervised resistance exercise can improve muscle strength (SMD= 2.36 95% confidence interval [CI] 1.38 to 3.34; p=0.00001) during weight loss in people living with obesity or overweight. The reasons underlying these improvements in muscle function despite no changes in body composition in our study, could be due to several reasons. There is evidence that resistance training exercise induces neural adaptations, such as increased recruitment of motor units, firing frequency, and coordinated movements between muscles, which can enhance force production and increase strength independent of hypertrophic or body composition changes (Folland and Williams, 2007, Škarabot et al., 2021). There is also, during weight loss, research which has shown that a negative energy balance can impair the muscle protein synthesis response to resistance exercise, limiting hypertrophic, but not necessarily strength, adaptations (Cava et al., 2017, Hector et al., 2015, Murphy and Koehler, 2020). This negative energy balance would have a lesser impact on the neural adaptations related to strength improvements (Murlasits and Reed, 2020, Sale, 1988). It is also worth highlighting that we employed bioelectrical impedance analysis to measure fat free mass and ultrasound to measure vastus lateral thickness, which are not the gold standard methods for assessment of muscle mass.

There has, recently, been significant discussion around the clinical significance of fat free mass loss during weight loss. Traditional thoughts emphasised the importance of preserving fat free mass during weight loss interventions, however, new research suggests that the clinical relevance of weight loss-induced muscle mass loss is more complex than previously recognised (Conte et al., 2024). Recent analysis indicates that although approximately 25% of total weight loss is fat free mass loss, the absolute decrease in skeletal muscle mass represents only a small fraction of total body muscle mass. This is particularly the case in people with obesity who generally have higher levels of fat free mass than lean individuals (Conte et al., 2024). Importantly, intentional weight loss reduces body fat more than fat free mass, resulting in a higher ratio of fat free mass to fat mass and this has associated benefits in physical function and mobility, even in older adults with lower baseline muscle mass. However, this perspective must be balanced against the broader metabolic and functional roles of skeletal muscle beyond simple strength and movement. Muscle serves crucial metabolic functions as a reservoir for amino acids essential for stress responses and immune function, synthesises glutamine for nitrogen transport, regulates glucose homeostasis and produces myokines that function as endocrine factors modulating systemic metabolism and inflammation (Prado et al., 2024). The substantial muscle loss observed with recent pharmacological weight loss interventions (25-39% of total weight lost) raises concerns about potential long-term metabolic and immune consequences that extend beyond traditional measures of physical function. In light of the systematic review and pilot trial findings of the current thesis, these perspectives suggest that although resistance exercise may not have a significant impact on absolute fat free mass preservation, its benefits for maintaining muscle strength and function may be clinically significant regardless of muscle mass changes.

Indeed, the improvements in muscular strength and physical function observed with resistance exercise training during weight loss have important clinical and functional implications (Khodadad Kashi et al., 2023, Orange et al., 2020). Preserving or increasing muscle strength and functional capacity can improve quality of life (Shaughnessy et al., 2020) and independence in everyday tasks, and lower the risk of falls and disabilities linked with ageing and obesity (Billot et al., 2020, Hillsdon and Foster, 2018). Resistance exercise training has also been found to have major metabolic health benefits, such as enhanced insulin sensitivity and better glucose management, which are vital for controlling and avoiding type 2 diabetes and other metabolic disorders (Abou Sawan et al., 2023, Pesta et al., 2017, Strasser and Schobersberger, 2011). Although weight loss can decrease muscle strength due to the reduction in body mass (Cava et al., 2017), it often improves physical function due to the lower mechanical load on the body

(Santanasto et al., 2011). Regardless, the further enhancement of muscle strength and physical function observed with resistance exercise training is still a positive outcome for long term health. Therefore, combining weight loss with a home-based resistance training programme seems to have further benefits for overall health and may be an effective way for people living with overweight or obesity to engage in an exercise intervention that is accessible and thus more likely to be adhered to, although this remains to be tested.

The improvements in muscle strength observed in the pilot trial have important implications beyond immediate functional benefits. Growing evidence demonstrates that muscle strength is a powerful independent predictor of mortality and cardiovascular disease risk. For example, low grip strength, in particular, has been consistently associated with higher risk of all-cause mortality, with some studies suggesting that grip strength may be a stronger predictor of death than systolic blood pressure (Leong et al., 2015). A large prospective study of over 140,000 adults found that each 5 kg lower grip strength was associated with a 16% higher risk of death from any cause and 17% increased risk of cardiovascular death (Leong et al., 2015). Similarly, poor performance on chair stand tests is associated with higher mortality risk in older adults, with those unable to complete the test having significantly higher death rates than those with good performance (Cooper et al., 2010). Therefore, maintaining or improving muscle strength may provide protective effects against long-term mortality and cardiovascular disease risk. This is particularly relevant for people living with overweight or obesity, who already at a higher risk for cardiovascular disease. The significant improvements in grip strength, knee extensor torque and sit-to-stand performance observed with the current home-based resistance exercise intervention suggest potential benefits that extend well beyond immediate functional improvements to include long-term health protection.

Summarising, the current thesis expends our knowledge of resistance exercise training during weight loss in people living with overweight or obesity through a systematic progression from evidence synthesis to intervention. The systematic review and meta-analysis showed that resistance exercise can improve muscle strength, preserve fat free mass and increase fat mass loss during dietary intervention, supporting the inclusion of resistance exercise in weight loss interventions. Then, the qualitative study indicated barriers to resistance exercise participation and revealed preferences for home-based alternatives, providing guidance for the development of more pragmatic and accessible resistance exercise intervention. Following this, the pilot trial demonstrated that home-based resistance exercise during weight loss can improve muscle strength and function in people living with overweight or obesity. Nonetheless, there are still questions remain regarding the ideal design of home-based programmes, their impact on body composition and their long-term success.

The studies in the current thesis employed multiple methodological approaches throughout the three research studies, each with individual strengths and limitations. The integration of quantitative and qualitative data represents a key strength of this thesis. The systematic review and meta-analysis provided strong quantitative evidence, while the qualitative study provided rich data around people views about resistance exercise experiences and preferences. This approach enabled a comprehensive understanding of both the effectiveness and implementation considerations of resistance exercise interventions during weight loss. The pilot study then made it possible to combine the knowledge from both approaches to test the developed intervention. In the systematic review and meta-analysis the inclusion of both body composition, muscle strength and cardiometabolic outcomes provided a broad evaluation of intervention effects. All the studies we included were randomised controlled trials, the highest quality of study design. The qualitative study used semi-structured interviews allowing for in depth exploration of experiences. Among the key strengths of the pilot study is that we used a randomised controlled design, which is considered the gold standard. We also employed a home-based resistance training programme to ensure high ecological validity and real world applicability of the findings.

The systematic review and meta-analysis had several limitations. Although we conducted comprehensive searches, we only considered English language publications, which could have resulted in language bias and missed relevant studies published in other languages. We also did not stratify our results by gender or BMI category, which could have revealed whether the impacts differed between men and women, as well as levels of obesity. Beyond this, most included studies failed to report the concealment of allocations or the blinding of assessment of outcomes. As a result, many studies were rated as having an unclear risk of bias, which may have influenced the heterogeneity of the analysis. Also, due to a few studies reported cardiometabolic health outcomes, the quality of evidence for these outcomes was therefore either low or moderate, and their effect estimates may lack accuracy. Furthermore, over half of the included studies (n=16) recruited only women, which may limit the generalisability of the findings. Finally, only seven of the studies included in this meta-analysis were of six-month duration, which increases uncertainty into our sub-group analysis and the longer-term effects of resistance exercise.

In the qualitative and pilot studies, the small sample sizes limit the certainty and generalisability of the findings. Although participants in the pilot study were asked to follow a dietary weight loss programme, dietary intake was not strictly controlled or monitored and it is possible that dietary compliance and macronutrient composition could have affected the findings, particularly in terms of body composition changes. Although the qualitative study provided valuable insights into participants' experiences of enjoyment, confidence and accessibility through thematic analysis, the absence of validated scales to measure these constructs in the pilot trial represents a limitation that should be addressed in future research.

In conclusion, the current thesis demonstrates that resistance exercise can be implemented during weight loss interventions for people living with overweight or obesity through simple and pragmatic, home-based approaches, and result in increasing in muscle function. This represents an important outcome that may have significant implications for long-term health and well-being, such as improved independence, decreased risk of falls and functional decline and the ability to carry out daily activities. As people age, these benefits in particular may be important for supporting quality of life and healthy aging. While questions remain and further research is needed, this thesis provides a substantial contribution to our understanding of how resistance exercise can be effectively incorporated into weight loss interventions for people living with overweight or obesity.

Future work

The current thesis's pilot study needs to be refined, repiloted and finally tested in an appropriately powered randomised controlled trial. As part of the refinement process, investigating the optimal duration, frequency, and intensity of home-based resistance training programmes for this population would be valuable in informing its design. Dose-response studies should examine different exercise frequencies (2 vs 3 vs 4 sessions per week), intervention durations (12 vs 24 vs 52 weeks) and equipment options (resistance bands vs bodyweight vs minimal weights) to identify the most effective approaches. In addition to the current pilot study outcomes, a larger randomised controlled trial should include:

- More sensitive measures of body composition.
- Metabolic health markers such as lipid profiles, glucose control and insulin sensitivity.
- Cardiometabolic markers
- like blood pressure and vascular function
- More functional assessments such as mobility and balance tests.
- Quality of life measures.
- Outcomes measures such as participants satisfaction, self-efficacy, confidence and adherence.
- Long-term health outcomes including cardiovascular diseases and mortality.

Future research should examine resistance exercise effectiveness across different dietary approaches, given the poor dietary adherence observed in the pilot study. Studies comparing resistance exercise during low-carbohydrate diets, intermittent fasting protocols, very low-calorie diets and medically supervised weight loss programmes (including GLP-1 agonists) would provide insights into optimal combinations and varying magnitudes of weight loss (5% vs 10% vs 15%). Essential research is also needed considering: 1) racial and ethnic minorities who experience higher rates of obesity but may face different cultural and socioeconomic barriers, 2) age-specific studies including younger adults (18-30 years), middle-aged adults (40-55 years) and older adults (65+ years) where sarcopenia risk is high, 3) gender-specific interventions addressing observed differences in confidence and exercise preferences, 4) populations including those with mobility limitations, chronic diseases and varying baseline fitness levels, and 5) participants from areas of high deprivation. Therefore, further investigations are needed to understand the effects of resistance exercise during dietary weight loss on these outcomes measures in people living with overweight or obesity. Additionally, long-term follow-up studies are needed to assess the sustainability of health improvements observed following the current short-term intervention.

Several areas of the thesis may have been improved using other approaches. In the systematic review and meta-analysis, stratification by sex would have provided additional understanding into effective applications of resistance exercise. For the qualitative study, longer interview durations (30-45 minutes rather than 10-20 minutes) would have allowed deeper exploration of participant experiences. Including objective adherence monitoring even in the feasibility phase would have strengthened the connection between reported experiences and actual engagement. The pilot trial would have benefited from adherence monitoring for both dietary and exercise interventions. Measures of exercise enjoyment, self-efficacy and perceived accessibility should have been included to validate whether the intervention achieved its intended design goals beyond primary outcomes.

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Appendices

Appendix 2-A PRISMA checklist

Section and Topic	Item #	Checklist item	Location where item is reported
TITLE			
Title	1	Identify the report as a systematic review.	Title Chapter Page
ABSTRACT			
Abstract	2	See the PRISMA 2020 for Abstracts checklist.	Section 2.1
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	Section 2.2
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	Section 2.2 & 2.3
METHODS			
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	Section 2.3
Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	Section 2.3
Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used.	Section 2.3
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.	Section 2.3
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process.	Section 2.3
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which results to collect.	Section 2.3

Section and Topic	Item #	Checklist item	Location where item is reported
	10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.	Section 2.3
Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.	Section 2.3
Effect measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results.	Section 2.3
Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)).	Section 2.3
	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.	Section 2.3
	13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	Section 2.3
	13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	Section 2.3
	13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta-regression).	Section 2.3
	13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.	Section 2.3
Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).	Section 2.3
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	Section 2.3
RESULTS			
Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	Section 2.4
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	Section 2.4
Study characteristics	17	Cite each included study and present its characteristics.	Section 2.4
Risk of bias in studies	18	Present assessments of risk of bias for each included study.	Section 2.4
Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	Section 2.4
Results of	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	Section 2.4

Section and Topic	Item #	Checklist item	Location where item is reported
syntheses	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	Section 2.4
	20c	Present results of all investigations of possible causes of heterogeneity among study results.	Section 2.4
	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	Section 2.4
Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.	Section 2.4
Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	Section 2.4
DISCUSSION			
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	Section 2.5
	23b	Discuss any limitations of the evidence included in the review.	Section 2.5
	23c	Discuss any limitations of the review processes used.	Section 2.5
	23d	Discuss implications of the results for practice, policy, and future research.	Section 2.5
OTHER INFORMATION			
Registration and protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	Section 2.3
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	Section 2.3
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	-
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.	-
Competing interests	26	Declare any competing interests of review authors.	-
Availability of data, code and other materials	27	Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.	-

Appendix 2-B Keywords and search terms

Search Number	Search Term
1	"Obesity"[Mesh] OR obes*[tw] OR overweight[tw]
2	"Weight Loss"[Mesh] OR “weight loss”[tw] OR “weight management”[tw] OR “weight-loss”[tw] OR “obesity treatment*”[tw] OR “weight loss treatment*”[tw] OR “weight reduction”[tw] OR “weight advice”[tw]
3	"Resistance Training"[Mesh] OR “resistance training”[tw] OR “resistance exercise*”[tw] OR “strength training”[tw] OR “strength exercise*”[tw] OR “weight training”[tw] OR “weight exercise*”[tw] OR “weight lifting”[tw] OR weightlifting[tw] OR “progressive resistance training”[tw] OR “progressive resistance exercise*”[tw] OR “resistance physical activity”[tw]
4	"Body Weight"[Mesh] OR "Body Composition"[Mesh] OR weight[tw] OR “body mass”[tw] OR “muscle mass”[tw] or “muscle size”[tw] OR “fat mass”[tw] OR “body fat”[tw] OR adiposity[tw] OR “lean mass”[tw] OR “lean body mass”[tw] OR “fat free mass”[tw] OR “body mass index”[tw] OR “body composition”[tw]
5	"Metabolic Syndrome"[Mesh] OR “blood pressure”[tw] OR hypertension[tw] OR cholesterol[tw] OR lipids[tw] OR lipoprotein[tw] OR triglyceride[tw] OR “glucose intolerance”[tw] OR “blood glucose”[tw] OR glucose[tw] OR “glucose metabolism disorder*”[tw] OR “glucose tolerance

	test"[tw] OR insulin[tw] OR "insulin resistance"[tw] OR "glycosylated haemoglobin A"[tw] OR HbA1c[tw]
6	"physical activit*"[tw] OR "physical function*"[tw] OR "functional status"[tw] OR "Exercise"[Mesh] OR step*[tw] OR "moderate to vigorous physical activity"[tw] OR "moderate-to-vigorous physical activity"[tw] OR "oxygen consumption"[tw] OR "oxygen uptake"[tw] OR "cardiorespiratory fitness"[tw] OR "Muscle Strength"[Mesh] OR "muscle strength*"[tw] OR "muscle endurance"[tw] OR "muscle function"[tw]
7	#4 or #5 or #6
8	#1 and #2 and #3 and #7

Appendix 2-C Data extraction form

Review title or ID	
Study ID *(surname of first author and year first full report of study was published e.g. Smith 2001)*	
Report ID	
Report ID of other reports of this study	
Notes	

General Information

Date form completed *(dd/mm/yyyy)*	
Name/ID of person extracting data	
Reference citation	
Study author contact details	
Publication type *(e.g. full report, abstract, letter)*	
Notes:	

Study eligibility

Study Characteristics	Eligibility criteria *(Insert inclusion criteria for each characteristic as defined in the Protocol)*	Eligibility criteria met? Yes No Unclear	Location in text or source *(pg & ¶/fig/table/other)*
Type of study	Randomised Controlled Trial	☐ ☐ ☐	
	Quasi-randomised Controlled Trial	☐ ☐ ☐	
Participants		☐ ☐ ☐	
Types of intervention		☐ ☐ ☐	
Types of comparison		☐ ☐ ☐	
Types of outcome measures		☐ ☐ ☐	

INCLUDE	☐	EXCLUDE	☐
Reason for exclusion			
Notes:			

Characteristics of included studies

Methods

	Descriptions as stated in report/paper	Location in text or source *(pg & ¶/fig/table/other)*
Aim of study *(e.g. efficacy, equivalence, pragmatic)*		
Design *(e.g. parallel, crossover, non-RCT)*		

Unit of allocation *(by individuals, cluster/ groups or body parts)*		
Start date		
End date		
Duration of participation *(from recruitment to last follow-up)*		
Ethical approval needed/ obtained for study	☐ ☐ ☐ Yes No Unclear		
Notes:		

Participants

	Description *Include comparative information for each intervention or comparison group if available*	Location in text or source *(pg & ¶/fig/table/other)*
Population description *(from which study participants are drawn)*		
Setting *(including location and social context)*		
Inclusion criteria		
Exclusion criteria		
Method of recruitment of participants *(e.g. phone, mail, clinic patients)*		
Informed consent obtained	☐ ☐ ☐	

	Yes No Unclear		
Total no. randomised *(or total pop. at start of study for NRCTs)*			
Clusters *(if applicable, no., type, no. people per cluster)*			
Baseline imbalances			
Withdrawals and exclusions *(if not provided below by outcome)*			
Age			
Sex			
Race/Ethnicity			
Severity of illness			

Co-morbidities		
Other relevant sociodemographics		
Subgroups measured		
Subgroups reported		
Notes:		

Intervention/comparison groups

Copy and paste table for each intervention and comparison group

	Description as stated in report/paper	Location in text or source *(pg & ¶/fig/table/other)*
Group name		
No. randomised to group *(specify whether no. people or clusters)*		

Theoretical basis *(include key references)*		
Description *(include sufficient detail for replication, e.g. content, dose, components)*		
Duration of treatment period		
Timing *(e.g. frequency, duration of each episode)*		
Delivery *(e.g. mechanism, medium, intensity, fidelity)*		

Providers *(e.g. no., profession, training, ethnicity etc. if relevant)*		
Co-interventions		
Economic information *(i.e. intervention cost, changes in other costs as result of intervention)*		
Resource requirements *(e.g. staff numbers, cold chain, equipment)*		
Integrity of delivery		

Compliance		
Notes:		

Outcomes

Copy and paste table for each outcome.

