Cardiometabolic Responses to Same-Session Concurrent Exercise Training, Incorporating High-intensity Interval Training (HIIT), in Overweight and Obesity

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Thesis Outputs

Several works from this thesis have been disseminated at scientific conferences.

Same-Session Concurrent Exercise Training in Overweight and Obesity: A Systematic Review and Meta-Analysis.

- Poster Presentation, **Future Physiology 2020**
- Poster Presentation, **North-East Postgraduate Conference 2020**
- Oral Communication, **BASES Student Conference 2021**

  Conference Abstract:
  Bell, J., Evans, W., Coulson, M. & Archer, D.T. (2021). Same-Session Concurrent Exercise Training in Overweight and Obesity: A Systematic Review and Meta-Analysis. *Journal of Sport and Human Performance*.

- Oral Communication, **BASES Physical Activity for Health Division Day 2021**

Establishing the Test-retest Reliability of the 'delta' (Δ) method of exercise prescription for high intensity interval training (HIIT) in overweight and obese adult males.

- Poster Presentation, **BASES Conference 2021**

Conference Abstract:
Bell, J., Evans, W., Coulson, M. & Archer, D.T. (2021). Establishing the test-retest reliability of the 'delta' (Δ) method of exercise prescription for high intensity interval training (HIIT) in overweight and obese adult males. *Journal of Sport Sciences.*39: sup2, 1-66.

- Oral Communication, **BASES Student Conference 2022**

The Feasibility of an 8-Week High-Intensity Interval Training (HIIT) or Concurrent Training (CT) Programme in Overweight and Obese Males: A Study Protocol

- Poster Presentation, **BASES Student Conference 2022**

Abstract

The majority of adults in England are classified as overweight or obese, with sedentary behaviours a contributing factor to an ever-increasing prevalence. Regular exercise and physical activity can combat obesity-related ill-health, with benefits sought from both cardiovascular- and strength-based exercise. As such, both exercise types are included in exercise guidelines, though few individuals meet recommendations. Same-session Concurrent exercise Training (CT) may be the most time-efficient manner to complete both exercise types. The incorporation of High-Intensity Interval Training (HIIT) as the cardiovascular component may further maximise time efficiency and physiological benefit. A review of the literature revealed that it was key to establish a feasible CT protocol, with an enjoyable and repeatable HIIT protocol with low between-subject variations in the intensity of exercise achieved. In respect to obesity-related health outcome measures, CT was evidenced to provide a wealth of beneficial adaptations to a wide range of cardiometabolic health factors, with body composition changes the primary outcome sought by individuals engaging in exercise interventions. Therefore, we aimed to; 1) synthesise the current evidence-base on the utility and effect of CT as an exercise mode for individuals with obesity, particularly including the use of HIIT and the common methodologies employed; 2) determine the efficacy, reliability and feasibility of using individualised HIIT designs, for more accurate prescription of HIIT for individuals with obesity; 3) establish the feasibility and evaluate the intervention fidelity of completing combined HIIT and RT exercise training programmes in overweight and obese persons; and 4) determine the use and effectiveness of CT compared to HIIT on improving cardiometabolic outcomes in individuals with obesity. A systematic review and meta-analysis of CT programmes in overweight and obesity alongside a test-retest reliability study for a HIIT protocol and an 8-week exercise training feasibility study were undertaken. Meta-analysis revealed that CT could improve body composition, though the true effect of reductions in body mass (MD -1.7kg, 95% CI: -3.6, 0.1) were unclear. CT was effective in improving components of cardiometabolic health, but little research examined the effect of including HIIT. We show that a 10 x 60 second HIIT protocol dosed at an intensity of 80% delta was both repeatable and reliable, with typical error of internal load (VO_2 2.2%, HR 2.8%) considerably lower than RPE (9.1%). We also demonstrate 8-week CT and HIIT exercise training programmes with good intervention fidelity and low between-subject variations in heart rate (0.03 & 0.02 beats·min^{-1}). The 8-week CT programme incorporating HIIT was feasible, enjoyable and well-adhered to with low rates of adverse events in overweight and obese males. Moreover, CT caused greater reductions in body mass (MD: 2.0kg 95% CI: -0.7, 4.6) than HIIT-only, alongside greater improvements in LV EDV (MD 21.55ml 95% CI: 8.72, 34.38) and other factors including strength. However, the observed changes are unclear, with a small sample size and wide confidence intervals demonstrating uncertainty in the true effect and whether this is a meaningful change. This work requires further investigation, though, it is clear that focus should be given to cardiometabolic health more generally, rather than a sole emphasis on weight loss from exercise interventions.

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Definitions

Body Mass Index (BMI) – a derivation of an individual's height and mass (expressed in kg.m2) utilised as an indicator of overweight (> 25) and obesity (>30).

Cardiometabolic Health – a series of factors relating to the cardiovascular (heart and blood vessels) and the metabolic systems.

Cardiorespiratory Fitness (CRF) – the capacity of an individual to supply oxygen to working skeletal muscle.

Cardiovascular Disease (CVD) – diseases concerning the heart and blood vessels.

Insulin Resistance – a state wherein cells are unresponsive to the effects of insulin.

$\dot{V}O_{2max}$ – the maximum rate of the uptake and utilisation of oxygen during exertion.

$\dot{V}O_{2peak}$ – the peak rate of the uptake and utilisation of oxygen attained during exertion.

Chapter 1.0. General Introduction

The research focus of this thesis has long been an interest of mine, which has stemmed from my undergraduate and postgraduate studies, leading me to this PhD project. For my undergraduate dissertation I undertook a systematic review on High Intensity Interval Training (HIIT) versus Moderate Intensity Continuous Training for individuals with Type II Diabetes Mellitus. This introduced me to low-volume HIIT and its use for health and high-risk populations, not just well-trained athletic populations. This led to my MSc project in which I explored different HIIT designs, manipulating the intensity of exercise, revealing the vast range of HIIT protocol designs available in the published literature. This led me to initially consider HIIT as a very powerful exercise tool, which was very effective particularly in high-risk populations. My research into Type II Diabetes Mellitus, as well as through my BSc and MSc, also emphasised both the prevalence and negative health consequences associated with overweight and obesity, as well as the multitude of further comorbidities these can lead to. Moreover, it became apparent that HIIT omitted a key part of exercise guidelines; resistance training. Therefore, for this PhD project, I wanted to delve deeper into the role of HIIT and focus on establishing the effects of combining HIIT and resistance training in order to improve health for individuals living with overweight and obesity. However, it was important to consider my positionality before undertaking this PhD project, particularly given my initial research had led me to a position whereby I felt HIIT was very effective. I soon came to realise that during my initial study of HIIT, I had barely touched the surface of the vast volume of research available on the subject. As such, becoming acquainted with more of the large literature base opened my eyes to HIIT research which fell on both sides of the argument for and against HIIT, ensuring I embarked on this project from a more neutral perspective and was not pre-emptively inclined to assume HIIT would be unwaveringly effective.

1.1. Obesity: the current picture

1.1.1. The status of obesity

The severe impact of obesity and its status as a major public health concern is now well established (International Diabetes Federation, 2019). There has been an alarming emergence of obesity and sedentarism in a global epidemic and a staggering preponderance of people living with overweight and obesity (World Health Organisation, 2021). As our understanding has developed, it has become evident that overweight and obesity is no simple matter.

Though it may appear from the outset to be simply governed by a positive energy balance, this is merely the tip of the metaphorical iceberg, with a wide range of additional variables lurking below the surface. ‘Calories in exceeds calories out’ is merely the proximate, not ultimate cause (Fung, 2016), explaining the *how* rather than the *why*.

When we explore *why* energy in exceeds energy out, we find no straight line connecting the dots. Rather, there is a vast, complex, intertwining network of factors that form a multifaceted web of influence. As the UK government’s Foresight report (2007) surmised; the current epidemic of obesity is not attributed to increased laziness or gluttony in the modern age, but instead to the augmentation of an obesogenic environment in which it is now easier than ever in human history to become obese (and harder than ever to overcome). A whole host of individual and obesogenic components including genetics, social and individual psychology, physiology, individual and environmental physical activity, as well as advertising, food production and consumption, contribute (Kopelman et al., 2007).

Though the true range of underlying factors are individualised and likely immeasurable, obesity inherently derives from genetics and biological variation (Yeo, 2020) which cause high energy intake, dysfunctional metabolism, sedentary behaviour and insufficient physical activity (De Lorenzo et al., 2019). As a consequence, we now find ourselves in a world where the majority of the population live in countries where overweight and obesity kills more people than underweight (World Health Organisation, 2021).

1.1.2. The progression of obesity

The World Health Organisation (WHO) define obesity as the state in which excess body fat has accumulated to such an extent that health may be adversely affected (WHO, 2000), and classify this as a body mass index (BMI) > 30 $kg{\cdot}m^2$. Incidence of obesity and its associated comorbidities have increased exponentially to become commonplace, with the fight against obesity gaining increased recognition and action. Indeed, UK Government initiatives have been enforced, such as a levy on the sugar content in soft drinks and the 2007 Foresight report was built upon by a review into a whole-systems approach to obesity (Bagnall et al., 2019), which demonstrated the benefit of systems approaches to combatting obesity. The National Institute for Healthcare and Excellence (NICE) published clinical guidelines for obesity in 2014 with the guidance on identification, assessment and management more recently updated (NICE, 2022). Owing to the incessant rise of its prevalence and subsequent financial burden and contribution to ill-health, obesity must remain firmly fixated in the spotlight, as we desperately seek effective solutions to an extensive public health emergency with staggering consequences.

1.1.3. The magnitude of the problem

Of all the statistics regarding overweight and obesity the simplest yet most alarming is that the majority (64%) of adults in England are living with overweight (BMI: 25.0 – 29.9 $kg{\cdot}m^2$) or obesity (BMI: > 30 $kg{\cdot}m^2$). This statistic is the most perturbing as it is to say that being of a 'normal' weight, is to be in the minority. The overweight category is the largest sub-cohort, which in itself presents with negative health consequences. In much the same way that an individual with pre-diabetes or prehypertension would be at risk of developing clinical type 2 diabetes or hypertension, overweight can present with many of the risks associated with – and often lead to – obesity.

Worldwide, the modern predominance of obesity is illustrated by the tripling of its occurrence since 1975, with most recent global estimates proposing that more than 1.9 billion adults were living with overweight and with over 650 million living with obesity (WHO, 2021). Latest estimates propose that overweight and obesity-related-illness cost the NHS £6.1bn over a two-year period, and that obesity was projected to cost the wider society £27bn (Public Health England, 2017). The World Obesity Federation predict the global cost of obesity will reach $1.2tn annually by 2025 (World Obesity Federation, 2019) and without efficacious interventions to halt and reverse the progression of the epidemic, Public Health England estimate that 70% of adults will be living with overweight or obesity by 2034 (Public Health England, 2017), exacerbating the current burden to catastrophic proportions.

1.2. Causes and Consequences of Obesity

1.2.1. Is there a definitive cause?

Whilst there exist a wide range of theories for the cause of obesity, spanning from feedback loops (Mayer, 1953), to gluco-lipostatic theories (Schwartz et al., 2017), the selfish brain theory (Peters et al., 2004), the hormonal hypothesis (Fung, 2016), or that predetermined heritability or polynomic genetic alterations contribute (Bouchard, 2021; Yeo, 2020), it is most likely that there is an amalgamation of genetic predisposition, environmental exposures and obesogenic behaviour (Bouchard, 2021). Ultimately, through a plethora of contributing factors **(Figure 1.1)**, body fat mass increases due to high energy intake and low energy expenditure. Thereafter, obesity and its subsequent deleterious effects can proliferate.

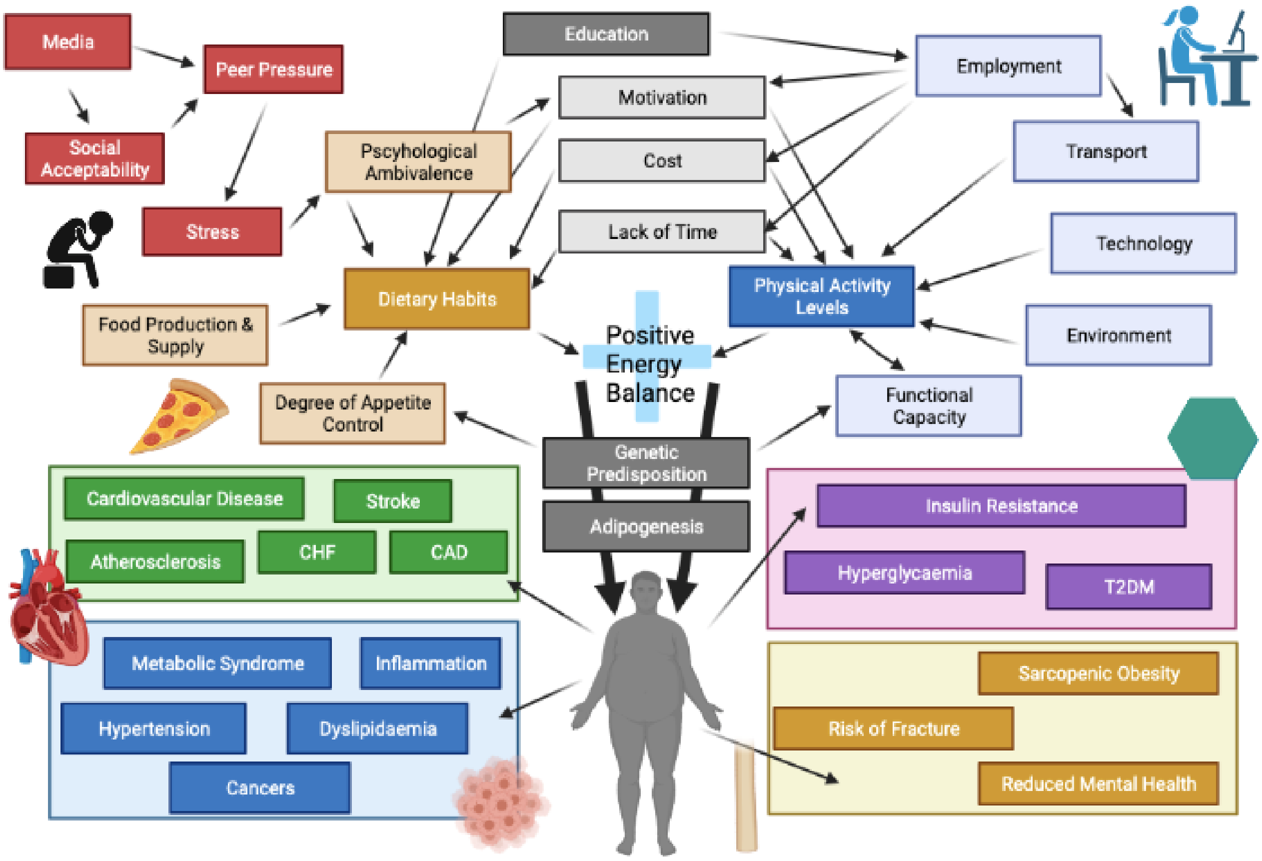

Figure 1.1. Causes and Consequences of Overweight and Obesity

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Fundamentally, obesity develops when fat, stored as Triglycerides (TG) in white adipose tissue, accumulate (Braun et al., 2018). This is exacerbated by a continued positive energy balance, as rather than metabolise dietary fats and carbohydrates, they are stored as TGs and glycogen. Owing to a small capacity for glycogen storage, surplus carbohydrate can also be converted to fat and stored in adipose tissue during *de novo* lipogenesis, expanding fat stores. Increased adiposity characterises obesity, which is defined as the accumulation of body fat to the extent that there are adverse health implications (Mayer, 1953). This adiposity can be distributed differently, with accumulation of fat mass around vital organs (visceral adipose tissue) of most concern for promoting deleterious health implications (Slentz et al., 2011; Tchernof and Després, 2013).

1.2.2. Major Consequences

One of the major consequences of increased adiposity is insulin resistance (IR) in insulin-targeting tissues (Zeyda and Stulnig, 2009), which occurs as a result of a build-up of fat in skeletal muscle cells (lipotoxicity). As a result of IR, glucose cannot enter cells to be metabolised when available. Likewise, the adipose tissue also becomes insulin resistant, diminishing the ability of insulin to inhibit lipolysis, allowing for the continued release of free fatty acids (FFA) into the bloodstream and exacerbation of lipotoxicity. Consequently, individuals living with obesity have an impaired capacity for fat oxidation, lower mitochondrial content and physical fitness (Nordby et al., 2006).

Ultimately, the body cannot readily switch between carbohydrate and fat as the primary fuel source. In a healthy metabolism, fuel selection can be successfully switched in response to changing metabolic states, with fat oxidation reduced upon increased availability of carbohydrate and vice versa (Hue and Taegtmeyer, 2009; Randle et al., 1963). As such, healthy individuals are deemed 'metabolically flexible' (Goodpaster and Sparks, 2017). Due to the mismanagement of carbohydrate and fat metabolism in obesity, individuals living with obesity are metabolically *inflexible* (Kelley et al., 1993). This poses the risk of deleterious consequences, including hyperglycaemia and the onset of type 2 diabetes mellitus (T2DM).

Obesity is also closely linked with the metabolic syndrome (MetS); a series of complications including IR, dyslipidaemia, hypertension, atherosclerosis and several major diseases (Jung and Choi, 2014). The root cause for the development of these antagonistic metabolic characteristics is suggested to be chronic inflammation of adipose tissue (Lumeng and Saltiel, 2011), as a consequence of obesity. As adipocytes enlarge and stretch, this is perceived as damage, causing an immune and inflammatory response, facilitating a general switch from an anti- to a pro-inflammatory state (Jung and Choi, 2014). Thus, the adipose tissue releases a succession of pro-inflammatory mediators, cytokines and adipokines, evoking several adverse responses. Taken together, it is clear that obesity-induced inflammation instigates a myriad of local and systemic consequences (Shoelson et al., 2007), particularly leading to the adverse effects of MetS.

Obesity also increases the risk of developing several accompanying diseases. Indeed, excessive fat mass is significantly associated with cardiovascular disease (CVD) mortality (Ortega et al., 2016), with the accumulation of visceral adipose tissue in particular proposed to increase CVD risk (Demerath et al., 2008). This may be exacerbated by a sedentary lifestyle which is also demonstrated to be strongly linked to CVD risk (Wilmot et al., 2012). Obesity-related IR, endothelial dysfunction, hypercoagulability and systemic inflammation promote atherosclerosis (Rocha and Libby, 2009) and the pathogenesis of many CVDs. Epidemiological evidence highlights that obesity provides an increased risk for a number of CVDs including coronary artery disease (CAD), stroke, congestive heart failure (CHF), peripheral arterial disease (PAD), atrial fibrillation and venous thromboembolism (Douketis and Sharma, 2005; Oktay et al., 2017). This is due to the development of several obesity-induced factors including atherosclerosis, hypertension, increased intra-abdominal pressure and pressure overload of the left ventricle (Douketis and Sharma, 2005).

Obesity is also a risk factor for the development of Type 2 Diabetes Mellitus (T2DM) (International Diabetes Federation, 2019). The aforementioned process of metabolic dysfunction in obesity leads to IR in insulin-targeting tissues, hyperglycaemia and subsequently the onset of T2DM. The accompanying hyperinsulinemia and hyperglycaemia can incur tissue damage, hypertension and impaired endothelial function (Fonseca, 2007; Jellinger, 2007), leading to diabetic retinopathy and renal difficulties if left untreated (Marathe et al., 2017). Individuals with obesity are also at risk of developing certain cancers (WHO, 2000). Indeed, research has well established links between obesity and cancers of the colon, breast, kidney, liver and pancreas as well as non-Hodgkins lymphoma and myeloma (Bianchini et al., 2002; Calle et al., 2003). Specifically, obesity-induced hypertension, inflammatory pathways, fatty liver cirrhosis and hyperinsulinemia are attributed to cancer pathogenesis (Wolin et al., 2010). Subsequently, many of these comorbidities culminate in a reduced quality of life in individuals with obesity (Kolotkin and Andersen, 2017).

1.2.3. The addition of sedentarism

An accompanying facet of obesity is sedentary behaviour, which in itself is an independent risk factor for cardiometabolic disorders (Hadgraft et al., 2021). Sedentarism is closely associated with weight status, independent of physical activity levels (Biddle et al., 2010) and increased sedentary time is linked to a plethora of negative health consequences (van Uffelen et al., 2010), including risk of CVD, T2DM and CVD-related mortality (Katzmarzyk et al., 2009; Wilmot et al., 2012), particularly when exceeding 10 hours per day (Pandey et al., 2016). Sedentary behaviours and low physical activity levels can promote reduced cardiorespiratory fitness (CRF) – ascertained by one's $\dot{V}O_{2peak}$ or $\dot{V}O_{2max}$ – which diminishes accordingly with increased adiposity (Lambert, 2020). Low CRF is linked with increased all-cause and CVD mortality (Harber et al., 2017; Nocon et al., 2008) and exacerbates the detrimental effects of obesity, further increasing risk of mortality (Barry et al., 2014). Indeed, each one metabolic equivalent (1 MET) increase in CRF (3.5 $ml{\cdot}kg^{-1}min^{-1}$) is demonstrated to reduce risk of all-cause mortality 13% and risk of CVD events 15% (Kodama et al., 2009). Increased CRF also has the capacity to curtail the unfavourable effects of adiposity, T2DM and the metabolic syndrome (Oktay et al., 2017).

Obesity and sedentary behaviour can also incur skeletal muscle wasting (Kuh et al., 2005) and sarcopenic obesity (Roubenoff, 2004) which is closely linked to the development of MetS (Lu et al., 2013). The effects of obesity are also observed in bone health, where, although heavier individuals are observed to have a higher bone mineral content (BMC) and bone mineral density (BMD), they are at increased risk of fracture (Ishii et al., 2014) due to poor metabolic health (Gower and Casazza, 2013). Moreover, the increased mechanical loading experienced as an inevitable consequence of excessive body weight increases risk of both knee and hand osteoarthritis (Blagojevic et al., 2010; Yusuf et al., 2010).

Finally, from a societal perspective, persons who are overweight or living with obesity are historically well-established to suffer from discrimination and prejudice (Puhl and Brownell, 2001). It is proposed that such individuals receive greater prejudice than other groups commonly targeted for mistreatment (Latner et al., 2008) and that, most concerningly, the incidence of prejudice and discrimination has increased alongside the prevalence of overweight and obesity (Andreyeva et al., 2008). As such, person-centred language is now proposed to combat the stigma associated with overweight and obesity (Fisch et al., 2022).

1.3. Treatment of obesity

Hospital admissions with a primary diagnosis of obesity continue to rise year-on-year (NHS, 2020), with bariatric surgeries an oft used treatment which contribute to the £6.1 bn burden of obesity to the NHS (Public Health England, 2017). Alternatively, dietary restriction can be undertaken, with significant reductions in body mass reported (Hemmingsson et al., 2012). However, low calorie diets are often monotonous and difficult to follow (Steven and Taylor, 2015), reducing the feasibility for long-term adherence, leading to a greater rebound weight regain compared to more moderate restrictions (Hemmingsson et al., 2012). Given that long-term weight loss through dietary means is often insufficient (Curioni and Lourenço, 2005), weight management guidelines recommend pharmacotherapy as a secondary treatment (Garvey et al., 2016). As such, anti-obesity medications are often prescribed, which are successful in achieving weight loss, but many have accompanying side effects and are very costly medications for long-term use (Tak and Lee, 2021). More recently, a 'whole-systems approach' to obesity has been reviewed in the literature (Bagnall et al., 2019), which notes that such an approach can be of benefit to tackle obesity. A whole-systems approach involves determining the underpinning causes of overweight and obesity, co-ordinated action from a variety of disciplines and stakeholders throughout the life course (Bagnall et al., 2019).

1.4. The role of exercise

Exercise or physical activity (PA) present as a cost-effective and enticing treatment for overweight and obesity, providing additional health-related benefits that cannot be sought from surgical, dietary or pharmacological intervention. Though closely linked, PA and exercise differ slightly, with Caspersen et al. (1985) defining PA as any movement causing energy expenditure and exercise as planned and structured PA to improve physical fitness. Though, there has been recent critique of this definition and a more holistic alternative proposed to account for the complex nature of PA (Piggin, 2020). However, Piggin does not claim definitional certainty and does not advocate for consensus around this definition. Nonetheless, as physical inactivity can cause a multitude of diseases and premature mortality (Lee et al., 2012), regular exercise and PA is of paramount importance.

As such, exercise and PA are observed to improve a plethora of health outcomes including CVD and T2DM risk (Gill and Cooper, 2008; Nocon et al., 2008) as well as specific obesity-related outcomes such as adiposity, inflammation, associated comorbidities, CRF and body composition (Church, 2011; Okay et al., 2009; Shaw et al., 2006; Strasser and Schobersberger, 2011). Furthermore, in high risk groups, such as individuals with obesity, increasing PA is of greater importance (Gill and Cooper, 2008), with increased fitness in obesity well established to attenuate many of the adverse health outcomes (Lee et al., 1999). Consequently, exercise guidelines propose that 150 – 300 minutes of moderate intensity or 75 – 100 minutes of vigorous intensity exercise and two muscle strengthening sessions should be completed per week (Piercy et al., 2018). Accordingly, regularly completing 150 minutes of moderate intensity exercise per week is associated with a 31% lower mortality rate (Arem et al., 2015). Though benefits can be sought from either aerobic or muscle strengthening activities, only those who complete both in recommended quantities observe the greatest reduction in all-cause, CVD and cancer mortality risk (Zhao et al., 2020).

Adaptations, particularly in skeletal muscle, occur in response to a series of acute exercise bouts, cumulating in increased protein content, enzyme function, and structural remodelling, preparing the body in anticipation of future exercise stimulus (Egan and Zierath, 2013; Perry et al., 2010). Both cardiovascular aerobic (e.g. running/cycling) and resistance (e.g. weight training) exercise contribute to physical and metabolic adaptations key for individuals with obesity via distinct metabolic signalling pathways (Egan and Zierath, 2013).

As well as a multitude of metabolic benefits, exercise also provides a positive impact on many physical and mental health outcomes (Penedo and Dahn, 2005). Importantly, exercise is effective in instigating a negative energy balance to promote weight loss, with reductions in body mass of 5% proposed to ensure clinically significant favourable health outcomes (Williamson et al., 2015). This ‘5%’ is based on several large-scale studies and systematic analyses which present compelling evidence that 5% weight loss can improve obesity-related risk factors (Williamson et al., 2015), though it is noted that some health improvements can be sought below this threshold and independent of weight loss (Johnson et al., 2009). However, a wealth of research demonstrates that exercise alone cannot provide large reductions in body mass (Cox, 2017; Franz et al., 2007; Pontzer et al., 2016), with diet an important accompanying factor (Caudwell et al., 2009). Improvements in body composition are also critical for obesity-related health, with factors such as waist circumference closely related to mortality (Cerhan et al., 2014). Reductions in BMI are also essential in order to improve health-related quality of life, which declines with increasing BMI and is mitigated by exercise (Hassan et al., 2003). Increased FFM may also provide a preventative role against sarcopenia and help maintain of quality of life with ageing (Evans, 1995).

Exercise also provides significant physiological changes to the cardiovascular system (Huonker et al., 1996). Chronic training results in cardiac remodelling to facilitate a greater cardiac output. Hypertrophy of the left ventricle and increased contractile strength positively affect physiological performance, leading to increased CRF (Lavie et al., 2015) and exercise tolerance (Myers, 2005). Alterations in the vasculature, such as reduced arterial stiffness and systemic inflammation, as well as increased vasodilation combine to reduce blood pressure, low-density lipoprotein (LDL) cholesterol and risk of CVD (Lavie et al., 2015; Myers, 2005). Exercise can also improve mental health outcomes, including major depression and other neurodegenerative diseases (Deslandes et al., 2009). This has been reflected in individuals with obesity, who are observed to significantly improve mental composite quality of life after a six-month exercise and weight loss intervention (Miller et al., 2018).

1.5. Barriers to exercise

Despite the plethora of benefits associated with regular PA and exercise, the prevalence of obesity remains high. Many individuals living with obesity do not meet minimum exercise guidelines (Tudor-Locke et al., 2010) and have been historically noted to be less active (Cooper et al., 2000; Tryon et al., 1992). Indeed, in the latest national statistics, 22% of the adult population were noted to be inactive (NHS, 2019). Therefore, understanding the barriers to regular exercise for individuals living with obesity is an important subject and is accordingly well-researched. Ekkekakis and Zenko (2016) propose that although a cognitivist approach would suggest the benefit of exercise to health is a compelling reason to participate, those who are sedentary negate these positive outcomes as they associate exercise with displeasure. Indeed, individuals living with obesity are observed to have a lower perception of enjoyment and tolerance of exercise (Leone and Ward, 2013). Consequently, Ekkekakis and Lind (2006) recommend that exercise prescription in obesity should be based on what is tolerable and enjoyable.

However, this must be compromised with sufficient exercise to allow for improvements in health-related outcomes, as factors such as high frustration due to unmet weight loss expectations is a common cause for the cessation of exercise in individuals living with overweight or obesity (Sears and Stanton, 2001). Often, individuals strive for a 'quick fix' (Dansinger et al., 2005) that exercise cannot satisfy, with many individuals aiming to lose considerable body mass for an aesthetically desirable appearance. Thus, many outcomes independent of weight loss, such as metabolic health, may be overlooked.

Table 1.1. Common barriers to exercise for individuals living with overweight and obesity.

Internal		**External**
Physical	**Psychological**	
Excess weight Poor fitness Health problems Injury/pain Exercise tolerance	Weight perception/body image Low mood Lack of enjoyment Lack of motivation Unmet weight loss expectation Bad exercise history Lack of coping skills Boredom Comparison to others	Lack of time Lack of exercise knowledge Weather Competing demands High cost of training programmes Low social/cultural support
(Sherwood and Jeffrey, 2000; Dalle Grave et al., 2011; McIntosh et al., 2016)		

Previous research has identified a 'lack of time' as a commonly cited barrier to exercise participation (Trost et al., 2002), which has been argued may be more due to how individuals want to spend their time, rather than the amount available (Biddle and Batterham, 2015). Other research has determined environmental factors and resources to also be of key importance in both middle-aged and older adults (Spiteri et al., 2019). However, other research has highlighted a myriad of factors specific to overweight and obesity. Mcintosh et al. (2016) reviewed common barriers to exercise in obesity and categorised these into internal (physical or psychological) and external barriers. An overview of the most prevalent barriers to exercise from overweight- and obesity-specific research (Dalle Grave et al., 2011; McIntosh et al., 2016; Sherwood and Jeffery, 2000) is provided in **Table 1.1**. Understanding these barriers is vital in order to develop exercise recommendations for individuals living with overweight and obesity that are engaging and enjoyable whilst maximising the associated health benefits.