	Description as stated in report/paper	Location in text or source *(pg & ¶/fig/table/other)*
Outcome name		
Time points measured *(specify whether from start or end of intervention)*		
Time points reported		

Outcome definition *(with diagnostic criteria if relevant)*		
Person measuring/ reporting		
Unit of measurement *(if relevant)*		
Scales: upper and lower limits *(indicate whether high or low score is good)*		
Is outcome/tool validated?	☐ ☐ ☐ Yes No Unclear		

Imputation of missing data *(e.g. assumptions made for ITT analysis)*		
Assumed risk estimate *(e.g. baseline or population risk noted in Background)*		
Power *(e.g. power & sample size calculation, level of power achieved)*		
Notes:		

Risk of Bias assessment

Domain	Risk of bias		

	Low High Unclear	Support for judgement *(include direct quotes where available with explanatory comments)*	Location in text or source *(pg & ¶/fig/table/other)*
Random sequence generation *(selection bias)*	☐ ☐ ☐		
Allocation concealment *(selection bias)*	☐ ☐ ☐		
Blinding of participants and personnel *(performance bias)*	☐ ☐ ☐	Outcome group: All/	

(if separate judgement by outcome(s) required)	☐ ☐ ☐	Outcome group:	
Blinding of outcome assessment *(detection bias)*	☐ ☐ ☐	Outcome group: All/	
(if separate judgement by outcome(s) required)	☐ ☐ ☐	Outcome group:	
Incomplete outcome data *(attrition bias)*	☐ ☐ ☐	Outcome group: All/	
(if separate judgement by outcome(s) required)	☐ ☐ ☐	Outcome group:	

Selective outcome reporting? *(reporting bias)*	☐ ☐ ☐		
Other bias	☐ ☐ ☐		
Notes:			

Data and analysis

For RCT/CCT

Continuous outcome

	Description as stated in report/paper	Location in text or source *(pg & ¶/fig/table/other)*
Comparison		
Outcome		
Subgroup		

<table>
<tr><td>Time point (specify from start or end of intervention)</td><td colspan="6"></td><td></td></tr>
<tr><td>Post-intervention or change from baseline?</td><td colspan="6"></td><td></td></tr>
<tr><td rowspan="3">Results</td><td colspan="3">Intervention</td><td colspan="3">Comparison</td><td rowspan="3"></td></tr>
<tr><td>Mean</td><td>SD (or other variance, specify)</td><td>No. participants</td><td>Mean</td><td>SD (or other variance, specify)</td><td>No. participants</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Any other results reported *(e.g. mean difference, CI, P value)*			
No. missing participants			
Reasons missing			
No. participants moved from other group			
Reasons moved			
Unit of analysis *(individuals, cluster/ groups or body parts)*			

Statistical methods used and appropriateness of these *(e.g. adjustment for correlation)*			
Reanalysis required? *(specify)*	☐ ☐ ☐ Yes No Unclear		
Reanalysis possible?	☐ ☐ ☐ Yes No Unclear		
Reanalysed results			
Notes:			

Appendix 2-D Study characteristics

Author/ Year	Groups/ No. randomised	Duration	Population/ Age/ BMI	Dietary interventions	Adherence to dietary interventions	Resistance exercise interventions	Adherence to resistance exercise interventions	Outcomes
(Andersen et al., 1997)	- Resistance training (RT) + Diet/ 12 - Diet only/ 9	24 weeks	- Women living with obesity - Age - RT + Diet (41.1 ± 11.1)- Diet only (38.1 ± 7.6) - BMI not reported	Structured meal plans - 900 to 925 kcal/d that consisted of four servings daily of a liquid meal replacement combined with a dinner and two cups of salad. Each serving of the liquid diet provided 150 kcal, 15 g protein, 11 g carbohydrate, 5 g fat, 200 mg calcium, 200 mg phosphorus,	Daily food diaries were kept and reviewed weekly. Adherence not reported.	Supervised RT attended 3x/week. Participants performed one set of the bench press, latissimus pull-down, chest fly, shoulder press, leg extension, leg curl, leg press, hip extension, arm curls and extensions, sit-ups, and back extension. From weeks 3 to 14, an additional set of exercises were added. Workout time was held constant between weeks 14 and 24, but resistance was increased whenever	Attended a mean of 61.4 ± 9 sessions out of 72 (≈85.3% adherence).	- Weight - FFM - Fat mass

				and 80 IU vitamin D. Each shelf-stable provided approximately 300 kcal, 20 g protein, about 40 g carbohydrate, and 7 g fat.		participants were able to perform more than 12 repetitions.		
(Avila et al., 2010)	- RT + Diet/ 15 - Diet only/ 12	10 weeks	- Men and women living with overweight or obesity - Age 67 ± 4 - BMI - (RT + Diet -31.6 (3.8)) (Diet only -31.9 (3.4))	Participants attended weekly diet education sessions and guided to follow the DASH diet with a 10% caloric reduction for gradual weight loss (~5%).	Diet only group 85% adherence RT + Diet group 98% adherence	RT sessions were supervised (3x/week) - 40 min of moderate intensity resistance training. A total of six lower and upper body exercises were utilized - four sets of 8-12 repetitions were completed by each participant including a warm-up set of five repetitions.	96% adherence	- Weight - Fat mass - Lean mass - Muscle strength

(Ballor et al., 1988)	- RT + Diet/ 10 - Diet only/ 10 - RT only/ 10 - Control/ 10	8 weeks	- Women living with obesity - Age 32.9 ± 1.5 - BMI - not reported	The nutritionally balanced diet consisted of 50% carbohydrate, 27% protein, and 23% fat and included a daily protein supplement with an aim to reduce energy intake by 1000kcal/day, delivered via dietary counsellors.	100% adherence (None of the participants missed any scheduled diet counseling meetings)	Resistance exercise was performed 3 days/week, supervised - included the following exercises: bench press, inverse leg press, lateral pull down, biceps curl, triceps extension, calf raise, leg extension, and hamstring curl. Ten repetitions were completed in the first two sets of each exercise and as many repetitions as the participant could perform were completed in the third set	22 sessions missed out of 495 (~95% compliance).	- Strength-Bench press - Weight - Lean body weight - Fat weight - Percent fat
(Beavers et al., 2017)	- RT + Diet/ 81 - Diet only/ 82	18 Months	- Older adults living with obesity, cardiovascular disease (CVD)	In accordance with the 2010 dietary guidelines, the macronutrient breakdown of the diet	Diet only group 71.1% (25th–75th percentile:	Sessions were supervised (4x/week), progressing to 45 minutes/day with an RPE of 15-18 as a target intensity for each RT exercise. Participants	Adherence not reported	-Body Mass -Fat Mass -Fat Mass (%) -Lean Mass -Lean Mass (%)

	- Aerobic training (AT) + Diet/ 86		and/or the metabolic syndrome (MetS) -Age 66.9±4.7 - BMI 34.4 (3.7) kg/m2/ The sample was largely women (71.1%)	was 20–25% protein, 25–30% fat, and 45–55% carbohydrate with an aim to reduce energy intake by ~330kcal/day.	40.5–83.3%) adherence RT + Diet group 85.7% (70.7-92.7%) adherence	completed three sets of 10-12 repetitions on 8 machines with initial resistance determined from one repetition maximum (1RM) testing (goal of 75% of 1RM). Exercises included a leg press, hip adduction, hip abduction, calf extension, seated-row, pectoral fly, shoulder press, and rotary torso, leg extension, leg curl, lateral pull down, seated chest press, lateral raise, arm curl, triceps extension, and abdominal crunch.		
(Benito et al., 2020b)	- RT + Diet/ 30 - Diet only/ 29	22 weeks	- Adults living with overweight - Age 18 to 50	Balanced, hypocaloric diets (between 1200 kcal (5020 kJ) and 1850 kcal (7732 kJ)) were	Diet only group 97 ± 17% adherence	All RT sessions were supervised (3x/week) - included shoulder presses, squats, barbell rows, lateral splits, bench presses,	92.3 ± 4.0% adherence	- VO2peak - Body weight - BMI - Total fat mass

	- AT + Diet/ 30 - RT + AT + Diet/ 30		- BMI ≥25-<30 kg/m2	prescribed individually for all participants by expert nutritionists - provided with 50%-55% carbohydrates, 30%-35% fat and 20% protein.	RT + Diet group 122 ± 32% adherence	front splits, biceps curls, and French presses for triceps		- Total lean mass
(Borges et al., 2019)	- RT + Diet/ 52 - Diet only/29 - AT + Diet/ 41	Not Reported	- Pre-menopausal women living with overweight - Age 23-46 - (BMI 27–29 kg/m2)	All participants followed an 800 kcal/day (58-62% carbohydrate, 20-22% fat and 18-22% protein) very-low-calorie diet, with food provided and picked up twice weekly.	Adherence not reported.	Resistance exercise was supervised (3x/week) - included elbow flexion, bench press, lateral pull-down, triceps extension, military press, squats, bent-leg sit-ups, leg extension, lower-back extension and leg curl.	Adherence not reported.	- Weight - BMI - %FM - VO_{2max} - Total cholesterol - LDL cholesterol - HDL cholesterol - Triglycerides
(Brochu et al., 2009)	- RT + Diet/ 48	Weight loss (6 months)	- Post-menopausal women living	Macronutrient composition of the	The average rate of participation	Resistance exercise was supervised (3x/week) - consisted of four progressive	Only 2 participants completed all sessions. 12	- Body weight - VO_{2peak} - BMI

	- Diet only/ 89	and weight maintenance (12 months) in total [18 months]	with overweight or obesity - Age - (RT + Diet (Intent to treat analyses)=57.2 ± 5.0)(RT + Diet (Efficacy subset analyses)=57.6 ± 4.1)(Diet only =58.0 ± 4.7) - BMI (RT + Diet (Intent to treat analyses)=32.6 ± 4.9)(RT + Diet (Efficacy subset analyses)=32.6 ± 5.0)(Diet only =32.2 ± 4.6)	diets was standardized: 55%, 30% and 15% of energy intake from carbohydrates, total fat, and protein with an aim to reduce body weight by 10% (500-800 kcal/day). Participants in both groups were invited to meet bimonthly with the study dietitian.	to nutrition classes was 28.1 ± 30.2% in the Diet only group and 29.9 ± 28.8% in the RT + Diet group. Adherence not reported.	phases [phase 1: introduction to training (3 wk, 15 repetitions or 65% of maximum, two to three sets per exercise, 90–120 sec between sets); phase 2 (5 wk, 12 repetitions or 70% of maximum, two to three sets per exercise, 90 sec between sets); phase 3 (9 wk, eight to 10 repetitions or 75–80% of maximum, two to four sets per exercise, 120–180 sec between sets) and phase 4 (8 wk, 10–12 repetitions or 70–75% of maximum, three to four sets per exercise, 60-90 sec between sets)]. RT included the following exercises: 1) leg press; 2) chest press; 3) lateral	participants attended ≥90% of sessions. Efficacy analyses used ≥80% adherence.	- %FM - Total FM - Total Lean body mass - Fasting insulin - Fasting glucose - Absolute glucose disposal - Relative glucose disposal - Triglycerides - Total cholesterol - LDL cholesterol - HDL cholesterol -Systolic - Diastolic

						pull downs; 4) shoulder press; 6) arm curls; and 7) triceps extensions.		
(Bryner et al., 1999)	- RT + Diet/ 10 - Diet only/ 10	12 weeks	Twenty participants (17 women, three men) with a mean age of 36.7±11.5 years and a BMI of 35.2±2.9 kg/m2	Participants followed VLCD consisting of a liquid formula ingested five times a day (total of 800 kcal/day)	Participants did weekly weight checks and gave verbal declarations of diet adherence. Self-reported compliance was excellent. Adherence not reported.	Supervised RT sessions 3x/week - included four lower body and six upper body exercises. Participants performed one set of six to eight repetitions with a weight that could be lifted 12 to 15 times. A second set of two to three repetitions with a slightly heavier weight was performed. The weight was then increased to a cautious estimate of the 1RM at which time participants attempted a single lift. If successful, the weight was gradually increased	Attended 91.4% ± 21.8% of sessions.	- Body weight - BMI - Fat - Lean body mass - Fat% - Peak VO2

						until the participant could not complete the one repetition lift. The 1RM test was conducted during week 2 and again at the end of week 12.		
(Donnelly et al., 1991)	- RT + Diet/ 18 - Diet only/ 26 - AT + Diet/ 16 - RT + AT + Diet/ 9	90 days	- Women living with obesity - Age not reported - BMI - each group (RT + Diet 38.2 ± 7.5)(AT + Diet 37.5 ± 6.0)(RT + AT + Diet 38.3 ± 5.2)(Diet only 38.2 ± 5.9)	All participants followed a very low calorie diet (VLCD, 2184 kJ/day) liquid formula diet.	Adherence was assumed if participants lost ≥1.4 kg/week and signed a weekly declaration. Adherence not reported.	Supervised resistance exercise was performed 4x/week - progressed from two sets of six to eight repetitions at 70% 1RM to three sets of six to eight repetitions at 80% 1RM. Performed exercises not reported.	90% minimum attendance required, verified by a research assistant. Adherence not reported.	- Body weight - Fat (%) - Fat weight - FFM - Peak VO2

(Donnelly et al., 1993)	- RT + Diet/ 7 - Diet only/ 7	90 days	- Women living with obesity - Age - (RT + Diet 44.4 ± 9.8)(Diet only 36.3 ± 8.9) - BMI not reported	Participants consumed a 3360 kJ/day liquid formula diet.	Adherence was checked weekly by signed declarations and monitored weight loss. Adherence not reported.	Supervised RT sessions 3x/week - RT was assigned at 70% of l-RM values for weeks 1-4 and the participants performed three sets of exercises in the descending order of 8-6-6 repetitions. During weeks 5-12, RT progressed to 80% of l-RM values and the participants performed four sets of exercises in the descending order of 8-6-6-4 repetitions. The exercises included the bench press (BP), lateral pull-down (LAT), knee extension (KE), knee flexion (KF), military press, arm pullover, biceps curl, and triceps extension.	Required to complete ≥90% of exercise sessions, verified by a research assistant. Adherence not reported.	- Body weight - FFM - Fat - Strength

(Dunstan et al., 2002)	- RT + Diet/ 19 - Diet only/ 17	6 months	- Participants living with diabetes and obesity - Age - (RT + Diet 67.6 ± 5.2)(Diet only 66.9 ± 5.3) - BMI - (RT + Diet 31.5±3.7)(Diet only 32.5±3.8)	Healthy eating plan (supplying ≤30% of total energy intake from fat and <10% from saturated fat, with the remainder distributed between carbohydrates and protein) was designed to elicit a moderate weight loss of 0.25 kg/week over the course of the intervention and was individually prescribed by a dietitian	Participants every 2 weeks completed dietitian interviews, weekly food checklists, and 3 day food records at baseline, 3 and 6 months. Adherence not reported.	All RT sessions were fully supervised (3x/week) - exercises included: bench press, leg extension, upright row, lateral pull-down, standing leg curl (ankle weights), dumbbell seated shoulder press, dumbbell seated biceps curl, dumbbell triceps kickback, and abdominal curls. All participants were required to perform each repetition in a slow, controlled manner, with a rest of 90–120 s between sets. Three sets of 8–10 repetitions were performed for all exercises.	Attended 88% of 72 sessions.	- Fasting plasma glucose - Fasting serum insulin - Insulin sensitivity - Total cholesterol - HDL cholesterol - LDL cholesterol - Triglycerides - Body mass - Fat mass - Lean body mass - Upper body - Lower body - Systolic - Diastolic

(Figueroa et al., 2013)	- RT + Diet/ 14 - Diet only/13 - RT/ 14	12 weeks	Postmenopausal women living with obesity - Age 54±6 - BMI 33.8±0.5kg/m2	Participants followed a commercial weight loss programme - a structured meal plan provides ~1250 kcal/day (carbohydrate 55%-60%, fat 20%-25%, and protein 20%-25%).	Adherence tracked with 3-day food record. Adherence not reported.	RT supervised sessions were 3x/week – included exercises (leg press, leg extension, leg flexion, and calf raise) performed 2 sets of exercises involving 18-22 repetitions of each exercise, to the point of volitional fatigue, during the first 2 weeks of the study, and 3 sets of such exercises thereafter.	Attendance at supervised sessions was >89%	- Body weight - Total fat mass - Total lean mass - Systolic - Diastolic - Insulin
(Fisher et al., 2012)	- RT + Diet/ 41 - Diet only/ 24 - AT + Diet/ 32	A mean of 154 ± 61 days and 1 year following the	- Pre-menopausal women living with overweight - Age 21-46/ - BMI 28±1	All food was provided during weight loss and consisted of 800 kcal/day that were 20-22% fat, 18-22% protein, and 58-62% carbohydrate.	Participants picked up food twice weekly and were instructed to remain on the 800 kcal/day diet until a BMI	RT was done 3x/week under full supervision - included exercises: squats, leg extension, leg curl, elbow flexion, triceps extension, lateral pull-down, bench press, military press, lower back extension, and bent leg sit-	Adherence not reported.	- Body weight - BMI - Body fat % - Lean mass - Vo2max - Fasting glucose - Fasting insulin

		weight loss			of <25 kg/m2 was reached. Adherence not reported.	ups. One set of 10 repetitions was performed during the first 4 wk, after which two sets of 10 repetitions were performed for each exercise with 2-min rest between sets. The training was progressive with intensity based on 80% of the maximum weight that an individual lifted one time (1 RM).		
(Hunter et al., 2015)	- RT + Diet/ 47 - Diet only/46 - AT + Diet/ 47	2.5 months mostly	- Pre-menopausal women living with overweight - Age 20-44 - (BMI >27 and <30 kg/m2)	Diet was 800 kcal/day of provided food during weight loss (20-22% fat, 20-22% protein, and 56-58% carbohydrate).	Adherence not reported.	Supervised resistance exercise was 3x/week - included exercises: squats, leg extension, leg curl, elbow flexion, triceps extension, lateral pull-down, bench press, military press, lower back extension, and bent leg sit-ups. The first week following	Adherence not reported.	- Weight - BMI - % Fat - Fat mass - Fat free mass - Knee extension strength - Elbow flexion strength - VO2max

						the 1 RM tests one set of 10 repetitions was performed at 65% 1 RM, with percent of 1 RM increasing on subsequent weeks until week four intensity was at 80% 1 RM. Starting at week five, two sets of 10 repetitions were attempted at 80% 1 RM for each exercise with 2 min rest between sets.		
(Geliebter et al., 2014)	- RT + Diet/ 27 - Diet only/ 27 - AT + Diet/ 27	8 weeks	- Men and women participants living with overweight or obesity, ranging in age from 19-49 (M = 35.4 ± 7.2 SD) and BMI	All participants followed a liquid formula diet (Pro-Cal) based on 70% of measured resting metabolic rate at entry into the study [5168 ± 1222 kJ (1235 ± 292 kcal)], with weekly	Body weights were measured weekly. Adherence not reported.	Resistance exercise sessions were supervised 3x/week - included exercise upper- and lower-body large muscle groups: leg extension (quadriceps), leg curl (hamstring), chest press (pectoralis major), pullover (latissimus dorsi), lateral raise	~5% of sessions missed were made up in the same week. Adherence not reported.	- Weight - BMI - Body Fat - FFM - LDL cholesterol - Insulin - Triglycerides - HDL cholesterol - Systolic BP

			from 25-52 kg/m2 (M = 33.8 ± 5.9)	individual nutrition counselling.		(deltoid), arm flexion (biceps), arm extension (triceps), and leg press (buttocks, hip, and quadriceps) - performed three sets of repetitions, 30 sec apart. The first two sets consisted of six repetitions each, followed by a third set of as many repetitions as possible. If the participants performed eight or more repetitions on the third set, the resistance was increased at the next session.		- Diastolic BP - Glucose
(Herring et al., 2014)	- RT + Diet/ 11 - Diet only/12	12 weeks	Men and women participants in a community weight-loss service with	Weekly multidisciplinary education sessions covering diet (kcal deficit not given).	Adherence not reported.	Resistance exercise was 3x/week fully supervised - performed at a moderate intensity expressed as 60% of their estimated one-repetition	91% completion rate.	- Body mass - Body mass index