1.6. Exercise training in overweight and obesity

1.6.1. Cardiovascular-based exercise

Aerobic exercise training (AT) programmes have historically been utilised in the treatment of obesity and are noted to improve a number of obesity-related health outcomes (Bouchard et al., 1993). Indeed, the ACSM propose that regular PA prevents weight gain, promotes clinically significant weight loss, prevents weight regain after loss and improves CVD risk factors (Donnelly et al., 2009). Incidentally, the ACSM recommend individuals to complete a minimum of 150 minutes of PA per week, though acknowledge dose-response effects that warrant up to 250 – 300 minutes or 2000 kcal per week (Piercy et al., 2018). Volume of exercise appears vital, though achieving such volumes via traditional AT methods are often time-consuming. High-intensity interval training (HIIT) may be a time efficient, enticing and feasible alternative to traditional AT, by splitting up workloads that would be otherwise unsustainable, into smaller more manageable chunks. Whilst there exists debate in the literature on the definition of HIIT it is generally accepted to consist of bouts of high-intensity exercise interspersed with low-intensity exercise or rest (Gibala et al., 2012), allowing for higher volumes of work to be completed with lower overall durations of exercise.

'High-intensity' exercise is a somewhat vague term, with various thresholds of intensity proposed in the literature, though HIIT is generally defined by workloads above that of the lactate threshold (Laursen and Buchheit, 2019). Historically, HIIT was utilised by athletes for the benefit of sports performance (Laursen and Buchheit, 2019), with the application of HIIT in exercise science, health and disease a burgeoning research interest, owing to an explosion of HIIT studies in the early twenty-first century (MacInnis and Gibala, 2017). HIIT can be undertaken in many forms, with the work to rest ratio, intensity and interval duration manipulated to create several HIIT designs (Laursen and Buchheit, 2019). The earliest HIIT studies focusing on improving health employed high volumes, adopting 4 x 4-minute designs (Rognmo et al., 2004; Wisløff et al., 2007). Despite their efficacy, these designs did not maximise time efficiency. Thus, low-volume HIIT was popularised (Gibala et al., 2012), which maximised time efficiency, whilst maintaining the cardiometabolic benefit (Sabag et al., 2018). Indeed, a 10 x 60 second design is established as safe, tolerable and successful in healthy, clinical, and sedentary individuals (Hood et al., 2011; Little et al., 2014, 2011). Low-volume HIIT is attributed to the improvement of a multitude of factors, most notably linked to increased mitochondrial capacity and function, as well as a unique capacity to exhaust glycogen stores (Sabag et al., 2021). Although longer durations (>12 weeks) of HIIT are noted to be required to result in meaningful body mass reductions (Batacan et al., 2012). Nonetheless, HIIT is recognised to be generally safe and effective (Gibala, 2018) and its use is acknowledged in the latest exercise guidelines for the general population in both the UK and US (Piercy et al., 2018; UK Chief Medical Officers, 2019).

As a time- and cost-effective exercise training modality, HIIT is well-suited to tackle some of the key barriers to exercise cited by individuals living with overweight and obesity, including a lack of time and high cost of training programmes **(Table 1.1)**. Moreover, HIIT may be a novel and engaging exercise type for many, eliciting greater adherence to and enjoyment from exercise (Shepherd et al., 2015; Thum et al., 2017), alleviating boredom and increasing motivation. However, the feasibility of widespread adoption of unsupervised HIIT in the general population is questioned (Biddle and Batterham, 2015; Roy et al., 2018) with the majority of HIIT research taking place in laboratory conditions (Gibala, 2018), which will see greater health improvements than unstructured real-world training programmes (Lunt et al., 2014).

Nonetheless, HIIT is proposed to provide greater physiological adaptations than traditional aerobic exercise. The increased intensity of exercise achieved with HIIT instigates a greater metabolic response for physiological adaptation (Gibala et al., 2012; Laursen and Buchheit, 2019) to the benefit of glycaemic control, mitochondrial biogenesis and lipid metabolism. A recent meta-analysis of exercise training modalities in overweight and obesity proposed HIIT was superior to aerobic or resistance exercise for improvements in cardiorespiratory fitness (defined by peak oxygen consumption; $\dot{V}O_{2max}$) (van Baak et al., 2021). A meta-analysis of HIIT versus MICT for CVD risk factors (Su et al., 2019), highlighted that although reductions in body mass were comparable between exercise types, these betterments were achieved in an average of 9.1 minutes fewer time per exercise session in HIIT versus MICT.

However, there are a plethora of HIIT protocols employed in the published literature (Batacan et al., 2017; Wewege et al., 2017), with many utilising different methods of exercise prescription. Particularly, exercise intensity is often prescribed relative to maximal anchors (such as maximum heart rate) causing dissimilar actual intensities of exercise achieved on an individual basis (Jamnick et al., 2020). This often results in an increase in between-subject variance, muddying the waters with respect to detecting effect sizes in outcome measures of exercise interventions. Therefore, some participants may respond more or less, depending on whether or not they have received the required ‘dose’ of exercise, which is noted to be important to achieve from HIIT in order to maximise outcome measures (Langan and Grosicki, 2021). As such, it is particularly difficult to establish the HIIT protocols which are the most effective, feasible or reliable, to prescribe for individuals with overweight or obesity. Indeed, there is no established threshold in the prescription of intensity or volume of HIIT from which cardiometabolic benefit can be sought.

1.6.2. Strength-based exercise

Though AT and HIIT can provide many favourable health-related outcomes, neither can provide certain adaptations sought from resistance (strength) based exercise training. Originally utilised for the benefit to athletic performance, the use of resistance training (RT) in health and disease is now well-documented (van Baak et al., 2021). Accordingly, exercise guidelines for all adults recommend strength-based training twice per week (Piercy et al., 2018) with 2 – 4 sets of 8 – 12 repetitions for all major muscle groups (ACSM, 2014). Consequently, RT may provide several favourable adaptations to physical and metabolic health for individuals living with overweight and obesity. RT is the superior exercise type to provide increases in muscular strength (van Baak et al., 2021). Chronic adaptations to RT programmes also include reduced risk of CVD, increased CRF, improved body composition and increased glycaemic control (Ahmadizad et al., 2007; Strasser and Schobersberger, 2011). Moreover, RT is the only exercise modality noted to increase skeletal muscle mass which, as a highly important metabolic tissue, provides a plethora of positive health outcomes (Bodine, 2006; Yan et al., 2019). RT is also demonstrated to reduce the risk of developing MetS independent of the amount of AT completed (Bakker et al., 2017). RT also provides some favourable adaptations in bone (Layne and Nelson, 1999), the health of which may often be compromised in overweight and obesity.

1.6.3. Concurrent exercise

There are a wealth of health-related benefits resulting from regular completion of AT, HIIT and RT, including specific adaptations unique to each exercise type. Consequently, exercise guidelines for the general population acknowledge the importance of completing both cardiovascular- and strength-based exercise (Piercy et al., 2018). As such, meeting both aerobic and strength guidelines reduce the incidence of obesity (Bennie et al., 2020). However, the need to include both aerobic- and strength -based exercises will increase the time commitment, noted as a barrier to exercise adherence (McIntosh et al., 2016). Therefore, finding a time-efficient and engaging form of incorporating both exercise types may be the best strategy to ensure widespread adoption, achievement of exercise guidelines and to maximise the health benefit. Concurrent Training (CT) – the simultaneous integration of both strength and endurance training (Laursen and Buchheit, 2019) – may present as a successful exercise strategy for individuals living with overweight and obesity. CT is typically used by athletes to gain adaptations from both endurance (e.g. CRF) and strength (e.g. power) training to facilitate an increase in sports performance (Nader, 2006), and has been published in the sport and exercise science literature since the first reported CT studies by Hickson (1980). When considering the efficacy of CT for the general betterment of health, examinations of the literature reveal combined aerobic and resistance exercises are successful in improving glycaemic control, insulin sensitivity, CRF, CVD mortality and reducing abdominal adiposity (Johannsen et al., 2016).

In theory, simultaneously training both endurance and strength should provide the same benefit as training both independently. However, an important facet of CT (acknowledged since the very first studies conducted by Hickson, and a popular research topic thereafter) is a phenomenon known as the interference effect. The interference effect describes the diminishing of adaptations to resistance exercises after CT compared with RT alone, with several studies demonstrating compromised gains in hypertrophy and strength (Jones et al., 2013; Kraemer et al., 1995; Rønnestad et al., 2012). The duration, frequency and mode of exercise also play a role in the magnitude of the interference effect (Wilson et al., 2012), with two primary theories established in the literature; that acutely fatigue from the AT component of CT results in a decreased ability to perform a sufficient intensity and volume of RT (Craig et al., 1991), or that chronically, separate metabolic pathways responsible for different adaptations inhibit each other (Leveritt et al., 1999). However, much of the research on the interference effect is conducted in recreational athletes (Wilson et al., 2012), with evidence to the contrary also provided (Murach and Bagley, 2016). Although increases in CRF have also been demonstrated to be lower after CT than AT alone (Nelson et al., 1990), this is not generally considered to be the case (Wilson et al., 2012).

A novel approach to exercise training is to include HIIT as the cardiovascular element of CT (Ramírez-Vélez et al., 2020), potentially maximising both time efficiency and cardiometabolic benefit. Emerging evidence suggests this may even ameliorate the magnitude of the traditional interference effect (Methenitis, 2018; Sabag et al., 2018) However, the wealth of research involving concurrent HIIT and resistance exercise focuses on sports performance (Methenitis, 2018; Sabag et al., 2018), untrained (Gentil et al., 2017) or elderly (Mueller et al., 2021) populations. More research is required to determine the effect of concurrent HIIT and CT on obesity-related health outcomes, particularly on changes in body composition.

1.7. Thesis Aims

Therefore, the aims of this thesis are to:

- Synthesise the current evidence-base on the utility and effect of CT as an exercise mode for individuals with obesity, particularly including the use of HIIT and the common methodologies employed.
- Determine the efficacy, reliability and feasibility of using individualised HIIT designs, for more accurate prescription of HIIT for individuals with obesity.
- Establish the feasibility and evaluate the intervention fidelity of completing combined HIIT and RT exercise training programmes in individuals living with overweight and obesity.
- Determine the use and effectiveness of CT compared to HIIT on improving cardiometabolic outcomes in individuals with obesity.

Chapter 2.0. General Literature Review

This chapter aims to detail the physiological mechanisms by which regular HIIT and RT exercise can be of benefit to the cardiometabolic health of individuals living with obesity, as well as to fully examine the current evidence-base to determine the utility and effectiveness of HIIT and RT exercise interventions to improve cardiometabolic health.

2.1. Underpinning Cell Biochemistry

In order to explore the effects of HIIT and RT on cardiometabolic health, it is important to first understand the underpinning cell biochemistry of these adaptations as well as the underlying cause of the interference effect.

2.1.1. Aerobic exercise: effects of AMPK

Adaptations to aerobic exercise primarily derive from the downstream effects of AMP-activated protein kinase (AMPK), a sensor of cellular energy charge and regulator of several biological processes (Kahn et al., 2005). AMPK acts to protect the cell when detecting a reduced energy state, ensuring maintenance of a catabolic over anabolic state (Richter and Ruderman, 2009). Concomitantly, AMPK acts to increase ability to manage future metabolic challenges and hence increases exercise capacity. A brief overview of the overriding mechanisms by which AMPK is increased during aerobic exercise and its subsequent effects in skeletal muscle is provided in **Figure 2.1**. AMPK increases in response to the detection of a number of metabolites incurred by exercise which promote a reduced cellular energy charge, occurring in an intensity-dependant manner (Chen et al., 2003). After acute bouts of exercise, AMPK acts to increase skeletal muscle glucose uptake via an insulin-independent pathway (Merrill et al., 1997; Richter and Ruderman, 2009) and a reduction in hyperglycaemia and hyperinsulinemia ensues. Acutely, activation of AMPK also acts to increase fat oxidation through inhibition of acetyl-CoA carboxylase [ACC] (Merrill et al., 1997; Richter and Ruderman, 2009). Subsequently, diminished ACC activity results in increased lipid delivery to the mitochondria and thus elevated oxidation flux. Acute activation of AMPK also reduces protein synthesis via inhibition of mammalian target of rapamycin complex-1 (mTORC1) (Atherton et al., 2005). As AMPK reacts to a reduced energy state, it acts to restrict anabolic process such as protein synthesis, prioritising the distribution of limited cellular resources.

With the repeated stress and stimulus from regular exercise bouts, long-term adaptations occur. Chronically, AMPK increases protein and enzymatic content, including GLUT4, hexokinase and other mitochondrial enzymes (Winder et al., 2000). As such, GLUT4 protein content is observed to increase markedly upon as little as two-weeks exercise training (Little et al., 2011). Coupled with the ability of AMPK to increase fat oxidation, exercise training can promote reduced lipotoxicity and increased insulin sensitivity in skeletal muscle. Moreover, AMPK phosphorylates and activates peroxisome proliferator-activated receptor gamma coactivator 1-alpha (PGC1α), resulting in mitochondrial biogenesis **(Figure 1)**. An increased number of mitochondria allow for a greater capacity for substrate oxidation,

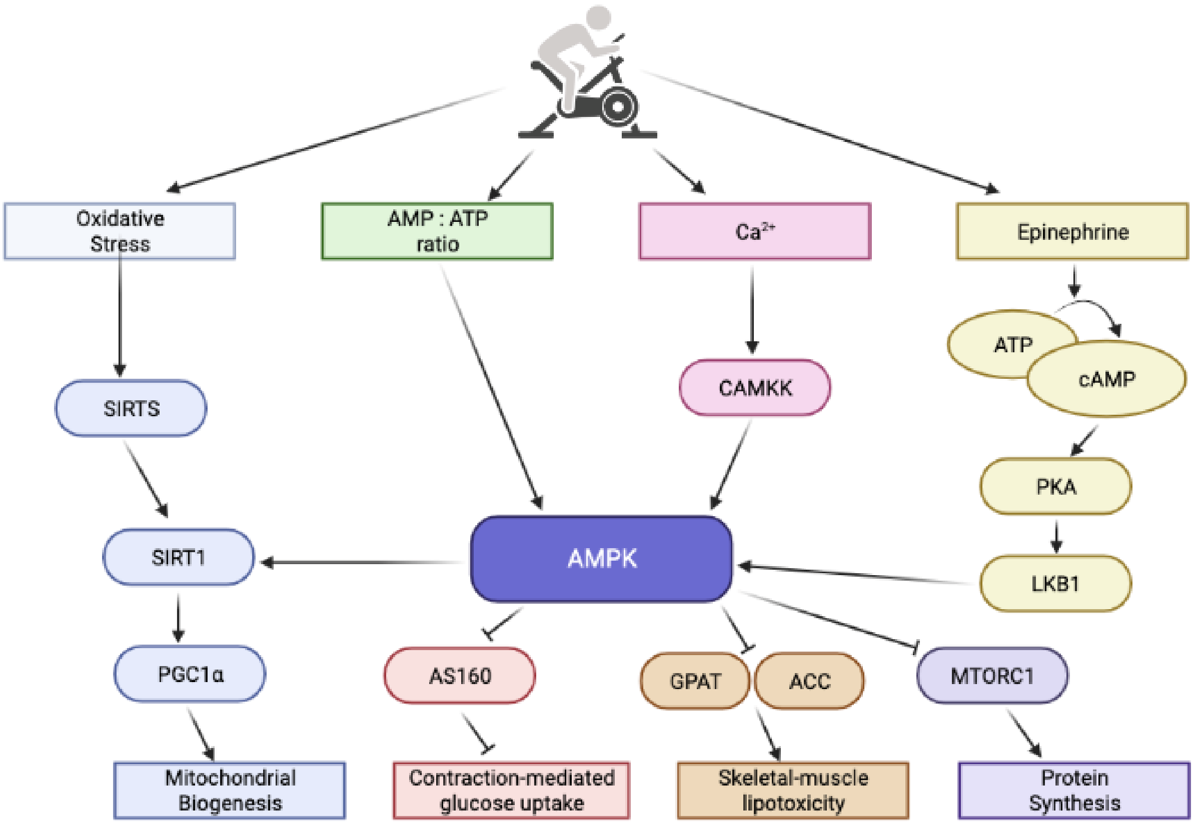

Figure 2.1. Overview of the activators of AMPK and its subsequent actions in skeletal muscle.

Exercise stimulates activation of AMPK via epinephrine release, Ca^{2+} release from muscle contraction and formation of AMP as ATP is hydrolysed for energy. AMPK subsequently causes acute and chronic adaptations including increased mitochondrial biogenesis, contraction-mediated glucose uptake, reduced skeletal-muscle lipotoxicity and protein synthesis.

Abbr. *ACC, acetyl-CoA carboxylase; AMP, adenosine monophosphate; AMPK, AMP-activated protein kinase; AS160, akt substrate of 160 kDa; ATP, adenosine triphosphate; cAMP, cyclic AMP; CAMKK, calcium-dependant protein kinase; GPAT, glycerol-3-phosphate acyltransferase; LKB1, liver kinase B 1; mTORC, mammalian target of rapamycin complex; PGC1a, peroxisome proliferator-activated receptor gamma coactivator 1-alpha; PKA, protein kinase A; SIRT1, sirtuin 1.*
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2.1.2. Resistance exercise: effects of mTORC1

Adaptations to resistance exercise also appear to have a master regulator; the mammalian target of rapamycin complex 1 (mTORC1). mTORC1 is a complex of proteins which promote anabolic cellular processes (Laplante and Sabatini, 2009). Just as AMPK responds to

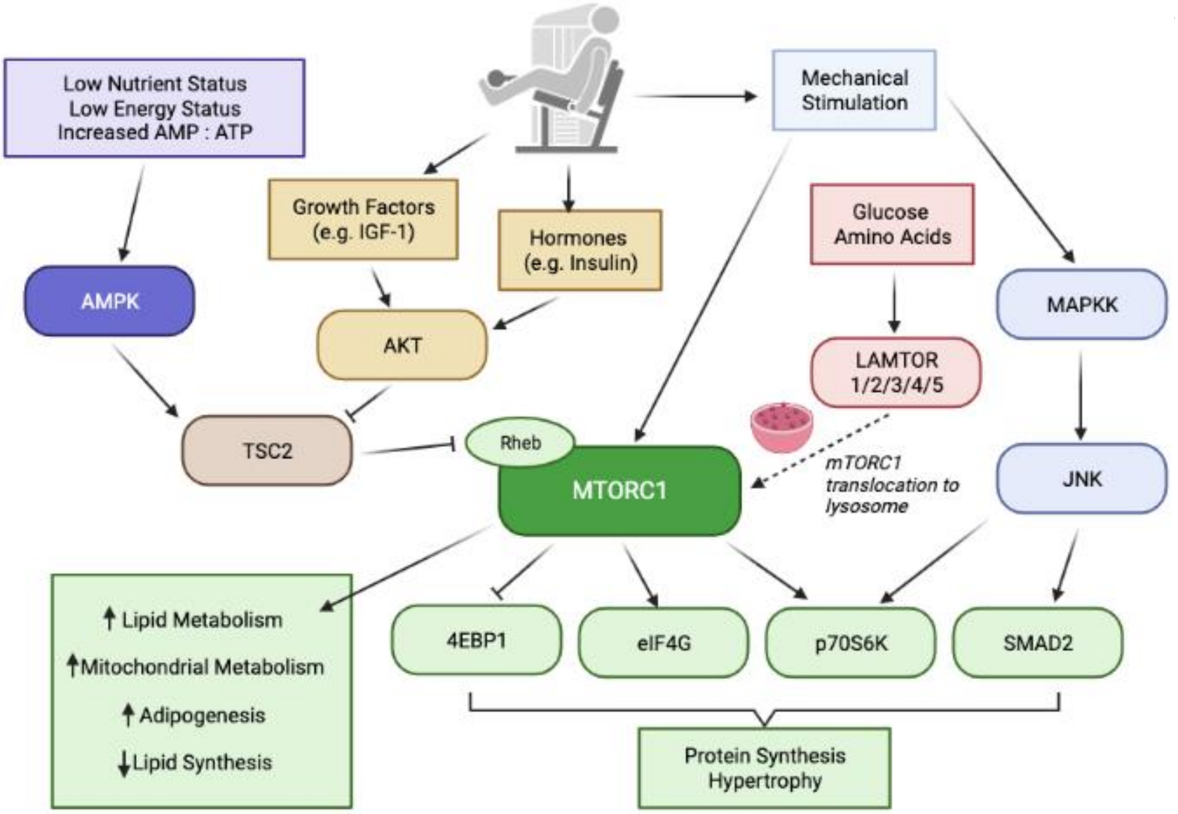

Figure 2.2. Overview of the activators of mTORC1 and its subsequent actions.

Resistance exercise initiates growth factors and hormones as well as mechanical stimulation of mTORC1. Other indicators of a positive energy status such as increased glucose and amino acid availability ready mTORC1 for activation via translocation to the lysosome. mTORC1 acts on protein synthesis factors, as well as other anabolic pathways including mitochondrial biogenesis and inhibits catabolic pathways such as autophagy and lipid metabolism.

Abbr. *AKT, protein kinase B; AMPK, AMP-activated protein kinase; 4EBP1, 4 eukaryotic binding protein 1; eIF4G, eukaryotic initiation factor 4G; LAMTOR, lysosomal adaptor and MTOR activator; mTORC1, mammalian target of rapamycin complex 1; PGC1α, peroxisome proliferator-activated receptor gamma coactivator 1-alpha; PPAR, peroxisome proliferator-activated receptor; P70S6K, P70 ribosomal protein S6 kinase beta-1; Rheb, ras homolog enriched in brain; SREBP1, sterol regulatory element-binding protein 1; TSC2, tuberous sclerosis complex 2.*
Created using BioRender.com.

Primarily, mTORC1 regulates muscle protein synthesis, increasing the amount of skeletal muscle mass in response to resistance exercise training (Bodine, 2006). As a key metabolic tissue, increased skeletal muscle mass provides a plethora of benefits, including improved glycaemic control, muscular strength and body composition (Ng et al., 2012; Strasser and Schobersberger, 2011). Importantly, whilst both resistance and aerobic training can improve factors such as adiposity and glycaemic control, only resistance training is effective in increasing muscle mass (Yan et al., 2019), which is of importance to maintain health-related quality of life. Increased grip strength is negatively associated with mortality risk (Celis-Morales et al., 2018). mTORC1 also acts to increase mitochondrial biogenesis through PGC1α (Cunningham et al., 2007), leading to a greater capacity for substrate metabolism.

Two distinct pathways regulate adaptations to aerobic and resistance exercise. As such, the mechanisms underlying the chronic interference effect hypothesis can be clearly observed. With increased aerobic exercise and subsequent activation of AMPK, there is a resultant inhibition of mTORC1 and diminishing of protein synthesis and muscular hypertrophy. Nonetheless, these biochemical mechanisms and pathways translate to a number of cardiometabolic improvements for those undertaking HIIT or CT exercises, to the betterment of obesity-related health factors.

2.3. Review of HIIT Programmes

2.3.1. Body composition

HIIT is evidenced to provide reductions in body mass (BM), waist circumference (WC) and body fat (BF) in a variety of populations (Boutcher, 2011; Martland et al., 2020), an important adaptation given the close relationship between increased adiposity and mortality (Lee et al., 2018) and the torrent of deleterious health consequences instigated from an increased adipose tissue (Jensen, 2008). HIIT is more time-efficient for increasing EE (Martins et al., 2016), which facilitates a negative energy balance and subsequent beneficial changes in body composition. However, HIIT may also provide greater improvements than EE-matched MICT via increased exercise and post-exercise fat oxidation (Abbasi, 2019), perhaps due to the capacity of HIIT to chronically adapt adipose tissue to prolong lipolysis post-exercise (Liu et al., 2020). HIIT may also provide concomitant reductions in appetite (Boutcher, 2011), simultaneously affecting body composition.

The effects of HIIT on body composition in overweight and obesity is demonstrated by several systematic reviews and meta-analyses. Batacan et al. (2017) demonstrate HIIT of over 12 weeks in duration can significantly decrease BF% (SMD (95% CI): -0.4 (-0.74, -0.06) and WC (SMD (95% CI): -0.2 (-0.38, -0.01), though confidence intervals reveal some uncertainty with the magnitude of these improvements, which are also not observed in HIIT programmes < 12 weeks in duration. Maillard et al. (2018) also present that HIIT significantly reduces BM (~2 kg), total, abdominal and visceral fat mass in a meta-analysis across 39 studies and 617 individuals living with overweight and obesity . Further analysis into the intensity and modality of HIIT suggested that running was superior to cycling for total and visceral fat loss, and higher intensities (> 90% HR_{peak}) were more successful for whole body adiposity reductions, whilst lower intensities (< 90% HR_{peak}) found greater decreases in abdominal and visceral fat.

HIIT has also been compared to MICT in the literature, with a meta-analysis of 424 individuals living with overweight and obesity undertaken by Wewege et al. (2017). Inclusion in this meta-analysis required each study to involve HIIT of up to 4-minute intervals at an intensity of > 85% HR_{max}, > 80% $\dot{V}O_{2max}$ or an RPE > 17, against a comparator MICT group performing exercise at intensities of 60 – 75% HR_{max}, 50 - 65% $\dot{V}O_{2max}$ or RPE 12 -15. Both HIIT and MICT were successful in reducing a number of body composition measures, but there were no significant changes between groups. Indeed, reductions in SMD were comparable for: BF (HIIT SMD (95% CI): -0.44 (-0.75, -0.13; MICT SMD (95% CI): -0.5 (-0.77, -0.22) and BM (HIIT SMD (95% CI): -0.17 (-0.36, 0.03); MICT SMD (95% CI): -0.18 (-0.37, 0.02). The authors concluded that 10 weeks exercise at any intensity was capable of reducing BF (~ 2 kg) and WC (~ 3 cm) in the absence of any significant change in BM. However, these improvements equated to ~ 6% and lie within the error range for repeated measures of BF (LaForgia et al., 2009). Further analysis into the modality of exercise determined that only running significantly reduced BF, reaffirming the findings of Maillard et al. (2018), this is perhaps attributed to the greater muscle recruitment and subsequent EE from running compared to cycling exercise (Millet et al., 2009). However, Wewege et al. (2017) present that running exercise had increased report of adverse effects, therefore further evidence must be examined before prescription as the superior exercise modality for individuals living with overweight and obesity.

Andreato et al. (2019) performed a meta-analysis in a similar population of individuals living with overweight and obesity, but with a wider age range (18 – 65 years) yielding a larger number of studies (n = 48) and participants (n = 1222) than Wewege et al. (2017). HIIT was similarly defined as exercise at an intensity at or above 80% $\dot{V}O_{2max}$, 80%

HRR or 85% HRmax. The authors performed meta-analyses on HIIT versus control and versus MICT, though performed separate analysis both of studies who did and did not equalise HIIT and MICT protocols (by EE, for example). HIIT was effective in reducing BM compared to control -1.45 kg (95% CI: -1.85, -1.05), comparison of all studies found MICT superior for BM reductions, but when only analysing equalised protocols, HIIT prevailed (SMD (95% CI): -0.41 (-0.79, -0.02), though the authors note that these reductions were not clinically relevant. Pooled analysis revealed HIIT was also effective versus control for reducing WC -2.3 cm (95% CI: -3.1, -1.4) and BF% -1.29% (95% CI: -1.7, -0.87), though there were no significant differences between HIIT and MICT, when equalised or not. HIIT was also revealed to reduce visceral, but not subcutaneous fat. Further meta-regressions found that running exercise was associated with greater reductions in BM and WC and that the greater the number of exercise sessions, the higher the decreases in BM. Despite the findings from these two meta-analyses (Andreato et al., 2019; Wewege et al., 2017) that HIIT provides comparable improvements to MICT for body composition measures, the strength of studies included in both reviews must be questioned. Many studies included small samples, high dropouts not accounted for with intention-to-treat analysis and some inadequate reporting of session attendance and adherence. Moreover, some studies included no non-exercise control group and those with additive nutritional interventions were included. The latter suggests that some of these changes in body composition may have resulted from changes in diet rather than HIIT or MICT interventions per se.

Nonetheless, these studies reported favourable effects on body composition with HIIT. In contrast, Keating et al. (2014) report that short-interval (30 - 60s) HIIT (4-6 intervals, 120% $\dot{V}O_{2peak}$) in sedentary individuals with overweight increased trunk and android fat mass (0.7%, 0.8%), whereas MICT provided small decreases. However, these exercise interventions do not appear to be equalised, an important aspect when considering changes in body composition, as highlighted in the meta-analysis performed by Andreato et al. (2019). Accordingly, HIIT and MICT exercise in individuals with overweight and obesity equalised for EE (300 KJ) demonstrates comparable reductions in visceral and subcutaneous fat, as well as BF% and BM (Zhang et al., 2017). However, the authors propose that HIIT should be the predominate strategy, given its time-efficiency. This is a finding echoed by Wewege et al. (2017) who highlight that HIIT provides a ~ 40% lower time commitment, and with comparable rates of dropout HIIT appears a superior exercise strategy for individuals with overweight and obesity, given that improvements in body composition are equal to those observed after MICT.

Taken together, all of the available research to date suggests that adaptations in body composition from HIIT are indistinguishable to those from MICT. Though there appears to be a beneficial effect of HIIT on measures of body composition, particularly with running modalities, these findings are not conclusive, and dietary-controlled research trials of longer durations are required to elucidate if HIIT alone can provide clinically significant adaptations in individuals with overweight and obesity. Nonetheless, due to its time-efficiency, HIIT may be a more appropriate strategy to adopt than MICT.