	- AT + Diet/ 12		ages ranging from 24 to 68 years and a BMI of 44.45 ± 6.11 kg m2			maximum - used compound exercises, utilizing the main muscles and opposing muscle groups. Performed exercises not reported.		
(Ibanez et al., 2010)	- RT + Diet/ 13 - Diet only/12 - Control/ 9	16 weeks	- Women living with obesity - Age 40-60 - BMI 30–40	Participants received a personalised hypocaloric diet (500 kcal/day deficit) (55% of calories as carbohydrates, 15% as proteins, and the rest as fat). Food intake was tracked via 3-day food records, reviewed with a dietitian.	Average compliance >95%.	Resistance exercise was supervised twice weekly for 16 weeks - included exercises for the leg extensor muscles (bilateral leg press and bilateral knee extension exercises), one exercise for the arm extensor muscle (the bench-press) and four to five exercises for the main muscle groups of the body. Resistance was progressively increased or	Average compliance >95%.	- Body weight - BMI - Fasting plasma glucose - Insulin - Triglycerides - Total cholesterol - LDL cholesterol - HDL cholesterol

						decreased every week for the 16-week training period using a repetition maximum approach, so that the loads that brought about a given relative intensity remained unchanged from week to week.		
(Janssen et al., 2002)	- RT + Diet/ 14 - Diet only/13 - AT + Diet/ 11	16 weeks	-Premenopausal women living with obesity - Age - (RT + Diet = 34.8 ± 5.8)(AT + Diet= 37.5 ± 6.0)(Diet only = 40.1 ± 6.7) - BMI - (RT + Diet = 31.6 ±4.3)(AT + Diet = 36.0	All participants were asked to reduce their energy intake by 1000 kcal/day. All foods were self-selected, store bought, and prepared by the participants, and no supplements were prescribed.	With few exceptions (<2%), complete dietary intake records were submitted, as required by all participants.	RT sessions were fully supervised 3x/week - included exercises: leg extension, leg flexion, super pullover (latissimus dorsi), bench press, shoulder press, triceps extension, and biceps curl. One set of 8-12 repetitions were performed to the point of volitional fatigue.	Attended 94% of sessions (range: 79–100%).	- Weight - BMI - Total fat - Fasting glucose - Fasting insulin - Triglycerides - Total cholesterol - LDL cholesterol - HDL cholesterol

			±7.1)(Diet only= 33.7 ±4.1)					
(Joseph et al., 2001)	- RT + Diet/ 11 - Diet only/ 11	7 weeks	- Postmenopausal women living with overweight or obesity - Age 63 ± 2 - BMI 29.9 ± 0.7	Diet provided by a metabolic kitchen. The diet (750 kcal) consisted of a 3-day rotating menu designed to provide 15%, 55% and 30% of total energy as protein, carbohydrate, and fat, respectively.	Participants met the dietitian daily and were weighed daily. Adherence not reported.	Resistance exercise training was 3x/week - included exercises: unilateral knee extension, unilateral knee flexion, double leg press, seated chest press and seated arm pull. The first two sets consisted of eight repetitions at 80% of one-repetition maximum (1RM), and the third set was continued until voluntary muscular fatigue or until 12 repetitions were completed.	100% adherence (12/12 sessions)	- Weight - BMI - BF (%) - FM - FFM (kg) - Muscle mass
(Marks et al., 1995)	- RT + Diet/ 11	20 weeks	- Inactive women living	The dietary programme was	Participants completed 4-	Resistance exercise training was 3x/week - included	Adherence was tracked weekly.	- FFM - FM

	- Diet only/ 10 - AT + Diet/ 8 - RT + AT + Diet/ 9 - Control/ 6		with overweight or obesity - Age 20 to 49 - BMI - each group (RT + Diet 30.4)(AT + Diet 28.7)(Diet only 30.1)(RT + AT + Diet 31.3)(Control 29.4)	individually designed, with a common goal to lose no more than 0.9 kg.wk while maintaining a energy intake of at least 1200 kcal/day.	day food diaries, which were reviewed by dietitians. Adherence not reported..	exercises: leg extension, leg curl, seated rower, chest press, abdominal curl, arm curl and triceps extension machine. Two sets of 12 repetitions (reps) - the first three reps progressively increased in load (70%, 80% and 90% of set up weight), the next six reps were 100% of the set up weight, and the last three reps progressively decreased in load (90%, 80% and 70% of the set up weight) as the muscle fatigued.	Only those who attended ≥85% of required sessions were included in final analyses. Adherence not reported..	- Percent body fat - Body mass - Muscular strength - VO2max
(Morencos et al., 2012)	- RT + Diet/ 30 - Diet only/ 29	24 weeks	- Adults living with overweight - Age - 18 to 50 - BMI - each group (RT + Diet	A hypocaloric individualised diet (between 1200 and 3000 kcal) was prescribed by expert	Adherence was assessed via 72-hour food recall, and "90%	All training sessions were supervised by certified personal trainers 3x/week - included exercises: shoulder press, squat, barbell row,	Adherence was tracked. "An adherence to training of 90% was demanded." Only	- Total cholesterol - HDL cholesterol - LDL cholesterol - Triglycerides - Weight

	- AT + Diet/ 30 - RT + AT + Diet/ 30		29.8 ± 2)(AT + Diet 29 ± 1.7)(RT + AT + Diet 28.2 ± 1.7)(Diet only 28.3 ± 1.3)	dieticians. Diet was lowered a 25% from Daily Energy Expenditure. Macronutrient distribution consisted of 29-34% of energy from fat, 12-18% from protein, and 50-55% from carbohydrates.	adherence was elicited"	lateral split, bench press, front split, biceps curl, and French press for triceps. The intensity of exercise was increased over the study period.	those who met this were included in the analysis.	
(Nakata et al., 2008)	- RT + Diet/ 21 - Diet only/ 21	14 weeks	- Premenopausal Japanese women living with overweight - Age - (RT + Diet 42.3 ± 7.4)(Diet only 40.3 ± 6.5)	All the participants were instructed to restrict energy intake to 1200 kcal/day.	An average adherence of 87.4% (range: 64.3–100%) to the 14 session.	Resistance exercise sessions were supervised 3x/week - included exercises: bench presses, squats, leg curls, leg extensions, and sit-ups. Participants began with 1 warm-up and 3 training sets (12-15 reps). Load intensity was decided based on the	An average adherence of 93.6% (range: 77.5–100%) across 40 sessions.	- Body weight - Percentage fat mass - Fat mass - Lean mass (kg)

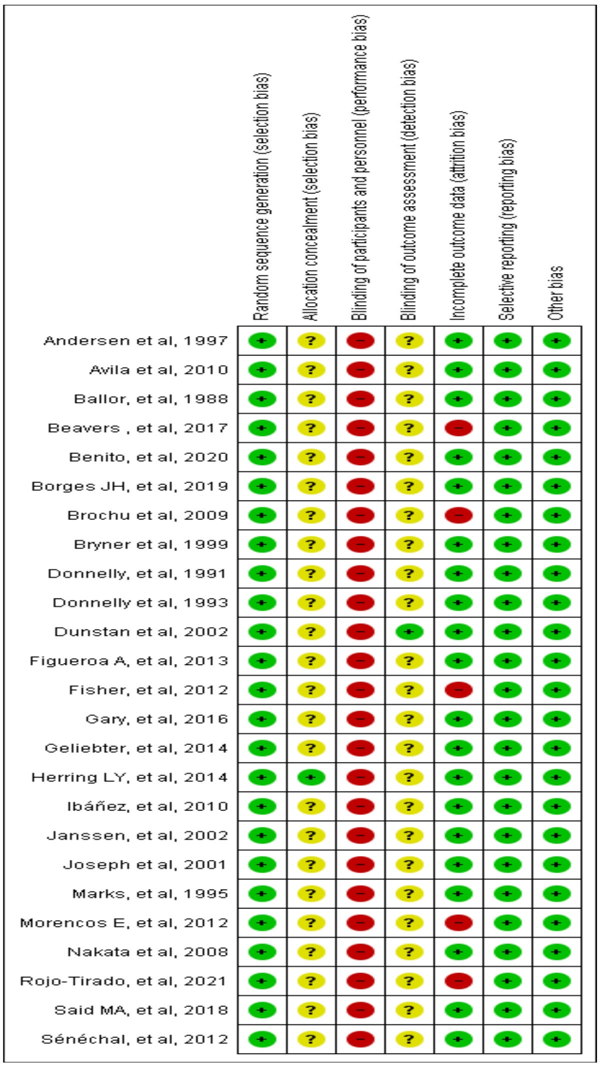
			- BMI - (RT + Diet 27.5 ± 2.5)(Diet only 27.4 ± 2.5)			rating of perceived exertion (RPE) scale; the criterion being what the participants considered to be "somewhat hard.". At week 5, after testing, intensity increased to 50% of maximal lifts, progressing whenever 3 sets of 15 reps were completed. During the final 4 weeks, intensity increased to 60% of maximal lifts, with final testing conducted at week 14.		
(Rojo-Tirado et al., 2021)	- RT + Diet/ 60 - Diet only/ 59 - AT + Diet/ 60	(24 weeks), and after 3 years of the follow-up	- Adults living with overweight or obesity - Age 18 to 50	Hypocaloric diets (25-30% less energy than total daily energy expenditure) were prescribed individually by expert dieticians	Adherence not reported - Only participants with >80% adherence	Resistance exercise sessions were supervised 3x/week - included exercises: shoulder press, squat, barbell row, lateral split, bench press, front split, biceps curl, and French	Adherence not reported - Only participants with >90% adherence to resistance exercise	- Body Weight - Body Mass Index - Fat Mass (%) - Fat Mass - Fat-Free Mass

	- RT + AT + Diet/ 60	period of the post-intervention programme.	- BMI between 25 and 34.9 kg/m2	(29–34% fat, 50–55% carbohydrates and 20% protein).	were included in final analysis.	press for triceps - performed 15 repetitions (45 s) for each exercise, including a rest period of 15 s between repetitions.	were included in final analysis.	
(Said et al., 2018)	- RT + Diet/ 23 - Diet only/ 11 - AT + Diet/ 18	16 weeks	- Sedentary male students - Age - 19-24 - BMI - (RT + Diet 31.98 ± 1.82) (AT + Diet 39.98 ± 4.02) (Diet only 36.47 ± 4.97)	Diets were personalised - each individual's diet was designed using the participant's dietary habits and other selected foods. The targeted daily caloric intake deficit was around 500 kcal/day (15-20% proteins, 25-30% lipids and the rest from carbohydrates).	Participants tracked intake 4 days/week using a structured diary + monthly review. Adherence not reported.	RT sessions were supervised 3x/week - included exercises: abdominal curl, sit-ups, leg extension, leg flexion, lateral pulldown, bench press, shoulder press, triceps extension, and biceps curl. After measuring the dynamic force using the one repetition maximum tests, strength exercises were performed at 40-50% of the personal recorded values for 2-3 sets of	≥80% adherence	- Weight - BMI - Fat (%) - FM - Blood sugar - Diastolic - Systolic - Total cholesterol - HDL cholesterol - LDL cholesterol - Triglycerides

						8-12 repetitions each one with 1-min rest between sets and 3-min rest between exercises. The intensity of the exercises was increased by 10% each month.		
(Sénéchal et al., 2012)	- RT + Diet/ 9 - Diet only/ 9 - RT only/ 10 - Control/ 10	12-week	- Dynapenic postmenopausal women living with obesity - Age 62.6 ± 4.1 - BMI - not reported	The dietary programme contained 55%, 30% and 15% of energy intake from carbohydrates, fats and proteins with an aim to reduce body weight by 0.5 to 1.0 kg of initial body weight per week. Food was self-selected with dietician supervision on macronutrient	Attended weekly nutritional sessions, completed food diaries, and were weighed weekly. Adherence not reported.	RT was 3 times per week, supervised by a kinesiologist. Three sets of eight repetitions for exercises: leg press, leg extension, calf extension, sit-up, chest press, shoulder press, seated rows, triceps extensions, arm curls - resting periods of 60 to 90 seconds were taken between sets. One-repetition maximum evaluation was initially performed for each exercise	Adherence not reported.	- Body weight - % FM - Total FM - Total LBM - Total cholesterol - Triglycerides - HDL cholesterol - LDL cholesterol - Glucose - Insulin - Systolic - Diastolic - Muscle strength

				selection, without the use of food supplements. Participants were invited to participate in a weekly nutritional information session.		and repeated at 6 and 12 weeks to adapt workload during training.		

Appendix 2-E Study quality assessment using Cochrane Risk of Bias tool. Green (+) = low risk of bias; yellow (?) = unclear risk of bias; red (-) = high risk of bias.



Appendix 2-F The Grades of Recommendation, Assessment, Development and Evaluation (GRADE) assessment

Question: RT Plus Diet compared to Diet Only for overweight or people living with obesity

Setting: Intervention: Resistance exercises plus Diet. Comparison: Diet only

Certainty assessment							№ of patients		Effect	Certainty
№ of studies	Study design	Risk of bias	Inconsistency	Indirectness	Imprecision	Other considerations	RT Plus Diet	Diet Only	Absolute-Relative (95% CI)	
Body weight (follow-up: range 2 months to 3 years)										

Certainty assessment							№ of patients		Effect	Certainty
№ of studies	Study design	Risk of bias	Inconsistency	Indirectness	Imprecision	Other considerations	RT Plus Diet	Diet Only	Absolute-Relative (95% CI)	
25	randomised trials	not serious	serious[a]	not serious	not serious	none	634	615	MD **0.32 kg lower** (1 lower to 0.35 higher)	⊕⊕⊕◯ Moderate
FFM (follow-up: range 2 months to 3 years)										
18	randomised trials	not serious	serious[b]	not serious	not serious	none	484	504	SMD **0.4 SD higher** (0.18 higher to 0.61 higher)	⊕⊕⊕◯ Moderate
FM (follow-up: range 2 months to 3 years)										
22	randomised trials	not serious	not serious[c]	not serious	not serious	none	580	564	SMD **0.36 SD lower** (0.49 lower to 0.23 lower)	⊕⊕⊕⊕ High
VO2 Max (follow-up: range 3 months to 1 years)										
8	randomised trials	not serious	not serious[d]	not serious	not serious	none	257	263	MD **0.46 (ml/kg/min) higher** (0.05 lower to 0.96 higher)	⊕⊕⊕⊕ High
Glucose (follow-up: range 2 months to 1 years)										
8	randomised trials	not serious	not serious[d]	not serious	serious[e]	none	194	202	MD **0.01 (mmol/l) lower** (0.05 lower to 0.04 higher)	⊕⊕⊕◯ Moderate
Insulin (follow-up: range 2 months to 1 years)										
8	randomised trials	not serious	not serious[d]	not serious	serious[e]	none	185	204	MD **0.28 mU/l lower** (1.18 lower to 0.62 higher)	⊕⊕⊕◯ Moderate
Total cholesterol (follow-up: range 3 months to 1 years)										
8	randomised trials	not serious	serious[f]	not serious	not serious	publication bias strongly suspected[g]	208	209	MD **0.01 mmol/L lower** (0.2 lower to 0.19 higher)	⊕⊕◯◯ Low

Certainty assessment							№ of patients		Effect	Certainty
№ of studies	Study design	Risk of bias	Inconsistency	Indirectness	Imprecision	Other considerations	RT Plus Diet	Diet Only	Absolute-Relative (95% CI)	
HDL cholesterol (follow-up: range 2 months to 1 years)										
9	randomised trials	not serious	not serious[h]	not serious	not serious	publication bias strongly suspected[g]	235	236	MD **0.01 mmol/L lower** (0.04 lower to 0.03 higher)	⊕⊕⊕◯ Moderate
LDL cholesterol (follow-up: range 2 months to 1 years)										
9	randomised trials	not serious	serious[i]	not serious	not serious	publication bias strongly suspected[g]	235	236	MD **0.1 mmol/L higher** (0.05 lower to 0.24 higher)	⊕⊕◯◯ Low
Triglycerides (follow-up: range 2 months to 1 years)										
9	randomised trials	not serious	not serious[d]	not serious	not serious	none	235	236	MD **0 mmol/L** (0 to 0.01 higher)	⊕⊕⊕⊕ High
Systolic (follow-up: range 2 months to 6 months)										
6	randomised trials	not serious	not serious[d]	not serious	serious[e,j]	none	140	166	MD **0.05 (mm Hg) higher** (0.94 lower to 1.04 higher)	⊕⊕⊕◯ Moderate
Diastolic (follow-up: range 2 months to 6 months)										
6	randomised trials	not serious	not serious[k]	not serious	serious[e,j]	publication bias strongly suspected[g]	140	160	MD **0.68 (mm Hg) lower** (1.64 lower to 0.28 higher)	⊕⊕◯◯ Low
Insulin sensitivity (follow-up: range 2 months to 1 years)										
6	randomised trials	not serious	not serious[d]	not serious	serious[e,j]	none	123	102	SMD **0.18 SD lower** (0.44 lower to 0.09 higher)	⊕⊕⊕◯ Moderate
Muscular strength (follow-up: range 2 months to 6 months)										

Certainty assessment							№ of patients		Effect	Certainty
№ of studies	Study design	Risk of bias	Inconsistency	Indirectness	Imprecision	Other considerations	RT Plus Diet	Diet Only	Absolute-Relative (95% CI)	
8	randomised trials	not serious	serious[l]	not serious	serious[e]	none	126	119	SMD **2.99 SD higher** (1.4 higher to 4.58 higher)	⨁⨁◯◯ Low

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

Explanations

a. high heterogeneity (I2 = 60%)

b. high heterogeneity (I2 = 59%)

c. Heterogeneity (I2 = 9%)

d. Heterogeneity (I2 = 0%)

e. Sample sizes are less than 400

f. high heterogeneity (I2 = 84%)

g. The funnel plot shows that the smaller studies are not symmetrically distributed around either the point estimate

h. Heterogeneity (I2 = 37%)

i. high heterogeneity (I2 = 69%)

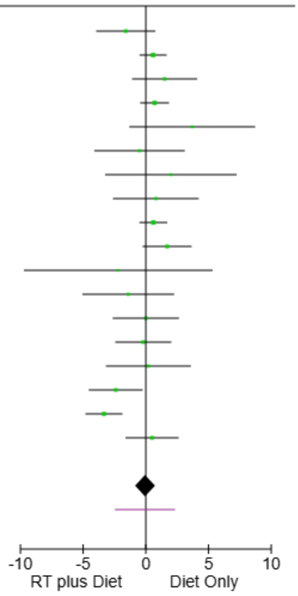
j. small number of trails evaluated RT during weight loss

k. Heterogeneity (I2 = 7%)

l. high heterogeneity (I2 = 89%)

Appendix 2-G Effect of dietary weight loss plus resistance exercise vs. diet-only weight loss on body mass in people living with overweight or obesity in studies of duration ≤ 5 months.