2.3.2. Cardiorespiratory fitness

HIIT is established to increase $\dot{V}O_{2max}$ to a greater extent than work-matched moderate-intensity continuous training (MICT) in both healthy and clinical participants (Helgerud et al., 2007; Rognmo et al., 2004). Generally, HIIT is proposed to mediate these improvements in CRF by upregulating mitochondrial biogenesis and increasing density, resulting in larger force generation by working muscles (Gibala, 2009; Gibala et al., 2012), an increased stroke volume via greater cardiac contractility (Helgerud et al., 2007), as well as increased capillarisation and arterial compliance (Kessler et al., 2012; Rakobowchuk et al., 2008).

The effect of HIIT on CRF in overweight and obesity has been well researched in the literature. Batacan et al. (2017) provide a comprehensive systematic review and meta-analysis on the effects of HIIT on CRF of both < 12 weeks (short-term) and > 12 weeks (long-term) in duration. HIIT was defined as any interval exercise with an intensity at or above 85% $\dot{V}O_{2max}$ or heart rate reserve (HRR), or 90% of HR_{max}. In overweight and obesity, short-term HIIT was shown to significantly increase CRF to a medium effect (SMD (95% CI), 0.74 (0.36, 1.12) $P < 0.001$). Though the authors presented results as SMD, they calculated an aggregate improvement in relative $\dot{V}O_{2max}$ of 4.43 $ml{\cdot}kg^{-1}min^{-1}$. Perhaps logically, long-term HIIT increased CRF to a greater extent, finding significant increases to a large effect (SMD (95% CI), 1.2 (0.57, 1.83), $P < 0.001$), with an aggregate improvement of 6.04 $ml{\cdot}kg^{-1}min^{-1}$. Indeed, duration of exercise intervention predicted increased CRF in meta-regression through the β-coefficient (β (95% CI) = 0.77 (0.35, 1.18), $R^2 = 0.94$). Interventions > 12 weeks, therefore, are more beneficial for improvements in CRF in overweight and obesity, though increases observed for short-term interventions would also provide considerable benefit to cardiometabolic health and CVD mortality risk reduction (Kaminsky et al., 2013).

Moreover, Batacan et al. (2017) demonstrated that increased BMI predicted a larger improvement in CRF (β (95% CI) = 0.84 (0.29, 1.38), $R^2 = 0.73$), likely due to lower baseline functional capacity in individuals with overweight and obesity, reinforcing conclusions from previous research that it is even more important for high-risk individuals to perform regular PA to reduce risk of mortality (Celis-Morales et al., 2017). Though these results provide strong evidence that HIIT can significantly increase CRF in individuals with overweight and obesity, the authors do not further explore intervention durations to determine at which point above or below 12 weeks there may be more or less favourable changes in CRF. Furthermore, the intensity established for inclusion in the review is higher than other researchers define as 'high-intensity' (De Feo, 2013; Laursen and Buchheit, 2019; Weston et al., 2014). Due to the low functional capacity of individuals with overweight and obesity and some of the common barriers to exercise they experience, HIIT programmes of this intensity may be difficult to adopt and maintain long-term. There may also be benefits to CRF observed when performing HIIT at lower intensities or for shorter durations.

Though HIIT is well-evidenced to increase CRF in individuals with overweight and obesity across a wide range of HIIT designs, intensities and durations, it is important to compare these adaptations to that of traditional aerobic exercise to determine if HIIT exhibits any superiority. Accordingly, the comparison of HIIT to moderate-intensity continuous exercise training (MICT) is common in the literature, which finds that HIIT improvements in CRF are often comparable to those attained from MICT (Tjonna et al., 2008; Martins et al., 2016; Gerosa-Neto et al., 2019). This is a conclusion echoed by Su et al. (2019), in a meta-analysis conducted in overweight and obesity, though the authors propose that superior CRF adaptations may be observed with HIIT intervals equal to or exceeding 2 minutes, or when EE-matched with MICT. However, each of these studies comparing HIIT to MICT in overweight and obesity are relatively low sample sizes, each employing such a wide variety of HIIT programmes and protocol designs that making a definitive conclusion is difficult. In order to provide a general comparison between HIIT and traditional forms of exercise in individuals with obesity Türk et al. (2017) completed a comprehensive systematic review and meta-analysis. Male and female participants with a BMI > 30 $kg{\cdot}m^2$ and aged 18 – 60 years were included. Though, there were no restrictions on PA level, therefore participants may not have been entirely sedentary. 11 studies were identified that compared HIIT to medium- or low-intensity continuous exercise, or a normal level of PA. However, no further specifications were provided on what a 'normal level of PA' or 'traditional exercise' may consist of. Indeed, in some studies the traditional exercise group performed thorough MICT programmes, such as 30 minutes cycling at 70-75% HR_{max} (Sawyer et al., 2016), whilst others compared HIIT to walking or cycling at 45-60% HRR (Roxburgh et al., 2014), or provided vague parameters such as 20 – 50 minutes continuous activity at 32.5% W_{peak} (Robinson et al., 2015) and ‘normal physical activity’ (Arad et al., 2015). Moreover, in the study by Roxburgh et al. (2014) the ‘HIIT’ group actually performed 4 of the MICT sessions and only 1 HIIT session per week.

These large methodological differences make the pooled comparison of mean differences between HIIT and ‘traditional exercise’ in a meta-analysis somewhat diluted, given that the authors provide no precise specification of what traditional exercise could be. Nonetheless, HIIT was demonstrated to be superior to traditional exercise for improvements in $\dot{V}O_{2max}$, with a significant effect in favour of HIIT (MD (95% CI) = 1.79 (0.21, 3.36), P = 0.03). The authors completed this meta-analysis on post-intervention mean difference rather than the change in mean, which may be inaccurate given that several of the studies presented with mismatched baseline values and elements of bias. The authors propose that even with these studies removed results did not change, but a meta-analysis of the change in mean difference between HIIT and traditional exercise would have been of interest to remove the bias of any baseline differences in CRF. As such, the results are far from conclusive. In further analysis, the duration, intensity and number of HIIT intervals were not associated with an increased $\dot{V}O_{2max}$. This tends to suggest that HIIT of any design was effective in increasing CRF.

A plethora of research demonstrates the ability of HIIT to exhibit superior increases in CRF to MICT in a range of populations including healthy and clinical participants (Helgerud et al., 2007; Rognmo et al., 2004). However, whilst it is clear HIIT can provide clear improvements in CRF in individuals with overweight and obesity which may be greater than those from MICT, that superiority is not yet extensively established in the literature. More large-scale research trials over longer periods are required in to elucidate this further, though research to date suggests HIIT is at minimum comparable to MICT for improvements in CRF in this population.

2.3.3. Other cardiometabolic factors

Acutely, exercise can instigate the contraction-mediated glucose uptake pathway, resulting in reduced hyperglycaemia and improved insulin sensitivity in the short-term. HIIT interventions have the capacity to increase protein content of GLUT4 (Little et al., 2011) and skeletal muscle oxidative capacity (Hood et al., 2011), which combine to generally improve glycaemic control and insulin sensitivity long-term. HIIT is also proposed to diminish hyperglycaemia via improved adipose and liver insulin sensitivity (Marcinko et al., 2015). Indeed, Jelleyman et al. (2015) report that in a meta-analysis of adults performing HIIT, HIIT was successful in reducing insulin resistance and Hb_{A1C} versus control. 11 weeks of HIIT cycling is also demonstrated to improve a number of measures related to glycaemic control and insulin resistance in T2DM patients, to a comparable or greater amount than MICT (Winding et al., 2018). Though, this was not an exclusive population living with overweight and obesity and the majority of participants were on glucose lowering medication, which acts as a confounding variable when assessing the magnitude of exercise-related benefit. In a recent systematic review, Campbell et al. (2019) report that adults living with overweight and obesity are more responsive than adults with normal weight to HIIT's effects on improving insulin sensitivity. This is most likely due to increased incidence of insulin resistance and metabolic dysregulation. The authors identified that HIIT protocols utilised in the literature varied wildly, with intensities ranging from 65% $\dot{V}O_{2max}$ to bouts of maximum effort, making comparisons difficult. However, under regression analysis, the characteristics of HIIT protocols (e.g., intensity, interval duration) did not predict changes in insulin resistance, perhaps suggesting HIIT of any form is beneficial. Conversely, one of the studies included (Batacan et al., 2017) was a systematic review itself, and found that HIIT only produced changes to a small effect in fasting glucose, and no significant changes in any other measure related to insulin sensitivity.

De Strijcker et al. (2018) demonstrate that HIIT is superior to MICT for improvements in insulin sensitivity and glucose tolerance. 16 individuals living with overweight and obesity were randomised into a HIIT group performing 15s cycling sprint bouts at 100% VT^1 resistance or a MICT group performing 30 minutes cycling at 100% HR at VT^1. Despite the slightly unconventional prescription of workload, this equated to intensities of ~86% HR_{peak} in the HIIT group. After 10 weeks, only HIIT significantly increased insulin sensitivity, insulin AUC and oral glucose tolerance test (OGTT) composite score. Muscle mitochondrial content also significantly increased with HIIT, perhaps suggesting that HIIT may be superior to MICT for improvements in glycaemic control and insulin sensitivity due to an increased skeletal muscle oxidative capacity, akin to conclusions drawn from researchers evaluating HIIT in a sedentary population (Hood et al., 2011). Asilah Za'don et al. (2019) also determined the effects of HIIT in overweight and obesity on insulin sensitivity via the homeostatic model assessment of insulin resistance (HOMA-IR). The

HOMA-IR is utilised to determine the relationship between glucose and insulin concentrations when fasted. In this study, 50 participants (22 – 29 years) were randomly assigned to HIIT or control, with the HIIT group exercising between intensities of 65-80% HR_{max} for 12 weeks, 3 days a week. Insulin sensitivity (HOMA-IR) increased 33% from baseline in the HIIT group. The authors also presented that the HIIT group increased expression of PGC1α and adiponectin receptor 1 (AdipoR1) three- and two-fold respectively. AdipoR1 is an upstream activator of AMPK, which in turn activates PGC1α to instigate mitochondrial biogenesis (Figure 2.1), which facilitates increased oxidative capacity in the skeletal muscle. These findings provide further evidence that improvements in glycaemic control and insulin sensitivity derive from increased skeletal muscle oxidative capacity and also support a rationale that there may be a superiority of HIIT over MICT due to greater intensity-related activation of AMPK.

This upregulation of PGC1α and subsequent increased mitochondrial content insinuates a greater capacity for fat oxidation. As discussed with regard to the effects of HIIT on adiposity, HIIT is suggested to provide increased exercise and post exercise fat oxidation rates (Boutcher, 2011). A greater capacity for fat oxidation, coupled with the action of AMPK to inhibit ACC (Figure 2.1), may help to reduce lipotoxicity in the skeletal muscle and improve insulin sensitivity and attenuate dyslipidaemia. The suggestion that HIIT can increase skeletal muscle oxidative capacity and AMPK activation to a greater extent than MICT posits that HIIT may provide superior changes in lipid profile. Accordingly, high-intensity exercise is observed to be preferable for improving lipid profile than lower intensities (Johnson et al., 2007; O’Donovan et al., 2005). With dyslipidaemia a concern in individuals with overweight and obesity, a trait of MetS and a CVD risk factor (Mora et al., 2007), improving lipid profile is an important physiological target of exercise training.

When comparing HIIT and MICT for lipid profile in a meta-analysis, Wood et al. (2019) demonstrate comparable changes between exercise types. There were no significant differences between-groups for changes in total cholesterol (TC), triglycerides (TG) and low-density lipoprotein cholesterol (LDL-C). However, HIIT was superior to MICT for improvements in high-density lipoprotein cholesterol (HDL-C). Though individuals with overweight and obesity were included in this meta-analysis, the review was completed on adults of any weight and no further sub-group analysis for overweight or obese was performed. Moreover, the authors’ loosely defined criterion for exercise protocols that constituted HIIT (60s – 8-minute intervals, > 70% HR_{max}) allowed for a broad range of protocols to be included, which may exist outside of typical HIIT designs (Laursen and

Buchheit, 2019). Likewise, many studies included did not ascertain changes in lipid profile as a primary outcome and thus exercise interventions were not designed with the aim of maximising lipid changes. Indeed, Wood et al. (2019) recommend that exercise of > 1200 kcals per week, at vigorous intensities, for > 8 weeks in duration are necessary for beneficial adaptations – an exercise prescription attained by few of the included studies. Though, previous research echoes the general conclusions that high-intensity exercise can frequently improve HDL-C, but no other markers of lipid profile (Tambalis et al., 2009), with a minimum of 8-weeks HIIT required for changes in HDL-C also previously suggested (Kessler et al., 2012).

These findings are generally mirrored in studies conducted solely in population with overweight and obesity, with the intensity and duration of HIIT an apparently key factor. Keating et al. (2014) report comparable changes in lipid profile between HIIT and MICT after 12 weeks training, but Fisher et al. (2015) suggest MICT to be superior after 6 weeks training. This reaffirms recommendations that HIIT protocols must be > 8 weeks (Wood et al., 2019; Kessler et al., 2012). Accordingly, Shepherd et al. (2015) find significant changes in HDL-C after 10 weeks HIIT, and non-significant reductions in TC, TG and LDL-C, with no changes between-groups against an MICT comparator. Moreover, Shepherd et al. (2015) and Keating et al. (2014) employ higher HIIT exercise intensities (> 90% HRmax and 120% $\dot{V}O_{2peak}$ respectively) than Fisher et al. (2015), 85% PPO, proposing both intensity and duration of exercise important to ensure favourable changes in lipid profile. Taken together, there seems no clear superiority of HIIT over MICT, apart from for changes in HDL-C, though interventions > 8 weeks are an apparent necessity to achieve changes in lipid profile comparable to those from MICT.

HIIT is also evidenced to provide favourable adaptations in the microvasculature, to the betterment of CRF, insulin sensitivity, muscle capillarisation and nitric oxide (NO) bioavailability (Cocks et al., 2016). This improved endothelial function promotes reductions in both systolic (Whyte et al., 2010) and diastolic (Schjevre et al., 2008) blood pressure, which is demonstrated to be comparable to MICT (Kessler et al., 2012).

Collectively, HIIT is well-evidenced to provide improvements in metabolic health in overweight and obesity, with several comprehensive systematic reviews concluding that HIIT is effective in improving cardiometabolic risk factors (Fisher et al., 2015; Batacan et al., 2017; Kessler et al., 2012), which is vital given the close relationship between obesity and the metabolic syndrome (Jung and Choi, 2014). Though these metabolic improvements largely appear only comparable to MICT, the nature of HIIT suggests these adaptations can be attained with a lower time commitment and HIIT may be a preferable exercise strategy for individuals with overweight and obesity as a result.

2.3.4. Enjoyment, Adherence and Adverse Effects

The adherence to and enjoyment of exercise may be closely linked. Indeed, a lack of enjoyment is a key barrier to adherence of lifestyle interventions in adults with obesity (Burgess et al., 2017) and is required for long-term adherence to exercise (Aaltonen et al., 2012). For individuals with obesity, strong predictors of enjoyment include early weight loss, lower baseline BMI and increased baseline mood (Burgess et al., 2017). Specifically, in HIIT, perceived tolerance of exercise also predicts engagement (Bradley et al., 2019). The perception of exercise is influenced by the core affective response, which Ekkekakis (2003) proposes is positive when exercising below VT^1 and negative when exercising above VT^1 in what is established as the 'Dual-Mode Theory'. As HIIT consists of exercise above VT^1 (Laursen and Buchheit, 2019), it is logical to assume that HIIT should provide more negative affective responses than MICT, which could decrease enjoyment and adherence. Accordingly, researchers propose that HIIT is not tolerable or viable for the general public (Biddle and Batterham, 2015; Roy et al., 2018). This response may be exacerbated in obesity as it has been proposed that obesity reacts with intensity of exercise, causing PA to be associated with displeasure, leading to avoidance (Ekkekakis et al., 2016).

Accordingly, some HIIT research reports that enjoyment is low and affective responses are negative. Roloff et al. (2020) propose that HIIT is deemed unpleasant and it limits its public health relevance, with affect closely tracking O_2 uptake, and ratings of affect (via the feeling scale) decreased in HIIT. However, other research suggests that HIIT can have a number of positive influences, including in affective valence, increasing cognitive and mental health (Costigan et al., 2016), increasing satisfaction, enjoyment and perceived value (Eather et al., 2019) and providing generally positive affective responses versus MICT in normal weight and overweight or individuals with obesity (Oliviera et al., 2018). Though, Foster et al. (2015) identify that there are few studies that measure enjoyment beyond 2 weeks, and that enjoyment of HIIT decreases over 8-weeks in university students. On the contrary, Vella et al. (2017) find the adherence and enjoyment of HIIT is comparable to MICT, with the high rates of adherence in this study (HIIT: 93.4%, MICT: 93.1%) perhaps attributed to the lower intensities of exercise and use of both gym-based and outdoor settings. Other research has reported HIIT superior for enjoyment versus MICT after a 5-week intervention in young women with obesity (Kong et al., 2016). Similarly, Thum et al. (2017) demonstrate higher enjoyment in response to HIIT versus MICT and that 92% of participants prefer HIIT, despite lower affective responses. The authors conclude that although HIIT may be more physically demanding, it is more enjoyable due to its time efficiency and constantly changing stimulus. This is echoed by Shepherd et al. (2015) who demonstrate increased time efficiency with HIIT versus MICT that subsequently leads to a greater adherence to exercise (83 ± 14% versus 61 ± 15%) after a 10-week intervention in a real-world gym setting. In a recent comprehensive systematic review and meta-analysis, Niven et al. (2020) evaluated 33 studies and determined that arousal and enjoyment levels were consistently higher after HIIT versus MICT, and although HIIT may be experienced less positively during exercise, it is considered more enjoyable post-exercise.

HIIT has been proposed to increase the risk of certain injuries and adverse events from exercise, though research in high-risk groups, such as those undergoing cardiac rehabilitation, finds HIIT to be as safe as MICT (Guiraud et al., 2012). Other research which provides evidence for the efficacy and safety of HIIT in sedentary and clinical populations (Hood et al., 2011; Little et al., 2011) employ 10 x 60s HIIT designs, with sub-maximal intensities and periods of passive recovery. Systematic reviews of HIIT in obesity determine that few studies report the occurrence of adverse events (Türk et al., 2017; Wewege et al., 2017). Wewege et al. (2017) report that from four running modality studies (N = 129) 13% of participants (HIIT = 8; MICT = 9) report adverse events, as well as one participant from one cycling study. These adverse events were not acute injuries from exercise, but due to chronic flare-ups or intolerances. Similarly, Türk et al. (2017) report that only 3 studies from their review reported adverse events. Lunt et al. (2014) found 3 injuries in their maximal volitional interval training group, but none in lower intensity groups. Whereas Nicklas et al. (2009) report one adverse event during vigorous-intensity and four during MICT. Similarly, Keating et al. (2015) provided evidence of one syncopal episode each in high- and low-intensity groups. Therefore, there is insufficient evidence to provide insight into comparing intensity and modality of exercise for the regularity of adverse events and reporting these must be a focus of future research in HIIT and obesity. Nevertheless, from studies which do report this, HIIT appears generally safe and feasible, with adverse events perhaps attributed to pre-existing injuries or conditions.

2.3.5. Summary of HIIT for Overweight and Obesity

HIIT provides improvements in body composition, CRF and metabolic health in overweight and obesity, though these adaptations are not unanimous, typically require training durations > 12 weeks and are largely comparable to MICT. However, due to increased time-efficiency and post-exercise enjoyment compared to MICT, HIIT appears a superior exercise strategy. Future research is required to further elucidate the effects of HIIT in overweight and obesity, particularly given the wide variety of findings presented in the literature, especially regarding the durations of exercise required to promote positive health outcomes.

2.4. The Addition of Resistance-Based Exercise

Concurrent Exercise Training (CT) programmes provide the additional benefit of resistance-type exercises to those which are cardiovascular-based (such as HIIT). Resistance Exercise Training (RT) provides a number of physiological adaptations which cannot be sought from HIIT alone, particularly to the betterment of obesity-related health factors.

2.4.1. Body composition

RT is proposed to improve body composition primarily through increased skeletal muscle mass (Bodine, 2006; Yan et al., 2019) and protein turnover rate (Evans, 2001), leading to increased resting metabolic rate (Westcott, 2012) and fat free mass, as well as decreased fat mass (Church, 2011; Donnelly et al., 2009). Whilst the relative energy expenditure of RT is low compared to other exercise modalities, post-exercise effects may lead to increases in energy expenditure (Melby et al., 1993). This has led to the inclusion of RT in exercise guidelines for weight loss and the prevention of weight gain in the general population (Donnelly et al., 2009). Although RT alongside a dietary intervention is effective for weight loss in men with obesity (Rice et al., 1999), randomised control trials suggest that RT alone may not be sufficient for weight loss. Indeed, Olson et al. (2007) report no change in body or fat mass after one year of RT in 16 overweight women, despite significant improvements in lean body mass. These conclusions led Willis et al. (2012) to compare body composition changes after an 8-month RT or AT intervention in overweight and adults with obesity. Whilst AT provided significant reductions in body mass and fat mass, participants in the RT group significantly *increased* body mass and presented with trivial decreases in fat mass. Accordingly, previous research provides evidence to support the notion that RT does not reduce body mass (Broeder et al., 1992; Prabhakaran et al., 1999). This appears to be driven by the ability of RT to increase lean body mass (Tresierras and Balady, 2009; Willis et al, 2012) and suggests that some favourable adaptations from RT may in fact cause increases in body mass, thus, body mass loss may not be the most pertinent measure to focus on as a result. Nonetheless, many favourable adaptations can be attained independent of weight loss, with strong evidence to suggest that RT can effectively increase lean body mass, resting metabolic rate, and mobilise visceral and subcutaneous adipose tissue from the abdominal region (Johnson et al., 2009; Strasser and Schobersberger, 2011; Tresierras and Balady, 2009).

RT is also proposed to reduce total body fat via increased resting metabolic rate, fat oxidation and free-living PA (Donnelly et al., 2009; Phillips and Winett, 2010; Westcott, 2012). As such, Schmitz et al. (2003) report that twice-weekly RT of nine exercises for 39 weeks results in significant fat loss (-0.98 kg, -1.63%) in women with an initial BMI of 20-35 $kg \cdot m^2$. When extending the same RT programme to a two-year period Schmitz et al. (2007) report reductions of fat mass -0.14 ± 1.04 kg and -3.68 ± 0.99%, which do not demonstrate a clear capacity to improve body compositions. In agreement, RT interventions exceeding one year in duration, propose trivial changes in fat mass (Olson et al., 2007; Schjerve et al., 2008; Willis et al., 2012). It appears that although RT may provide reductions in body fat for some individuals, this is not conclusive and is certainly inferior to AT. The primary adaptations to body composition from RT are increases in lean body mass, resting metabolic rate and mobilisation of abdominal fat.

2.4.2. Muscular Strength

RT is well-evidenced to increase skeletal muscle mass, but this may not necessarily translate to increases in muscular contractile force (strength) per se. Muscular strength may be a vital adaptation in overweight and obesity to reduce risk of mortality and improve health-related quality of life (Kell et al., 2001). RT in previously sedentary individuals can significantly increase muscular strength (Treuth et al., 1994) as well as in obesity. Ross et al. (1996) conducted a 16-week RT programme in 11 men with obesity, who completed 8 RT exercises 3 days per week. Upper body strength increased 12% and lower body strength 20%. However, actual changes may have been much greater, with strength only assessed between weeks 4 and 16, in order to solely observe strength improvements as a result of skeletal muscle mass, rather than neuromuscular factors that could play a role in early strength improvements. Sarsan et al. (2006) constructed an RT programme that progressed from 1 to 3 sets per exercise and from 40-60% to 75-80% 1RM. Regardless of the mechanism responsible, be it neuromuscular factors, increased skeletal muscle mass or an amalgamation of both, simple progressive RT programmes appear successful in making noteworthy increases in muscular strength.

Though increasing strength and muscle mass are often discussed in the context of aging; preventing or ameliorating sarcopenia and dynapenia, it is also vital to combat sarcopenic obesity. Sarcopenic obesity is a confluence of both phenotypes and a chronic issue as aging individuals with obesity become weaker whilst needing to carry increased weight (Launer et al., 1994; Roubenoff, 2004). Both conditions appear inexorably linked, with common origins of sedentarism. Both also appear to exacerbate the other, with reduced skeletal muscle mass linked to insulin resistance and the development of MetS and obesity and increased fat mass associated with increased adipokines and a subsequent catabolic effect on muscle (Reaven, 1993; Roubenoff, 2004, 2000). Long-term studies are required to examine the effects of RT programmes and the preventative or protective effects over sarcopenic obesity.

2.4.3. Other cardiometabolic health factors

An increased skeletal muscle mass is associated with a reduction in metabolic risk factors (Williams et al., 2007). This may be logical, given that skeletal muscle is the primary site for glucose and triacylglycerol disposal, which should ensure an improvement in glycaemic control and dyslipidaemia with increased content as a result of RT. The importance and potency of RT to improve metabolic health is observed after just a single session, with insulin sensitivity increased for at least 24 hours in healthy men (Koopman et al., 2005). A systematic review of RT programmes conducted by Tresierras and Balady (2009) provides evidence that RT has a positive effect on glucose metabolism, with reports of reduced fasting plasma insulin (Miller et al., 1994), increased glucose disposal (Ishii et al., 1998; Zachwieja et al., 1996), and reduced Hb_{A1C} (Durak et al., 1990). These improvements appear to be driven by the capacity of RT to increase GLUT4 protein content (Derave et al., 2003; Holten et al., 2004; Tabata et al., 1999), which can be achieved through low to moderate intensity and low volume RT protocols in short time periods, suggesting a feasible exercise strategy for untrained, sedentary individuals with overweight and obesity (Tresierras and Balady, 2009). Though low-volume and intensity RT may be effective, there does appear to be a dose-response relationship between volume and intensity of RT for improvements in insulin sensitivity and fasting blood glucose in a crossover-design study of acute RT protocols (Black et al., 2010).

Though RT and the immediate actions of mTORC1 may favour lipid synthesis over metabolism, the chronic effects of upregulated PGC1α increases mitochondrial content in the skeletal muscle **(Figure 2.2)**. This proposes that RT may have the capacity to increase substrate oxidation. Indeed, 6 months of just 9 set (~11 mins) RT sessions in sedentary and overweight young adults significantly increases 24-hour energy expenditure and respiratory quotient (RQ) (Kirk et al., 2009). Though actual fat oxidation (g/day) was not significantly increased, the RT group found a 1.3% increase versus a 12.9% decrease in a non-exercising control group. Despite promising results from a low volume of exercise, the authors suggest that a larger sample and greater volume would exhibit greater increases in fat oxidation. The beneficial effects of RT may also encompass the general lipid profile, which becomes detrimentally altered in obesity-induced MetS (Lumeng and Saltiel, 2011). Lira et al. (2010) report that high-volume low- to moderate-intensity RT results in the greatest benefits to the lipid profile and Fett et al. (2009) present significant reductions in total cholesterol for women with overweight and obesity after 3-4 times weekly RT circuit training 60 minutes in duration, positing a vital role for high-volume of RT. As such, reviews in the published literature suggest that RT is effective in improving lipid profile and that, in particular, increased volume of sets and repetitions of RT is the most important for lipid profile improvements (Mann et al., 2014; Strasser and Schobersberger, 2011). Mann et al. also provide exercise recommendations of moderate- to high-intensity RT at 75-85% 1RM to reduce LDL and total cholesterol and to increase HDL cholesterol. Though the mechanisms by which RT can favourably alter lipid profile have not currently been elucidated, leading hypotheses speculate an increase in the exchange of cholesterol ester between tissues and lipoproteins to HDL, thus decreasing total cholesterol (Lira et al., 2010; Mann et al., 2014; Ohashi et al., 2005).

If RT can increase mitochondrial content and subsequently substrate oxidation, there appears a logical link to an increased oxidative capacity and CRF. Accordingly, research in healthy individuals demonstrates that 8 weeks of heavy RT significantly increased both fat oxidation and $\dot{V}O_{2peak}$(Alvehus et al., 2014). RT appears to mainly alter CRF in individuals with lower baseline fitness, with thresholds of < 25 $ml \cdot kg^{-1}min^{-1}$ for > 60 years and < 40 $ml \cdot kg^{-1}min^{-1}$ 20-40 years suggested (Ozaki et al., 2013). Given the sedentary nature and low functional capacity of individuals with overweight and obesity, RT should be an effective means of increasing CRF. Indeed, previously sedentary females with obesity have been reported to increase $\dot{V}O_{2max}$ 0.42 L·min^{-1} (18.5%) after 12 weeks of RT, similar to improvements in an AT-only group (0.51 L·min^{-1}, 21.4%) (Sarsan et al., 2006).

2.4.4. Enjoyment, Adherence and Adverse Effects

The enjoyment and adherence to RT is greatly under-researched in comparison to HIIT (Greene and Petruzzello, 2015), particularly in overweight and obesity. Nonetheless, RT is demonstrated to decrease anxiety (Arent et al., 2005) and have similar effects to AT with in-task affect closely related with enjoyment (Greene and Petruzzello, 2015). Though, after 12-weeks exercise training in women with obesity, AT is demonstrated to lower depression score to a much greater extent (-44.3%) than RT (-22.6%), though both decrease significantly from baseline and control (Sarsan et al., 2006). In the same manner as HIIT, the constantly changing stimulus of RT exercises may provide greater enjoyment, though measures of this, including comparisons to modalities such as HIIT in overweight and obesity are required in the literature.

Though the safety of RT programmes, namely rate of attrition and injury, is a highly researched area in relation to paediatric obesity (Faigenbaum et al., 2009; Faigenbaum and Myer, 2010; Sothern et al., 2000) this is not mirrored in adults. However, in a review on RT use in obesity and T2DM Hills et al. (2010) propose that due to a lower functional capacity required to commence RT, this should be a fundamental part of any weight loss programme and may promote a lower rate of attrition. Most research suggests that RT is generally safe, though this is often demonstrated in low-risk individuals (McCartney, 1999). Indeed, concerns have been raised around individuals with hypertension and CVD completing RT which often occur as a consequence of obesity. However, modifying the intensity, duration and techniques utilised during RT can ameliorate adverse effects and render RT generally safe even in high-risk clinical populations (Williams et al., 2007).