Study or Subgroup	RT plus Diet Mean	RT plus Diet SD	RT plus Diet Total	Diet Only Mean	Diet Only SD	Diet Only Total	Weight	Mean difference IV, Random, 95% CI
Avila et al, 2010	-3.3	3.0984	15	-1.7	3.1177	12	5.9%	-1.60 [-3.96 , 0.76]
Ballor, et al, 1988	-3.89	1.0119	10	-4.47	1.423	10	10.0%	0.58 [-0.50 , 1.66]
Benito, et al, 2020	-4.6	4.5	30	-6.1	5.6	29	5.3%	1.50 [-1.10 , 4.10]
Borges JH, et al, 2019	-11.8	2.69	52	-12.5	2.44	29	9.7%	0.70 [-0.45 , 1.85]
Bryner et al, 1999	-14.46	5.27	10	-18.16	6.15	10	2.1%	3.70 [-1.32 , 8.72]
Donnelly et al, 1993	-20.9	6.2	18	-20.4	5.7	26	3.5%	-0.50 [-4.11 , 3.11]
Donnelly, et al, 1991	-15.1	4.7	7	-17.1	5.3	7	1.9%	2.00 [-3.25 , 7.25]
Figueroa A, et al, 2013	-4.8	3.31	14	-5.6	5.42	13	3.7%	0.80 [-2.62 , 4.22]
Gary, et al, 2016	-11.6	2.3	47	-12.2	3.1	46	9.9%	0.60 [-0.51 , 1.71]
Geliebter, et al, 2014	-7.5	4	27	-9.2	3.3	27	7.0%	1.70 [-0.26 , 3.66]
Herring LY, et al, 2014	-2.9	7.46	11	-0.7	9.84	10	1.0%	-2.20 [-9.73 , 5.33]
Ibáñez, et al, 2010	-7.1	4.29	13	-5.7	4.98	12	3.4%	-1.40 [-5.06 , 2.26]
Janssen, et al, 2002	-10	3	14	-10	3.9	13	5.2%	0.00 [-2.64 , 2.64]
Joseph et al, 2001	-3.2	2.39	11	-3	2.93	11	6.2%	-0.20 [-2.43 , 2.03]
Marks, et al, 1995	-3.5	3.4	11	-3.7	4.4	10	3.8%	0.20 [-3.19 , 3.59]
Nakata et al, 2008	-8.6	3.6	21	-6.2	3.5	21	6.4%	-2.40 [-4.55 , -0.25]
Said MA, et al, 2018	-9.37	1.99	23	-6.03	2.08	11	8.6%	-3.34 [-4.81 , -1.87]
Sénéchal, et al, 2012	-3.8	1.8	9	-4.3	2.7	9	6.5%	0.50 [-1.62 , 2.62]
Total (Wald[a])			**343**			**306**	**100.0%**	**-0.07 [-0.86 , 0.73]**
95% prediction interval								[-2.46 , 2.33]

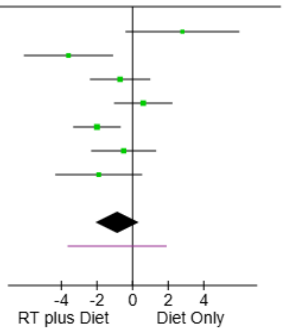


Test for overall effect: Z = 0.17 (P = 0.87)
Test for subgroup differences: Not applicable
Heterogeneity: Tau² (DL[b]) = 1.33; Chi² = 38.20, df = 17 (P = 0.002); I² = 55%

Footnotes
[a]CI calculated by Wald-type method.
[b]Tau² calculated by DerSimonian and Laird method.

Appendix 2-H Effect of dietary weight loss plus resistance exercise vs. diet-only weight loss on body mass in people living with overweight or obesity in studies of duration ≥ 6 months.

Study or Subgroup	RT plus Diet Mean	RT plus Diet SD	RT plus Diet Total	Diet Only Mean	Diet Only SD	Diet Only Total	Weight	Mean difference IV, Random, 95% CI
Andersen et al, 1997	-16.6	4.3	12	-19.4	3.18	9	9.0%	2.80 [-0.40 , 6.00]
Beavers , et al, 2017	-8.9	8.1404	81	-5.3	8.1921	82	11.9%	-3.60 [-6.11 , -1.09]
Brochu et al, 2009	-5.8	4.9	48	-5.1	4.7	89	16.3%	-0.70 [-2.40 , 1.00]
Dunstan et al, 2002	-2.5	2.9	19	-3.1	2.1	17	16.6%	0.60 [-1.04 , 2.24]
Fisher, et al, 2012	-9	2.65	41	-7	2.65	24	18.5%	-2.00 [-3.33 , -0.67]
Morencos E, et al, 2012	-6.4	3.93	30	-5.9	3.2	29	15.5%	-0.50 [-2.33 , 1.33]
Rojo-Tirado, et al, 2021	-3.2	6.92	60	-1.3	6.66	59	12.2%	-1.90 [-4.34 , 0.54]
Total (Wald[a])			**291**			**309**	**100.0%**	**-0.87 [-2.09 , 0.35]**
95% prediction interval								[-3.65 , 1.91]

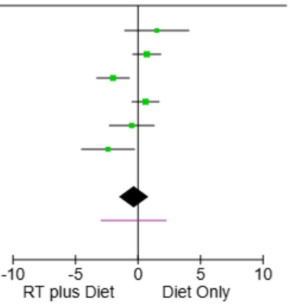


Test for overall effect: Z = 1.40 (P = 0.16)
Test for subgroup differences: Not applicable
Heterogeneity: Tau² (DL[b]) = 1.63; Chi² = 16.27, df = 6 (P = 0.01); I² = 63%

Footnotes
[a]CI calculated by Wald-type method.
[b]Tau² calculated by DerSimonian and Laird method.

Appendix 2-I Effect of dietary weight loss plus resistance exercise vs. diet-only weight loss on body mass in studies living with overweight.

Study or Subgroup	RT plus Diet Mean	RT plus Diet SD	RT plus Diet Total	Diet Only Mean	Diet Only SD	Diet Only Total	Weight	Mean difference IV, Random, 95% CI
Benito, et al, 2020	-4.6	4.5	30	-6.1	5.6	29	11.3%	1.50 [-1.10 , 4.10]
Borges JH, et al, 2019	-11.8	2.69	52	-12.5	2.44	29	20.2%	0.70 [-0.45 , 1.85]
Fisher, et al, 2012	-9	2.65	41	-7	2.65	24	18.9%	-2.00 [-3.33 , -0.67]
Gary, et al, 2016	-11.6	2.3	47	-12.2	3.1	46	20.4%	0.60 [-0.51 , 1.71]
Morencos E, et al, 2012	-6.4	3.93	30	-5.9	3.2	29	15.6%	-0.50 [-2.33 , 1.33]
Nakata et al, 2008	-8.6	3.6	21	-6.2	3.5	21	13.6%	-2.40 [-4.55 , -0.25]
Total (Wald[a])			**221**			**178**	**100.0%**	**-0.35 [-1.53 , 0.83]**
95% prediction interval								[-2.98 , 2.28]

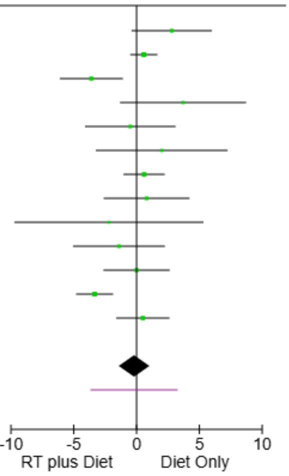


Test for overall effect: Z = 0.58 (P = 0.56)
Test for subgroup differences: Not applicable
Heterogeneity: Tau² (DL[b]) = 1.44; Chi² = 17.11, df = 5 (P = 0.004); I² = 71%

Footnotes
[a]CI calculated by Wald-type method.
[b]Tau² calculated by DerSimonian and Laird method.

Appendix 2-J Effect of dietary weight loss plus resistance exercise vs. diet-only weight loss on body mass in studies living with obesity.

Study or Subgroup	RT plus Diet Mean	RT plus Diet SD	RT plus Diet Total	Diet Only Mean	Diet Only SD	Diet Only Total	Weight	Mean difference IV, Random, 95% CI
Andersen et al, 1997	-16.6	4.3	12	-19.4	3.18	9	7.2%	2.80 [-0.40 , 6.00]
Ballor, et al, 1988	-3.89	1.0119	10	-4.47	1.423	10	12.8%	0.58 [-0.50 , 1.66]
Beavers , et al, 2017	-8.9	8.1404	81	-5.3	8.1921	82	8.9%	-3.60 [-6.11 , -1.09]
Bryner et al, 1999	-14.46	5.27	10	-18.16	6.15	10	4.2%	3.70 [-1.32 , 8.72]
Donnelly et al, 1993	-20.9	6.2	18	-20.4	5.7	26	6.3%	-0.50 [-4.11 , 3.11]
Donnelly, et al, 1991	-15.1	4.7	7	-17.1	5.3	7	3.9%	2.00 [-3.25 , 7.25]
Dunstan et al, 2002	-2.5	2.9	19	-3.1	2.1	17	11.3%	0.60 [-1.04 , 2.24]
Figueroa A, et al, 2013	-4.8	3.31	14	-5.6	5.42	13	6.7%	0.80 [-2.62 , 4.22]
Herring LY, et al, 2014	-2.9	7.46	11	-0.7	9.84	10	2.2%	-2.20 [-9.73 , 5.33]
Ibáñez, et al, 2010	-7.1	4.29	13	-5.7	4.98	12	6.3%	-1.40 [-5.06 , 2.26]
Janssen, et al, 2002	-10	3	14	-10	3.9	13	8.5%	0.00 [-2.64 , 2.64]
Said MA, et al, 2018	-9.37	1.99	23	-6.03	2.08	11	11.7%	-3.34 [-4.81 , -1.87]
Sénéchal, et al, 2012	-3.8	1.8	9	-4.3	2.7	9	9.9%	0.50 [-1.62 , 2.62]
Total (Wald[a])			**241**			**229**	**100.0%**	**-0.20 [-1.42 , 1.02]**
95% prediction interval								[-3.67 , 3.27]

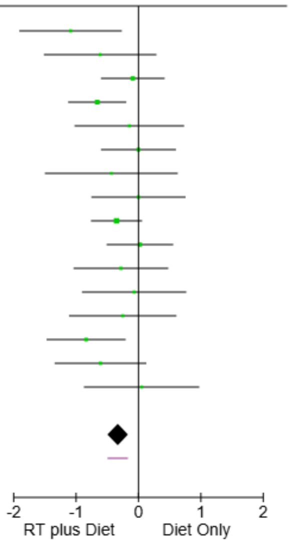


Test for overall effect: Z = 0.32 (P = 0.75)
Test for subgroup differences: Not applicable
Heterogeneity: Tau² (DL[b]) = 2.75; Chi² = 35.06, df = 12 (P = 0.0005); I² = 66%

Footnotes
[a]CI calculated by Wald-type method.
[b]Tau² calculated by DerSimonian and Laird method.

Appendix 2-K Effect of dietary weight loss plus resistance exercise vs. diet-only weight loss on fat mass in people living with overweight or obesity in studies of duration ≤ 5 months.

Study or Subgroup	RT plus Diet Mean	RT plus Diet SD	RT plus Diet Total	Diet Only Mean	Diet Only SD	Diet Only Total	Weight	Std. mean difference IV, Random, 95% CI
Avila et al, 2010	-4.1	3.4857	15	-0.2	3.4641	12	4.0%	-1.09 [-1.91 , -0.27]
Ballor, et al, 1988	-4.32	1.2017	10	-3.56	1.17	10	3.3%	-0.61 [-1.52 , 0.29]
Benito, et al, 2020	-4.24	2.02	30	-3.94	4.18	29	10.3%	-0.09 [-0.60 , 0.42]
Borges JH, et al, 2019	-10.8	1.89	52	-9.5	2.05	29	12.3%	-0.66 [-1.13 , -0.19]
Bryner et al, 1999	-14.5	15.19	10	-12.8	4.09	10	3.5%	-0.15 [-1.02 , 0.73]
Donnelly et al, 1993	-16.1	4.1	18	-16.1	5.1	26	7.4%	0.00 [-0.60 , 0.60]
Donnelly, et al, 1991	-6.1	2.2	7	-5.1	2.1	7	2.4%	-0.44 [-1.50 , 0.63]
Figueroa A, et al, 2013	-4.4	3.06	14	-4.4	4.48	13	4.7%	0.00 [-0.75 , 0.75]
Gary, et al, 2016	-12	2.4	47	-11.2	2.1	46	15.9%	-0.35 [-0.76 , 0.06]
Geliebter, et al, 2014	-5.8	5	27	-5.9	3.2	27	9.4%	0.02 [-0.51 , 0.56]
Janssen, et al, 2002	-8.6	2.4	14	-7.8	3.1	13	4.6%	-0.28 [-1.04 , 0.48]
Joseph et al, 2001	-3.2	2.58	11	-3	2.93	11	3.8%	-0.07 [-0.91 , 0.77]
Marks, et al, 1995	-4.2	2.3	11	-3.4	3.7	10	3.6%	-0.25 [-1.11 , 0.61]
Nakata et al, 2008	-6.9	3	21	-4.5	2.6	21	6.7%	-0.84 [-1.47 , -0.21]
Said MA, et al, 2018	-5	1.27	23	-4.22	1.21	11	5.0%	-0.61 [-1.34 , 0.13]
Sénéchal, et al, 2012	-3.1	1.8	9	-3.2	2	9	3.1%	0.05 [-0.87 , 0.97]
Total (Wald[a])			**319**			**284**	**100.0%**	**-0.33 [-0.50 , -0.17]**
95% prediction interval								[-0.50 , -0.17]

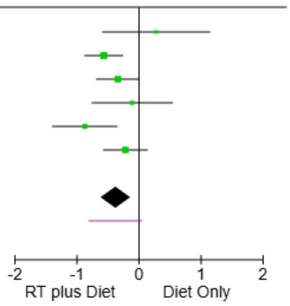


Test for overall effect: Z = 3.99 (P < 0.0001)
Test for subgroup differences: Not applicable
Heterogeneity: Tau² (DL[b]) = 0.00; Chi² = 14.32, df = 15 (P = 0.50); I² = 0%

Footnotes
[a]CI calculated by Wald-type method.
[b]Tau² calculated by DerSimonian and Laird method.

Appendix 2-L Effect of dietary weight loss plus resistance exercise vs. diet-only weight loss on fat mass in people living with overweight or obesity in studies of duration ≥ 6 months

Study or Subgroup	RT plus Diet Mean	RT plus Diet SD	RT plus Diet Total	Diet Only Mean	Diet Only SD	Diet Only Total	Weight	Std. mean difference IV, Random, 95% CI
Andersen et al, 1997	-15.3	4.64	12	-16.6	4.36	9	6.4%	0.28 [-0.59 , 1.15]
Beavers , et al, 2017	-7.9	5.8792	81	-4.4	6.3716	82	25.0%	-0.57 [-0.88 , -0.25]
Brochu et al, 2009	-5.3	4.3	48	-4	3.5	89	22.4%	-0.34 [-0.69 , 0.01]
Dunstan et al, 2002	-2.4	2.8	19	-2.1	2.5	17	10.2%	-0.11 [-0.77 , 0.54]
Fisher, et al, 2012	-6	2.08	41	-4	2.55	24	14.0%	-0.87 [-1.40 , -0.35]
Rojo-Tirado, et al, 2021	-2.4	6.81	60	-0.9	6.75	59	21.9%	-0.22 [-0.58 , 0.14]
Total (Wald[a])			**261**			**280**	**100.0%**	**-0.38 [-0.62 , -0.14]**
95% prediction interval								[-0.82 , 0.05]



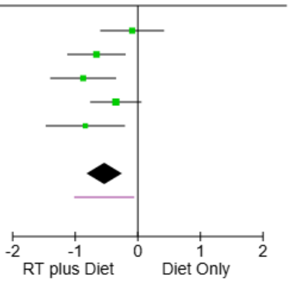
Test for overall effect: Z = 3.13 (P = 0.002)
Test for subgroup differences: Not applicable
Heterogeneity: Tau² (DL[b]) = 0.03; Chi² = 8.35, df = 5 (P = 0.14); I² = 40%

Footnotes
[a]CI calculated by Wald-type method.
[b]Tau² calculated by DerSimonian and Laird method.

Appendix 2-M Effect of dietary weight loss plus resistance exercise vs. diet-only weight loss on fat mass in studies living with overweight.

	RT plus Diet			Diet Only				Std. mean difference
Study or Subgroup	**Mean**	**SD**	**Total**	**Mean**	**SD**	**Total**	**Weight**	**IV, Random, 95% CI**
Benito, et al, 2020	-4.24	2.02	30	-3.94	4.18	29	19.5%	-0.09 [-0.60 , 0.42]
Borges JH, et al, 2019	-10.8	1.89	52	-9.5	2.05	29	21.9%	-0.66 [-1.13 , -0.19]
Fisher, et al, 2012	-6	2.08	41	-4	2.55	24	18.8%	-0.87 [-1.40 , -0.35]
Gary, et al, 2016	-12	2.4	47	-11.2	2.1	46	25.3%	-0.35 [-0.76 , 0.06]
Nakata et al, 2008	-6.9	3	21	-4.5	2.6	21	14.6%	-0.84 [-1.47 , -0.21]
Total (Wald[a])			**191**			**149**	**100.0%**	**-0.54 [-0.82 , -0.25]**
95% prediction interval								[-1.02 , -0.06]

Std. mean difference
IV, Random, 95% CI



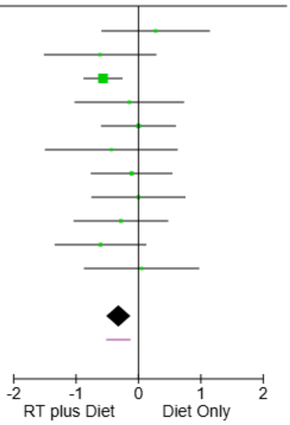
Test for overall effect: Z = 3.71 (P = 0.0002)
Test for subgroup differences: Not applicable
Heterogeneity: Tau² (DL[b]) = 0.04; Chi² = 6.41, df = 4 (P = 0.17); I² = 38%

Footnotes
[a]CI calculated by Wald-type method.
[b]Tau² calculated by DerSimonian and Laird method.

Appendix 2-N Effect of dietary weight loss plus resistance exercise vs. diet-only weight loss on fat mass in studies living with obesity.

	RT plus Diet			Diet Only				Std. mean difference
Study or Subgroup	**Mean**	**SD**	**Total**	**Mean**	**SD**	**Total**	**Weight**	**IV, Random, 95% CI**
Andersen et al, 1997	-15.3	4.64	12	-16.6	4.36	9	5.0%	0.28 [-0.59 , 1.15]
Ballor, et al, 1988	-4.32	1.2017	10	-3.56	1.17	10	4.6%	-0.61 [-1.52 , 0.29]
Beavers , et al, 2017	-7.9	5.8792	81	-4.4	6.3716	82	38.4%	-0.57 [-0.88 , -0.25]
Bryner et al, 1999	-14.5	15.19	10	-12.8	4.09	10	4.9%	-0.15 [-1.02 , 0.73]
Donnelly et al, 1993	-16.1	4.1	18	-16.1	5.1	26	10.4%	0.00 [-0.60 , 0.60]
Donnelly, et al, 1991	-6.1	2.2	7	-5.1	2.1	7	3.3%	-0.44 [-1.50 , 0.63]
Dunstan et al, 2002	-2.4	2.8	19	-2.1	2.5	17	8.8%	-0.11 [-0.77 , 0.54]
Figueroa A, et al, 2013	-4.4	3.06	14	-4.4	4.48	13	6.6%	0.00 [-0.75 , 0.75]
Janssen, et al, 2002	-8.6	2.4	14	-7.8	3.1	13	6.5%	-0.28 [-1.04 , 0.48]
Said MA, et al, 2018	-5	1.27	23	-4.22	1.21	11	7.0%	-0.61 [-1.34 , 0.13]
Sénéchal, et al, 2012	-3.1	1.8	9	-3.2	2	9	4.4%	0.05 [-0.87 , 0.97]
Total (Wald[a])			**217**			**207**	**100.0%**	**-0.32 [-0.52 , -0.13]**
95% prediction interval								[-0.52 , -0.13]

Std. mean difference
IV, Random, 95% CI

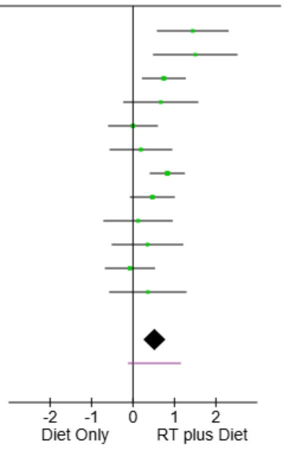


Test for overall effect: Z = 3.26 (P = 0.001)
Test for subgroup differences: Not applicable
Heterogeneity: Tau² (DL[b]) = 0.00; Chi² = 8.21, df = 10 (P = 0.61); I² = 0%

Footnotes
[a]CI calculated by Wald-type method.
[b]Tau² calculated by DerSimonian and Laird method.

Appendix 2-O Effect of dietary weight loss plus resistance exercise vs. diet-only weight loss on fat free mass in people living with overweight or obesity in studies of duration ≤ 5 months

Study or Subgroup	RT plus Diet Mean	RT plus Diet SD	RT plus Diet Total	Diet Only Mean	Diet Only SD	Diet Only Total	Weight	Std. mean difference IV, Random, 95% CI
Avila et al, 2010	0.8	1.5492	15	-1.4	1.3856	12	6.4%	1.44 [0.58 , 2.31]
Ballor, et al, 1988	0.43	0.8222	10	-0.91	0.8854	10	5.1%	1.50 [0.48 , 2.52]
Benito, et al, 2020	0.03	0.9	30	-0.94	1.59	29	11.3%	0.74 [0.22 , 1.27]
Bryner et al, 1999	-0.8	4	10	-4.1	5.33	10	6.0%	0.67 [-0.24 , 1.58]
Donnelly, et al, 1991	-4.7	4.6	18	-4.7	4.3	26	10.0%	0.00 [-0.60 , 0.60]
Figueroa A, et al, 2013	-0.8	2.16	14	-1.3	2.88	13	7.7%	0.19 [-0.57 , 0.95]
Gary, et al, 2016	0.3	1.4	47	-1	1.7	46	13.5%	0.83 [0.40 , 1.25]
Geliebter, et al, 2014	-2.9	3.4	27	-4.4	2.9	27	11.1%	0.47 [-0.07 , 1.01]
Joseph et al, 2001	0.1	1.03	11	-0.1	1.97	11	6.7%	0.12 [-0.71 , 0.96]
Marks, et al, 1995	0.7	3	11	-0.2	1.7	10	6.4%	0.35 [-0.51 , 1.21]
Nakata et al, 2008	-1.8	1.2	21	-1.7	1.5	21	9.9%	-0.07 [-0.68 , 0.53]
Sénéchal, et al, 2012	-0.4	0.9	9	-0.8	1.2	9	5.8%	0.36 [-0.57 , 1.29]
Total (Wald[a])			**223**			**224**	**100.0%**	**0.52 [0.25 , 0.78]**
95% prediction interval								[-0.12 , 1.16]

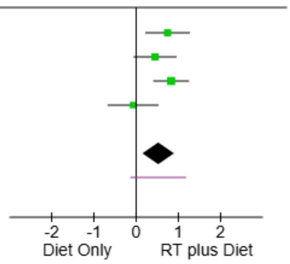


Test for overall effect: Z = 3.82 (P = 0.0001)
Test for subgroup differences: Not applicable
Heterogeneity: Tau² (DL[b]) = 0.09; Chi² = 19.20, df = 11 (P = 0.06); I² = 43%

Footnotes
[a]CI calculated by Wald-type method.
[b]Tau² calculated by DerSimonian and Laird method.

Appendix 2-P Effect of dietary weight loss plus resistance exercise vs. diet-only weight loss on fat free mass in studies living with overweight.

Study or Subgroup	RT plus Diet Mean	RT plus Diet SD	RT plus Diet Total	Diet Only Mean	Diet Only SD	Diet Only Total	Weight	Std. mean difference IV, Random, 95% CI
Benito, et al, 2020	0.03	0.9	30	-0.94	1.59	29	24.3%	0.74 [0.22 , 1.27]
Fisher, et al, 2012	0.2	2.11	41	-0.7	1.74	24	25.2%	0.45 [-0.06 , 0.96]
Gary, et al, 2016	0.3	1.4	47	-1	1.7	46	29.4%	0.83 [0.40 , 1.25]
Nakata et al, 2008	-1.8	1.2	21	-1.7	1.5	21	21.1%	-0.07 [-0.68 , 0.53]
Total (Wald[a])			**139**			**120**	**100.0%**	**0.52 [0.15 , 0.90]**
95% prediction interval								[-0.14 , 1.18]

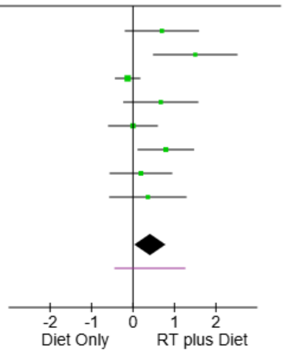


Test for overall effect: Z = 2.74 (P = 0.006)
Test for subgroup differences: Not applicable
Heterogeneity: Tau² (DL[b]) = 0.08; Chi² = 6.39, df = 3 (P = 0.09); I² = 53%

Footnotes
[a]CI calculated by Wald-type method.
[b]Tau² calculated by DerSimonian and Laird method.

Appendix 2-Q Effect of dietary weight loss plus resistance exercise vs. diet-only weight loss on fat free mass in studies living with obesity.

Study or Subgroup	RT plus Diet Mean	RT plus Diet SD	RT plus Diet Total	Diet Only Mean	Diet Only SD	Diet Only Total	Weight	Std. mean difference IV, Random, 95% CI
Andersen et al, 1997	-1.3	2.01	12	-2.8	2.14	9	10.2%	0.70 [-0.20 , 1.59]
Ballor, et al, 1988	0.43	0.8222	10	-0.91	0.8854	10	8.7%	1.50 [0.48 , 2.52]
Beavers , et al, 2017	-1.2	1.809	81	-0.9	2.7307	82	20.7%	-0.13 [-0.44 , 0.18]
Bryner et al, 1999	-0.8	4	10	-4.1	5.33	10	10.1%	0.67 [-0.24 , 1.58]
Donnelly, et al, 1991	-4.7	4.6	18	-4.7	4.3	26	14.9%	0.00 [-0.60 , 0.60]
Dunstan et al, 2002	0.5	1.2	19	-0.4	1	17	13.4%	0.79 [0.11 , 1.48]
Figueroa A, et al, 2013	-0.8	2.16	14	-1.3	2.88	13	12.2%	0.19 [-0.57 , 0.95]
Sénéchal, et al, 2012	-0.4	0.9	9	-0.8	1.2	9	9.7%	0.36 [-0.57 , 1.29]
Total (Wald[a])			**173**			**176**	**100.0%**	**0.41 [0.03 , 0.78]**
95% prediction interval								[-0.45 , 1.26]

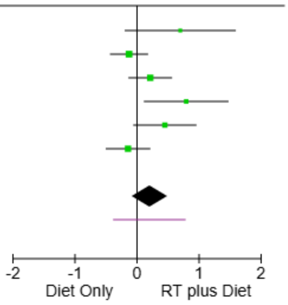


Test for overall effect: Z = 2.12 (P = 0.03)
Test for subgroup differences: Not applicable
Heterogeneity: Tau² (DL[b]) = 0.15; Chi² = 16.32, df = 7 (P = 0.02); I² = 57%

Footnotes
[a]CI calculated by Wald-type method.
[b]Tau² calculated by DerSimonian and Laird method.

Appendix 2-R Effect of dietary weight loss plus resistance exercise vs. diet-only weight loss on fat free mass in people living with overweight or obesity in studies of duration ≥ 6 months

Study or Subgroup	RT plus Diet Mean	RT plus Diet SD	RT plus Diet Total	Diet Only Mean	Diet Only SD	Diet Only Total	Weight	Std. mean difference IV, Random, 95% CI
Andersen et al, 1997	-1.3	2.01	12	-2.8	2.14	9	7.7%	0.70 [-0.20 , 1.59]
Beavers , et al, 2017	-1.2	1.809	81	-0.9	2.7307	82	23.1%	-0.13 [-0.44 , 0.18]
Brochu et al, 2009	-0.4	2.2	48	-0.9	2.4	89	21.3%	0.21 [-0.14 , 0.57]
Dunstan et al, 2002	0.5	1.2	19	-0.4	1	17	11.3%	0.79 [0.11 , 1.48]
Fisher, et al, 2012	0.2	2.11	41	-0.7	1.74	24	15.7%	0.45 [-0.06 , 0.96]
Rojo-Tirado, et al, 2021	-1	4.13	60	-0.4	4.1	59	21.0%	-0.14 [-0.50 , 0.21]
Total (Wald[a])			**261**			**280**	**100.0%**	**0.20 [-0.09 , 0.48]**
95% prediction interval								[-0.39 , 0.78]

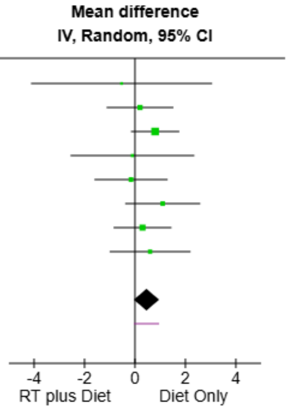


Test for overall effect: Z = 1.36 (P = 0.17)
Test for subgroup differences: Not applicable
Heterogeneity: Tau² (DL[b]) = 0.07; Chi² = 11.76, df = 5 (P = 0.04); I² = 57%

Footnotes
[a]CI calculated by Wald-type method.
[b]Tau² calculated by DerSimonian and Laird method.

Appendix 2-S Effect of dietary weight loss plus resistance exercise vs. diet-only weight loss on cardiorespiratory fitness (VO2max or VO2peak) in people living with overweight or obesity.

	RT plus Diet			Diet Only				Mean difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
Benito, et al, 2020	5.61	7.65	30	6.14	6.38	29	2.0%	-0.53 [-4.12 , 3.06]
Borges JH, et al, 2019	4.4	2.87	52	4.2	2.94	29	14.3%	0.20 [-1.12 , 1.52]
Brochu et al, 2009	0.6	2.8	48	-0.2	2.6	89	27.4%	0.80 [-0.16 , 1.76]
Bryner et al, 1999	6.3	3.37	10	6.4	2.08	10	4.2%	-0.10 [-2.55 , 2.35]
Donnelly, et al, 1991	-1.13	2.22	18	-0.975	2.67	26	11.9%	-0.15 [-1.61 , 1.30]
Fisher, et al, 2012	2.9	3.26	41	1.8	2.76	24	11.4%	1.10 [-0.39 , 2.59]
Gary, et al, 2016	4.3	3.2	47	4	2.4	46	19.1%	0.30 [-0.85 , 1.45]
Marks, et al, 1995	2.39	1.6	11	1.79	2.09	10	9.8%	0.60 [-1.00 , 2.20]
Total (Wald[a])			**257**			**263**	**100.0%**	**0.46 [-0.05 , 0.96]**
95% prediction interval								[-0.05 , 0.96]

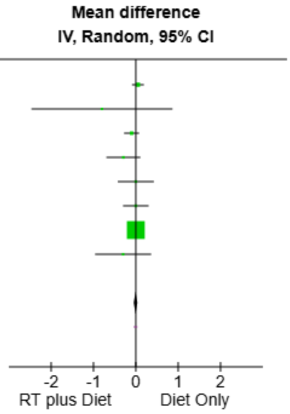


Test for overall effect: Z = 1.78 (P = 0.08)
Test for subgroup differences: Not applicable
Heterogeneity: Tau² (DL[b]) = 0.00; Chi² = 2.63, df = 7 (P = 0.92); I² = 0%

Footnotes
[a]CI calculated by Wald-type method.
[b]Tau² calculated by DerSimonian and Laird method.

Appendix 2-T Effect of dietary weight loss plus resistance exercise vs. diet-only weight loss on glucose in people living with overweight or obesity.

	RT plus Diet			Diet Only				Mean difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
Brochu et al, 2009	0.03	0.37	48	-0.02	0.45	89	9.5%	0.05 [-0.09 , 0.19]
Dunstan et al, 2002	-1.4	2.7	19	-0.6	2.4	17	0.1%	-0.80 [-2.47 , 0.87]
Fisher, et al, 2012	0.1	0.32	41	0.2	0.37	24	5.9%	-0.10 [-0.28 , 0.08]
Geliebter, et al, 2014	-0.3	0.8	27	-0.0056	0.7	27	1.2%	-0.29 [-0.70 , 0.11]
Ibáñez, et al, 2010	-0.2	0.62	13	-0.2	0.46	12	1.0%	0.00 [-0.43 , 0.43]
Janssen, et al, 2002	-0.1	0.4	14	-0.1	0.4	13	2.0%	0.00 [-0.30 , 0.30]
Said MA, et al, 2018	-0.06	0.07	23	-0.06	0.066	11	79.9%	0.00 [-0.05 , 0.05]
Sénéchal, et al, 2012	-0.2	0.52	9	0.1	0.87	9	0.4%	-0.30 [-0.96 , 0.36]
Total (Wald[a])			**194**			**202**	**100.0%**	**-0.01 [-0.05 , 0.04]**
95% prediction interval								[-0.05 , 0.04]

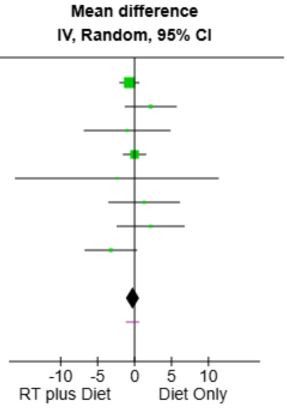


Test for overall effect: Z = 0.29 (P = 0.77)
Test for subgroup differences: Not applicable
Heterogeneity: Tau² (DL[b]) = 0.00; Chi² = 5.37, df = 7 (P = 0.62); I² = 0%

Footnotes
[a]CI calculated by Wald-type method.
[b]Tau² calculated by DerSimonian and Laird method.

Appendix 2-U Effect of dietary weight loss plus resistance exercise vs. diet-only weight loss on insulin in people living with overweight or obesity.

	RT plus Diet			Diet Only				Mean difference
Study or Subgroup	**Mean**	**SD**	**Total**	**Mean**	**SD**	**Total**	**Weight**	**IV, Random, 95% CI**
Brochu et al, 2009	-2.4	3.6	48	-1.7	4.3	89	44.4%	-0.70 [-2.05 , 0.65]
Dunstan et al, 2002	1.512	6.6672	19	-0.6768	3.9168	17	6.5%	2.19 [-1.34 , 5.72]
Figueroa A, et al, 2013	-0.6	7.78	14	0.4	7.79	13	2.4%	-1.00 [-6.88 , 4.88]
Fisher, et al, 2012	-2	2.98	41	-2	3.24	24	32.5%	0.00 [-1.59 , 1.59]
Gelieber, et al, 2014	-13.7	34.3	27	-11.3	12.7	27	0.4%	-2.40 [-16.20 , 11.40]
Ibáñez, et al, 2010	-4	5.24	13	-5.3	6.93	12	3.5%	1.30 [-3.55 , 6.15]
Janssen, et al, 2002	-4.752	5.6016	14	-6.9264	6.552	13	3.8%	2.17 [-2.44 , 6.79]
Sénéchal, et al, 2012	-2.9232	3.17	9	0.288	4.43	9	6.4%	-3.21 [-6.77 , 0.35]
Total (Wald[a])			**185**			**204**	**100.0%**	**-0.28 [-1.18 , 0.62]**
95% prediction interval								[-1.18 , 0.62]

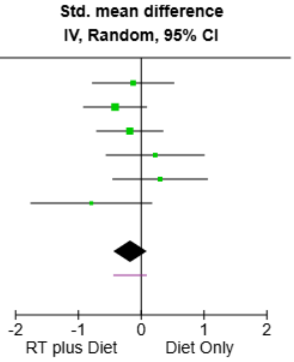


Test for overall effect: Z = 0.61 (P = 0.54)
Test for subgroup differences: Not applicable
Heterogeneity: Tau² (DL[b]) = 0.00; Chi² = 6.62, df = 7 (P = 0.47); I² = 0%

Footnotes
[a]CI calculated by Wald-type method.
[b]Tau² calculated by DerSimonian and Laird method.

Appendix 2-V Effect of dietary weight loss plus resistance exercise vs. diet-only weight loss on insulin sensitivity in people living with overweight or obesity.

	RT plus Diet			Diet Only				Std. mean difference
Study or Subgroup	**Mean**	**SD**	**Total**	**Mean**	**SD**	**Total**	**Weight**	**IV, Random, 95% CI**
Dunstan et al, 2002	0.03	5.2	19	0.8	6.5	17	16.5%	-0.13 [-0.78 , 0.53]
Fisher, et al, 2012	0.8	1.59	41	1.4	1.08	24	27.4%	-0.42 [-0.93 , 0.09]
Gelieber, et al, 2014	-4.2	9.4	27	-2.9	3.3	27	24.8%	-0.18 [-0.72 , 0.35]
Ibáñez, et al, 2010	-1	1.55	13	-1.4	1.92	12	11.4%	0.22 [-0.56 , 1.01]
Janssen, et al, 2002	12	11	14	9	8	13	12.3%	0.30 [-0.46 , 1.06]
Sénéchal, et al, 2012	-0.73	0.73	9	-0.06	0.87	9	7.5%	-0.79 [-1.76 , 0.17]
Total (Wald[a])			**123**			**102**	**100.0%**	**-0.18 [-0.44 , 0.09]**
95% prediction interval								[-0.44 , 0.09]

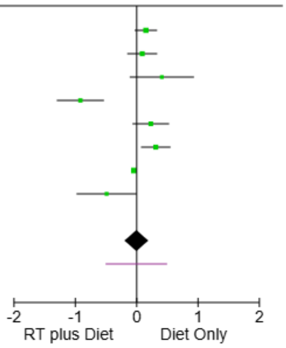


Test for overall effect: Z = 1.31 (P = 0.19)
Test for subgroup differences: Not applicable
Heterogeneity: Tau² (DL[b]) = 0.00; Chi² = 4.93, df = 5 (P = 0.42); I² = 0%

Footnotes
[a]CI calculated by Wald-type method.
[b]Tau² calculated by DerSimonian and Laird method.

Appendix 2-W Effect of dietary weight loss plus resistance exercise vs. diet-only weight loss on total cholesterol in people living with overweight or obesity.

	RT plus Diet			Diet Only				Mean difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
Borges JH, et al, 2019	-0.145	0.39	52	-0.295	0.41	29	15.4%	0.15 [-0.03 , 0.33]
Brochu et al, 2009	0.02	0.73	48	-0.07	0.63	89	13.9%	0.09 [-0.15 , 0.33]
Dunstan et al, 2002	-0.09	0.8	19	-0.5	0.8	17	7.8%	0.41 [-0.11 , 0.93]
Ibáñez, et al, 2010	-0.89	0.43	13	0.028	0.54	12	10.5%	-0.92 [-1.30 , -0.53]
Janssen, et al, 2002	-0.6	0.43	14	-0.83	0.36	13	12.5%	0.23 [-0.07 , 0.53]
Morencos E, et al, 2012	-0.106	0.44	30	-0.417	0.5	29	14.0%	0.31 [0.07 , 0.55]
Said MA, et al, 2018	-0.07189	0.08379	23	-0.02586	0.030515	11	17.6%	-0.05 [-0.08 , -0.01]
Sénéchal, et al, 2012	-0.85	0.68	9	-0.36	0.32	9	8.3%	-0.49 [-0.98 , 0.00]
Total (Wald[a])			**208**			**209**	**100.0%**	**-0.01 [-0.20 , 0.19]**
95% prediction interval								[-0.51 , 0.50]

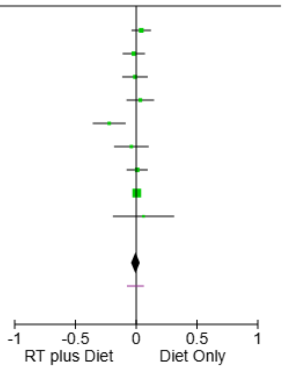


Test for overall effect: Z = 0.06 (P = 0.96)
Test for subgroup differences: Not applicable
Heterogeneity: Tau² (DL[b]) = 0.06; Chi² = 42.48, df = 7 (P < 0.00001); I² = 84%

Footnotes
[a]CI calculated by Wald-type method.
[b]Tau² calculated by DerSimonian and Laird method.