2.4.5. Summary of RT in Overweight and Obesity

RT is generally safe and feasible in this population and increases skeletal muscle mass, with ample evidence to reflect this. As a result of an increased skeletal muscle mass several health-related improvements including increased resting metabolic rate, mobilisation of abdominal fat, insulin sensitivity and improved lipid profile are observed. Muscular strength is also increased after RT programmes in this population, protecting against sarcopenic obesity, prolonging health-related quality of life and improving bone health. As such, RT appears key to improving obesity-related health, though an exact prescription of the most suitable modality, duration and frequency of RT is not clear.

2.5. Combined HIIT and RT

With HIIT demonstrated to match or better the adaptations achieved through MICT or AT, and RT to provide myriad additional benefits over HIIT-alone, a novel concept to maximise time-efficiency and physiological adaptation is to replace the cardiovascular element of CT with HIIT. Although a relatively new research area, current evidence suggests that concurrent HIIT and RT may also reduce the impact of the interference effect and provide greater physiological adaptations than traditional CT (Tremmel et al., 2017)(Dutheil et al., 2013; Methenitis, 2018; Petré et al., 2018). Though higher intensities of exercise are regularly reported to be the most beneficial in increasing aerobic adaptations (Petré et al., 2018; Sousa et al., 2019) it was initially believed that high-intensity exercise may attenuate anabolic responses in the body (Fyfe et al., 2014) by increasing glycogen depletion and fatigue, compromising muscle regeneration and training adaptations (Egan and Zierath, 2013). In order to determine the feasibility and effectiveness of combined HIIT and RT as well as explore the role of CT in overweight and obesity, a systematic review of the available literature must be undertaken in order to assess the current knowledgebase.

Chapter 3.0. Same-Session Concurrent Exercise Training in Overweight and Obesity: A Systematic Review and Meta-Analysis.

The previous chapter highlighted the wealth of HIIT and RT interventions employed in the literature and their respective abilities to improve a number of factors relating to cardiometabolic health. This chapter aims to synthesise the current evidence-base of exercise interventions performing combined concurrent exercise training interventions, including an examination of the modalities undertaken and the effects of these interventions on cardiometabolic health.

3.1. Introduction

A multifaceted web of influences cause overweight and obesity, though inherently, sedentary lifestyle contributes to the incidence and accompanying co-morbidities (Manson et al., 2004; Wilmot et al., 2012). The World Health Organisation (WHO) report that the prevalence of obesity has almost tripled since 1975 (WHO, 2021). Indeed, most recent estimates suggest that 64% of all adults in England are overweight (body mass index [BMI] = 25.0 – 29.9 kg·m^2) or obese (BMI ≥ 30.0 kg·m^2) (Health Survey for England, 2017) with the overweight category being the largest sub-cohort. It is well established that obesity increases the risk of many comorbidities including coronary heart disease (CHD), type 2 diabetes mellitus and certain types of cancer, contributing to a substantial economic cost to society (WHO, 2000; Tremmel et al., 2017). Therefore, developing low-cost efficacious solutions for both prevention and treatment has become of paramount importance.

It has been well established that exercise and physical activity (PA) improves a number of the deleterious facets associated with obesity, including adiposity, inflammation, and several other comorbidities (Bouchard et al., 1993; Church, 2011; Shaw et al., 2006; Okay et al., 2009). Particularly, exercise is associated with reduced risk of cardiovascular disease (CVD) and type 2 diabetes mellitus (Gill and Cooper, 2008; Nocon et al., 2008). Exercise is additionally important in overweight and obesity in order to improve overall health outcomes (Celis-Morales et al., 2017; Gill and Cooper, 2008), with increased PA associated with reduced risk for CVD, T2DM and all-cause mortality in obesity (Petridour et al., 2019).

Most notably, exercise prompts favourable changes in cardiorespiratory fitness (CRF), quantified via measurement of one's peak oxygen uptake ($\dot{V}O_{2peak}$), or maximal oxygen uptake ($\dot{V}O_{2max}$), and improved body composition in the overweight and obese phenotype. Furthermore, improvements in $\dot{V}O_{2peak}$ per se result in reductions in all-cause mortality (Harber et al., 2017). Therefore, PA and exercise interventions provide a potent stimulus for evoking a variety of protective and indeed preventative effects on a plethora of diseases and comorbidities associated with sedentary behaviour and obesity. Consequently, current exercise guidelines for adults propose that 150 minutes of moderate intensity exercise (e.g. walking briskly) or 75 minutes of vigorous intensity exercise (e.g. running) is completed per week, as well as strength-based exercise twice per week (ACSM, 2013; Piercy et al., 2018). Strength-based exercises, in the form of resistance training (RT) are beneficial for overweight and obesity, often evoking similar effects as aerobic based training interventions glycaemic control (Ahmadizad et al., 2007; Strasser and Schobersberger, 2011). Furthermore, RT increases both muscle and bone mass. RT increases fractional protein synthesis rates through the activation of mammalian target of rapamycin complex-1 (mTORC1) and its downstream effects, leading to increased skeletal muscle mass (Bodine et al., 2001). Skeletal muscle is a highly important active metabolic tissue, accounting for ~80% of insulin-stimulated glucose uptake (DeFronzo et al., 1981), and is therefore critical for glycaemic control. The capacity of RT to provide a significant mechanical stimuli to bone also establishes an increased bone mineral density (BMD) and decreased risk factors for osteoporosis (Layne and Nelson, 1999).

Despite the plethora of benefits of regular exercise, few individuals achieve the recommended minimum guideline, with estimates suggesting only 66% of adults in England are considered active (NHS, 2019). A commonly referenced barrier to participation is ‘lack of time’ (Trost et al., 2002). However, there is likely a complex interplay between a myriad of factors including poor functional capacity and a lack of motivation (McIntosh et al., 2016) to engage in such interventions. Subsequently, more time-efficient exercise modalities such as high-intensity interval training (HIIT) have been proposed. HIIT is characterised by bouts of high-intensity exercise interspersed with periods of low-intensity exercise or rest (Gibala et al., 2012) resulting in higher volumes of work being completed with lower overall durations. Evidence (Hood et al., 2011; Little et al., 2011; Gibala et al., 2012) for the utility and efficacy of HIIT for various populations including obese and sedentary (Little et al., 2014) is compelling. Moreover, there is evidence to suggest such interventions are more enjoyable than regular moderate intensity continuous training (MICT), despite higher physical demands (Thum et al., 2017), though evidence also exists to the contrary (Jung et al., 2014). Furthermore, HIIT may even surpass traditional aerobic exercise for inducing certain metabolic adaptations (Gibala et al., 2012), via greater stimulation for the metabolic master switch 5’ adenosine monophosphate activated protein kinase (AMPK) which controls many physiological processes including glycaemic control, lipid metabolism, mitochondrial biogenesis and protein synthesis (Egan et al., 2016; Liu and Chang, 2018). Indeed, HIIT has recently been acknowledged as an effective form of exercise for the general population in the latest exercise guidelines for the US (Piercy et al., 2018), as well as in the latest UK chief medical officers' report on PA (UK Chief Medical Officers, 2019).

However, HIIT-based training focuses largely on improving CRF, therefore, the addition of RT should also be considered. Concurrent training (CT) programmes aim to overcome time constraints by combining the benefits of both aerobic training (AT) and RT in a single session, increasing time efficiency. CT has been utilised in athletic populations (Wilson et al., 2012), and in some clinical (Libardi et al., 2012) and sub-clinical populations (Álvarez et al., 2019). The aerobic element traditionally takes the form of more continuous moderate- to high-intensity forms of exercise combined with RT. CT is evidenced to provide comparable strength adaptations to RT (Wood et al., 2001) and similar improvements to AT for CRF (Wilson et al., 2012), body composition and metabolic profile (Monteiro et al., 2015). In individuals with obesity, CT of both 3- and 5-days per week is effective in reducing body mass, BMI and body fat (Medeiros et al., 2015). A potential limitation of CT is evidence of an 'interference effect' wherein metabolic adaptations to RT are compromised by endurance exercise (Wilson et al., 2012). A wealth of studies demonstrate this effect, with compromised gains in hypertrophy and strength in CT compared to RT (Jones et al., 2013; Kraemer et al., 1995; Rønnestad et al., 2012), which appears to act in a duration- and frequency-dependant manner, with the mode of exercise also having an effect (Wilson et al., 2012). However, much of this research has been conducted in recreational athletes (Wilson et al., 2012) and contradictory evidence is also reported (McCarthy et al., 2002; Murach and Bagley, 2016). Ultimately, the interference effect may be more individualised, with some individuals presenting with large strength gains and some large strength losses (Karavirta et al., 2011).

Nonetheless a novel approach to CT is to include HIIT and RT rather than continuous forms of exercise, with the intention of further increasing time efficiency, and ultimately improving exercise participation. Concurrent HIIT and RT is also proposed to attenuate some of the interference effect with strength adaptations (Methenitis, 2018; Pugh et al., 2018; Sabag et al., 2018). However research on concurrent HIIT and RT is mainly undertaken in trained populations and focuses on improvements in sports performance (Methenitis, 2018; Sabag et al., 2018) or in elderly populations (Müller et al., 2021), with research in untrained populations also centred on reversing the interference effect (Gentil et al., 2017) rather than obesity-related health outcomes. A previous systematic review and meta-analysis comparing AT, RT and CT in population with overweight and obesity s found CT more beneficial for improvements in body composition compared to RT (Schwingshackl et al., 2013). However, this meta-analysis included participants with the metabolic syndrome, as well as some older adults, which may have acted as confounding variables. More recently, CT has been established to be effective in improving measures of body composition in a meta-analysis on paediatric obesity (Garcia-Hermoso et al., 2019). Therefore, the aim of this systematic review was to update the current knowledge base on otherwise healthy overweight and adults with obesity performing same-session concurrent HIIT/AT and RT to improve cardiometabolic health outcomes, namely body composition and CRF.

3.2. Methods

This review was preliminarily recorded on the International Prospective Register of Systematic Reviews (PROSPERO) as CRD42019139853 and was undertaken in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher et al., 2009; Page et al., 2021). Five databases were searched electronically (PubMed, CINAHL, SPORTDiscus, MedLine, and Web of Science) from January 1980 to May 2019, with a later updated search to October 2022. Independent variables included 'concurrent training' 'multi-component exercise' 'multi-modal exercise' and 'same-session training' as well as dependant variables such as 'strength training' 'HIIT' 'aerobic exercise' 'continuous exercise' or 'control'. An information scientist was consulted on the full search strategy, with this and all search terms and initial hits available at **Appendix M**. Reference lists were manually searched and individual hand searches were also conducted for eligible studies.

3.2.1. Inclusion Criteria

Only full-text studies available in English with a randomised or non-randomised control design were included. Participants were sedentary male and female adults (18 - 66 years) classified as overweight or obese (BMI ≥ 25 $kg{\cdot}m^2$). Studies were excluded if participants presented with comorbidities (such as the metabolic syndrome or type 2 diabetes mellitus) in order to sample an overweight and obese but otherwise healthy population.

3.2.2. Exercise Intervention

Studies which included same-session CT, with clearly specified exercise workloads, ≥ 2 weeks in length and ≥ 2 days per week were included. CT was defined as that which consisted of same-session separate cardiovascular and strength-based exercises. HIIT was included as a form of cardiovascular training – strength based HIIT was not included. Studies were required to include comparator groups of one of the following; 1) non-exercising control 2) HIIT- or AT-only 3) RT-only.

3.2.4. Outcome Measures

Studies were required to have assessed at least one of the following primary outcome measures pre- and post-intervention: 1) body composition via body mass (kg), body fat percentage (BF%) or waist circumference (WC) for inclusion in meta-analysis or 2) CRF via $\dot{V}O_{2peak}$ or $\dot{V}O_{2max}$. Pre to post-intervention changes in the following secondary outcome measures were also of interest if included: strength, insulin sensitivity, glycaemic control, fat free mass and adherence to exercise, though these parameters were not used for the meta-analysis.

3.2.5. Screening and data extraction

All studies identified from the search strategy were added to a database and independently screened and assessed for eligibility against the inclusion criteria. Articles that were duplicated or deemed irrelevant based on the title and abstract were removed, and the full texts of 73 articles **(Figure 3.1)** were obtained to determine suitability of inclusion, which were verified by the PhD supervisors. Participant characteristics were extracted from each study including sex, age, body mass, BMI, BF%, WC and baseline $\dot{V}O_{2peak}$. Pre-and post-intervention group means, standard deviations and sample sizes were taken for primary and secondary outcome measures, with this data used for the meta-analysis of primary outcome measures. In addition to the meta-analysis, the average per cent change (Δ %) and mean improvement were calculated.

3.2.6. Data analysis

All meta-analysis was conducted using Review Manager (RevMan) V.5.3 (Nordic Cochrane Centre, Copenhagen, Denmark) with figures recreated in GraphPad Prism 8 (GraphPad Software Inc., California, USA). The meta-analysis was conducted on the mean differences from pre- to post-intervention in both the CT and control groups, rather than the relative effect sizes. Separate random-effects analyses were conducted for each primary outcome measure if there were results from ≥ 4 studies. The overall effect (Z), 95% confidence intervals (CI) and significance values (p) were reported. Heterogeneity was assessed through the I^2 statistic. Publication bias and meta-regression analysis would only be employed with a sufficient number ($n \geq 10$) of studies (Higgins and Green, 2011).

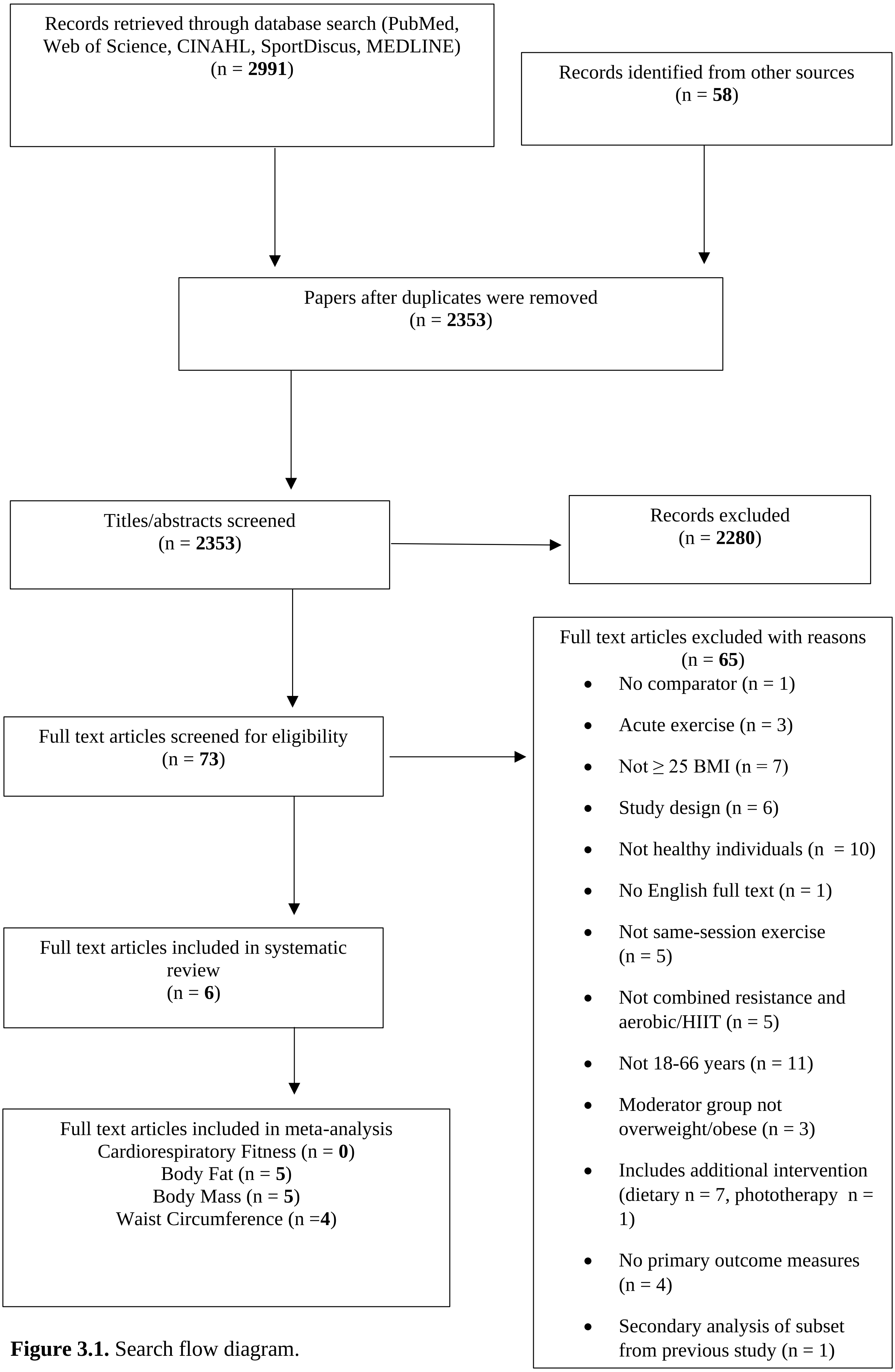

Figure 3.1. Search flow diagram.

3.2.7. Methodological Quality

The methodological quality of the included studies was assessed using the 15-point tool for the assessment of study quality and reporting in exercise (TESTEX – Smart et al., 2015). The TESTEX was developed specifically for exercise interventions and includes criteria of adherence and exercise programme characteristics not evaluated in other tools such as the physiotherapy evidence database (PEDro) scale (Smart et al., 2015).

3.3. Results

Six studies were included at the conclusion of full-text screening (Atashak et al., 2016; Brunelli et al., 2015; Donges et al., 2013; Duft et al., 2017; Ho et al., 2012; Ramirez-Velez et al., 2020) with 234 total participants analysed. All but one study (Ramirez-Velez et al., 2020) included a non-exercise control group and two studies (Donges et al., 2013; Ho et al., 2012) included additional AT- and RT-only groups. The CT element in five studies consisted of same-session concurrent AT and RT. Only one study (Ramirez-Velez et al., 2020) was identified that utilised HIIT as the cardiovascular component. The mean TESTEX score of the studies was 8.2/15, with an average of 2.3/5 for study quality and 5.8/10 for study reporting **(Appendix L)**. Study design, exercise interventions and modality of training are detailed in **Table 3.1**.

The influence of diet was controlled for by three studies (Brunelli et al., 2015; Duft et al., 2017; Ho et al., 2012) by calculating 3-day nutritional intake via self-reported diet diaries pre- and post-intervention. There were no significant changes in dietary intake. Donges et al. (2013) instructed participants to maintain their normal diets throughout the intervention but did not monitor this and Atashak et al. (2015) offered no dietary control. All studies completed fully supervised exercise sessions apart from Ho et al. (2012) who completed three supervised and two home-based exercise sessions per week. All studies stated that adherence to exercise sessions was > 85% for all participants included in final analysis apart from Ho et al. (2012), who presented adherence of 67-74%. Results for primary and secondary outcome measures across all groups in each study are outlined in **Table 3.2**. Meta-analysis of the variables are presented in **Figure 3.2**.

Table 3.1. Study characteristics

Study	Groups	*n* (F)	Exercise Intervention	Frequency	Measures
Ho et al., 2012	CT	17 (14)	50% AT, 50% RT	5 days p/w 12 weeks	$\dot{V}O_{2peak}$ (AR), BM, BF% (DXA), WC
	AT	15 (12)	Treadmill walk/run at 60% HRR ± 10 beats (30 mins).		
	RT	16 (13)	4 x 8-12 reps of 5 exercises at 10RM. 30s on 1min rest. (30 mins). Supervised: lower body (LP, LE, LC), upper body (BP, RD). Unsupervised: lower body (LL, CR), upper body (BC, DR, TE).		
	CON	16 (13)	None	12 weeks	
Donges et al., 2013	CT	13 (0)	50% AT, 50% RT	3 days p/w 12 weeks	BM, BF% (DXA)
	AT	13 (0)	Mixed cycling and elliptical cross training. Weeks 1-4; 40min 75% HRM, 4-8; 50min 80% HRM, weeks 8-12; 60min 80% HRM.		
	RT	13 (0)	9 exercises. 3 x 10 at 75% 1RM. 4 x 8 at 80% 1RM for weeks 5-12. Exercises: upper body (BP, SP, SR, LDP), lower body (LP, LC, LL, Sq.).		
	CON	8 (0)	None	12 weeks	
Brunelli et al., 2015	CT	17 (0)	AT: Outdoor walking/running, weeks 1-8: 50-85%VO2peak (30 mins), weeks 8-24: duration maintained, time at higher intensity increased. RT: weeks 1-8: 6 exercises 3 x 10RM. 1min rest between sets. (30 mins). Weeks 8-24: 6 exercise 3 x 8RM. 90s between sets to 3 x 6RM. Exercises: upper body (BP, LDP, BC), lower body (LP, LE, LC).	3 days p/w 24 weeks	$\dot{V}O_{2peak}$ (GXT), BM, BF% (SF), WC
	CON	13 (0)	None	24 weeks	
Atashak et al., 2016	CT	15 (0)	AT: Interchanged walking and running (20mins) between 55-85% MHR. RT: 3 x 10-12 reps at 50-85% 1RM 90s recovery between sets. Training started at 50% HRM/1RM and progressed 5% p/w to 85%. RT exercises not reported.	3 days p/w 8 weeks	BM, BF% (SF), WC
	CON	15 (0)	none	8 weeks	
Duft et al., 2017	CT	11 (0)	AT: 30 min walking/running, 55-85% VO2peak. RT: weeks 1-8: 6 exercises, 3 x 10RM, 1min rest between sets (30 mins), weeks 8-16: increased to 8RM, 90s rest, weeks 16-24: 6RM, 90s rest. Exercises: upper body (BP, LDP, BC), lower body (LP, LE, LC).	3 days p/w 24 weeks	$\dot{V}O_{2peak}$ (GXT), BM, BF% (SF), WC
	CON	11 (0)	None	24 weeks	
Ramírez-Vélez et al., 2020	CT	15	50% HIIT (200 – 250 kcal EE), 50% RT (200 – 250 kcal EE) total 400 – 500 kcal EE	3 days p/w 12 weeks	$\dot{V}O_{2peak}$ (GXT), BF% (BI), WC
	HIIT	14	4 x 4 min intervals at 85-95% HRmax with 4 min active recovery at 65% HRmax (400 – 500 kcal EE), 40 mins.		
	RT	12	6 exercises of 12 – 15 reps for major muscle groups at 50 – 70% 1RM (400 – 500 kcal EE), 30 – 40 mins.		
	CON	6 (0)	None.		

Abbr. *AR; Astrand-Rhyming test, AT; aerobic training, BC; bicep curls, BF%; body fat percentage, BI; bioelectrical impedance, BM; body mass, BP; bench press, CON; control, CR; calf raises, CT; concurrent training, DR; dumbbell raises, DXA; dual energy x-ray absorptiometry, GXT; graded exercise test, HRM; heart rate max, HRR; heart rate reserve, p/w; per week, LC; leg curls, LDP; latissimus dorsi pulldown LE; leg extensions, LL; leg lunges, LP; leg press, M/F; male/female, Min; minute, p/w; per week, RD; rear deltoid row, RM; repetition max, RT; resistance training, SF; Skinfold, SP; shoulder press, SR; seated row, Sq.; squat, TE; triceps extension, WC; waist circumference.*

Table 3.2. Results for primary outcome measures.

Author	Group		$\dot{V}O_{2peak}$		Body Mass		Body Fat		Waist Circumference	
			ml·kg^{-1}·min^{-1}	Δ	kg	Δ	%	Δ	cm	Δ
Ho et al., 2012	CT	Pre Post	26.5 ± 1.3 28.2 ± 0.8	**↑Δ 6.4%***	90.0 ± 4.0 88.4 ± 3.6	**↓Δ 1.7%***	45.8 ± 1.6 44.8 ± 1.8	**↓Δ 2.2%***	102.2 ± 3.2 99.6 ± 3.0	**↓Δ 2.5%***
	AT	Pre Post	24.8 ± 1.1 26.2 ± 0.9	**↑Δ 5.7%**	91.9 ± 4.1 91.0 ± 4.0	**↓Δ 1.0%**	44.6 ± 1.9 44.1 ± 1.8	**↓Δ 1.1%**	100.3 ± 3.6 99.1 ± 3.6	**↓Δ 1.2%**
	RT	Pre Post	24.8 ± 1.8 26.8 ± 0.8	**↑Δ 8.1%**	89.3 ± 4.5 89.2 ± 4.4	**↓Δ 0.1%**	43.7 ± 1.3 43.2 ± 1.4	**↓Δ 1.1%**	103.7 ± 2.6 101.6 ± 2.9	**↓Δ 2.0%***
	CON	Pre Post	27.2 ± 1.4 24.9 ± 0.8	**↓Δ 8.5%**	85.1 ± 4.2 85.1 ± 4.3	**↔Δ 0.0%**	46.5 ± 1.7 46.7 ± 1.8	**↑Δ 0.4%**	104.0 ± 3.2 101.4 ± 3.3	**↓Δ 2.5%***
Donges et al., 2013	CT	Pre Post	-	-	96.4 ± 1.7 95.7 ± 1.7	**↓Δ 0.7%**	24.0 ± 1.2 22.6 ± 1.3	**↓Δ 5.6%****	-	-
	AT	Pre Post	-	-	103.1 ± 4.6 101.1 ± 4.4	**↓Δ 1.9%***	27.8 ± 1.3 27.0 ± 1.3	**↓Δ 2.8%***	-	-
	RT	Pre Post	-	-	96.4 ± 3.3 96.6 ± 3.4	**↑Δ 0.2%**	27.6 ± 1.4 26.8 ± 1.3	**↓Δ 2.9%***	-	-
	CON	Pre Post	-	-	92.2 ± 6.9 92.3 ± 7.2	**↑Δ 0.1%**	23.9 ± 2.2 24.4 ± 2.3	**↑Δ 2.2%**	-	-
Brunelli et al., 2015	CT	Pre Post	28.0 ± 1.0 31.1 ± 1.0	**↑Δ 11.0%***	93.5 ± 1.6 92.7 ± 1.9	**↓Δ 0.9%**	36.0 ± 1.4 28.6 ± 1.6	**↓Δ 20.5%***	103.0 ± 1.3 100.7 ± 1.4	**↓Δ 2.2%**
	CON	Pre Post	29.1 ± 1.2 29.0 ± 1.1	**↓Δ 0.1%**	94.8 ± 3.1 95.0 ± 3.0	**↑Δ 0.1%**	32.4 ± 1.8 31.1 ± 1.0	**↓Δ 3.9%**	101.8 ± 1.3 102.5 ± 1.4	**↑Δ 0.7%**

Atashak et al., 2016	CT	Pre Post	-	-	84.3 ± 4.8 80.1 ± 4.3	**↓Δ 5.0%****	24.3 ± 5.8 19.4 ± 3.9	**↓Δ 20.4%****	95.5 ± 3.6 92.9 ± 3.0	**↓Δ 2.7%***
	CON	Pre Post	-	-	85.0 ± 4.4 85.4 ± 4.2	**↑Δ 0.4%**	23.0 ± 3.3 23.1 ± 3.3	**↓Δ 0.6%**	94.4 ± 3.6 94.5 ± 3.6	**↑Δ 0.1%**
Duft et al., 2017	CT	Pre Post	28.2 ± 4.7 31.5 ± 5.0	**↑Δ 11.7%***	94.0 ± 7.8 93.3 ± 8.8	**↓Δ 0.8%****	36.4 ± 6.1 28.9 ± 7.0	**↓Δ 20.6%***	103.9 ± 6.3 101.6 ± 6.7	**↓Δ 2.2%***
	CON	Pre Post	29.1 ± 4.7 29.0 ± 4.1	**↓Δ 0.3%**	85.0 ± 4.4 85.4 ± 4.2	**↑Δ 0.4%**	32.8 ± 5.5 31.4 ± 5.1	**↓Δ 4.3%**	101.5 ± 4.6 102.4 ± 4.8	**↑Δ 0.9%**
Ramírez-Vélez et al., 2020	CT	Pre Post	33.8 ± 8.6 40.2 ± 10.7	**↑Δ 18.9%***	-	-	41.4 ± 7.3 40.4 ± 8.0	**↓Δ 2.4%**	91.7 ± 7.9 88.9 ± 7.6	**↓Δ 3.1%***
	HIIT	Pre Post	37.4 ± 8.0 45.7 ± 8.1	**↑Δ 22.2%***	-	-	39.6 ± 5.0 36.6 ± 5.8	**↓Δ 7.6%***	90.4 ± 8.6 86.0 ± 9.1	**↓Δ 4.9%**
	RT	Pre Post	40.0 ± 9.8 44.1 ± 9.9	**↑Δ 10.3%**	-	-	39.4 ± 7.4 36.2 ± 8.1	**↓Δ 8.1%***	96.2 ± 6.9 92.2 ± 8.8	**↓Δ 4.2%**

Note; Data is presented as baseline mean ± standard deviation (SD) followed by post-intervention mean ± SD and the relative per cent change from pre- to post-intervention **(Δ%).** All results are rounded to 1 decimal place. ***Key;*** *significant difference from baseline, **significant difference from control group, [+]assessed via 5-repetition maximum, [§]assessed via 1-repetition maximum, [†]measured in mg/dL, [^]sum of bench press, leg press and dumbbell curl 1-repetition maximums. ***Abbr.*** AT; aerobic training, CON; control, CT; concurrent training FFM; fat free mass, NR; not reported, RT; resistance training, WC; waist circumference

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Table 3.3. Results for Secondary Outcome Measures.