Appendix 2-X Effect of dietary weight loss plus resistance exercise vs. diet-only weight loss on HDL cholesterol in people living with overweight or obesity.

	RT plus Diet			Diet Only				Mean difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
Borges JH, et al, 2019	0.1706	0.17	52	0.1293	0.18	29	12.9%	0.04 [-0.04 , 0.12]
Brochu et al, 2009	-0.01	0.29	48	0.01	0.2	89	10.8%	-0.02 [-0.11 , 0.07]
Dunstan et al, 2002	0.06	0.1	19	0.07	0.2	17	8.8%	-0.01 [-0.12 , 0.10]
Geliebter, et al, 2014	-0.16292	0.19654	27	-0.19654	0.22757	27	7.9%	0.03 [-0.08 , 0.15]
Ibáñez, et al, 2010	-0.2145	0.12	13	0.0077	0.21	12	5.9%	-0.22 [-0.36 , -0.09]
Janssen, et al, 2002	-0.09	0.11	14	-0.05	0.24	13	5.4%	-0.04 [-0.18 , 0.10]
Morencos E, et al, 2012	0.0362	0.18	30	0.0284	0.16	29	11.6%	0.01 [-0.08 , 0.09]
Said MA, et al, 2018	0.016292	0.021464	23	0.011637	0.01474	11	34.7%	0.00 [-0.01 , 0.02]
Sénéchal, et al, 2012	-0.08	0.23	9	-0.14	0.31	9	1.9%	0.06 [-0.19 , 0.31]
Total (Wald[a])			**235**			**236**	**100.0%**	**-0.01 [-0.04 , 0.03]**
95% prediction interval								[-0.08 , 0.06]

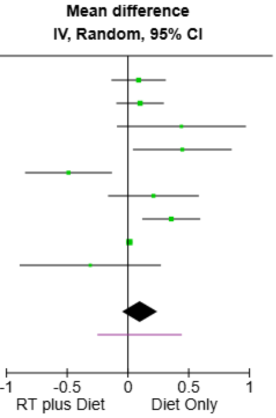


Test for overall effect: Z = 0.36 (P = 0.72)
Test for subgroup differences: Not applicable
Heterogeneity: Tau² (DL[b]) = 0.00; Chi² = 12.68, df = 8 (P = 0.12); I² = 37%

Footnotes
[a]CI calculated by Wald-type method.
[b]Tau² calculated by DerSimonian and Laird method.

Appendix 2-Y Effect of dietary weight loss plus resistance exercise vs. diet-only weight loss on LDL cholesterol in people living with overweight or obesity.

Study or Subgroup	RT plus Diet Mean	RT plus Diet SD	RT plus Diet Total	Diet Only Mean	Diet Only SD	Diet Only Total	Weight	Mean difference IV, Random, 95% CI
Borges JH, et al, 2019	-0.1967	0.44	52	-0.2846	0.52	29	14.0%	0.09 [-0.14 , 0.31]
Brochu et al, 2009	0.14	0.55	48	0.04	0.57	89	15.3%	0.10 [-0.10 , 0.30]
Dunstan et al, 2002	-0.06	0.7	19	-0.5	0.9	17	5.5%	0.44 [-0.09 , 0.97]
Geliebter, et al, 2014	-0.5405	0.6775	27	-0.9879	0.8379	27	7.9%	0.45 [0.04 , 0.85]
Ibáñez, et al, 2010	-0.528	0.44	13	-0.039	0.47	12	9.2%	-0.49 [-0.85 , -0.13]
Janssen, et al, 2002	-0.34	0.5	14	-0.55	0.49	13	8.8%	0.21 [-0.16 , 0.58]
Morencos E, et al, 2012	-0.003	0.38	30	-0.3595	0.54	29	13.4%	0.36 [0.12 , 0.60]
Said MA, et al, 2018	-0.03672	0.019654	23	-0.04888	0.036204	11	21.0%	0.01 [-0.01 , 0.04]
Sénéchal, et al, 2012	-0.35	0.8	9	-0.04	0.39	9	4.8%	-0.31 [-0.89 , 0.27]
Total (Wald[a])			**235**			**236**	**100.0%**	**0.10 [-0.05 , 0.24]**
95% prediction interval								[-0.25 , 0.44]

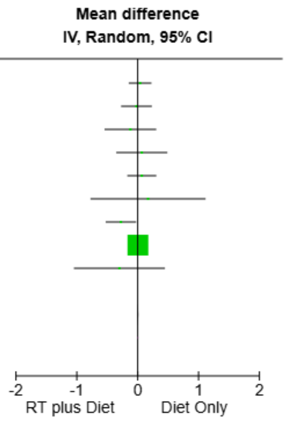


Test for overall effect: Z = 1.30 (P = 0.19)
Test for subgroup differences: Not applicable
Heterogeneity: Tau² (DL[b]) = 0.03; Chi² = 25.67, df = 8 (P = 0.001); I² = 69%

Footnotes
[a]CI calculated by Wald-type method.
[b]Tau² calculated by DerSimonian and Laird method.

Appendix 2-Z Effect of dietary weight loss plus resistance exercise vs. diet-only weight loss on triglycerides in people living with overweight or obesity.

Study or Subgroup	RT plus Diet Mean	RT plus Diet SD	RT plus Diet Total	Diet Only Mean	Diet Only SD	Diet Only Total	Weight	Mean difference IV, Random, 95% CI
Borges JH, et al, 2019	-0.262	0.35	52	-0.3015	0.44	29	0.1%	0.04 [-0.15 , 0.23]
Brochu et al, 2009	-0.25	0.73	48	-0.23	0.7	89	0.1%	-0.02 [-0.27 , 0.23]
Dunstan et al, 2002	-0.2	0.7	19	-0.08	0.6	17	0.0%	-0.12 [-0.54 , 0.30]
Geliebter, et al, 2014	-0.18854	0.9167	27	-0.2563	0.63	27	0.0%	0.07 [-0.35 , 0.49]
Ibáñez, et al, 2010	-0.0959	0.21	13	-0.1636	0.37	12	0.1%	0.07 [-0.17 , 0.31]
Janssen, et al, 2002	-0.35	0.82	14	-0.52	1.55	13	0.0%	0.17 [-0.78 , 1.12]
Morencos E, et al, 2012	-0.3252	0.48	30	-0.0497	0.5	29	0.1%	-0.28 [-0.53 , -0.03]
Said MA, et al, 2018	-0.015354	0.009596	23	-0.01863	0.00971	11	99.6%	0.00 [-0.00 , 0.01]
Sénéchal, et al, 2012	-0.3	0.89	9	0	0.72	9	0.0%	-0.30 [-1.05 , 0.45]
Total (Wald[a])			**235**			**236**	**100.0%**	**0.00 [-0.00 , 0.01]**
95% prediction interval								[-0.00 , 0.01]

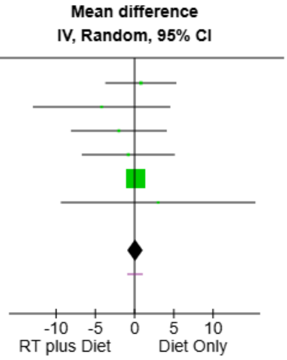


Test for overall effect: Z = 0.88 (P = 0.38)
Test for subgroup differences: Not applicable
Heterogeneity: Tau² (DL[b]) = 0.00; Chi² = 6.39, df = 8 (P = 0.60); I² = 0%

Footnotes
[a]CI calculated by Wald-type method.
[b]Tau² calculated by DerSimonian and Laird method.

Appendix 2-AA Effect of dietary weight loss plus resistance exercise vs. diet-only weight loss on systolic blood pressure in people living with overweight or obesity.

Study or Subgroup	RT plus Diet Mean	RT plus Diet SD	RT plus Diet Total	Diet Only Mean	Diet Only SD	Diet Only Total	Weight	Mean difference IV, Random, 95% CI
Brochu et al, 2009	0.2	13.1	48	-0.6	12.5	89	4.8%	0.80 [-3.73 , 5.33]
Dunstan et al, 2002	-6.7	10	19	-2.5	15.8	17	1.3%	-4.20 [-12.95 , 4.55]
Figueroa A, et al, 2013	-9	8.55	14	-7	7.63	13	2.6%	-2.00 [-8.10 , 4.10]
Geliebter, et al, 2014	-4.9	12.2	27	-4.1	9.9	27	2.8%	-0.80 [-6.73 , 5.13]
Said MA, et al, 2018	-1.2	1.78	23	-1.34	1.29	11	87.9%	0.14 [-0.91 , 1.19]
Sénéchal, et al, 2012	-14.5	13.42	9	-17.5	13.41	9	0.6%	3.00 [-9.39 , 15.39]
Total (Wald[a])			**140**			**166**	**100.0%**	**0.05 [-0.94 , 1.04]**
95% prediction interval								[-0.94 , 1.04]

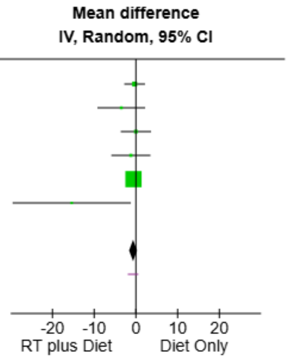


Test for overall effect: Z = 0.10 (P = 0.92)
Test for subgroup differences: Not applicable
Heterogeneity: Tau² (DL[b]) = 0.00; Chi² = 1.77, df = 5 (P = 0.88); I² = 0%

Footnotes
[a]CI calculated by Wald-type method.
[b]Tau² calculated by DerSimonian and Laird method.

Appendix 2-BB Effect of dietary weight loss plus resistance exercise vs. diet-only weight loss on diastolic blood pressure in people living with overweight or obesity.

Study or Subgroup	RT plus Diet Mean	RT plus Diet SD	RT plus Diet Total	Diet Only Mean	Diet Only SD	Diet Only Total	Weight	Mean difference IV, Random, 95% CI
Brochu et al, 2009	-1.6	7.2	48	-1.3	6.8	89	13.5%	-0.30 [-2.78 , 2.18]
Dunstan et al, 2002	-4.4	6.9	19	-0.9	10.1	17	2.8%	-3.50 [-9.22 , 2.22]
Figueroa A, et al, 2013	-5	4.9	14	-5	4.72	13	6.6%	0.00 [-3.63 , 3.63]
Geliebter, et al, 2014	-5.5	9.5	27	-4.3	8	27	4.1%	-1.20 [-5.88 , 3.48]
Said MA, et al, 2018	-0.85	0.74	23	-0.27	1.19	11	72.6%	-0.58 [-1.35 , 0.19]
Sénéchal, et al, 2012	-20.27	18.07	9	-4.89	11.99	9	0.5%	-15.38 [-29.55 , -1.21]
Total (Wald[a])			**140**			**166**	**100.0%**	**-0.68 [-1.64 , 0.28]**
95% prediction interval								[-1.94 , 0.59]



Test for overall effect: Z = 1.38 (P = 0.17)
Test for subgroup differences: Not applicable
Heterogeneity: Tau² (DL[b]) = 0.18; Chi² = 5.39, df = 5 (P = 0.37); I² = 7%

Footnotes
[a]CI calculated by Wald-type method.
[b]Tau² calculated by DerSimonian and Laird method.

Appendix 3-A Interview topic guide 1

Questions
Q1. Can you start by telling me what types of physical activity you do/or have done in the past *(Prompt: gym, running, boxing, walking, home chores, etc.)*
Q2. Why do you do these *(Prompt: being physically active, weight control, etc).*
Q3. Have you ever tried to use physical activity to help with weight loss? *(If they have already mentioned this, refer back to their first mention)*
Q4. If answered Yes to Q3: A) What type of physical activity have you done to lose weight B) How did you find it?
Q5. Can you tell me if you have heard about RT? If YES, then can you tell me what you know about it?
Q6. Have you ever tried RT yourself? if yes, What did you do? Why did you do it?
IF yes, Q7. Can you please talk me through a typical session when you did RT? *(Prompt: Where did you do it? How often? Did someone show/guide you with it?)*
Q8. Would you ever think of using RT to lose weight? Why do you say this?
We are now going to demonstrate some resistance exercises for you. Q9. What are your initial views of the exercise?
Q10. We would like you to perform these exercises 3 sets (reaching the RPE scale between 8 and 10) of each exercise at least 2 times a week for the 4-week period . What do you think about doing that? *(Prompt: Do you think you'll manage? Why do you say that?)*

Q11. Before we draw this discussion to a close, is there anything else you would like to add?

Appendix 3-B Interview topic guide 2

Questions
Q1.Can you tell me how you have got on with the exercises I showed you before? If no for all or any of the exercises, ask why.
Q2. A) Where did you do the exercises? (*Prompts:* home (and where), work (and where), park, gym? Why did you do this? B) Did you use bands or household objects? How did you find this?) C) When did you do the exercises?
Q3. Was there anything, if at all, that helped you do the exercises? Why was this? Was there anything that made doing the exercises harder? Why was this? (*Prompts:* Is there any particular exercise that you found easy or hard to do?) *Prompts:* if they did not do an exercise – What do you think could help you do it?
Q4. How would you describe your overall experience with trying RT? (For people who didn't perform it – why, what were the barriers to performing it/trying it?)
Q5. What did you like or dislike about doing RT exercises?
Q6. How does your body feel after doing RT? (*Prompts:* What has been your experience of how RT impacted you physically? or, any muscle soreness)
Q7. How often do you think you would be willing to do RT exercises now that you have tried it? For people who haven't done the exercises: is there anything that could motivate you to try RT? If yes, what?

Q8. (Only for those who have done the exercises) How likely are you to keep going with RT exercises? (*Prompts*: What could help going forward to stick with RT?)
Q9. A) How useful do you think RT is for weight-management? Why do you say this?
Q10. Before we draw this discussion to a close, is there anything else you would like to add?

Appendix 3-C Exercise guideline

<u>Exercise Guideline</u>

A qualitative study of the experiences and perceptions of resistance training in people who are overweight or obese and are trying to lose weight

ABOUT THIS MANUAL

This manual contains the details of the exercises we will ask you to try for 12 weeks in this study.

A member of the research team will guide you through this manual during a study visit and if there is anything you do not understand, then please let us know.

Contact details: If you have any questions then please contact the study team using the details below.

Researcher _________________ Tel __________________ Email ________________

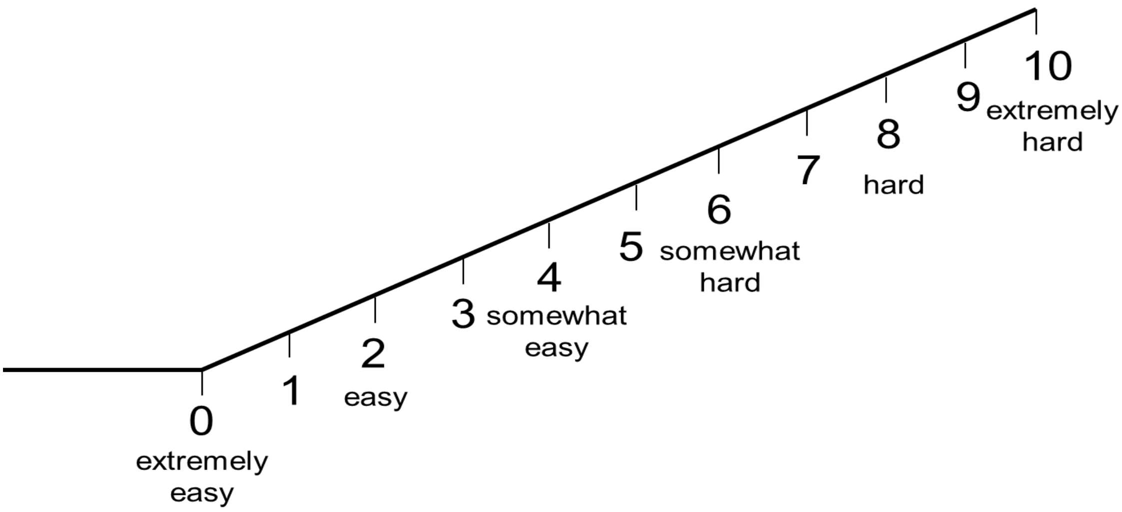
Rating of 'Effort Level'

- the Perceived Exertion (RPE) Scale

Instructions for use

Definition: The perception of physical effort is the level of effort, strain, discomfort, and/or fatigue that you feel during exercise.

Instructions: We would like you to use the scale below to describe how your body feels during the exercises. You are going to perform muscle strengthening exercises using your upper and lower body. If you feel that the exercises are EXTREMELY EASY then you would rate this as number zero. If you feel like the exercises are EXTREMELY HARD then you rate this as number 10. If you feel somewhere in between Extremely Easy (0) and Extremely Hard (10), then you can rate this anywhere between 0 and 10. Remember, there are no right or wrong numbers. Use the words to help select the numbers. Use any of the numbers to describe how you feel when performing the muscle strengthening exercises.



Exercises: Most of these exercises can be performed using items from around the house, e.g. a bottle of water, a bottle of milk, a tin of food etc or using resistance bands which we will provide. Each exercise can be made harder by using a stronger resistance band or by using a heavier object (e.g. progressing from half size can of tuna to full size can e.g. soup, to larger bottle of milk/water) or by moving up a level for exercises that do not use bands or objects. Each exercise below has pictures and a QR code to scan to remind you how to safely perform these exercises.

Taking care if using exercise bands

To avoid injury, if you are using the exercise band please see guidance below.

- Before starting your exercises:

- Always check the condition of your band before using.
- Do not place the resistance band handles over your feet. They can easily slip off and strike the user
- Avoid jerking the band
- Do not stretch a band over 2 ½ times their length
- Begin all exercises slowly to ensure band strength
- Do not release a resistance band while under tension
- Never exercise with resistance bands on uneven surfaces
- Resistance bands should only be used for the specific exercises they were designed for and not as toys
- Avoid placing bands in hot areas or in direct sunlight

Summary of the resistance training exercises

We will ask you to perform 3 sets of each exercise at least 2 times a week for the 12-week study period. During the first week performing each exercise we would like you to stop when you reach 4-6 on the RPE scale above. In following weeks, we would like you to stop each exercise when you reach 8-10 on the RPE scale. This may be any number of repetitions, but we suggest that adjust the level of each exercise to reach these points on the RPE scale within the range of 8-20 repetitions. Once you find yourself doing more than 20 repetitions of an exercise it is time to move up a level.

You can do these exercises all in a single session on the same day, or you can break them up throughout the day or even do them on different days. The order you do the exercises in is also up to you. As long as you do 3 sets of each exercise 3 times a week the choice is yours! The exercises will be upper body exercises (press-ups, band lateral raises, band seated low row) and lower body exercises (squat, lunge and calf raise).

<u>Upper body exercises</u>

The QR code video to scan

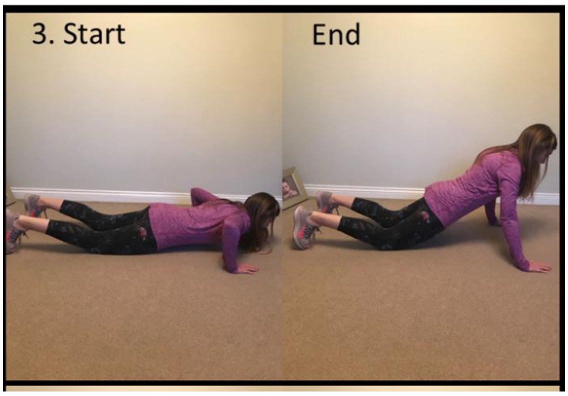
Press-ups

Begin with your arms shoulder height and just a bit wider than shoulder width apart, against the surface chosen from the options below (see pictures, with 1 being the easiest and 4 the hardest). Bend your elbows as you lower your upper body toward the surface in a slow controlled manner, keeping your feet planted in position. Slowly push yourself back until your arms are straight but don't lock your elbows. Repeat.