Author	Group	Strength					
		Chest (kg)			Leg (kg)		
		Pre	**Post**	**Δ**	**Pre**	**Post**	**Δ**
Donges et al., 2013	CT	67.0 ± 2.0^{+}	92.0 ± 4.0^{+}	**↑Δ38%****	156.0 ± 11.0^{+}	267.0 ± 19.0^{+}	**↑Δ73%****
	AT	66.0 ± 3.0^{+}	73.0 ± 4.0^{+}	**↑Δ11%**	148.0 ± 13.0^{+}	186.0 ± 16.0^{+}	**↑Δ28%***
	RT	53.0 ± 4.0^{+}	87.0 ± 4.0^{+}	**↑Δ68%****	130.0 ± 10.0^{+}	258.0 ± 15.0^{+}	**↑Δ99%****
	CON	62.0 ± 5.0^{+}	64.0 ± 7.0^{+}	**↑Δ3%**	190.0 ± 13.0^{+}	183.0 ± 16.0^{+}	**↓Δ4%**
Brunelli et al., 2015	CT	68.3 ± 3.9§	82.6 ± 4.1§	**↑Δ17%****	302.8 ± 18.1§	365.2 ± 15.0§	**↑Δ17%****
	CON	71.0 ± 3.7§	61.7 ± 3.6§	**↓Δ13.1%***	310.0 ± 19.0§	332.7 ± 20.0§	**↑Δ7.3%**
		Total Strength (kg)					
		Pre		**Post**		**Δ**	
Duft et al., 2017	CT	423.1 ± 67.4$^{\wedge}$		505.3 ± 67.1$^{\wedge}$		**↑Δ 19.4%****	
	CON	433.0 ± 84.5$^{\wedge}$		426.7 ± 82.4$^{\wedge}$		**↓Δ 1.5%**	
		Fat Free Mass					
		Pre		**Post**		**Δ**	
Donges et al., 2013	CT	71.0 ± 1.4 kg		71.7 ± 1.3 kg		**↑Δ 1.1%**	
	AT	72.1 ± 2.6 kg		71.5 ± 2.4 kg		**↓Δ 0.8%**	
	RT	67.5 ± 1.8 kg		68.5 ± 1.9 kg		**↑Δ 1.5%**	
	CON	67.4 ± 3.7 kg		66.9 ± 3.7 kg		**↓Δ 0.8%**	

Brunelli et al., 2015	CT	64.0 ± 1.4 %	71.4 ± 1.6 %	**↑Δ 11.6%***
	CON	67.7 ± 1.8 %	71.4 ± 1.6 %	**↑Δ 1.8%**
Duft et al., 2017	CT	63.5 ± 6.1 %	69.5 ± 5.5 %	**↑Δ 9.4%***
	CON	68.6 ± 5.1 %	65.3 ± 6.2%	**↓Δ 4.8%**
		Glucose		
		Pre	**Post**	**Δ**
Ho et al., 2012	CT	5.4 ± 0.1 mmol/L	5.6 ± 0.1 mmol/L	**↑Δ 3.7%**
	AT	5.7 ± 0.2 mmol/L	5.7 ± 0.1 mmol/L	**↔Δ 0%**
	RT	5.8 ± 0.5 mmol/L	5.8 ± 0.2 mmol/L	**↔Δ 0%**
	CON	5.4 ± 0.1 mmol/L	5.3 ± 0.2 mmol/L	**↓Δ 1.9%**
Brunelli et al., 2015	CT	96.7 ± 2.1 mg/dL	89.9 ± 2.2 mg/dL	**↓Δ 7%***
	CON	97.4 ± 1.8 mg/dL	97.0 ± 3.1 mg/dL	**↓Δ 0.4%**
Duft et al., 2017	CT	93.1 ± 9.6 mg/dL	87.1 ± 14.2 mg/dL	**↓Δ 6.4%***
	CON	99.1 ± 10.1 mg/dL	99.0 ± 12.7 mg/dL	**↓Δ 0.1%**
		Insulin		
		Pre	**Post**	**Δ**
Ho et al., 2012	CT	14.2 ± 1.0 µUl/mL	14.3 ± 1.3 µUl/mL	**↑Δ 0.7%**
	AT	13.1 ± 1.0 µUl/mL	15.9 ± 1.9 µUl/mL	**↑Δ 21.4%**
	RT	14.0 ± 1.4 µUl/mL	13.5 ± 1.2 µUl/mL	**↓Δ 3.6%**
	CON	14.9 ± 2.3 µUl/mL	14.8 ± 1.7 µUl/mL	**↓Δ 0.7%**
Brunelli et al., 2015	CT	13.7 ± 1.4 µUl/mL	9.9 ± 0.7 µUl/mL	**↓Δ 27.7%***
	CON	11.0 ± 1.5 µUl/mL	14.2 ± 1.7 µUl/mL	**↑Δ 29.1%**
Duft et al., 2017	CT	3.8 ± 2.0 µUl/mL	3.9 ± 2.6 µUl/mL	**↑Δ 2.6%**
	CON	6.6 ± 5.5 µUl/mL	4.3 ± 3.8 µUl/mL	**↓Δ 34.8%**

Note; Data is presented as baseline mean ± standard deviation (SD) followed by post-intervention mean ± SD and the relative per cent change from pre- to post-intervention **(Δ%).** All results are rounded to 1 decimal place. ***Key;*** *significant difference from baseline, **significant difference from control group, ***Abbr.*** AT; aerobic training, CON; control, CT; concurrent training, RT; resistance training.

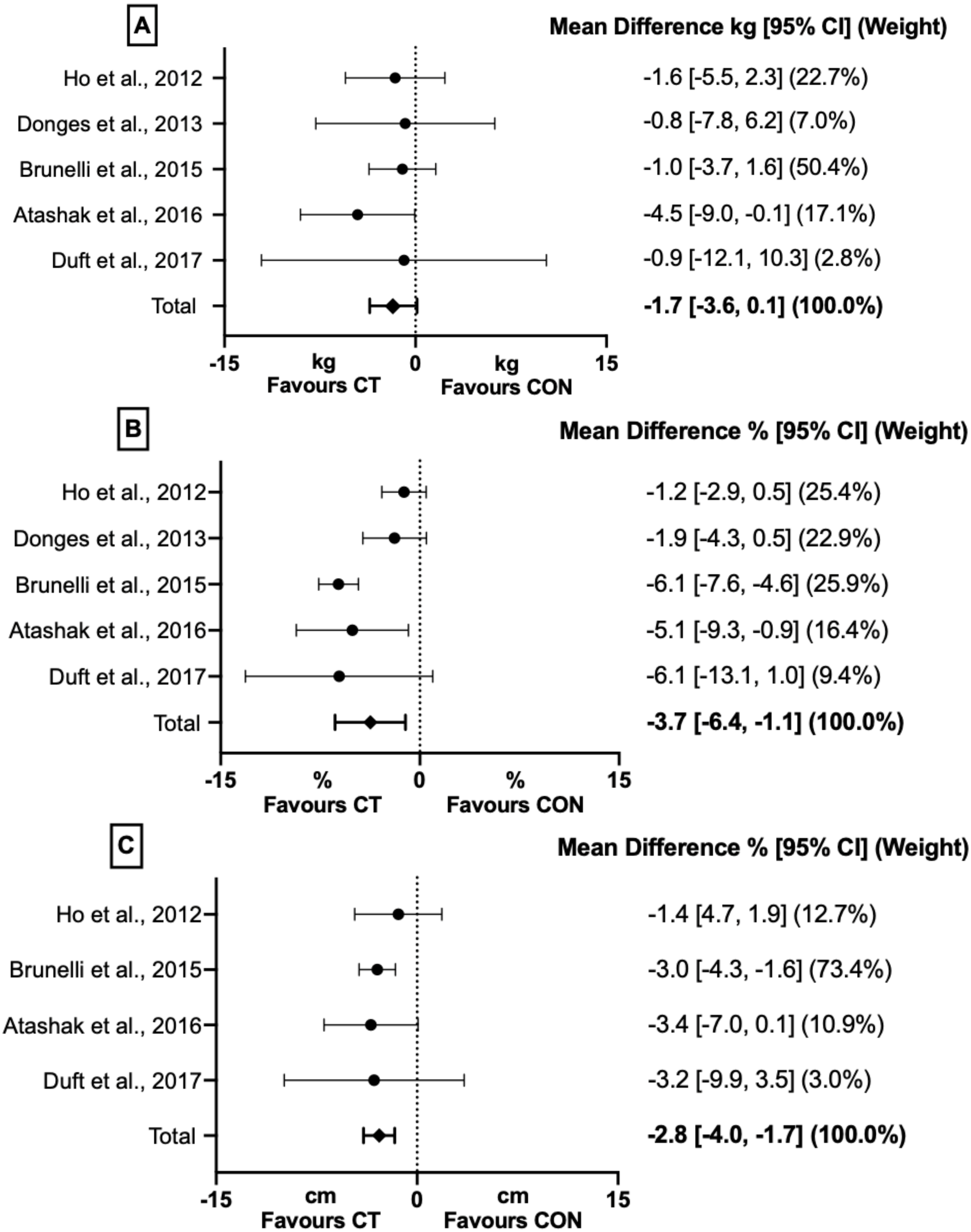

Figure 3.2. Meta-analysis of pre- to post-intervention mean differences in concurrent (CT) and control (CON) groups for: **A)** Body mass (kg) with confidence intervals (95% CI). Total effect; n = 136, Z = 1.84 (P = 0.07), $\tau^2 = 0.00$. **B)** Body fat (%) with 95% CI. Total effect; n = 136, Z = 2.76 (P = 0.006), τ^2 = 6.45.**C)** Waist circumference (cm) with 95% CI. Total effect; n = 115, Z = 4.79 (P < 0.001), $\tau^2 = 0.00$.

3.4. Discussion

The aim of this systematic literature review was to establish the effectiveness of same-session concurrent HIIT/AT and RT in overweight and adults with obesity to improve obesity-related health outcomes. The primary findings from this review were; 1), CT is effective in improving the CRF and body composition of individuals with overweight and obesity, as well as additional health outcome measures such as strength. 2), there may also be superior improvements in CT over either exercise type alone, particularly for body composition. Notably, the systematic review of the literature yielded only one study that implemented a combined HIIT and RT exercise intervention, highlighting a major shortfall of research in this area. To the authors' knowledge few concurrent HIIT and RT studies are published in the literature, which are conducted in healthy or elderly populations (Sabag et al., 2018; Müller et al., 2021), acute interventions (Pugh et al., 2018), or are presumably ongoing studies (De Lorenzo et al., 2018).

3.4.1. Body mass

The meta-analysis for BM **(Figure 3.2A)** revealed a pooled mean difference of -1.7 kg (95% CI -3.6, 0.1) across the five studies with a control comparator, with no significant benefit of CT versus control. These findings are comparable to those after AT-only exercise. Indeed, a meta-analysis of five studies in individuals with obesity presented absolute changes of -1.6 kg and -1.7 kg after 6- and 12-months of AT respectively (Thorogood et al., 2011). The authors concluded that AT exercise in isolation was ineffective as an intervention for weight loss, which reaffirms the conclusions of previous research that proposed a combined diet and exercise intervention is required for the greatest reductions in body weight (Shaw et al., 2006). However, CT may provide greater decreases in BM than either exercise type alone, despite the meta-analysis in the current study indicating wide confidence intervals. Both studies with four comparator groups (Donges et al., 2013; Ho et al., 2012) found greater reductions in the CT group to RT, and Ho et al. also determined CT was superior for reductions in body mass to AT. This is a finding replicated in type 2 diabetics with obesity after 9 months of exercise (Church et al., 2010), where the CT group reduced body mass by a greater margin (-1.6 kg) compared to AT (-0.8 kg) and RT (-0.2 kg) alone, as well as in a recent meta-analysis of exercise interventions in paediatric obesity (García-Hermoso et al., 2018). Nonetheless, the small sample size made determining assertions difficult in this meta-analysis, and more studies are required, though the wide confidence intervals may indicate that reductions in BM after CT are not well-established.

This may be explained by the inclusion of RT, which is well established to increase FFM in individuals with obesity (Tresierras and Balady, 2009) and subsequently demonstrated by several studies from this review **(Table 3.2)**. Increased FFM would counteract any decreased adiposity, diminishing total body weight reductions. Thus, whole body mass may not be the most pertinent measure to focus on in CT interventions, as positive changes in body composition may cause increased weight in some individuals and the beneficial effects of exercise are exerted beyond weight loss alone. Indeed, reductions in detrimental visceral adipose tissue can be observed without corresponding weight loss (Johnson et al., 2009), although, reducing BM may still be a potent motivator and incentive to continue exercising for individuals with obesity.

Atashak et al. (2016) observed a much larger reduction in BM (4.2 ± kg) than any other study. This result becomes increasingly atypical when it is considered that this study has the shortest intervention length (8 weeks) and the participants in the CT group have the lowest baseline body mass and BMI (84.3 ± 4.8 kg; 28.3 ± 1.6 $kg{\cdot}m^2$). However, this study had no form of dietary control or randomised design. Although no dietary interventions were incorporated into the study, the absence of appropriate dietary control could suggest that reduced energy intake could have also played a role. The non-randomised design of this study also allows for the possibility of bias to be introduced into the group selection process. Those allocated into the exercise intervention group may have been individuals actively seeking to lose weight, and thus may have altered their diet accordingly. Other research which has observed reductions in BM after CT also noted concomitant reductions in energy intake (Amarao-Gahete et al., 2020). Therefore, reductions in body mass from CT may not commonly be as large in individuals with overweight and obesity.

3.4.2. Waist Circumference

Consistent and comparable decreases in waist circumference were observed in each study **(Table 3.2)**. Moreover, the meta-analysis **(Figure 3.2C)** revealed pooled mean differences significantly favoured CT to reduce waist circumference (-2.8 cm, 95% CI -4.0, -1.7) to control. These findings hold significant relevance for the health of individuals with overweight and obesity, as there exists a conclusive link between waist circumference and mortality (Koster et al., 2008), with previous research demonstrating that each 5 cm increase in waist circumference equates to an increased mortality risk of 7% and 9% for males and females respectively (Cerhan et al., 2014). The present study suggests that CT may be effective in reducing WC for all participants, with the lower confidence interval observed demonstrating reductions in WC, though further confirmatory studies are required to add to a larger meta-analysis. Ramirez-Velez et al. (2020) demonstrate the greatest reductions of any CT programme (3.1%) in CT inclusive of HIIT. Indeed, the HIIT group demonstrated the largest reductions of any experimental group (4.9%), though the absence of a control group excluded the results from the meta-analysis. Therefore, further research should explore the apparent capacity of HIIT to have greater increases in WC over other exercise modalities.

3.4.3. Body fat

Methodological differences in the assessment of BF% between studies **(Table 3.1)** made comparisons difficult, as there exist many discrepancies in BF% measured by skinfold or DXA (Bacchi et al., 2017), and the accuracy of DXA is well-debated (Albanese et al., 2003; LaForgia et al., 2009). Nevertheless, there was an average change of Δ -13.8% across the five studies **(Table 3.2)**, though results varied between the studies which used the skinfold calliper method (Δ -20.5%) and the DXA (Δ -3.9%), highlighting the notably large variations between assessment measures (Bacchi et al., 2017). Nonetheless, all studies found a significant reduction in BF% from baseline. Meta-analysis revealed the pooled mean difference between studies (-3.73% 95% CI -6.38, -1.08) significantly favoured CT **(Figure 3.2B)**, though DXA results did not hold independent significance in further analysis. In the two studies which used the DXA measure there also existed obvious methodological disparity. Ho et al. (2012) predominately recruited female participants, with a higher baseline BF%, in comparison to the male participants recruited by Donges et al. (2013). There were also no significant differences between-groups in these two studies which also assessed changes to body composition in AT- and RT-only groups. However, the CT groups found greater reductions in body fat (Δ -3.9%) than the AT and RT groups (both Δ -2.0%). In conjunction with the corroborating results for body mass, Ho et al. (2012) propose that the effects of CT interact to produce greater improvements in body composition than either exercise type in isolation, the mechanism for which has not yet been established. However, Ramirez-Velez et al. (2020) demonstrate that HIIT alone is superior for improvements in BC compared to CT, perhaps suggesting HIIT must be performed in sufficient volume to evoke the greatest changes. Nonetheless, CT may yet hold superiority over HIIT alone, inducing improvements in other factors such as strength and FFM. These factors were, however, not measured by RV and further research is required on the effects of HIIT in CT programmes.

3.5.4. Cardiorespiratory Fitness

Five studies determined CRF via relative $\dot{V}O_{2peak}$ or $\dot{V}O_{2max}$, the results of which are presented in **Table 3.2**. Significant increases from baseline in the CT group were observed (Brunelli et al., 2015; Duft et al., 2017; Ho et al., 2012; Ramirez-Velez et al., 2020) alongside large improvements compared to the control group, though only one study demonstrated between-group significance (Ho et al., 2012). Improvements after the 12-week (1.7 $mL{\cdot}kg^{-1}min^{-1}$ Ho et al., 2012) and 24-week (3.1 $mL{\cdot}kg^{-1}min^{-1}$ Brunelli; 3.3 $mL.kg^{-1}min^{-1}$ Duft) interventions may highlight the importance of training length, perhaps reflecting the dose-response change in fitness observed with increasing energy-expenditure dosages of exercise which was highlighted by Church et al. (2007) and subsequently demonstrated in both males and females with obesity (Donnelly et al., 2013). As such, the AT component employed by Ho et al. (2012) of 15 minutes at 60% HRR may have been insufficient to incur substantial improvements.

Thus, several studies observed improvements close to clinical relevance, with increases in $\dot{V}O_{2peak}$ of ≥ 3.5 $mL{\cdot}kg^{-1}min^{-1}$ associated with 10-25% improvements in all-cause and cardiovascular mortality in the general population (Kodama et al., 2009; Kaminsky et al., 2013). However, this review collates CRF improvements that are diminished in comparison to other CT interventions in slightly older population with overweight and obesity s after both 8-week (4.9 $mL{\cdot}kg^{-1}min^{-1}$ – Schroeder et al., 2019) and 8-month (4.3 $mL{\cdot}kg^{-1}min^{-1}$ – Willis et al., 2012) interventions. Though, the findings are analogous to a similar age group in a 12-week intervention-only study (3.1 $mL{\cdot}kg^{-1}min^{-1}$ – Colato et al., 2014). Nonetheless, the largest increase was observed when including HIIT in CT (Ramirez-Velez et al., 2020), which may reflect the intensity-dependant nature of CRF increases. However, the participants recruited in the study by Ramirez Velez et al. (2020) had the greatest baseline fitness of any CT group included in this review (33.8 ± 8.6 ml.kg.min-1) and whilst increases were significant, the widespread feasibility and adoption of such a HIIT protocol in less fit individuals with overweight and obesity must be considered by future research. Moreover, the lack of a no-intervention control group in this study further distances these results from drawing meaningful conclusions for the population with overweight and obesity as a whole.

In exploration of these adaptations, previous research has observed significant increases in left ventricular end diastolic diameter (2.6 ± 1.5 mm) after CT, positing the underlying physiological adaptation prompting increased CRF (Amaro-Gahete et al., 2020).

Indeed, CT has previously been demonstrated to increase end diastolic diameter maximally over AT or RT, due to the combination of both exercise types amalgamating pressure *and* volume overloads (Hosseini et al., 2012).

When examining changes in $\dot{V}O_{2peak}$ in AT- and RT-only groups (Ho et al., 2012) all groups increased from baseline, but only in the CT group were these increases statistically significant. In other research comparing increases in $\dot{V}O_{2peak}$ in CT to AT-only groups the CT group has likewise found more favourable increases (4.25 $ml \cdot kg^{-1} min^{-1}$ versus 3.43 $ml \cdot kg^{-1} min^{-1}$) after 8 months in a slightly older population (Willis et al., 2012). However, in this study, the CT group completed the same aerobic intervention plus RT, meaning they had a higher total exercise time. Indeed, in duration-matched exercise, a group of 45 – 74-year-old overweight and adults with obesity had a higher increase in $\dot{V}O_{2peak}$, in the AT group (7.7 $ml \cdot kg^{-1} min^{-1}$) compared to the CT group (4.9 $ml \cdot kg^{-1} min^{-1}$ - Schroeder et al., 2019)

The value of these results are, however, questionable. During the 4 x 4 HIIT intervals, the target HR (85 – 95% HR_{max}) was reportedly reached within ~2 minutes of each interval. Therefore, there is a wide range of potential intensities each individual actually completed each workout at, narrowing the ability to accurately prescribe an exact workload. This is compounded by the wide range (400 – 500 kcal) of targeted EE per session, wherein some individuals may have completed a higher workload than others. Moreover, the 4 x 4 minute design may not be feasible for the general population with overweight and obesity , particularly those with baseline fitness values well below those observed by Ramirez-Velez et al. (2020). Indeed, modified 10 x 60 s HIIT designs incorporating rest rather than active recovery are more commonly utilised in clinical populations (Little et al., 2014). Though, it should be noted similar 4 x 4 HIIT designs have been successfully completed in clinical populations with lower baseline fitness (Stoa et al., 2017) and suggests further exploration is warranted.

CT is effective in improving CRF in individuals with overweight and obesity, likely due to structural cardiac changes, though other potential contributing factors were not assessed. But these improvements are clearly inferior to AT and – particularly – HIIT. Despite the findings reported, these studies were difficult to compare and evaluate due to methodological differences. In each study the CT group had a lower baseline $\dot{V}O_{2peak}$ to the control. Therefore, there would be a smaller post-intervention difference and a reduced likelihood of a statistical significance and results should have been adjusted for baseline (Vickers, 2003). Similarly, in the study by Ho et al. the CT group had a higher baseline

$\dot{V}O_{2peak}$ to the AT- and RT-only groups and the statistical significance observed in the CT group may be as a result of the statistical modelling undertaken (Vickers, 2003). Furthermore, methodological differences in the methods of determining $\dot{V}O_{2peak}$ as well as the intensity and progression of training (Table 1), provide additional confounding variables for the comparison of results between studies. Indeed, research has clearly established that increases in $\dot{V}O_{2peak}$ are intensity dependant (Swain and Franklin, 2002) with far greater increases observed after HIIT compared to moderate-intensity exercise (Weston et al., 2014). Though an early Cochrane review on exercise in populations with obesity (Shaw et al., 2006) suggested only marginal benefits of favouring higher-intensity exercise, more recent HIIT research postulates that intensity holds a key role for improving CRF (Bacon et al., 2013).

3.4.5. Secondary outcome measures

Three studies measured strength from pre- to post-intervention in CT groups **(Table 3.2)**. Two studies (Donges et al., 2013; Brunelli et al., 2015) found significant increases from baseline and to control for chest strength. Donges et al. (2013) found greater magnitude increases from pre-intervention in the CT group and compared to the control group in leg strength (both significant), whereas the CT group in Brunelli et al. (2015) only found significant increases in leg strength from baseline, as leg strength in the control group also increased. Donges et al. (2013) demonstrated superior strength gains, despite a shorter intervention length, most likely due to an increased number of resistance exercises included in the CT protocol. Moreover, Donges et al. (2013) incorporated cycling into the AT component, which may have contributed to the large increases in leg strength, as cycling is noted to increase both hypertrophy and strength (Ozaki et al., 2015). Duft et al. (2017) also observed significant increases in total strength from baseline and compared to the control group proposing that CT is an effective means of increasing strength in individuals with overweight and obesity. Donges et al. (2013) also assessed chest and leg strength in RT- and AT-only groups **(Table 3.2)**. CT exceeded AT but was inferior to RT for both chest and leg strength. CT and RT groups were both significantly different from baseline and control condition, whilst the AT group only found significant increases from baseline for leg strength. This increase in leg strength may be logical given that the AT group performed the same protocol involving cycling exercise. Though the superior results of the CT group compared to the AT group may be explained by the inclusion of resistance-type exercises, the ability of the RT group to provide much greater strength gains could reflect the commonly acknowledged interference effect observed in CT (Wilson et al., 2012). Generally, theories for the interference effect propose that; acutely the inclusion of AT results in fatigue and thus a decreased intensity and volume of RT or that, chronically, different adaptations involving separate metabolic pathways impede one another (Laursen and Buchheit, 2019).

The inclusion of RT in the CT interventions is a key factor in the findings of significant increases in whole-body strength, FFM and decreased BF%. This highlights the importance of the RT component, with resistance exercises having previously been demonstrated to improve body composition, glycaemic control, lipid profile and to reduce adiposity in individuals with obesity (Strasser and Schobersberger, 2011; Tresierras and Balady, 2009). Resistance exercise may also be key to combat a phenomenon known as sarcopenic obesity, wherein low muscle mass and strength accompanies high fat mass, an issue of particular importance for individuals with obesity as they age. Sarcopenic obesity presents with the cumulative risk of both phenotypes (Roubenoff, 2004), and is closely associated with the metabolic syndrome (Lu et al., 2013). CT appears an efficient and effective means for individuals to include RT in their exercise sessions for the improvement of strength, though future research should also examine the effect on other RT-related health outcomes.

Studies measuring changes in insulin and glucose concentrations found inconsistent results **(Table 3.2)**. The lack of consistent results is surprising, as insulin sensitivity is demonstrated to increase post-exercise after even a single low-intensity session in adults with obesity (Newsom et al., 2013), as a result of improved skeletal muscle insulin sensitivity from the contraction-mediated metabolic pathways instigated by exercise (Sjoberg et al., 2017). Improved insulin sensitivity is an important adaptation due to the strong links between overweight and obesity and type 2 diabetes mellitus (International Diabetes Federation, 2017). Glycaemic control may be of equal importance, as the presence of hyperglycaemia instigates the process of insulin resistance and the onset of type 2 diabetes mellitus. Indeed, two studies report significant decreases in circulating glucose after 24 weeks of CT and one study reported a non-significant small decrease in glucose area under the curve after 12 weeks of CT (Table 2). Ho et al. (2012) however, find a small increase after 12 weeks of CT. This may further indicate the importance of adopting exercise interventions long-term for favourable adaptations.

3.4.6. Limitations and conclusions

This systematic review and meta-analysis was not without its limitations. Making assumptions from the meta-analysis was made difficult by the small sample size, and as a result publication bias and further meta-regression analysis could not be performed. Additional studies are required to be added to analysis to confirm the results of the present study. Moreover, the strict inclusion criteria omitted studies with a slightly different age range, participants with co-morbidities and insufficient quantification of overweight or obesity. Nonetheless, the findings suggest that CT is effective for improving CRF and body composition in individuals with overweight and obesity. Furthermore, CT inclusive of HIIT may potentially have the greatest effects – though more evidence is required on the efficacy and feasibility of this in other (particularly less fit) individuals with overweight and obesity. CT was also an effective means of introducing RT and improved a number of factors including muscular strength and FFM, though effects on circulating insulin and glucose concentrations were contradictory and require further research. The lack of studies identified highlights the necessity for more research in this area, particularly including HIIT, to address the current shortage of such interventions currently in the literature.

Chapter 4.0. General Materials and Methods

Based on our findings from the systematic review and meta-analysis of the literature we designed a test-retest reliability and training study. In order to avoid the repetition of standard procedures, we present a detailed overview of the general methods employed. In addition to the general methods outlined in this chapter, prior to the implementation of the studies, pilot work was carried out. This pilot work included testing the HIIT and CT exercise sessions in order to familiarise the research team with the sessions and measures required, as well as the timings for exercise, rest and recording of physiological measures. The pilot testing highlighted the time participants would be needed for at the research laboratory, the necessity for two members of the research team to be present in order to collect measures in an accurate and timely manner and to load or de-load barbells for each exercise.

4.1. Ethical Approval

All research conducted was approved by the University of Sunderland Research Ethics Group **(Appendix A)** and was carried out in accordance with the Declaration of Helsinki (2008). Each participant provided informed consent **(Appendix B)** prior to the study, having been provided with participant information sheets **(Appendix C)** and given the opportunity to ask questions to the research team and the independent local research ethics coordinator. Participants were made aware that they were free to withdraw from the study at any point and that participation was entirely voluntary.

4.2. Participants

Participants were recruited from the University of Sunderland and surrounding area. Initially, recruitment of both males and females were sought. However, limited numbers of females responded to requests for volunteers; thereafter, recruitment was limited to males. In order to be included in the research, a strict inclusion criterion was set in place:

- Adult males (18 - 66 years)
- Living with overweight or obesity (>25 $kg{\cdot}m^2$ body mass index - BMI)
- Normally complete less than 150 minutes of moderate-intensity or 75 minutes of vigorous-intensity physical activity per week
- No existing comorbidities (e.g. type 2 diabetes mellitus, hypertension)
- Have not completed an exercise training programme in the previous 3 months
- Are not currently completing a weight loss intervention (e.g. pharmacological/dietary)

- No existing musculoskeletal injury

In light of the global pandemic, COVID-19 was deemed a confounding variable in the study. Thus, from March 2020, any participants were also excluded if they had tested positive for COVID-19 within the previous 6 months or were currently symptomatic. All participants were assessed for compliance with the inclusion criteria both verbally prior to the study and at the first visit to the laboratory.

Before the commencement of any form of exercise each participant underwent full pre-exercise screening procedures in line with American College of Sports Medicine (ACSM) and University of Sunderland guidelines. Participants were assessed for CVD risk factors via questionnaire, anthropometrics **(Chapter 4.4)**, heart rate, blood pressure and bloodwork **(Chapter 4.8).** Participants were excluded with the presence of more than two risk factors. As per University of Sunderland exercise testing guidelines, pre-exercise screening involved a medical history questionnaire, list of current medications and general practitioner details **(Appendix D)**. Resting heart rate was measured via Polar H10 Bluetooth heart rate monitors and wristwatches (Polar, Finland), resting blood pressure was determined from Omron automatic sphygmomanometers (Omron Corporation, Japan). Participants were instructed to rest in a seated position for five minutes before assessment, with the average of three measurements taken as the final value.

4.3. Recruitment

4.3.1. Reliability study

Ethical approval was granted for the use of a study poster **(Appendix E)** and recruitment emails. In May 2019, School and Faculty leaders from the University of Sunderland were contacted to circulate emails to members of staff. Module leaders were contacted to circulate emails to students and to promote on shared virtual spaces, such as the University Virtual Learning Environment (VLE). The research academic development officer was contacted to promote the study on the postgraduate research VLE. Local businesses were also contacted to advertise the study to their employees. Study posters were placed around both University of Sunderland campuses and were promoted on social media by members of the research team and the wider faculty. Potential participants who were interested in taking part in the research study were requested to contact the lead researcher. A total of 24 participants contacted the lead researcher via email or telephone and were provided with a participant information sheet and any other additional study information they required. Seven participants were excluded by the lead researcher via email or telephone (Meeting exercise guidelines n = 4, Type II

Diabetes Mellitus n = 2, Type I Diabetes Mellitus n = 1), and one further participant did not respond to follow-up. The remaining 16 participants attended the laboratory for an initial screening, from which three participants were excluded for having a Body Mass Index (BMI) < 25kg·m^2. Thirteen participants commenced the research study.