Option 1

Option 2

Option 3



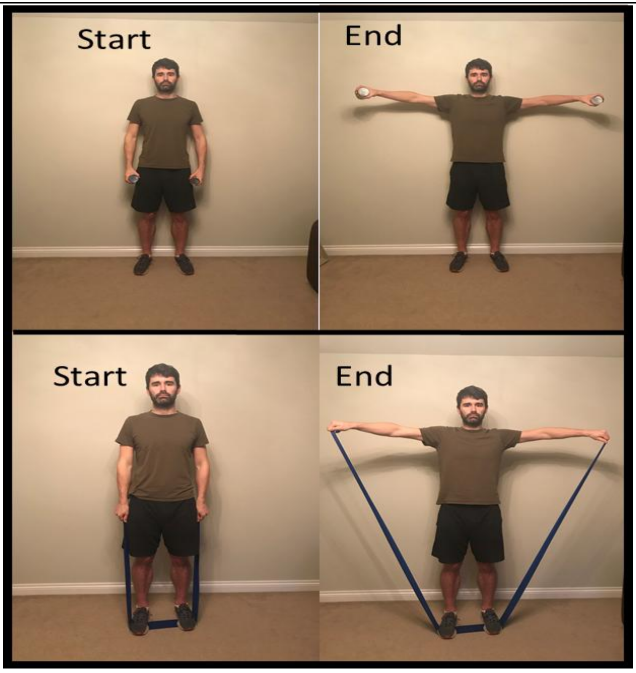
Option 4

The QR code video to scan

Standing arm raises

This exercise can be performed either using a household object in each hand such as a bottle of water, a bottle of milk, a tin of food etc or using a resistance band. Remember you can make the exercise harder or easier by adjusting the weight of the object or moving up or down the resistance band colour chart (see page 3).

Stand up and if using a household object hold one in each hand, or if using a band stand on the band with both feet and hold one end in each hand. Start with your arms straight down with your hands at side of legs. Raise both arms to the side, until they reach shoulder height, pause and then return to your starting position (see picture below).



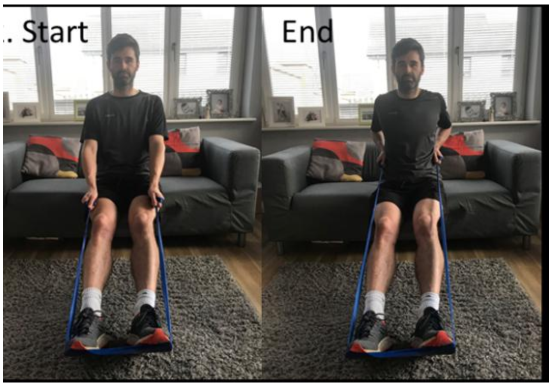
The QR code video to scan

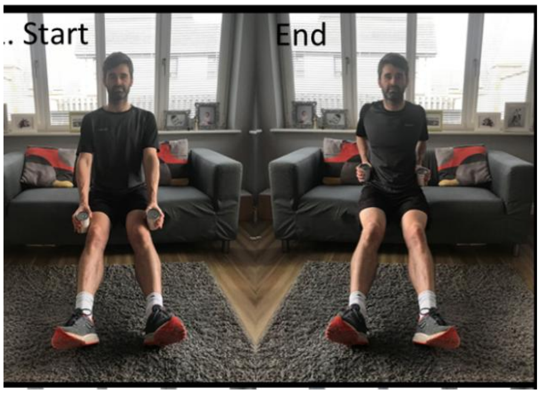
Seated rows

This exercise can be performed either using a household object in each hand such as a bottle of water, a bottle of milk, a tin of food etc or using a resistance band. Remember you can make the exercise harder or easier by adjusting the weight of the object or moving up or down the resistance band colour chart (see page 3).

Sit with feet firmly planted on the ground. Hold an end of the exercise band in each hand. Lower the middle section of the band to the floor. The band should be flat, not twisted. Step on the band with both feet. Sit up tall and hold the band in each hand; it doesn’t have to be at the end of the band. Start with the arms straight, hands near the outside of the lower thighs. Pull hands back toward the waist, tightening muscles between the shoulder blades. Be sure to keep your wrists straight and in line with your forearm. Slowly lower hands back to starting position. Repeat. Alternatively carry out the same motion holding a household object in each hand (see pictures).

With a band With an object

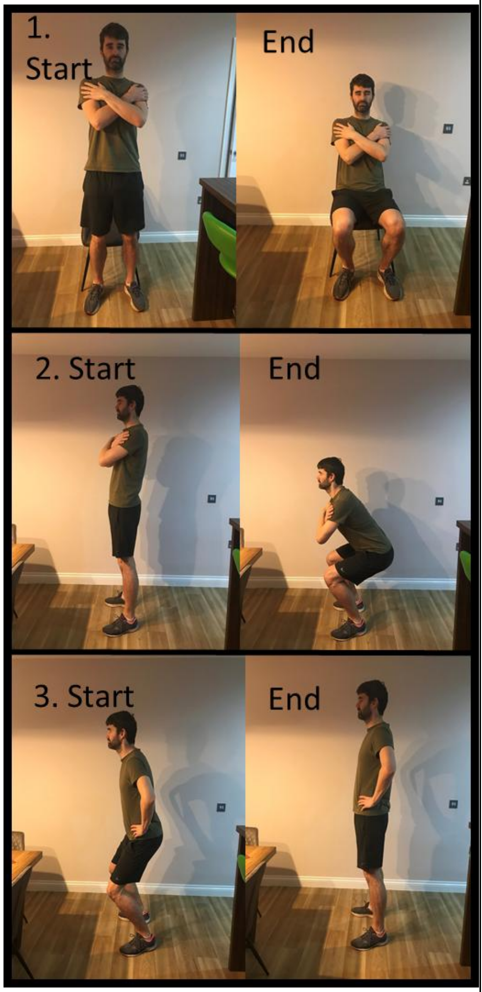




Lower body exercises

The QR code video to scan

Squats



This exercise can be done chosen from the three options below (see pictures, with 1 being the easiest and 3 the hardest):

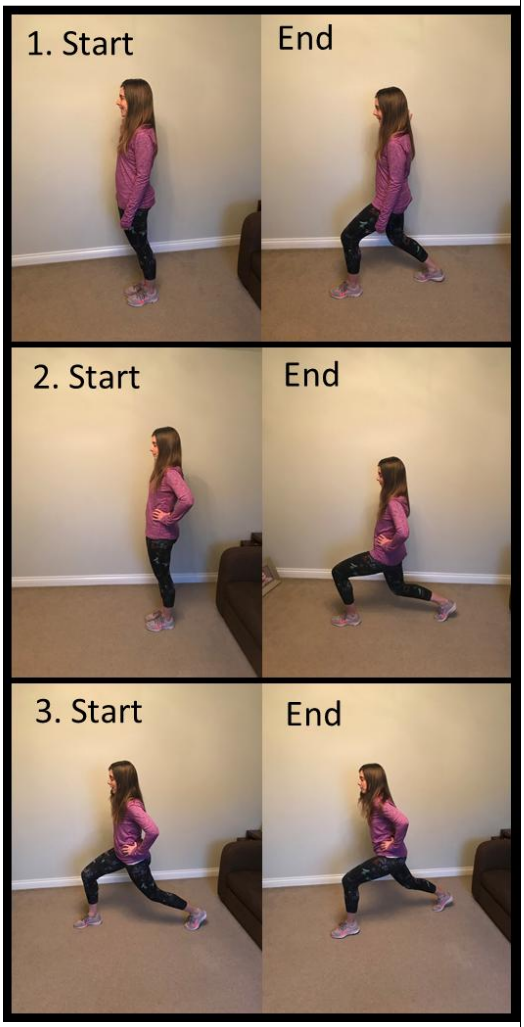
1. Rise up and down from chair (arms folded across chest). Stand up straight with your feet shoulder width apart. Squat down as far as you can, aiming to get your legs parallel to the ground. Pause for a second and then stand up again. Repeat.
2. No chair and slow on way down (arms folded across chest). Stand up straight with your feet shoulder width apart. Squat down as far as you can, aiming to get your legs parallel to the ground. Pause for a second and then stand up again. Repeat.

3. No chair and add a small jump in to the squat. Stand up straight with your feet shoulder width apart. Squat down as far as you can, aiming to get your legs parallel to the ground. Pause for a second and then jump. Repeat.

The QR code video to scan

Lunges

Stand up straight with your feet shoulder width apart and balancing yourself against a wall or your hands on your hips . Step forward with your right foot, as far as you feel comfortable with, keeping your back straight. Pause for a second and bring your foot back to the starting position. Repeat with the left leg. Repeat.



Three options you have when performing exercises (see pictures, with 1 being the easiest and 3 the hardest):

1. Lunges holding on to wall for balance
2. Lunges – progress via increase in distance foot is planted
3. Lunges with jump: step forward and drop into a lunge position quickly jump straight up switching your feet in the air and landing back in a lunge.

The QR code video to scan

Calf raises

Stand up straight with your feet shoulder width apart and your hands on your hips or balancing yourself against a wall or a chair. Push through the balls of your feet and raise your heel until you are standing on your toes. Return to starting position and repeat.

Three options you have when performing exercises (see pictures, with 1 being the easiest and 3 the hardest):

1. On floor both feet
2. On step both feet
3. On step single foot

Appendix 3-D Coding framework

Name Code	Description
Physical activity previous and current	Any physical activity that participants have previously engaged in or are currently doing at the start of the programme or including anything they say about barriers.

Physical activity identity	What participants say about their relationship (how they see themselves/feel about) to physical activity or resistance training exercises.
Reasons for doing/not doing physical activity	Participants' reasons for being involved or not being involved in physical activity pre-programme, including the benefits of PA.
Physical activity and weight loss or diet	Anything participants say about physical activity, weight loss, and diet.
Prior resistance training exercises experiences	Anything participants say pre-programme about doing resistance training exercises including reasons, and anything they know about RTE (except in relation to weight loss diet)
Resistance training exercises and weight loss or diet	Anything participants say about resistance training exercises, weight loss, and diet.
Resistance training exercises needs	Anything participants used to perform resistance training exercises (equipment formal/improvised and what they wore).
Initial response to resistance training exercises (Pre-Interview)	Participants' responses to being shown how to do resistance training exercises.
Reasons for joining the study	Anything participants say about why they wanted to take part in the study, including what they wanted to achieve by doing so.

Intentions and expectations of the resistance training programme	Anything participants say about what they plan to do or expect from the programme (in relation to doing the exercises).
When, where and how	Anything participants say about when and where they did the resistance exercises during the programme (and currently) and fitting them into their other daily activities
Experience of resistance training exercises during the programme	Anything participants say about how they engage in the exercises, including how many and any difficulties/challenges or facilitators
Post-programme maintenance of resistance exercises	Anything participants say about continuing to perform with resistance training exercises and physical activity post-programme
Impact of resistance training exercises	Anything participants say about how they feel, changes, benefits, disbenefits as a result of taking part in the programme including changes and weight.

Appendix 3-E The development process of codes to themes

Code	**Sub- Code**		**Example**	**Theme**
Physical activity previous and current	Types of previous physical activity		So in the past I've done yoga and I've done some gym exercises.	**Knowledge, barriers and motivations to physical activity and resistance exercise training**
	Current physical activity		And recently this year, I started going to a Pilates class, I do a little bit of walking.	
	Barriers to physical activity		That kind of stopped, obviously because of the COVID lockdown and we couldn't go.	
Physical activity identity	**Pre-Interview Sub-Code**	Physical activity identity types of exercise-sports	I'm not traditionally sporty, so I don't play any sports.	
		Physical activity identity general	I've always found physical exercise tricky, I've always found it a bit of a pain.	

	Post-Interview Sub- Code	Physical activity identity types of exercise	I've been a bit lazy with the push ups and I've not gone past ten.	
Reasons for doing/not doing physical activity	Overall health benefits		I do it more just to keep myself supple,	
	Weight lose		Because I'm getting to an age where I'm getting…I'm putting on too much weight, and I want to lose the weight.	
Reasons for joining the study	**None**		I'm willing to try resistance exercises, I think because it was part of a study, I was motivated to do it.	
			Because I think I don't quite know the right exercises that I need, and that's why I want to do your study,	

Physical activity and weight loss or diet	**Pre-Interview Sub- Code**	PA perceptions to lose weight	Yeah, that's when I joined the gym, thinking the gym would fix all my weight problems. The gym doesn't fix your weight problems, it's your diet that fixes your weight problems.	
		PA to help with weight loss and benefits	I feel the Pilates classes doesn't really help you lose weight, I feel it helps maybe to tone a little bit, but not really to lose weight.	
		PA preferences to lose weight	Because I know I'm too…I'm overweight and I would like to lose weight again, so I know that's…and I'm not very good at dieting, I'm awful at dieting, so I would up my exercise rather than reduce my calories.	
	Post-Interview Sub- Code	PA perceptions to lose weight	I think if you want, if you want to lose weight and you're really, really heavy, then I think you've got to kind of add some sort of aerobic exercise into your routine, as well as kind of	

			like weight resistance and aerobic, and follow a sensible kind of eating.	
		PA to help with weight loss and benefits	because I mean good resistance exercises, it's fine for obviously muscles in terms of having muscle tone, muscle strength.	
		PA preferences to lose weight	So, I'm not doing the high impact aerobics anymore and I'm going to move to doing these resistance exercises.	
		PA motivation to lose weight	I think combined with the other things that I'm doing, so really is a motivational tool, combined with the yoga and the weight class, I think it's good, very good.	
Resistance training exercises and	**Pre-Interview Sub-Code**	RT or RT plus Diet to lose weight	obviously I'm going to the slimming club just now so I'm trying actively to lose weight and if this…and I'm thinking this is probably quite a good time to do this	**Perceptions, preferences and anticipations of resistance exercise**

weight loss or diet			because I feel like my…the weight loss is going to slow down now	
		RT knowledge for losing weight	I know that you can use resistance training to help with weight loss in terms of converting fat to muscle and various other bits like that. So, you might not lose mass, but you can lose body fat.	
		RT benefits for losing weight	To build up the muscle. I want the muscles, but also I believe it can prevent, what's that thing called, loose skin. I think that it might help my flexibility and prevent injuries.	
		RT perceptions for losing weight	I think exercise is a good way to maintain your weight.	

	Post-Interview Sub-Code	RT motivations for losing weight	I think doing the resistance exercise, it's also made me more aware of my diet, because it's resistance for weight loss, and I've been more attuned to my diet	
		RT benefits for losing weight	I mean good resistance exercises, it's fine for obviously muscles in terms of having muscle tone, muscle strength, that it's good for long-term sort of metabolic reasons.	
		RT perceptions for losing weight	if you manage between exercise and food intake, you will end up with a good body weight.	
		RT preferences	I think, compared to people who have, like, tried to run, like they're not runners	

		for losing weight	and they try to run, or other things, I think this is a lot easier to get into. So yeah, a big advocate of it, yeah, massive.	
Resistance training exercises needs	**Pre-Interview Sub-Code**	Equipment needs or options	Yeah, cool, I've used dumb-bells. Yeah, okay. I've never used a band before, that’s why I keep saying, I use dumb-bells.	
	Post-Interview Sub-Code	Equipment preferences, used	I just used the bands, I found the bands really good, they were great. Great, yeah, the bands were great.	
Initial response to resistance training exercises	Preferences for RT		Oh, squats, I don’t mind squats. I think I definitely need to do those, my calves are fat.	
	Feeling the effect or perceptions of RT		It’s a different exercise. Oh, yeah. Feel that, actually. Yeah, I can feel that actually.	

	Difficulty or RT challenges	A full push up, I know I can do them on my knees, not a full push up. I struggled.	
Prior resistance training exercises experiences and knowledge	Previous exercise preferences	So I was doing, kind of, free weights at home, and doing some kind of body weight exercises.	
	Experience with resistance machines	So I was in the gym, and started off doing, kind of the machines,	
	Intensity of resistance training	I will do 30 minutes or an hour using the weights machines.	
	Experience with resistance bands	Things like free weights, I don't mind every now and then and things like resistance bands and that I don't mind	
Intentions and expectations of the resistance	Anticipation	No questions at all, that'll be good, and I'm eager to get started, so I'll start tomorrow morning.	
	Daily routine	I think that'll fit into my normal morning routine very well, and they look quite fun, so	

training programme		I'd be happy to do even twice during the week and at the weekend, if you stick an extra wee set in, so yeah.	
When, where and how	Time of exercise	Evening. Yeah. So after the kids went to bed, about half seven at night.	**Engagement and experiences of resistance exercise**
	Location of exercise	At home. So, in our front room, and then on the steps. Easiest	
	Equipment used	So I used the bands. Bands, and I used kettlebells for the lats. and then just a mat for all the others. Yeah, fine.	
Experience of resistance training exercises during the programme	Exercise routine	I have been doing them during my morning routine when I get up in the morning. I've been doing them Monday to Friday when I get up to go to work.	
	Difficulty with specific exercises	Yeah, the push-up is most…harder.	

	adjustments	I had to figure out some of my own exercises for some physiotherapy for my hip, I have a chronic hip problem, and I used the bands to do that. So they were useful for other exercises as well.	
	Overall experience	Good, I liked them, yeah, and easy to do, easy to do anywhere as well, you know, if you were away or if you weren't in your…you know, if you couldn't get to a gym, you could just take one of them with you and do it, so very portable, so yeah, I think good. I'll keep doing them.	
	challenges	The pain afterwards, obviously, but it eased off. Obviously the first week or so that I did them, my body was sore because it's not used to doing it, and then it kind of eased off a bit, yeah, so…	

Post-programme	Motivation to continue	I think I will increase the times of the number of exercise per week.	**Overall impact of the resistance exercise programme**
	Commitment to routine	Yeah, I would do that as part of my regular exercise regime, two or three times a week.	
Impact of resistance training exercises	Exercise benefits	Well, I do feel as if I've gained a little bit of strength, and I do feel as if I've trimmed a little bit.	
	Exercise discomforts	So my arms here ached a bit, but they eased off after a few times of doing it.	
	Overall impact	Good. And the only reason I say that is because I've stopped drinking since…since starting this. It's not immediately related, but as soon as you start doing strength exercises, it forces you to focus on other parts of your life that are making things a bit harder.	

Appendix 4-A CONSORT checklist

Section/Topic	Item No	Checklist item	Reported on page No
Title and abstract			
	1a	Identification as a randomised trial in the title	Section 4
	1b	Structured summary of trial design, methods, results, and conclusions (for specific guidance see CONSORT for abstracts)	Section 4.1
Introduction			
Background and objectives	2a	Scientific background and explanation of rationale	Section 4.2
	2b	Specific objectives or hypotheses	Section 4.2
Methods			
Trial design	3a	Description of trial design (such as parallel, factorial) including allocation ratio	Section 4.3.1
	3b	Important changes to methods after trial commencement (such as eligibility criteria), with reasons	N/A
Participants	4a	Eligibility criteria for participants	Section 4.3.3
	4b	Settings and locations where the data were collected	Section 4.3.3

Interventions	5	The interventions for each group with sufficient details to allow replication, including how and when they were actually administered	Section 4.3.5
Outcomes	6a	Completely defined pre-specified primary and secondary outcome measures, including how and when they were assessed	Section 4.3.6
	6b	Any changes to trial outcomes after the trial commenced, with reasons	N/A
Sample size	7a	How sample size was determined	Section 4.3.2
	7b	When applicable, explanation of any interim analyses and stopping guidelines	N/A
Randomisation:			
Sequence generation	8a	Method used to generate the random allocation sequence	Section 4.3.4
	8b	Type of randomisation; details of any restriction (such as blocking and block size)	Section 4.3.4
Allocation concealment mechanism	9	Mechanism used to implement the random allocation sequence (such as sequentially numbered containers), describing any steps taken to conceal the sequence until interventions were assigned	Section 4.3.4

Implementation	10	Who generated the random allocation sequence, who enrolled participants, and who assigned participants to interventions	Section 4.3.4
Blinding	11a	If done, who was blinded after assignment to interventions (for example, participants, care providers, those assessing outcomes) and how	Section 4.3.4
	11b	If relevant, description of the similarity of interventions	Section 4.3.7
Statistical methods	12a	Statistical methods used to compare groups for primary and secondary outcomes	Section 4.3.7
	12b	Methods for additional analyses, such as subgroup analyses and adjusted analyses	N/A
Results			
Participant flow (a diagram is strongly recommended)	13a	For each group, the numbers of participants who were randomly assigned, received intended treatment, and were analysed for the primary outcome	Section 4.4
	13b	For each group, losses and exclusions after randomisation, together with reasons	Section 4.4
Recruitment	14a	Dates defining the periods of recruitment and follow-up	Section 4.4
	14b	Why the trial ended or was stopped	N/A
Baseline data	15	A table showing baseline demographic and clinical characteristics for each group	Section 4.4

Numbers analysed	16	For each group, number of participants (denominator) included in each analysis and whether the analysis was by original assigned groups	Section 4.4
Outcomes and estimation	17a	For each primary and secondary outcome, results for each group, and the estimated effect size and its precision (such as 95% confidence interval)	Section 4.4.1
	17b	For binary outcomes, presentation of both absolute and relative effect sizes is recommended	Section 4.4.1
Ancillary analyses	18	Results of any other analyses performed, including subgroup analyses and adjusted analyses, distinguishing pre-specified from exploratory	N/A
Harms	19	All important harms or unintended effects in each group (for specific guidance see CONSORT for harms)	N/A
Discussion			
Limitations	20	Trial limitations, addressing sources of potential bias, imprecision, and, if relevant, multiplicity of analyses	Section 4.5
Generalisability	21	Generalisability (external validity, applicability) of the trial findings	Section 4.5
Interpretation	22	Interpretation consistent with results, balancing benefits and harms, and considering other relevant evidence	Section 4.5
Other information			

Registration	23	Registration number and name of trial registry	Section 4.3
Protocol	24	Where the full trial protocol can be accessed, if available	N/A
Funding	25	Sources of funding and other support (such as supply of drugs), role of funders	N/A

Exercise Guideline

The effects of a home-based resistance training programme on body composition and muscle function during weight loss in people living with overweight or obesity: a randomised controlled pilot trial

ABOUT THIS MANUAL

This manual contains the details of the exercises we will ask you to try for 12 weeks in this study.

A member of the research team will guide you through this manual during a study visit and if there is anything you do not understand, then please let us know.

Contact details: If you have any questions then please contact the study team using the details below.

Researcher ________________ Tel _________________ Email ________________

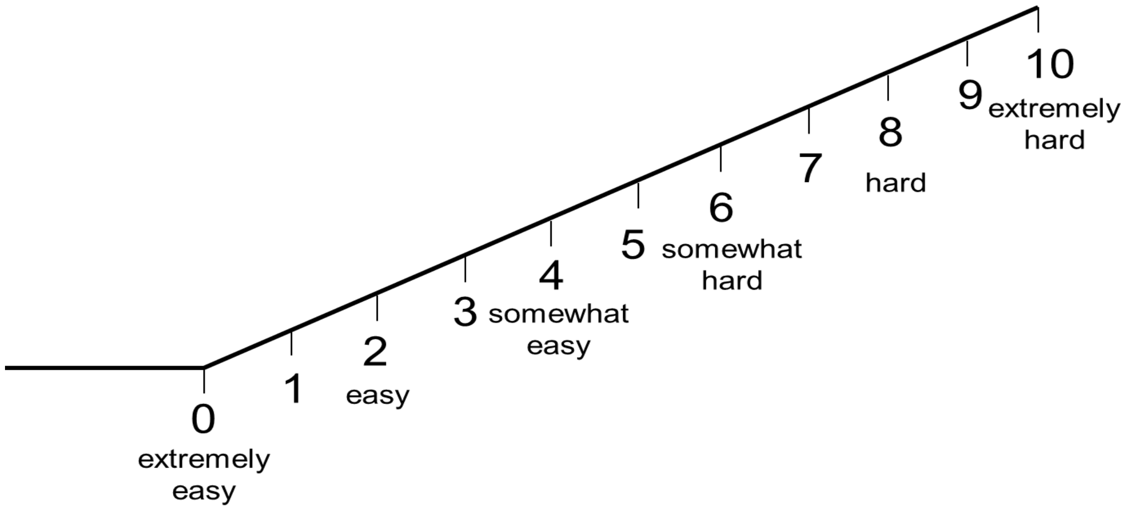
Rating of 'Effort Level'

- **the Perceived Exertion (RPE) Scale**

Instructions for use

Definition: The perception of physical effort is the level of effort, strain, discomfort, and/or fatigue that you feel during exercise.

Instructions: We would like you to use the scale below to describe how your body feels during the exercises. You are going to perform muscle strengthening exercises using your upper and lower body. If you feel that the exercises are EXTREMELY EASY then you would rate this as number zero. If you feel like the exercises are EXTREMELY HARD then you rate this as number 10. If you feel somewhere in between Extremely Easy (0) and Extremely Hard (10), then you can rate this anywhere between 0 and 10. Remember, there are no right or wrong numbers. Use the words to help select the numbers. Use any of the numbers to describe how you feel when performing the muscle strengthening exercises.



Exercises: Most of these exercises can be performed using items from around the house, e.g. a bottle of water, a bottle of milk, a tin of food etc or using resistance bands which we will provide. Each exercise can be made harder by using a stronger resistance band or by using a heavier object (e.g. progressing from half size can of tuna to full size can e.g. soup, to larger bottle of milk/water) or by moving up a level for exercises that do not use bands or objects. Each exercise below has pictures and a QR code to scan to remind you how to safely perform these exercises.

Taking care if using exercise bands

To avoid injury, if you are using the exercise band please see guidance below.

- Before starting your exercises:

- Always check the condition of your band before using.
- Do not place the resistance band handles over your feet. They can easily slip off and strike the user
- Avoid jerking the band
- Do not stretch a band over 2 ½ times their length
- Begin all exercises slowly to ensure band strength
- Do not release a resistance band while under tension
- Never exercise with resistance bands on uneven surfaces
- Resistance bands should only be used for the specific exercises they were designed for and not as toys
- Avoid placing bands in hot areas or in direct sunlight

Summary of the resistance training exercises

We will ask you to perform 3 sets of each exercise at least 3 times a week for the 12-week study period. During the first week performing each exercise we would like you to stop when you reach 4-6 on the RPE scale above. In following weeks, we would like you to stop each exercise when you reach 8-10 on the RPE scale. This may be any number of repetitions, but we suggest that adjust the level of each exercise to reach these points on the RPE scale within the range of 8-20 repetitions. Once you find yourself doing more than 20 repetitions of an exercise it is time to move up a level.

You can do these exercises all in a single session on the same day, or you can break them up throughout the day or even do them on different days. The order you do the exercises in is also up to you. As long as you do 3 sets of each exercise 3 times a week the choice is yours! The exercises will be upper body exercises (press-ups, band lateral raises, band seated low row) and lower body exercises (squat, lunge and calf raise).

Upper body exercises

The QR code video to scan

Press-ups

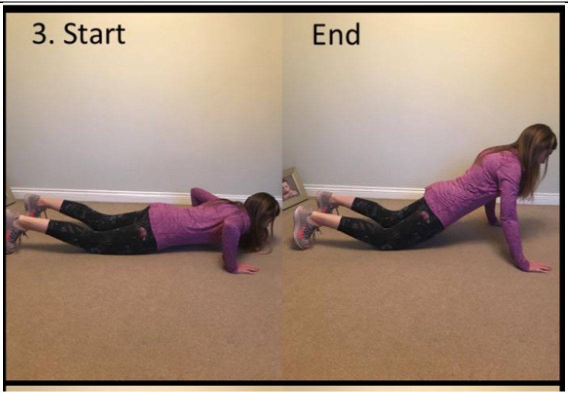
Begin with your arms shoulder height and just a bit wider than shoulder width apart, against the surface chosen from the options below (see pictures, with 1 being the easiest and 4 the hardest). Bend your elbows as you lower your upper body toward the surface in a slow controlled manner, keeping your feet planted in position. Slowly push yourself back until your arms are straight but don't lock your elbows. Repeat.

Option 1

Option 2

Option 3

Option 4

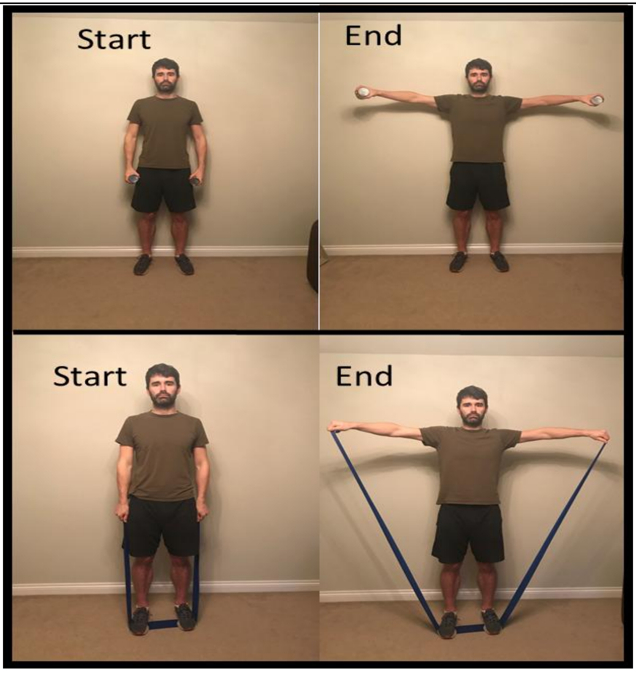


The QR code video to scan

Standing arm raises

This exercise can be performed either using a household object in each hand such as a bottle of water, a bottle of milk, a tin of food etc or using a resistance band. Remember you can make the exercise harder or easier by adjusting the weight of the object or moving up or down the resistance band colour chart (see page 3).

Stand up and if using a household object hold one in each hand, or if using a band stand on the band with both feet and hold one end in each hand. Start with your arms straight down with your hands at side of legs. Raise both arms to the side, until they reach shoulder height, pause and then return to your starting position (see picture below).



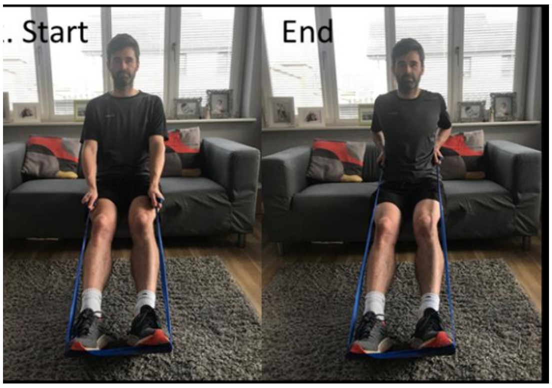
The QR code video to scan

Seated rows

This exercise can be performed either using a household object in each hand such as a bottle of water, a bottle of milk, a tin of food etc or using a resistance band. Remember you can make the exercise harder or easier by adjusting the weight of the object or moving up or down the resistance band colour chart (see page 3).

Sit with feet firmly planted on the ground. Hold an end of the exercise band in each hand. Lower the middle section of the band to the floor. The band should be flat, not twisted. Step on the band with both feet. Sit up tall and hold the band in each hand; it doesn't have to be at the end of the band. Start with the arms straight, hands near the outside of the lower thighs. Pull hands back toward the waist, tightening muscles between the shoulder blades. Be sure to keep your wrists straight and in line with your forearm. Slowly lower hands back to starting position. Repeat. Alternatively carry out the same motion holding a household object in each hand (see pictures).

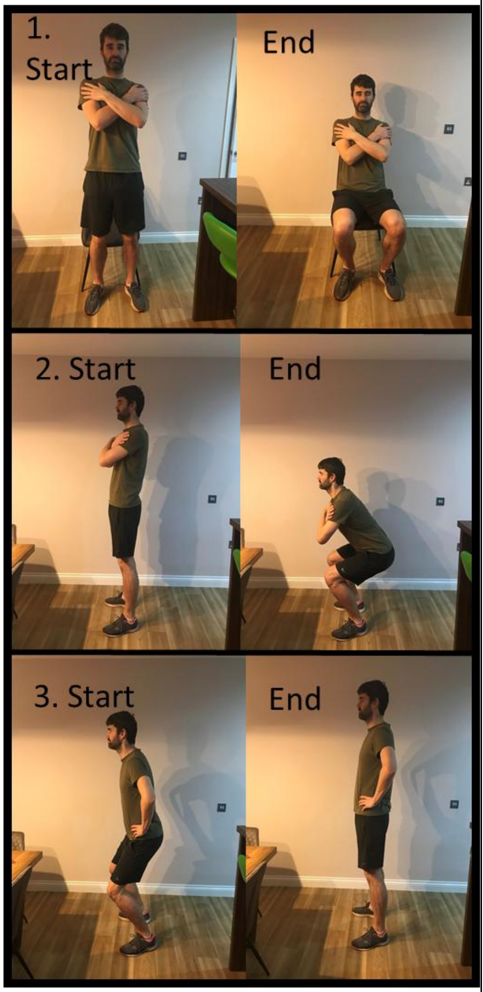
With a band   With an object



Lower body exercises

The QR code video to scan

Squats



This exercise can be done chosen from the three options below (see pictures, with 1 being the easiest and 3 the hardest):

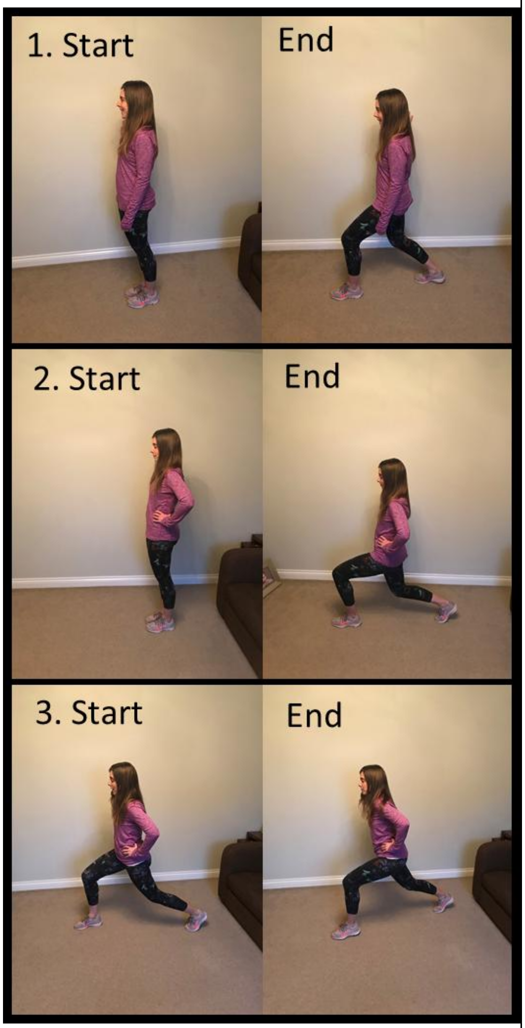
4. Rise up and down from chair (arms folded across chest). Stand up straight with your feet shoulder width apart. Squat down as far as you can, aiming to get your legs parallel to the ground. Pause for a second and then stand up again. Repeat.
5. No chair and slow on way down (arms folded across chest). Stand up straight with your feet shoulder width apart. Squat down as far as you can, aiming to get your legs parallel to the ground. Pause for a second and then stand up again. Repeat.

6. No chair and add a small jump in to the squat. Stand up straight with your feet shoulder width apart. Squat down as far as you can, aiming to get your legs parallel to the ground. Pause for a second and then jump. Repeat.

The QR code video to scan

Lunges

Stand up straight with your feet shoulder width apart and balancing yourself against a wall or your hands on your hips . Step forward with your right foot, as far as you feel comfortable with, keeping your back straight. Pause for a second and bring your foot back to the starting position. Repeat with the left leg. Repeat.



Three options you have when performing exercises (see pictures, with 1 being the easiest and 3 the hardest):

4. Lunges holding on to wall for balance
5. Lunges – progress via increase in distance foot is planted
6. Lunges with jump: step forward and drop into a lunge position quickly jump straight up switching your feet in the air and landing back in a lunge.

The QR code video to scan

Calf raises

Stand up straight with your feet shoulder width apart and your hands on your hips or balancing yourself against a wall or a chair. Push through the balls of your feet and raise your heel until you are standing on your toes. Return to starting position and repeat.

Three options you have when performing exercises (see pictures, with 1 being the easiest and 3 the hardest):

4. On floor both feet
5. On step both feet
6. On step single foot

Appendix 4-C Tests of normality and assumptions

Outcome Variable	[a] Kolmogorov-Smirnov				[b] Linearity assumption	[c] Assumption of homogeneity of regression slopes	[d] Assessing the normality of within-group residuals		[e] Testing for homoscedasticity	[f] Testing for homogeneity of variances	[g] Testing for outliers
	RT+WL group		WL group				RT+WL group	WL group			
	Pre	Post	Pre	Post							
[h] BMI (kg/m2)	.200	.200	.156	.200	✓	.240	.584	.297	✓	.371	✓
Weight (kg)	.200	.059	.174	.200	✓	.576	.328	.131	✓	.230	✓
Fat mass (kg)	.084	.008	.200	.200	✓	.267	.075	.454	✓	.499	✓
Fat percentage (%)	.112	.174	.125	.200	✓	.665	.322	.991	✓	.795	✓
Fat free mass (kg)	.200	.200	.200	.196	✓	.147	.678	.983	✓	.065	✓
Muscle thickness (mm)	.200	.200	.200	.129	✓	.121	.166	.063	✓	.983	✓
[I] MVC (N)	.200	.200	.200	.200	✓	.309	.070	.117	✓	.063	✓
Grip strength (kg)	.007	.109	.200	.200	✓	.778	.062	.445	✓	.351	✓
[j] STS (n)	.200	.200	.144	.131	✓	.706	.494	.919	✓	.279	✓

a. Normality tests.
b. There was a linear relationship between pre- and post-outcomes measured between groups, as assessed by visual inspection of a scatterplot.
c. There was homogeneity of regression slopes as the interaction term was not statistically significant between the covariate and the independent variable, ($p > .05$).
d. Standardized residuals for both groups were normally distributed, as assessed by Shapiro-Wilk's test ($p > .05$).
e. There was homoscedasticity, as assessed by visual inspection of the standardized residuals plotted against the predicted values.
f. There was homogeneity of variances, as assessed by Levene's test of homogeneity of variance ($p > .05$).
g. There were no outliers in the data, as assessed by no cases with standardized residuals greater than ±3 standard deviations.
h. BMI: Body mass index.
i. MVC: Maximum Voluntary Contraction.
j. STS: 30-second sit-to-stand test