4.3.2. Feasibility exercise training programme

Ethical approval was granted for the use of a study poster **(Appendix E)** and recruitment emails. In August 2021, the University virtual newsletter was contacted to promote the study via email to all University staff. Module leaders were contacted to circulate emails to students and to promote on the VLE. The research academic development officer was contacted to email all postgraduate research students and to promote the study on the postgraduate research VLE. Local businesses, as well as the local Change4Life officer were contacted to advertise the study. Study posters were placed around both University of Sunderland campuses and were promoted on social media by members of the research team and the wider faculty.

A CONSORT flow diagram is provided at **Figure 4.1**. Potential participants who were interested in taking part in the research study were requested to contact the lead researcher. A total of 41 participants contacted the lead researcher via email or telephone and were provided with a participant information sheet and any other additional study information they required. A total of 16 participants were excluded by the lead researcher via email or telephone (Meeting exercise guidelines n = 5, Type II Diabetes Mellitus n = 1, Hypertension n = 1, work commitments n = 3), with six further participants not responding to follow-up correspondence. The remaining 25 participants attended the laboratory for an initial screening, from which three participants were excluded for having a Body Mass Index (BMI) < 25kg·m^2. A total of 22 participants commenced the research study.

4.4. Anthropometrics

A series of anthropometric measures were taken for both studies. Height was determined from a Seca Stadiometer (Seca GmbH, Germany). Participants were barefoot and positioned themselves with their heels facing toward the stadiometer, standing upright with their shoulders back and face forward in the Frankfurt plane. Height was taken to the nearest 0.1 cm from the vertex, when the participant inhaled maximally. Body mass was recorded to the nearest 0.1 kg from Seca digital scales with participants barefoot and stripped to shorts. Body mass index (BMI) was calculated from these two measures whereby:

$$BMI\ = Body\ Mass\ (kg) \div Height\ (m)^2.$$

Waist circumference was measured by tape measure to the nearest 0.1 cm when placed directly on the skin, in the horizontal plane midway between the lowest rib and the iliac crest (Ma et al., 2013). Hip circumference was determined in the same manner, in the horizontal plane at the maximum posterior extension of the buttocks (Wang et al., 2000). The waist to hip ratio (WHR) was derived from these two values by dividing the waist measurement by the hip measurement. Body fat percentage was determined via single frequency (50 kHz) bioelectrical impedance (BodyStat 1500, Douglas, Isle of Man, UK), noted as a valid method to determine body fat (Jebb et al., 2000), with participants requested to consume 400 ml water 1 hour prior to their visit. Participants remained in a supine position, with electrodes affixed to their right wrist and ankle.

Lean Body Mass (LBM) was calculated from these body mass and body fat measures whereby:

$$LBM = Body\ Mass\ (kg)\ \times \frac{(100 - Body\ Fat\ \%)}{100}.$$

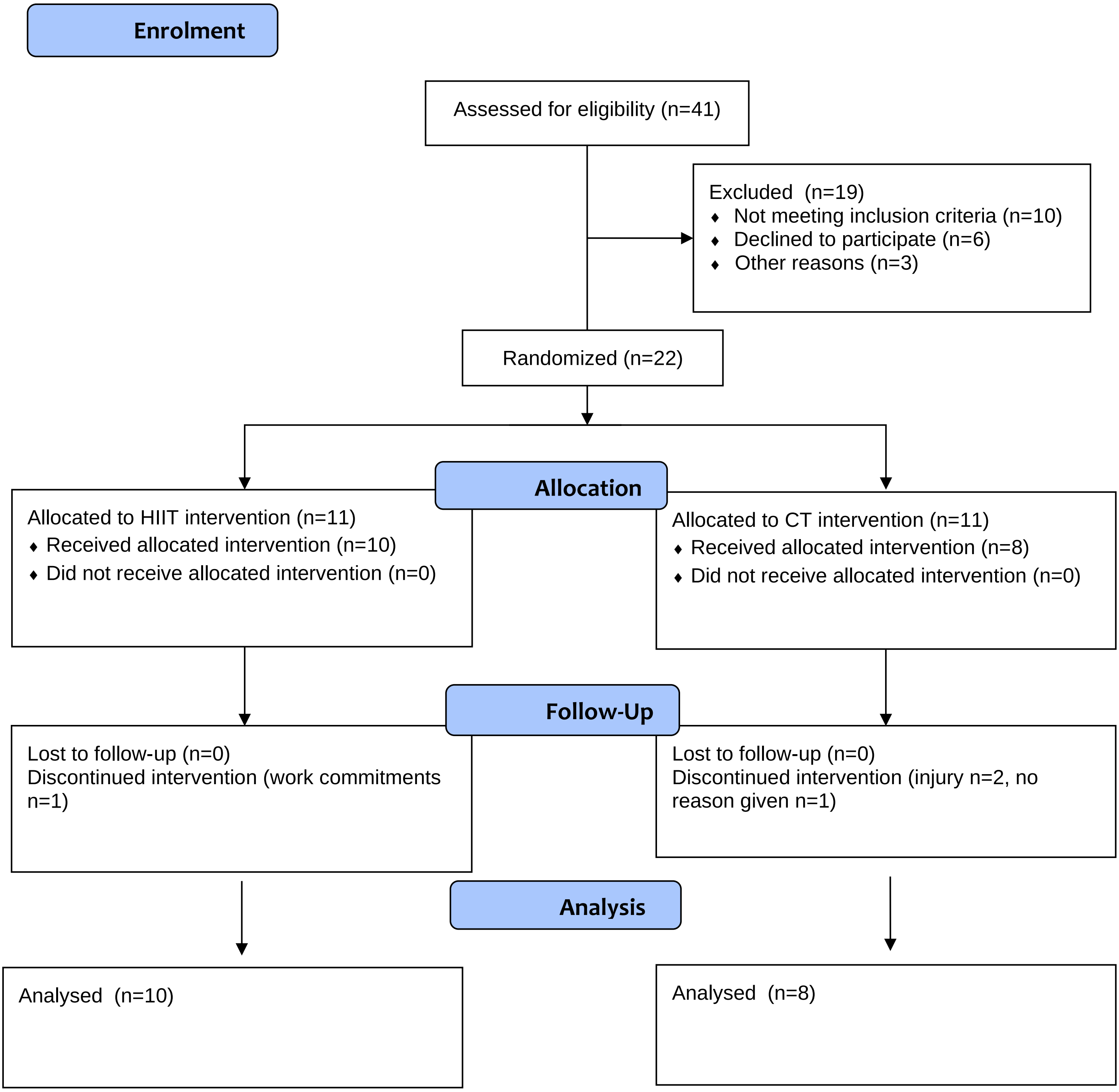

Figure 4.1. CONSORT Flow Diagram for Feasibility Study.

4.5. Questionnaires, Scales and Interviews

The 16-point 2-factor preference and tolerance of intensity of exercise questionnaire (PRETIE-Q) (Ekkekakis et al., 2005) was used to establish individual differences in response to exercise, with a maximum score of 40 for both tolerance and preference **(Appendix F)**. The PRETIE-Q was completed on the initial visit to the laboratory, before any exercise was completed.

During exercise, subjective physiological load was monitored via ratings of perceived exertion (RPE), utilising Borg category-ratio (CR) scales (Borg, 1982) expressed as arbitrary units (AU). The CR20 scale was used during the CPET and the CR100 during HIIT, RT and CT protocols **(Appendix G)**. A session-RPE was recorded using the CR100 scale at 10 minutes post-exercise during both studies; at the culmination of the HIIT protocol and the HIIT, RT and CT sessions. The enjoyment of exercise sessions was assessed via the 18-point self-report physical activity enjoyment scale (PACES), which is observed to provide valid and reliable measures of enjoyment (Kendzierski and DeCarlo, 1991), with each 7-point Likert scale item providing scores ranging 18 – 126 and higher scores reflecting increased enjoyment **(Appendix H)**. Participants also completed the feeling scale (Hardy & Rejeski, 1989), to determine affective valence post-exercise, with the scale ranging from -5 (very bad) through 0 (neutral) to +5 (very good) **(Appendix I)**.

4.6. Breakfast

During the feasibility study baseline testing, participants were provided with a breakfast of toasted white bread and strawberry jam (178 kcal, 38.5 g CHO), in order to minimise any feelings of nausea or presyncope.

4.7. Echocardiography and Electrocardiography

4.7.1. Echocardiography

Participants underwent a standard transthoracic echocardiogram (TTE) to determine structural cardiac adaptations and volume changes. Echocardiography was performed by Jakki Colwill (a British Society of Echocardiography (BSE) accredited echocardiographer) using a GE Versana Active Ultrasound (GE Healthcare, USA) equipped with a GE 3Sc Cardiac Probe (GE Healthcare, USA) with the patient lying in the left lateral position at approximately 45°. Two TTEs per participant were performed at the University of Sunderland in the testing laboratory, with an initial assessment at baseline and a second assessment at the end of the training programme.

All protocols and measurements were undertaken in accordance with British Society of Echocardiography (BSE) guidelines (Robinson et al., 2020), with each measurement recorded from one sinus beat during a cardiac cycle. Patients were studied with two-dimensional echocardiography in standard views, all measurements were recorded in cm and all volumes in ml. Measurements of the left ventricle inclusive of Left Ventricular Diameter (LVD), Posterior Wall (PW) and Intraventricular Septum (IVS) were recorded at end diastole. Left Atrium (LA) was measured during ventricular systole. Aortic dimensions were measured inner-edge to inner-edge at end-diastole. Left-ventricular volume measurements were measured in systole and diastole in both two- and four-chamber views. Stroke Volume (SV) was calculated from left-ventricular End Diastolic Volume (EDV) and End Systolic Volume (ESV) using the equation:

$$SV = EDV - ESV.$$

Ejection Fraction was thereafter determined via the equation:

$$EF(\%) = \frac{SV}{EDV} \times 100.$$

Left ventricular mass was calculated via the following equation set out by the BSE from 2D measurements identified from the echocardiogram:

$$LV\ Mass = 0.8 \times (1.04 \times (LVD + PW + IVS)^3 - (LVD)^3)) + 0.6.$$

4.7.2. Electrocardiogram (ECG)

Alongside the TTE, a resting electrocardiography (ECG) trace was obtained. A 12-lead ECG with the Mason-Likar electrode placement, was taken using a portable Custo Cardio 300 resting and stress ECG (Custo Med, Germany) at a paper speed of 25 mm/s. This trace was captured and saved for further analysis. The screening was carried out by Jakki Colwill (a clinical cardiologist). Participants were immediately excluded from the study with the presence of any cardiac abnormalities and advised to seek further medical assessment.

4.7.3. Quality Control

The reliability of the operator was determined in order to establish the typical variation in the echocardiography measures. Ten participants from the feasibility study volunteered to undergo a same-day test-retest echocardiogram. The reliability of the assessment for each echocardiogram measure utilised in the study was determined. Measures were recorded using an identical protocol **(Chapter 4.7.1)** five to ten minutes apart, with the results blinded from the echocardiographer. Participants were requested to stand up from the bed for the duration of the break before returning to the left lateral position.

In order to determine test-retest reliability, the mean difference, 90% confidence limits, smallest worthwhile change, typical error, coefficient of variation and intraclass correlation coefficient were determined **(Chapter 4.15.1.)**. The reliability statistics are presented in **Table 4.1** which demonstrates that cardiac measurements had likely trivial to moderate mean differences, with moderate typical error. Changes in aorta, LV and LA measurements were all below 1%, with IVS and PW demonstrating higher variability. The reliability of these measurements as assessed by qualitative inferences of ICC (3,1) measures were good to excellent, with LV and LA likely moderate to excellent.

Left ventricular volume measurements proved slightly more variable with respect to percentage changes. However, mean differences in diastolic measurements were interpreted as trivial to small with small to moderate typical error and excellent reliability. Systolic measurements were less reliable, as LVESV two-chamber view volumes exhibited moderate to large typical error, with large ICC (3,1) confidence intervals, spanning poor to excellent reliability.

4.8. Metabolic Measures

4.8.1. Blood Sampling and Analysis

Blood-based metabolic measures were assessed via a fingertip capillary blood sampling. Blood sampling was undertaken in accordance with World Health Organisation guidelines on drawing blood (WHO, 2010). Each fingertip capillary sample was performed using a safety lancet. Blood samples were immediately analysed and disposed of in clinical waste. Once sterilised with an alcohol wipe, skin perforations were made on the fingertips, and participants were provided with adhesive dressings upon request. Plasma glucose concentrations were assessed via Biosen Analyser (EKF Diagnostics, Germany). Total cholesterol, triglycerides, low-density lipoprotein and high-density lipoprotein concentrations were measured via CardioChek PA analyser (PTS Diagnostics, USA). Hb A1c was measured via Quo-Test analyser (EKF Diagnostics, Germany). All blood samples were measured in duplicate and an average of the two was recorded as the final result.

Table 4.1. Reliability of Echocardiographer.

Cardiac Measure	Percentage Change (%)	MD	90% CL	Magnitude	Typical Error	TE (CV) %	Magnitude	ICC (3,1)	95% CI	Magnitude
Aorta (cm)	0.92	0.0	-0.01, 0.07	Trivial – Mod.	0.05	1.5	Mod.	0.952	0.806, 0.988	Gd. – Ex.
IVS (cm)	2.69	0.0	-0.01, 0.07	Trivial – Mod.	0.05	4.4	Mod.	0.958	0.832, 0.990	Gd. – Ex.
LV (cm)	0.41	0.0	-0.13, 0.09	Small – Mod.	0.13	2.9	Mod.	0.923	0.690, 0.981	Mod. – Ex.
PW (cm)	3.18	0.0	0.00, 0.07	Trivial – Mod.	0.04	3.8	Mod.	0.950	0.800, 0.988	Gd. – Ex.
LA (cm)	0.42	0.0	-0.12, 0.15	Small – Mod.	0.17	4.6	Mod. - Large	0.892	0.565, 0.973	Mod. – Ex.
LV EDV 4C (ml)	2.40	-3.0	-6.88, 0.93	Trivial - Small	4.77	4.8	Small – Mod.	0.983	0.934, 0.996	Excellent
LV ESV 4C (ml)	5.15	2.1	-0.7, 4.96	Trivial – Mod.	3.45	10.0	Small – Mod.	0.959	0.836, 0.990	Gd. – Ex.
LV EDV 2C (ml)	0.77	0.7	-1.84, 3.30	Trivial	3.13	3.7	Small – Mod.	0.989	0.954, 0.997	Excellent
LV ESV 2C (ml)	3.79	1.2	-0.93, 3.32	Small – Mod.	2.59	9.5	Mod. – Large	0.851	0.402, 0.963	Poor – Ex.

Abbr. LV, Left Ventricle; EDV, End Diastolic Volume; ESV, End Systolic Volume; 4C, Four Chamber View; 2C, Two Chamber View

4.8.2. OGTT

During baseline and post-intervention testing of the feasibility study **(Chapter 6.0.)** participants completed an oral glucose tolerance test (OGTT) to assess insulin sensitivity and glucose uptake. Participants attended the laboratory having completed a 12 hour fast and a fasted plasma glucose concentration was recorded from a fingertip capillary blood sample. Thereafter, participants consumed 75 g of carbohydrate in the form of a dextrose solution – a safe and standardised amount to administer (Belfiore et al., 1998). The participant then remained in the laboratory for 120 minutes, with fingertip capillary blood samples taken at 20-minute intervals and measured in duplicate to determine plasma glucose concentrations via Biosen analyser.

4.8.3. Area Under the Glucose Curve

The seven plasma glucose concentrations were plotted against time in order to calculate an area under the curve (AUC) for each OGTT. AUC was calculated by plotting each glucose concentration on the Y-axis of an XY scatter graph in Microsoft Excel, against seven timepoints on an X-axis. The area under the graph was calculated by determining the cumulative areas of trapezoids for each two time points and glucose concentrations, whereby the area for each trapezoid was calculated by:

$$\frac{(y_1 + y_2)}{2 \times (x_2 - x_1)}$$

The sum of the area of the six trapezoids provided the AUC.

4.9. Cardiopulmonary Exercise Test (CPET)

Each CPET was completed in a temperature-controlled physiology laboratory at the University of Sunderland, on a Lode Excalibur Cycle Ergometer (Lode, Netherlands). Pre-exercise screening inclusive of resting heart rate and blood pressure measures were conducted prior to exercise. A 12-lead electrocardiograph (ECG), with the Mason-Likar electrode placement, was taken at rest and throughout exercise using a portable Custo Cardio 300 resting and stress ECG (Custo Med, Germany) at a paper speed of 25 mm/s. The CPET was immediately terminated with the presence of any cardiac contraindications (acute myocardial infarction, left bundle branch block, high unstable angina, aortic stenosis, uncontrolled arrythmia). Participants adjusted the ergometer seat and handlebars to comfort under supervision of the research team, the measurements were recorded by the measure function on the cycle ergometer software (LodeErgometer 10) and replicated for any other visit. Each participant rested on the ergometer for three minutes before completing a 3-

minute warm-up consisting of unloaded pedalling (Pritchard et al., 2021), which led into a ramped cycle test to volitional exhaustion, progressing at a ramp rate of 20 W·min^{-1} (Pritchard et al., 2021), in order to achieve a test duration of 10 ± 2 minutes (Glaab & Taube, 2022) whilst participants were advised to maintain an approximate cadence of 60 rpm (Glaab & Taube, 2022).

Respiratory gases were collected and analysed via metabolic gas-cart (Meta-max, Cortex, Germany). The Metalyzer was calibrated before each CPET using standard calibration gases of 16.4% O_2 and 4.5% CO_2 (Cryoservice Ltd., UK). The turbine flow meter was calibrated with a 3L syringe. Room temperature, relative humidity and barometric pressure were recorded from an Oregon Scientific Weather Station (Oregon Scientific, USA). The highest $\dot{V}O_2$ measure attained from 30-second averages derived from continuous breath-by-breath data was recorded as the participants $\dot{V}O_{2peak}$ (Astorino, 2009). Ratings of perceived exertion (RPE) ≥ 18 on the CR20 scale (Borg, 1982), alongside a respiratory exchange ratio (RER) ≥ 1.15, were noted to evaluate maximal effort levels. The ventilatory threshold (VT) was identified as the point at which the ventilatory rate (Ve) and volume of carbon dioxide ($\dot{V}CO_2$) break linearity with the volume of oxygen ($\dot{V}O_2$), using the v-slope method (Beaver et al., 1986) from the middle 5 of 7 average derived from breath-by-breath data, which was corroborated with assessment of the ventilatory equivalents (Levett et al., 2018). After the CPET participants completed a cooldown consisting of 5 minutes of unloading pedalling (Glaab & Taube, 2022), during which cardiovascular measures were continually monitored. At the cessation of exercise, participants were transferred to a bed, where they rested in the supine position for a further three minutes under the supervision of a member of the research team. Verbal encouragement was standardised across all participants and no music was played during sessions. All sessions were supervised by a first aider (Jordan Bell, Abbie Taylor or Jack Patton).

4.10. Strength Testing

During baseline and post-intervention testing for the feasibility study **(Chapter 7.0)** each participant completed 8-repetition maximum (8RM) strength testing in a temperature-controlled gym for each of the following exercises: barbell squat, deadlift, barbell bench press and machine shoulder press (Technogym, Italy). For all free-weight exercises 20kg barbells (Eleiko, Sweden) were used alongside weight plates (Eleiko, Sweden) in increments of 1.25kg, 2.5kg, 5kg, 10kg and 20kg as required.

For each exercise participants performed a warm-up with an unloaded barbell until appropriate form was achieved. This provided participants with a familiarisation of the exercise in order to limit the risk of injury and also to maximise the effect of the exercise session (by ensuring participants were performing exercises correctly and therefore achieving a true 8RM). Thereafter, increasing amounts of load were added to the barbell until participants could complete an 8th but not a 9th repetition. If more than 8 repetitions could be performed the load was increased 5 - 10%, with 3 minutes rest allowed between attempts, and 5 minutes between exercises. 8RM was selected due to the sedentary baseline characteristics of the participants and likely unfamiliarity with resistance exercises and was also used to ascertain working sets during CT workouts. This protocol of attempting maximal sets is demonstrated to have high to very high rates of reliability and agreement in high-risk individuals (dos Santos et al., 2019). The strength tests were the first exercise assessments completed in order to minimise influence of the interference effect (Laursen and Buchheit, 2019).

4.11. HIIT protocols

4.11.1. The delta method

The intensity of exercise during the HIIT protocols was set using the delta (Δ) method established by Lansley et al. (2011), in order to create individualised workloads, well matched between-subjects (Lansley et al., 2011). The intensity was set as a percentage of the difference between the workload at the ventilatory threshold (W_{VT}) and the workload at peak oxygen uptake (W_{peak}) achieved during CPET. Thus, the prescribed intensities were individualised, and allowed for a more appropriate intensity for the participant. In order to work out a given percentage of an individual's delta ($x\%\ \Delta$) the following was established:

$$x\Delta = \left(W_{VT} - \frac{2}{3} ramp\ rate \right) + \frac{x}{100}\left(W_{peak} - W_{VT} \right).$$

Two-thirds of the 20 W·min^{-1} CPET ramp rate (13.7) was subtracted from the VT and $\dot{V}O_{2peak}$ to account for the mean response time of $\dot{V}O_2$ during ramped exercise (Whipp et al., 1981). The workload for each HIIT interval was set at 80% Δ (rounded to the nearest whole W) which Lansley et al. (2011) recommend as severe-intensity exercise, corresponding to ~90% $\dot{V}O_{2max}$. A schematic and worked example further demonstrate the delta method in **Appendix J**.

4.11.2. Exercise protocol

The HIIT protocol was completed on a Lode Excalibur cycle ergometer, with a 5-minute warm-up at 60 W to prevent musculoskeletal injury. The protocol followed a modified-style HIIT design with 10 x 60 s intervals interspersed with 60 s rest. The 10 x 60 s design is a safe and well-tolerated HIIT design that is well established in both healthy, clinical, sedentary and overweight populations (Hood et al., 2011; Little et al., 2011, 2014). Each participant cycled at a self-selected cadence for 60 s at 80% Δ followed by 60 s rest, for a total of 20 minutes. Following the final HIIT interval participants continued cycling for 5 minutes at 60 W in a cooldown phase. This constituted a total session duration of 30 minutes. All HIIT sessions were supervised by a member of the research team and a first aider. Verbal encouragement was standardised across all participants and no music was played during sessions.

4.12. Concurrent Training Protocol

All concurrent training sessions were carried out in a temperature-controlled testing gym at the University of Sunderland. Participants completed a 5-minute warm-up at 60 W on a Lode Excalibur cycle ergometer. Concurrent sessions consisted of 50% strength training and 50% HIIT. The strength training element of the session consisted of four separate resistance exercises: barbell squat, deadlift, barbell bench press and machine shoulder press. These exercises were selected in order to target major muscle groups with dynamic movements (ACSM, 2013). All sets utilised the 8RM measured during baseline testing for each participant. For each resistance exercise the participants completed: 4 repetitions at 100% of their 8RM for the relevant exercise, 30 seconds rest, then 1 set of 8 repetitions at 100% of their 8RM, with 60 s rest between exercises. For the HIIT component of the sessions, participants completed 5 x 60 s intervals at 80%Δ on a Lode Excalibur cycle ergometer, interspersed with 5 x 60 s passive recovery for a total of 10 minutes. A 5-minute cool down on the cycle ergometer at 60 W followed the session. This ensured a duration of 10 minutes for strength exercises, 10 minutes for HIIT and 30 minutes per session. All concurrent training sessions were supervised by a first aider and member of the research team ((Jordan Bell, Morc Coulson, Abbi Taylor or Jack Patton). Verbal encouragement was standardised across all participants and no music was played during sessions.

4.13. Feasibility Training Study Methodology

The protocol for the feasibility study was preliminarily recorded on ClinicalTrials (Identifier: NCT05351177) in April 2022. Preregistration was undertaken as it is key in sport and exercise science research in order to improve transparency and replicability by ensuring hypotheses and main analyses are less susceptible to bias through questionable research practices (Caldwell et al., 2020).

4.13.1. Participants

Having gained ethical approval for the study through the University of Sunderland **(Chapter 4.1.)**, 41 participants were recruited from the University and local area and were screened against inclusion criteria **(Chapter 4.2.)** to ensure each were sedentary males with overweight or obesity with no existing co-morbidities. Participants were withdrawn from the study if they did not meet inclusion criteria, or by their own decision, having considered the study requirements or not responded to further communications. A total of 22 remaining participants were randomised into a high-intensity interval training (HIIT) or concurrent exercise training (CT) group via a computerised randomiser (Sealed Envelope Ltd., 2020). A total of 18 participants completed the 8-week exercise intervention in either the HIIT or CT group and were included in analyses **(Figure 4.1)**. The participant characteristics of the 18 participants at baseline that completed the study are presented in **Table 4.2.**

Table 4.2. Participant Baseline Characteristics – Feasibility Study.

	CT	**HIIT**
n	8	10
Age (years)	36 ± 6	38 ± 12
Height (cm)	172.9 ± 5.9	179.1 ± 7.9
Body Mass (kg)	92.7 ± 10.7	106.6 ± 27.0
Body Mass Index (kg·m^2)	31.0 ± 2.6	32.9 ± 6.3
Resting Heart Rate (beats·min^{-1})	73 ± 12	78 ± 6
Systolic Blood Pressure (mmHg)	130 ± 6	133 ± 9
Diastolic Blood Pressure (mmHg)	81 ± 6	85 ± 5
$\dot{V}O_{2peak}$ (ml·kg^{-1}min^{-1})	31.5 ± 6.7	28.7 ± 7.1

Data presented as Mean ± SD.

4.13.2. Exercise Training

A study schematic is presented at **Figure 4.2.** Participants were randomised into one of: High-Intensity Interval Training (HIIT) or Concurrent Exercise Training (CT) groups. Both exercise groups’ training sessions consisted of 30-minute sessions in the exercise testing gym at the University of Sunderland, on two days per week for eight weeks. Each group completed a 5-minute warm-up and a 5-minute cooldown on a Lode Excalibur Cycle Ergometer at a workload of 60 W. The HIIT or CT components of each exercise session constituted 20 minutes. The HIIT group completed 10 x 60 second intervals at an intensity of 80% delta on the Lode Excalibur Cycle Ergometer (**Chapter 4.10.**).

After the final resistance training exercise, participants were provided with 60 seconds rest, before returning to the Lode Excalibur Cycle Ergometer to complete 5 x 60 s cycling intervals at an intensity of 80% delta. RPE and HR were collected at the end of each HIIT interval. At the end of exercise, total session duration was recorded. Exercise intensity was progressed 5% per week (ACSM, 2009) for resistance exercises (kg), which was matched for HIIT intervals (in W) upon a session-to-session relative reduction in RPE. As we previously demonstrated that markers of internal physiological load upheld greater reliability to RPE in this HIIT protocol **(Chapter 5.0)**, the reduction in RPE was corroborated with HR data for the HIIT protocols (a general session-to-session reduction for the relative HIIT interval).

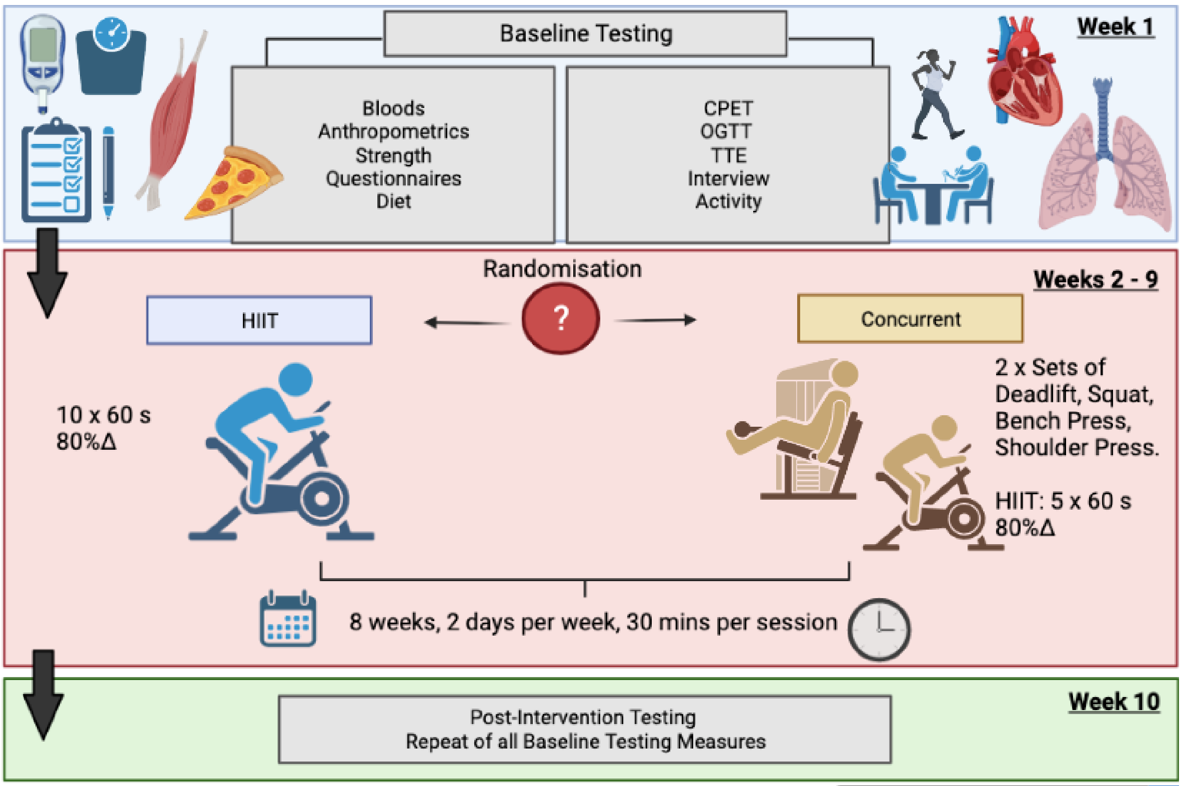

Figure 4.2. Feasibility Study Schematic.

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4.14. Activity and Dietary monitoring

Diet and exercise outside of the study were controlled for during the feasibility training study **(Chapter 6.0.** & **Chapter 7.0.)**. A representative four-day period inclusive of two weekdays and both weekend days, was selected in which a diet diary **(Appendix K)** was self-reported by all participants, with each instructed on how this should be completed. This was analysed for energy intake and relative macronutrient intakes (Nutritics Software, Ireland). Though individuals living with obesity are often noted to underreport dietary intakes (Ravelli & Schoeller, 2020), no incidences of underreporting were recorded. Habitual physical activity levels were assessed via ActiGraph wGT3X-BT (ActiGraph, USA) raw-signal accelerometers. Each participant was instructed on how to correctly place the monitor around the waist, which was in place for a minimum of four days across the week of baseline testing (two weekday and both weekend days). The raw accelerometer data was uploaded to Actilife Software (ActiGraph, USA), from which energy expenditure was calculated using the Freedson equation (Freedson et al., 1998) and total energy expenditure was calculated by the addition of resting metabolic rate and diet induced thermogenesis (calculated in Nutritics Software). Time spent in moderate to vigorous exercise (MVPA) was extracted using the Freedson Adult cut-points. Data was collected during baseline (Week 1) and post-intervention (Week 10) of the study. The results of the dietary and activity monitoring are presented in **Table 4.3.** for pre- and post-intervention for participants in both groups. The data indicates that there were negligible changes pre- and post-intervention for dietary intakes and energy expenditure. Interestingly, energy intake exceeded energy expenditure, despite the capacity of individuals living with obesity to underreport energy intake, perhaps reaffirming that the participants were in a positive energy balance.

Table 4.3. Four-Day Average Dietary and Activity Monitoring Results.

	CT		**HIIT**	
	Pre	Post	Pre	Post
Energy Intake (kcal)	2894 ± 327	2910 ± 347	2799 ± 402	2826 ± 374
Carbohydrate (%)	50.4 ± 9.3	52.6 ± 10.1	55.2 ± 11.4	56.1 ± 10.9
Fat (%)	34.2 ± 6.2	31.1 ± 5.5	29.8 ± 7.5	30.3 ± 6.6
Protein (%)	14.2 ± 3.6	15.7 ± 2.9	16.0 ± 4.2	15.8 ± 4.1

Energy Expenditure (kcal)	2549 ± 457	2611 ± 414	2613 ± 399	2658 ± 433
Time in MVPA (minutes)	57 ± 43	84 ± 40	67 ± 55	69 ± 64

Data presented as a 4-day mean average ± SD.

4.15. Statistical Analysis

All data was analysed using IBM SPSS Statistics ver. 27 (IBM Corp., USA) and was initially assessed for normal distribution via evaluation of Q-Q plots and histograms. The alpha level was set at 0.05 with confidence intervals at 95% unless stated otherwise. All figures were recreated using GraphPad Prism 7 (GraphPad, USA). Meta-analyses **(Chapter 3.0)** were completed using RevMan ver. 5 (RevMan, Cochrane).

4.15.1. Reliability analysis

Reliability analyses were undertaken to establish the test-retest reliability between HIIT protocols **(Chapter 5.0.)** and the reliability of the echocardiograph operator **(Chapter 4.7.3.)**. In order to determine test-retest reliability, the mean difference (MD) and 90% confidence limits (CL) of each variable were calculated to establish the range of systemic change. To qualitatively interpret the magnitude of the MD the smallest worthwhile change (SWC) was determined by multiplying pooled standard deviations by standard thresholds (< 0.2 = trivial, 0.2 = small, 0.6 = moderate, 1.2 = large), with the 90% CL assessed against the SWC (Smith and Hopkins, 2011). The typical error between-protocols was calculated both in the units of each variable, and as a coefficient of variation (CV) percentage via log-transforming and back-transforming the data (Hopkins et al., 2009).

To assess the magnitude, SWC thresholds were halved and compared to the typical error value to make qualitative inferences. Intraclass correlation coefficient (ICC) estimates and their 95% confidence intervals were calculated based on an average measurement, consistency, 2-way mixed effects model (3,1) (Shrout and Fleiss, 1979). ICC (3,1) was calculated on log-transformed data for between-protocol changes in variables across the 20-minute protocol and additionally in five-minute increments for $\dot{V}O_2$, HR and RPE. Interpretation of confidence intervals to establish reliability level was based on the thresholds identified by Koo and Lee (2016) whereby each threshold showed reliability to be: < 0.5 = poor; 0.5 – 0.75 = moderate (mod.); 0.75 – 0.9 = good (gd.); > 0.9 = excellent (ex.).

4.15.2. Linear Mixed Modelling

Linear Mixed Models (LMM) were utilised in order to establish rates of change to quantify variances during the test-retest reliability of the HIIT protocol **(Chapter 5.0.)** and HR results during workouts in the 8-week exercise training programme **(Chapter 7.0.)**.

In the statistical analysis of the reliability study **(Chapter 5.0)** order to quantify the variance in internal load over time during the HIIT protocol both between-protocols and within-subjects, the rate of change for HR and $\dot{V}O_2$ were determined using linear mixed models (LMM). Raw HR data taken from 60 second averages of breath-by-breath data was not normally distributed, therefore both $\dot{V}O_2$ and HR data were first log-transformed to reduce non-uniformity of error, and back-transformed post-analysis to present fixed effect estimates as percentage changes (Hopkins et al., 2009). Conditions (HIIT 1 and 2) were split, and time was added as a fixed effect (covariate), in order to estimate the rate of change in HR or $\dot{V}O_2$ per minute of the HIIT protocols. A random intercept for subject and a slope for time were added in an unstructured covariance matrix. The U2,2 (slope SD) was used to quantify the size of variation in slope changes between individuals. The SWC was calculated by multiplying the SD by standard thresholds, with the slope SD value doubled and measured against these thresholds to determine magnitude of change (Smith and Hopkins, 2011). Conditions were compared using the split file function with and without passive recovery data, then compared together, using the same LMM procedure, but with condition added as a fixed factor and 'Condition*Time' added as a fixed effect model, providing pairwise comparisons.

In the statistical analysis of the exercise training programme **(Chapter 7.0)** the rate of change of HR data collected during both the CT and HIIT exercise sessions was quantified via LMM. HR data was collected at the end of each HIIT interval or resistance exercise set. This data was normally distributed. Conditions (HIIT and CT) were split, and time was added as a fixed effect (covariate), in order to estimate the rate of change in HR per minute of the exercise protocols. A random intercept for subject and a slope for time were added in an unstructured covariance matrix. The U2,2 (slope SD) was used to quantify the size of variation in slope changes between individuals. 'Condition*Time' was added as a fixed effect model, providing pairwise comparisons.

4.15.3. ANCOVA

Changes in measures pre- to post-intervention from the eight-week exercise training programme **(Chapter 6.0. & 7.0.)** were sought to determine any significant statistical differences in group mean values. One-way Analysis of Covariance (ANCOVA) tests were performed to incorporate baseline data as a covariate, accounting for any differences between-groups at baseline (Vickers 2001, 2009; Funatogawa et al., 2011). Assumptions for ANCOVA (independence of the covariate and treatment effect and homogeneity of regression slopes) were checked (Field, 2013). Post data was included as the dependant variable, with the group a fixed factor and pre data as a covariate. Main effects for groups were compared with descriptive statistics and estimates of effect sizes displayed with Bonferroni confidence interval adjustment. As such, statistically significant differences were sought between adjusted means, to account for any pre-intervention differences between groups. The results were reported as unstandardised effect sizes (mean differences and point estimates) with confidence intervals presenting a range of plausible effect sizes compatible with the data and underlying statistical model.

Chapter 5.0. Establishing the test-retest reliability of the 'delta' (Δ) method of exercise prescription for high intensity interval training (HIIT) in individuals with overweight and obesity

Chapter 3.0. demonstrated the lack of CT designs incorporating HIIT protocols for this population in the literature. As such, an important objective is to establish a protocol which is feasible, reliable, and repeatable for this population, with low between-subject variations in the actual exercise intensities achieved. Moreover, **Chapter 2.0.** highlighted the vast range of HIIT protocol designs that currently exist in the literature. This chapter aims to establish a HIIT protocol design which is feasible, reliable, and repeatable with low between-subject variation.

5.1. Introduction

High-intensity interval training (HIIT) may be an appealing exercise strategy due to its suggested time efficiency (Gibala et al., 2012) and the reported enhanced cardiometabolic benefits over other means of exercise including; moderate intensity continuous exercise [MICT (Hwang et al., 2011; Tjønna et al., 2008)]. Indeed, in overweight and obesity, HIIT provides favourable adaptations in cardiorespiratory fitness, body composition, metabolic health and enjoyment, which are comparable or superior to moderate intensity continuous exercise training (Andreato et al., 2019; Batacan et al., 2017; De Strijcker et al., 2018; Su et al., 2019; Thum et al., 2017; Wewege et al., 2017; Wood et al., 2019). Thus, due to its time-efficiency, HIIT may be a superior exercise strategy for individuals with overweight and obesity, although both its time-efficiency and feasibility for widespread adoption by the general public have been challenged (Biddle and Batterham, 2015; Roy et al., 2018).

HIIT is characterised by short intervals of high-intensity exercise interspersed with low-intensity exercise or rest (Gibala et al., 2012). Whilst a plethora of HIIT definitions exist in the literature (Batacan et al., 2017; Laursen and Buchheit, 2019; Weston et al., 2014), the intensity of HIIT intervals are commonly accepted to be those above the lactate threshold (Laursen and Buchheit, 2019). Well-established HIIT protocols follow 10 x 60 s interval designs, interspersed with 60 s rest (Little et al., 2010). These models have been established as safe and effective in sedentary, clinical and populations with obesity (Hood et al., 2011; Little et al., 2014, 2011). However, the intensity of the exercise is often pre-specified and made relative to one's heart rate or $\dot{V}O_{2peak}$. The use of dosing exercise intensity based on maximal anchors (e.g. $\dot{V}O_{2peak}$ or HR_{max}) has been shown to produce wide heterogeneity in HIIT protocol designs, and normalisation of the intensity of exercise prescribed (Jamnick et al., 2020; Whipp et al., 2005). Indeed, assessment of $\dot{V}O_{2peak}$ from a graded exercise test (GXT) is often difficult due to a delayed steady state of O_2 uptake (the 'slow component') and constant moderation of the work rate is required to maintain a specific percentage of $\dot{V}O_{2peak}$ (Jamnick et al., 2020). Moreover, prescribing exercise intensity as a percentage of $\dot{V}O_{2peak}$ leads to inter-individual physiological differences, including lactate concentration and the percentage of $\dot{V}O_{2peak}$ at which the lactate threshold occurs (Scharhag-Rosenberger et al., 2010). This establishes difficulty comparing research studies and consistent prescription of HIIT for the population with overweight and obesity .

An alternate method of exercise intensity prescription is the delta (Δ) method (Lansley et al., 2011) wherein the exercise intensity is set relative to the workload at the VT (W_{VT}) and $\dot{V}O_{2peak}$ (W_{peak}); [$W_{VT} + x(W_{peak} – W_{VT})$]. The delta method is proposed to reduce inter-subject variability in pulmonary gas exchange, heart rate (HR) and ratings of perceived exertion (RPE), more effectively normalising exercise intensity versus traditional exercise prescription (Lansley et al., 2011). Indeed, exercising at intensities set relative to the VT result in similar metabolic and cardiac stresses in those with differing fitness levels, whereas exercising relative to $\dot{V}O_{2peak}$ causes significant variations (Baldwin et al., 2000). Lansley et al. (2011) suggest the delta method should become the preferred means of intensity prescription in human exercise physiology. However, much of the attention to this concept has been explored using constant-work-rate exercise in healthy individuals and concerns have been raised over the use of unreliable physiological variables (e.g., end-exercise HR and absolute blood lactate concentration) to determine validity (Jamnick et al., 2020). Although the delta method has been used for exercise prescription (McGinley et al., 2016), previous authors have found no research directly relating to the reliability of physiological responses (Jamnick et al., 2020). The use of the delta method for exercise prescription in HIIT is limited, though it has been utilised effectively in healthy moderately trained men (Granata et al., 2016). However, in this study, the wide variation in number of intervals (5 – 12), intensity (30 – 80% Δ) and lack of account for the mean response time of $\dot{V}O_2$in the exercise prescription (Whipp et al., 1981) make assumptions on validity and reliability difficult.

To our knowledge only one study has determined the reliability of physiological responses to the delta method of exercise prescription in HIIT (Bossi et al., 2019). In this study, male and female cyclists completed four HIIT sessions at 70% Δ to exhaustion. Peak HR, rating of perceived exertion (RPE) and blood lactate concentrations were consistently achieved across each HIIT session, although there were inter-individual variabilities in time to exhaustion. However, as the HIIT protocol was performed to exhaustion, the relative time spent completing HIIT also differed between individuals, and the research was performed in highly active participants. There exist no guidelines in the published literature on how the delta method compares to more traditional exercise intensity parameters, and how this equates to exercise intensity guidelines.

Further research on the reliability of physiological responses to the delta method of exercise prescription in HIIT is required in order to determine the inter- and intra-individual variability. To our knowledge, no previous research has determined the reliability of the delta method of exercise prescription for intermittent exercise in sedentary, individuals with overweight and obesity. It is essential to establish the reliability of the delta method in this population to accurately prescribe HIIT intensities that provide a consistent physiological response. Moreover, given that lack of enjoyment is a key barrier to adherence of lifestyle interventions in adults with obesity and long-term adherence to exercise (Aaltonen et al., 2012; Burgess et al., 2017) the feasibility of completion, enjoyment and widespread adoption of HIIT protocols utilising the delta method of exercise prescription for individuals with overweight and obesity is key to ascertain. Therefore, the aim of our study was to establish the test-retest reliability of the delta method for exercise prescription in a HIIT protocol completed by individuals with overweight and obesity by examining the reliability of enjoyment, RPE and measures of internal physiological load.

5.2. Methods

5.2.1. Participants

Upon local research ethics approval from the University of Sunderland, adult (18 – 66 years) male volunteers were recruited from the local area **(Chapter 4.3.1)**. The inclusion criteria for the study were; 1) a body mass index (BMI) > 25 $kg{\cdot}m^2$, 2) have no associated co-morbidities (such as type 2 diabetes mellitus), and 3) not currently meeting minimal exercise and physical activity guidelines (Piercy et al., 2018). In total, 16 individuals were recruited, three of whom were excluded for not meeting BMI criteria and three participants who did not fully complete the study (work commitments n = 2, injury n = 1). 10 participants were included in the final analysis, baseline characteristics are included in **Table 5.1**.

Table 5.1 Participant Characteristics

Variable	Baseline Measure
Age (years)	36 ± 10
Body Mass (kg)	102.0 ± 16.8
BMI ($kg \cdot m^2$)	32.4 ± 5.5
SBP (mmHg)	122 ± 11
DBP (mmHg)	82 ± 9
Waist Circumference (cm)	109.5 ± 15.5
$\dot{V}O_{2peak}$ ($ml \cdot kg^{-1} min^{-1}$)	29.7 ± 6.3
W_{peak}	237 ± 33
VT^1 (W)	70 ± 27
VT^1 (%)	42 ± 6
80% Δ (W)	190 ± 31
80% Δ expressed as $\%W_{max}$	80 ± 2
80% Δ expressed as $\%\dot{V}O_{2peak}$	84.9 ± 1.8
PRETIE-Q Tolerance	21 ± 4
PRETIE-Q Preference	25 ± 5

Note. Presented as mean ± SD. **Abbr.** *BMI, body mass index; DBP, diastolic blood pressure; PRETIE-Q, preference for and tolerance of the intensity of exercise questionnaire; SBP, systolic blood pressure; VT, ventilatory threshold; Wmax, maximum Watts.*

5.2.2. CPET

Participants attended the laboratory on three separate occasions completing: a cardiopulmonary exercise test (CPET) to volitional exhaustion, and two single-session HIIT protocols. For the CPET **(Chapter 4.9.)** participants attended the laboratory having been advised to consume a light carbohydrate-containing meal two hours prior and asked to avoid consumption of caffeine and alcohol for the previous 24 hours. After providing informed consent and completing pre-exercise screening in-line with American College of Sports Medicine (ACSM) guidance **(Chapter 4.2.)**, anthropometric measures were also taken **(Chapter 4.4.)**.

5.2.3. HIIT Protocol

Participants attended the laboratory twice, in the morning one week apart, having completed a 12-hour fast. Participants were advised to perform no physical activity or exercise three days prior to each visit. The HIIT protocol **(Chapter 4.11.)** consisted of 10 x 60 s intervals at a self-selected cadence, interspersed with 10 x 60 s rest, constituting a total of 20 minutes (Little et al., 2010). The workload for each HIIT interval was set at 80% Δ (rounded to the nearest W) which Lansley et al. (2011) recommend as severe-intensity exercise, corresponding to ~90% $\dot{V}O_{2max}$ **(Chapter 4.11.1.)**. For comparative purposes this workload was also expressed as a percentage of the participant's W_{max} and $\dot{V}O_{2peak}$ by dividing the wattage at 80% Δ by the wattage at $\dot{V}O_{2peak}$ minus two-thirds ramp rate **(Table 5.1)**. Throughout each HIIT protocol HR and respiratory gases were continuously collected via Metalyzer (Cortex, Germany) and a Polar H10 Bluetooth heart rate monitor (Polar, Finland). Breath-by-breath data was converted to 60-second averages for each HIIT interval or rest period, providing 20 data points per protocol. RPE was assessed at the end of each HIIT interval via the Borg category ratio scale (CR100) (Borg and Borg, 2001). At 10-minutes post-exercise, session-RPE and the physical activity enjoyment scale (PACES) score were recorded (Kendzierski and DeCarlo, 1991) **(Chapter 4.5.)**.

5.2.4. Statistical Analysis

All data was assessed for normal distribution **(Chapter 4.15.)** through IBM SPSS Statistics ver. 27 (IBM Corp., USA). In order to establish the test-retest reliability between the HIIT protocols mean differences (MD), smallest worthwhile changes (SWC), typical error and intraclass correlation coefficients (ICC) were calculated **(Chapter 4.15.1.).** In order to quantify the variance in internal load over time both between-protocols and within-subjects, the rate of change for HR and $\dot{V}O_2$ were determined using linear mixed modelling **(Chapter 4.15.2.)**.

5.3. Results

Each participant completed all 10 HIIT intervals in both workouts with no reported adverse events. The average intensity of exercise (dosed individually at 80% Δ) equated to ~190 W or ~80% W_{max} respectively, which corresponded to an average of ~67% $\dot{V}O_{2peak}$ and ~81% HR_{peak} during the HIIT intervals. The mean values for measures across the entire 20-minute HIIT protocols and, where relevant, intervals only are summarised in **Table 5.2**. Mean enjoyment from both bouts assessed via the PACES was ~97.

Table 5.2 Mean values of selected variables across both conditions.

Measure		HIIT 1	HIIT 2
RHR (beats·min^{-1})		79.2 ± 12.3	78.0 ± 12.0
RPE		39.1 ± 7.1	37.9 ± 8.5
Session RPE		43.0 ± 18.0	47.5 ± 18.1
HR (beats·min^{-1})	Total	135.0 ± 12.5	136.7 ± 13.0
	Intervals	137.3 ± 11.8	139.1 ± 12.3
%HR_{peak}	Total	78.6 ± 5.8	79.6 ± 5.9
	Intervals	80.3 ± 5.5	81.3 ± 5.0
%HRR	Total	63.1 ± 9.7	64.7 ± 10.4
	Intervals	64.6 ± 9.3	66.1 ± 9.4
Absolute $\dot{\boldsymbol{V}}\boldsymbol{O_2}$ (L·min^{-1})	Total	1.8 ± 0.2	1.8 ± 0.2
	Intervals	2.0 ± 0.2	2.0 ± 0.2
Relative $\dot{\boldsymbol{V}}\boldsymbol{O_2}$ (ml·kg^{-1}min^{-1})	Total	18.2 ± 3.6	18.4 ± 3.4
	Intervals	19.8 ± 4.5	20.1 ± 4.2
% $\dot{\boldsymbol{V}}\boldsymbol{O_{2peak}}$	Total	61.7 ± 5.2	62.4 ± 5.8
	Intervals	66.7 ± 6.3	67.7 ± 6.0
Enjoyment		98.2 ± 11.2	95.7 ± 11.6
Adverse Events		0 ± 0	0 ± 0
Intervals Completed		10 ± 0	10 ± 0

Note. Presented as mean ± SD for the entire HIIT protocol (20mins) unless otherwise stated as for HIIT intervals only (total 10 minutes). ***Abbr.*** HR, heart rate; HRR, heart rate reserve; RHR, resting heart rate; RPE, rating of perceived exertion.

Measures of test-retest reliability for variables measured across the full 20 minutes of each HIIT protocol are presented in **Table 5.3**. All variants of $\dot{V}O_2$ had trivial to moderate typical error (≤ 2.3%) and ICC (3,1) 95% CIs demonstrated good to excellent reliability. Measures of HR had moderate to excellent measures of reliability, with a higher typical error (moderate) particularly for HRR (6.0%) than any other measure of internal load. Measures of RPE held small to moderate degrees of typical error, though maintained moderate to excellent reliability and the 18-point PACES displayed good to excellent reliability.

When split into five-minute increments, measures of subjective and internal load appeared to maintain homogeneity between-conditions. Accordingly, measures of test-retest reliability for each five-minute increment established low typical error in $\dot{V}O_2$ and HR (≤ 4.5%) with moderate to excellent reliability **(Table 5.4)**. However, typical error in RPE reached maximum values of 20.5% for the 0 – 5 min period, with 95% CI indicating poor to excellent reliability. Test-retest reliability for RPE improved over subsequent time periods, but demonstrated greater typical error than $\dot{V}O_2$ and HR. The results for the between-subject variation in internal physiological load are presented in **Table 5.5**. The back-transformed fixed effect estimates suggest a rate of change of ~1.0% per minute for all variables in both HIIT bouts with a moderate to large between-subject variation in the rate of change of 2.0%. Pairwise comparisons **(Table 5.6)** show non-significant differences in the rate of change for total $\dot{V}O_2$ and HR between-conditions. Though, when passive recovery data was omitted, significant differences existed for both $\dot{V}O_2$ (p = 0.01) and HR (p = 0.03).

Table 5.3. Test-retest reliability for measures of enjoyment, subjective and internal load between-conditions

Outcome Measure	Mean Difference	90% CI of mean difference		Magnitude	Typical Error	Typical Error as CV (%)	Magnitude	ICC (3,1)	ICC (3,1) 95% CI		ICC CI Interpretation
		Upper	Lower						Upper	Lower	
Absolute $\dot{V}O_2$ (L·min^{-1})	0.0	0.1	-0.0	Trivial to Small	0.0	2.3%	Trivial to Small	0.968	0.992	0.872	Gd. to Ex.
Relative $\dot{V}O_{2peak}$ (ml·kg^{-1}min^{-1})	0.1	0.5	-0.2	Trivial	0.4	2.2%	Trivial to Small	0.993	0.998	0.972	Ex.
$\dot{V}O_{2peak}$ (%)	0.6	1.9	-0.6	Trivial to Small	1.5	2.3%	Small to Moderate	0.962	0.962	0.849	Gd. to Ex.
Heart Rate (beats·min^{-1})	1.7	4.8	-1.4	Trivial to Small	3.8	2.8%	Moderate	0.957	0.989	0.827	Gd. to Ex.
HR_{peak} (%)	1.0	2.7	-0.8	Trivial to Small	2.1	2.8%	Moderate	0.930	0.983	0.718	Mod. to Ex.
HRR (%)	1.6	4.5	-1.4	Trivial to Small	3.6	6.0%	Moderate	0.947	0.987	0.786	Gd. to Ex.
RPE (AU)	-1.2	1.2	-3.7	Small	3.0	9.1%	Moderate	0.899	0.975	0.595	Mod. to Ex.
Session RPE (AU)	4.5	8.0	1.0	Trivial to Small	4.2	11.6%	Small	0.951	0.988	0.802	Gd. to Ex.
Enjoyment	-2.5	0.2	-5.2	Trivial to Small	3.3s	3.6%	Small	0.954	0.989	0.815	Gd. to Ex.

Abbr. AU, arbitrary units; CI, confidence intervals; CL, confidence limits; CV, coefficient of variation; Ex, excellent; Gd, good; HR_{peak}, peak heart rate; HRR, heart rate reserve; ICC, intraclass correlation coefficient; MD, mean difference; Mod, moderate; PACES, physical activity enjoyment scale; RPE, rating of perceived exertion; TE, typical error.

Table 5.4. Test-retest reliability for measures of subjective and internal load at five-minute increments between-conditions

Measure	Time Increment (mins)	Mean Difference	90% CL of Mean Difference		Typical Error	Typical Error as CV	ICC (3,1)	95% CI of ICC (3,1)		ICC (3,1) CI Interpretation
			Upper	Lower				Upper	Lower	
$\dot{V}O_2$ (L·min^{-1})	0 – 5	0.0	0.1	0.0	0.1	4.2 %	0.925	0.981	0.699	Mod. to Ex.
	6 – 10	0.0	0.1	0.0	0.1	3.6 %	0.930	0.983	0.720	Mod. to Ex.
	11 – 15	0.0	0.1	0.0	0.0	1.9 %	0.974	0.994	0.896	Gd. to Ex.
	16 – 20	0.0	0.0	- 0.1	0.1	4.5 %	0.904	0.976	0.612	Mod. to Ex.
HR (beats·min^{-1})	0 – 5	0.1	2.2	- 2.0	2.6	2.2 %	0.973	0.993	0.891	Gd. to Ex.
	6 – 10	1.5	4.6	- 1.7	3.8	2.9 %	0.961	0.990	0.842	Gd. to Ex.
	11 – 15	3.0	7.1	- 1.1	5.0	3.5 %	0.937	0.984	0.748	Mod. to Ex.
	16 – 20	2.0	6.0	- 2.0	4.9	3.2 %	0.948	0.987	0.792	Gd. to Ex.
RPE (CR100)	0 – 5	- 4.2	- 1.8	- 6.6	2.9	20.5 %	0.862	0.966	0.444	Poor to Ex.
	6 – 10	- 2.7	- 1.3	- 4.1	1.7	6.4 %	0.957	0.989	0.825	Gd. to Ex.
	11 – 15	1.7	5.4	- 2.0	4.5	10.0 %	0.889	0.972	0.554	Mod. to Ex.
	16 – 20	0.4	4.4	- 3.6	4.8	8.8 %	0.952	0.988	0.805	Gd. to Ex.

Abbr. CI, confidence intervals; CL, confidence limits; CV, coefficient of variation; Ex, excellent; Gd, good; HR, heart rate; ICC, intraclass correlation coefficient; Mod, moderate; RPE, rating of perceived exertion.

Table 5.5. Rate of change for measures of internal load

Measure	Condition	Fixed Effect Estimate (%)	95% CI		P-Value	SD of the Fixed Effect	SD of the Fixed Effect (95% CI)		SD Magnitude
			Upper	Lower			Upper	Lower	
Interval HR (beats·min^{-1})	HIIT 1	1.04	1.05	1.03	< 0.001	2.00	2.00	2.00	Mod. to Lg.
	HIIT 2	1.05	1.06	1.04	< 0.001	2.00	2.00	2.00	Mod. to Lg.
Interval $\dot{V}O_2$ (L·min^{-1})	HIIT 1	1.04	1.06	1.02	0.002	2.00	2.00	2.00	Mod. to Lg.
	HIIT 2	1.04	1.05	1.02	< 0.001	2.00	2.00	2.00	Mod. to Lg.
Total HR (beats·min^{-1})	HIIT 1	1.02	1.02	1.03	< 0.001	2.00	2.00	2.00	Mod. to Lg.
	HIIT 2	1.02	1.02	1.03	< 0.001	2.00	2.00	2.00	Mod. to Lg.
Total $\dot{V}O_2$ (L·min^{-1})	HIIT 1	1.01	1.02	1.01	0.006	2.00	2.00	2.00	Mod. to Lg.
	HIIT 2	1.01	1.02	1.01	< 0.001	2.00	2.00	2.00	Mod. to Lg.

Abbr. CI, confidence intervals; HR, heart rate; Lg, large; Mod, moderate; SD, standard deviation.

Table 5.6. Pairwise comparisons for measures of internal load between-conditions

Measure	Mean Difference	95% CI		P-Value
		Upper	Lower	
Interval HR (beats·min^{-1})	0.01	0.00	0.02	0.010
Interval $\dot{V}O_2$ (L·min^{-1})	0.02	0.00	0.03	0.032
Total HR (beats·min^{-1})	0.01	- 0.03	0.05	0.702
Total $\dot{V}O_2$ (L·min^{-1})	0.01	- 0.01	0.03	0.358

Abbr. CI, confidence intervals; HR, heart rate.

5.4. Discussion

The aim of our study was to establish the test-retest reliability of the delta method for exercise prescription in a HIIT protocol completed by individuals with overweight and obesity by examining the reliability of enjoyment, ratings of perceived exertion and measures of internal physiological load. The main findings from this study were 1) a 10 x 60 s HIIT protocol dosed at delta 80 was successfully completed and corresponded to vigorous intensity exercise in males with overweight and obesity 2) all variables demonstrated moderate to excellent reliability, with internal load the most consistent, and 3) RPE was the least reliable, whilst measures of enjoyment via the PACES maintained good test-retest reliability. Our study is the first to demonstrate the efficacy of the delta method of HIIT prescription in overweight and obesity and to determine the reliability of measures of physiological load in shorter time increments across a HIIT protocol.

5.4.1. Intensity of exercise

Lansley et al. (2011) report that exercise at 80% Δ comprised 'severe-intensity' exercise, equivalent to 90% $\dot{V}O_{2max}$. However, we report that in our sample of males with overweight and obesity, HIIT intervals at 80% Δ corresponded to a mean of ~67% $\dot{V}O_{2peak}$, despite our estimation that this should have been equivalent to ~85% $\dot{V}O_{2peak}$ **(Table 5.1)**. This is likely due to the slow component of oxygen uptake and reaffirms the pitfalls of basing exercise prescription relative to $\dot{V}O_{2peak}$ (Jamnick et al., 2020). Our design used an intermittent high intensity rather than continuous moderate intensity protocol as utilised by Lansley et al. (2011), with the short HIIT intervals allowing for insufficient time to achieve a steady state of oxygen consumption, reflected by lower measurements of inspired O_2 (Whipp and Wasserman, 1972). Nonetheless, this intensity satisfies ACSM guidance of vigorous-intensity exercise (64 – 90.9% $\dot{V}O_{2max}$ – ACSM, 2014), albeit at the low end of the range. Indeed, recent systematic reviews and meta-analyses in individuals with overweight and obesity define 85% (Batacan et al., 2017) and 80% $\dot{V}O_{2max}$ (Andreato et al., 2019; Wewege et al., 2017) as the minimum intensity required to constitute HIIT.

When calculated with respect to HR, intensity of HIIT intervals equated to ~81% HR_{peak} and ~65% HRR, both of which satisfy ACSM criteria for vigorous-intensity exercise (76 – 96% HR_{peak}; 60 – 90% HRR). However, a wealth of research proposes that intensities of ≥ 85% HR_{max} should be utilised for HIIT in population with overweight and obesity s (Andreato et al., 2019; Batacan et al., 2017; Wewege et al., 2017). Indeed, HIIT research incorporating a 10 x 60 s design has successfully utilised intensities of 90% HR_{max} in clinical, and sedentary individuals as well as those living with obesity (Little et al., 2014, 2011). However, use of $\%HR_{max}$ to prescribe intensity receives similar criticism to $\dot{V}O_{2peak}$ (Jamnick et al., 2020), with high variability in individual metabolic responses – including the point at which the VT is reached – suggesting it is inaccurate for controlling exercise intensity (Iannetta et al., 2020).

In our study, 80% Δ also corresponded to a mean intensity of ~80% W_{peak} across all participants. The peak wattage, or peak power output (PPO), has previously been utilised to prescribe HIIT intensity for individuals with overweight and obesity. Fisher et al. (2015) used 85% PPO as the intensity for shorter cycling intervals of 30-seconds interspersed with four-minutes rest in young individuals with overweight and obesity. However, in an identical 10 x 60 s HIIT design to the present study Smith-Ryan et al. (2016, 2015) report successful completion at 90% PPO in both females and males with overweight and obesity. In our study, mean RPE across both conditions (~45) suggested intensity of exercise was between 'somewhat strong' and 'strong (heavy)' on the CR100 scale, equating to 13-15 on the 6-20 scale based on descriptors (Borg, 1982; Borg and Borg, 2001). HIIT prescription based on RPE in a similar population has also previously used a range of 13-15 on the 6-20 scale (Jakicic et al., 2003), with ACSM guidelines proposing that an RPE of 14-17 constitutes vigorous intensity (ACSM, 2014).

Taken together, the evidence suggests that HIIT at 80% Δ does correspond to vigorous-intensity exercise and as such 75 minutes per week of the protocol would be required to meet exercise guidelines for males with overweight and obesity. However, when compared to traditional exercise prescription methods utilised in previous research, 80% Δ does not appear to be the upper limit that can feasibly be completed by this population in a 10 x 60 s HIIT design. Nonetheless, in this study a sample of previously sedentary males with overweight and obesity moderate tolerance (~53% maximum PRETIE-Q score) and preference (~63% maximum PRETIE-Q score) of high-intensity exercise, successfully completed all HIIT intervals with no adverse effects and good enjoyment scores (~77% of maximum PACES score). Thus, 80% Δ may reflect an efficacious initial intensity of exercise for males with overweight and obesity wishing to commence HIIT.

5.4.2. Reliability of enjoyment, subjective and internal load

Although previous research has proposed that HIIT is deemed unpleasant in individuals with overweight and obesity (Roloff et al., 2020), our findings tend to concur with other studies which report high satisfaction, enjoyment and generally positive affective responses after

HIIT in overweight and obesity (Eather et al., 2019; Oliviera et al., 2018). Enjoyment is a key factor for those living with overweight or obesity, with lack of enjoyment a barrier to adherence in lifestyle interventions (Burgess et al., 2017). Previous research has also demonstrated that higher affective responses to exercise results in greater long-term adherence and reduced post-exercise calorie consumption (Schneider et al., 2009) and that PACES score is demonstrated to be a predictor of increased moderate- to vigorous-intensity exercise completion (Schwaneberg et al., 2017). Though research on the reliability of enjoyment across exercise sessions in overweight and obesity is limited, previous findings exhibit suboptimal agreement (ICCs 0.02 – 0.60) in measures of affective responses from pre- to post-exercise across 3 identical MICT sessions in females with overweight and obesity (Unick et al., 2015). Although in the current study we used a different method of determining affective responses (the PACES) and only assessed enjoyment post-exercise, we present good to excellent reliability of the affective response to HIIT **(Table 5.2)**. This is likely due to our use of an intermittent exercise protocol, which is proposed to elicit increased enjoyment and preference over MICT due to its constantly changing stimulus (Thum et al., 2017).

Mean RPE exhibited wide ICC (3,1) CIs which highlighted individual variations in test-retest RPE which was superseded in reliability by session-RPE **(Table 5.2)**. Previous research has concluded that HIIT is viewed as unpleasant and physically challenging during exercise, but more enjoyable post-exercise (Niven et al., 2020; Thum et al., 2017). Therefore, future research may wish to assess session-RPE at later timepoints, to determine if perceived exertion decreases or remains higher than during-exercise RPE, as we observe. RPE demonstrated higher typical error than measures of internal load **(Table 5.5)**, with the largest variations in the first five minutes between-protocols. Our findings concur with historical research which has questioned the test-retest reliability of RPE, particularly as exercise intensity increases (Lamb et al., 1999). Similarly, although session-RPE was reliable across a range of intensities, it remained less precise than $\dot{V}O_2$ or HR for establishing physiological load, which has also previously been observed (Herman et al., 2006). Though RPE may be more practical for continued use of intensity monitoring in unsupervised exercise, individuals may need to be coached to improve the reliability of RPE.

Measures of $\dot{V}O_2$ had trivial to moderate typical error (2.2 – 2.3%) and demonstrated good to excellent reliability between-protocols **(Table 5.3)** and was the superior measure of load in terms of reliability. However, when examining the reliability in five-minute increments **(Table 5.4)**, $\dot{V}O_2$ generally had a higher typical error than HR, with the greatest error measurements in the first and last five-minute periods. A possible explanation for this may be that the HIIT protocols were completed at an individual's self-selected cadence and not controlled. Therefore, participants may have increased their cadence in the initial and final intervals (when free from fatigue or motivated by nearing the end of the protocol). Indeed, previous research has highlighted pedalling cadence affects the $\dot{V}O_2$ response profile (Sylvester et al., 2011). Though these changes are not reflected in HR data, nor was cadence recorded and could be explained by erroneous measurements, tighter cadence controls should be applied in future HIIT protocols.

Historically, HR and $\dot{V}O_2$ are demonstrated to be equally reliable (Becque et al., 1993). In the present study, HR had good to excellent reliability, with small changes between-protocols (MD 95% CL: -1.4, 4.8) and its low typical error was maintained when expressed as a percentage of HR_{peak}, though ICC (3,1) measures decreased, falling within the moderate reliability threshold. When calculated as a percentage of HRR, typical error measurements were the highest of any measure of internal load. As determining HR_{peak} and HRR involves accurate calculation of peak and resting heart rate, there may have been some measurement error. Indeed, HR_{peak} was established as the highest heart rate recorded in the test to volitional exhaustion and may not have been a true HR_{max}. Despite measures of HR exhibiting slightly worse reliability than $\dot{V}O_2$, when split into five-minute increments typical error appeared generally lower **(Table 5.4)**. Whereas the highest error measurements were reported in the first and last five-minute period with $\dot{V}O_2$, there were no such observations in the HR data, where typical error remained relatively constant. Although VO_2 and HR were the most reliable measures of physiological load, our analysis of reliability across smaller time increments revealed discrepancies between the two. Therefore, when utilising the delta method for HIIT prescription in future research and practical application, tighter cadence controls should be applied as well as more accurate assessment of $\dot{V}O_{2peak}$ and HR_{peak} via repeated maximal testing or additional verification stages (Poole and Jones, 2017).

5.4.3. Rate of change of internal load

There was a similar rate of change in total and interval HR and $\dot{V}O_2$ of ~1.0% per minute in both HIIT protocols **(Table 5.5)**. However, the SD value indicates that for every minute, each participant may have varied by 2.0% above and below this, which was quantified as a moderate to large magnitude. This suggests there is considerable variation in the magnitude of change for measures of internal load between-participants. The delta method is proposed to reduce inter-subject variation (Lansley et al., 2011), therefore the results from this study should both be examined over longer durations and compared to future research implementing a similar HIIT design using $\%\dot{V}O_{2max}$ to prescribe intensity. However, based on the wattage corresponding to delta 80 in this study (~190W), we calculate that this should have been equivalent to ~85% $\dot{V}O_{2peak}$, based on each participant's test to volitional exhaustion **(Table 5.1)**. The actual observed intensity of exercise across both HIIT protocols was ~67% $\dot{V}O_{2peak}$, insinuating a considerable gap between predicted and observed intensity, which would have rendered exercise prescription based on $\%\dot{V}O_{2peak}$ inaccurate. This is due to both the limitations of using VO_2 due to the slow component of oxygen uptake (Jamnick et al., 2020) and our use of an intermittent exercise protocol. Pairwise comparisons for rate of change **(Table 5.6)** reveal small mean differences for interval HR and $\dot{V}O_2$. However, when assessing internal load over the course of the entire HIIT protocol, there were no significant changes between-conditions. This suggests that the delta method provided a consistent rate of change across both HIIT protocols.

5.4.4. Limitations

In our study, only a small sample of males with overweight and obesity were included, therefore caution should be employed when applying results to the population with overweight and obesity as a whole, particularly females. The study involved only two acute HIIT sessions when ideally a HIIT programme would be adopted long-term. The fidelity and feasibility of this protocol should be examined over a longer period to determine adherence and adaptations to a number of cardiometabolic measures. Though it was proposed that HIIT prescription using $\%\dot{V}O_{2max}$ would have resulted in more variable individual responses and that the delta method is established as superior in other populations (Lansley et al., 2011), there was no comparator group which completed the same HIIT protocol with intensity prescribed using $\%\dot{V}O_{2max}$ to establish this directly. There was also no familiarisation session for participants in the current study, despite some never having completed HIIT before. Therefore, factors such as their self-selected cadence and psychological approach to the workout may have differed between-conditions as they became more accustomed in the second visit.

5.4.5. Conclusions

In conclusion, a 10 x 60 s HIIT protocol at an intensity of 80% 'delta' corresponded to vigorous intensity exercise, though higher intensities of exercise may be feasible for individuals with overweight or obesity. Internal load held a similar rate of change across the protocols and was established as more reliable than subjective load, though mean differences were not consistent when examining five-minute increments. Enjoyment was high and similar between-conditions, demonstrating good to excellent reliability. This HIIT protocol may be an effective initial intensity for previously sedentary individuals living with overweight and obesity wishing to commence HIIT, which can be reliably assessed for enjoyment via the PACES. Future research should explore a larger sample, compare reliability to general exercise prescription methods and establish the feasibility and fidelity of the protocol as well as progressions of intensity over longer durations.

Chapter 6.0. The feasibility and fidelity of an 8-week same-session combined high-intensity interval training (HIIT) and resistance training programme

In the previous chapter we demonstrated a HIIT protocol dosed using the 'delta' method which was reliable and repeatable in individuals with overweight and obesity. We therefore have a robust approach to incorporate this HIIT protocol into a CT programme to establish adherence, enjoyment, engagement, and the intervention fidelity of such a training programme in the target population.

6.1. Introduction

It has been demonstrated that cardiovascular exercise and resistance exercise training provide independent adaptations to the benefit of a plethora of health outcomes (Strasser and Schobersberger, 2011) and subsequently, both exercise types are included in exercise guidelines (Piercy et al., 2018). Promisingly, meeting exercise guidelines for both cardiovascular- and strength-based exercise reduces the incidence of obesity (Bennie et al., 2020). High-intensity interval training (HIIT) presents as a potentially superior form of cardiovascular-based exercise due to its ability to stimulate greater physiological adaptations in time-matched bouts of work (Gibala et al., 2012) and is an important exercise training type for individuals with overweight and obesity to undertake.

Despite this, a myriad of internal and external barriers deters individuals with overweight and obesity from completing guideline amounts of exercise (McIntosh et al., 2016). Most prevalently, a lack of time, low perception of enjoyment and tolerance of exercise impede regular engagement in physical activity (Trost et al., 2002; Leone and Ward, 2013; McIntosh et al., 2016). Consequently, combining HIIT and resistance exercises together into same-session concurrent exercise training (CT) may be the most proficient approach to maximise time efficiency and physiological benefit. However, a dearth in research of same-session CT incorporating HIIT in overweight and obesity exists in the literature, including whether same-session CT is superior to just HIIT alone and requires further exploration.

The development of novel exercise interventions requires an evaluation into how feasible the intervention is for the target population. Feasibility of the exercise intervention can be quantified by factors such as adherence, recruitment and safety of the intervention (Thabane et al., 2010; El-Kotob & Giangregorio, 2018). Exercise training interventions are required to be achievable and tolerable to ensure long-term adoption by individuals with overweight and obesity.

Individuals with obesity often encounter high exercise intensities and associate PA with displeasure, leading to avoidance (Ekkekakis et al., 2016). Conceptually, higher intensities of exercise are proposed to lead to reduced enjoyment, given that Dual Mode Theory suggests affect is positive during exercise <VT^1 and negative >VT^1. As such, it has been suggested by some researchers that HIIT is not viable for general populations (Biddle and Batterham, 2015; Roy et al., 2018). Indeed, some research suggests HIIT is unpleasant for individuals with overweight and obesity (Roloff et al., 2020). However, the nature of intermittent exercise is also proposed to be superior for enjoyment due to its constantly changing stimulus (Thum et al., 2017) and as such other research reports high satisfaction and enjoyment after HIIT in individuals with overweight and obesity (Costigan et al., 2016; Oliviera et al., 2018; Eather et al., 2019; Marillier et al., 2022). These findings are supported by Niven et al. (2020) who performed a meta-analysis of 33 studies and determined that whilst enjoyment may be lower during exercise and more enjoyable following exercise, HIIT-based protocols exhibited consistently higher enjoyment levels compared to MICT-based protocols. Indeed, we observed PACES scores > 95 during acute bouts of HIIT dosed at delta 80 for 10 x 60s intervals **(Chapter 5.0.)**.

The enjoyment of resistance exercise in overweight and obesity is largely under-researched in comparison to HIIT-based interventions, though during exercise affect is related closely with enjoyment (Greene and Petruzzello, 2015). To date, no research has examined the enjoyment of same-session concurrent exercise training in individuals with overweight and obesity; We hypothesise that the additional components of concurrent training would add further stimulus which may increase enjoyment further in CT compared to HIIT-based interventions alone.

Adverse events in response to novel exercise interventions must also be reported to determine their feasibility (Thabane et al., 2010). Musculoskeletal injury is the primary adverse event observed during exercise and is often a common reason why individuals stop exercising (Hootman et al., 2002). However, research demonstrates that adults with overweight and obesity completing prescribed exercise do not increase the risk of injury occurrence versus those that do not exercise (Janney & Jakicic, 2010). However, the vast majority of injuries sustained during HIIT are attributed to chronic flare-ups rather than acute injuries for individuals with overweight and obesity, with a higher proportion in running versus cycling modalities (Wewege et al., 2017). Interestingly, whilst some studies observe higher rates of injury in high-intensity versus low-intensity exercise in overweight and obesity (Lunt et al., 2014), other studies find the opposite (Nicklas et al., 2009). Though, these findings may relate to the intensity of exercise, with Lunt et al. (2014) employing a 3 x 30 s ‘all-out’ design whilst Nicklas et al. (2009) utilised a continuous 10–30 minute protocol at 70–75% HRR.

With regard to resistance exercise training, whilst concerns have been raised around high-risk individuals such as those with obesity, modifying the intensity, duration and technique can ameliorate any adverse effects, rendering RT safe for high-risk populations (Williams et al., 2007). With such little research undertaken in the population with overweight and obesity for the rate of injury during same-session CT, it is hypothesised that the eight-week training intervention will mirror the general findings of the previous HIIT literature to exhibit low rates of injury and that for those who may experience injury this may be linked to chronic existing injuries.

An important facet to any exercise training programme is to establish that the exercise has been implemented as intended (Horner et al., 2006; Ljunggren et al., 2019). As such, the fidelity of exercise intensity during training sessions is fundamental to ascertain. If exercise is dosed at a particular intensity, understanding the individual variability in this intensity can inform how well-controlled the protocol is for practical applications. In order to establish this during exercise training programmes, previous research has estimated the variability across sessions and within-individuals by use of Linear Mixed Modelling (LMM) of within-session HR data (Weston et al., 2015).

Therefore, our study aimed to establish the fidelity and feasibility of an 8-week exercise training programme, comparing HIIT alone to a novel low-volume CT-HIIT protocol.

6.3. Methods

Following ethical approval **(Chapter 4.1)** and protocol pre-registration **(Chapter 4.13)**, 41 participants were recruited from the University and local area **(Chapter 4.3.2)** and were screened against inclusion criteria **(Chapter 4.2.)** to ensure each were sedentary, living with overweight or obesity with no existing co-morbidities. A total of 18 participants completed an 8-week exercise intervention in either a HIIT or CT group **(Figure 4.1)**, with full details of baseline participant characteristics are presented at **Table 4.2.** Participants in both groups completed either a HIIT or CT twice-weekly 8-week exercise training intervention as outlined in **Chapter 4.13**, with a full study schematic presented at **Figure 4.2.** Participants completed their exercise sessions at the same time of day on each visit and were asked to ensure they had the same meal prior to visiting for each session.

RPE and HR were collected at the end of each HIIT interval **(Chapter 4.11.2.)**. For resistance exercises, HR was collected at the end of each set and RPE was taken at the end of each exercise. At the end of each of the exercise sessions a series of questionnaires were completed **(Chapter 4.5.)**; each participant's session-RPE was determined via the CR100 scale, affective valance was assessed via the Feeling Scale (FS) and enjoyment was measured via completion of the Physical Activity Enjoyment Scale (PACES). The 18-point 2-factor preference and tolerance of intensity of exercise questionnaire (PRETIE-Q) was used to establish individual differences in response to exercise, with a maximum score of 40 for both tolerance and preference. Adverse events were recorded upon the incidence of any unfavourable and unintended sign or symptom related to the physical activity intervention (Gauss et al., 2021) when occurring either during exercise sessions or when used as reason for missing an exercise session. Attendance of exercise sessions was also recorded for each participant.

6.3.3. Statistical analysis

Between-group differences in Tolerance and Preference were established via one-way ANCOVA **(Chapter 4.15.3)** with pre (baseline) measures used as a covariate to account for regression to the mean (Senn et al., 2006; Vickers, 2009). Background (auxiliary) assumptions for the model were assessed including normal distribution. Descriptive statistics are displayed as mean ± SD unless otherwise stated, the point estimate and 95% confidence (compatibility) intervals are presented. We applied linear mixed modelling to HR data collected across the sessions to establish the within- and between-participant variance (reported as SDs) **(Chapter 4.15.2)**. For clarity, we split analysis and performed mixed modelling on the CT an HIIT sessions separately. Fixed effect estimates for Session*Time determined the change per minute in beats·min^{-1} for HR across the 20-minutes of exercise training and were reported alongside 95% confidence intervals. SDs were determined by calculating the square-root of values for the subject random effect, individual variance of the slope and overall between-subject SD.

6.4. Results

A total of 18 participants completed the training programme with all HIIT intervals and resistance repetitions completed by all individuals across both groups **(Table 6.1)**. All adverse events during exercise were musculoskeletal in nature, with participants citing either "muscular" or "joint" pain, which were mild and did not stop any participants from completing the protocol. Four adverse events were recorded during HIIT sessions and eight were recorded during CT sessions **(Table 6.1)**. A total of three participants missed sessions due to muscular pain, with one occurrence in the HIIT group and two in the CT group. Attendance to the exercise sessions exceeded 90% in both groups, with each participant missing one exercise session on average over the duration of the study.

Table 6.1. Adverse Events, Adherence and Attendance

Adverse Events				
Group	**During Session** *Muscular Pain*	**Missed Session** *Muscular Pain*	**During Session** *Joint Pain*	**Missed Session** *Joint Pain*
HIIT	3	1	1	0
CT	6	2	2	0
Adherence				
Group	**HIIT Intervals Completed**		**Resistance Reps Completed**	
HIIT	10 ± 0		-	
CT	5 ± 0		48 ± 0	
Attendance				
Group	**Sessions Completed**		**Attendance (%)**	
HIIT	15 ± 1		92.5 ± 6.5	
CT	15 ± 1		93.0 ± 7.0	

Data presented as Mean ± Standard Deviation

Table 6.2 shows that the tolerance and preference of exercise, as assessed via PRETIE-Q score, increased in both groups from pre- to post-intervention. Tolerance and preference appeared to increase to a greater extent in the HIIT group, with confidence intervals indicating the likely mean difference between groups was between -1.6, 5.9 and -1.5, 8.4 respectively.

Table 6.2. ANCOVA Results for Tolerance and Preference

	Group	**Pre**	**Post**	**Mean Difference**	**95% Confidence Intervals**		**P value**
					Lower Bound	Upper Bound	
Tolerance	CT	23 ± 3	25 ± 4	2.0	-1.6	5.9	0.238
	HIIT	23 ± 3	27 ± 3				
Preference	CT	27 ± 4	28 ± 7	3.4	-1.5	8.4	0.159
	HIIT	25 ± 6	30 ± 4				

Total session enjoyment, assessed by PACES score, remained > 90 throughout all 16 training sessions **(Figure 6.1)**. Mean session enjoyment scores for participants in the CT group decreased steadily from session 6 to session 10, where they reached a low of 93 ± 9, before climbing to peak enjoyment in the final week of exercise training (113 ± 10). The mean enjoyment score in the HIIT group was maintained > 100 up to a peak at session 11 (111 ± 13), before decreasing steadily to the lowest average enjoyment for the final training session in week 8 (95 ± 13).

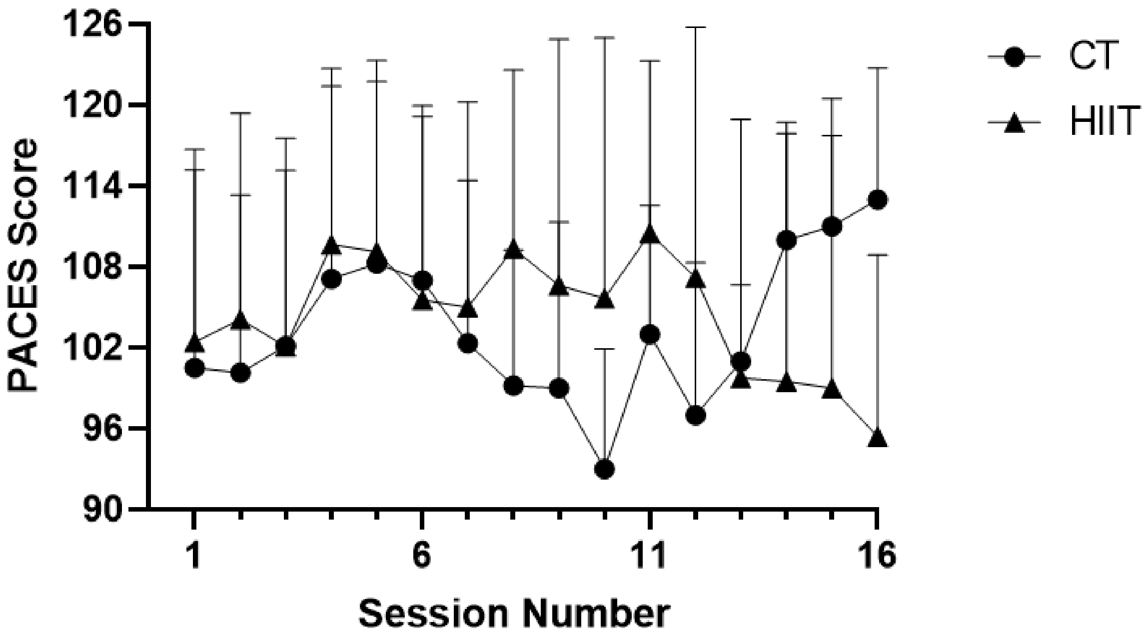

Figure 6.1. Mean Total Session Enjoyment (Data presented as Mean with SD, HIIT n = 10 versus CT n = 8).

Affect results, determined by Feeling Scale score, were more inconsistent than enjoyment, with larger fluctuations session to session **(Figure 6.2)**. The average Feeling Scale score in the CT group began high after session 1 around ‘Good’ before dropping between sessions 7 – 10, akin to CT group enjoyment scores. Thereafter, affect in the CT group steadily increased to 4 ± 1 in the final week of training. Affect in the HIIT group began much lower, at the lowest value for the entire programme after the first exercise session (2 ± 2). Affect subsequently steadily increased, before a continual decrease from session 11 to the end of the programme.

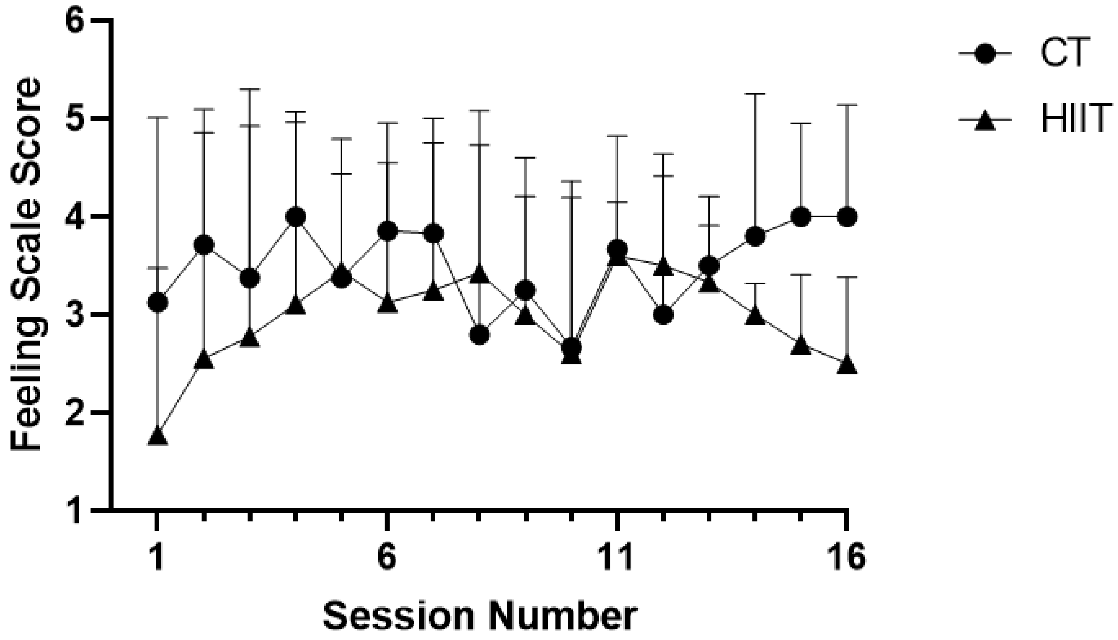

Figure 6.2. Mean Total Session Affect (Data presented as Mean with SD, HIIT n = 10 versus CT n = 8).

Session RPE (S-RPE) on the Borg CR-100 scale, returned to a more consistent pattern across the 16 training sessions, with the majority of average S-RPE ratings between 40 and 50 AU (‘Strong’/’Heavy’). The perceived difficulty of the session remained relatively constant in the CT group across sessions 1 to 8, rising to a peak of 56 ± 9 in session 9 **(Figure 6.3)**. There was then a steady drop in perceived session difficulty to the end of the programme, with a peak low of 40 ± 8 for the final training session. Participants in the HIIT group found the first session less difficult in comparison to the CT group (42 ± 7), before an instant spike to a peak average S-RPE rating in session 2 (54 ± 10), after which ratings remained fairly consistent.

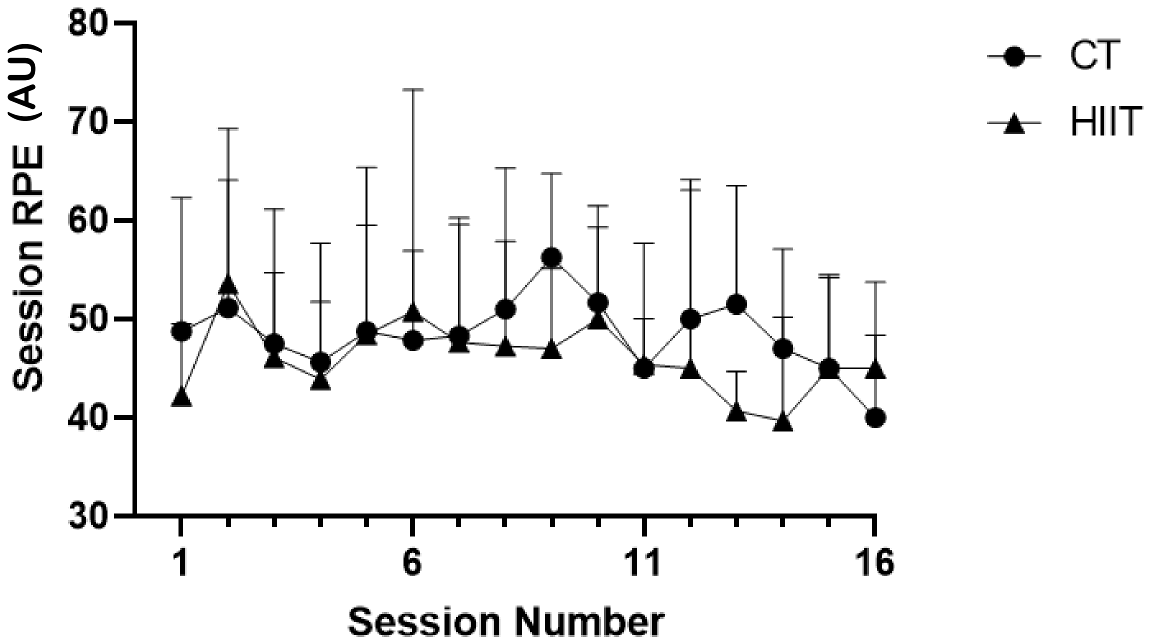

Figure 6.3. Mean Total Session Rating of Perceived Exertion (Data presented as Mean with SD, HIIT n = 10 versus CT n = 8).

SDs calculated from the LMM for the HIIT group showed that there was an individual variance around the slope of 0.03 beats·min^{-1} per 60 seconds, with 95% confidence intervals estimating the precision of this variance between 0.02 and 0.05 beats·min^{-1}. The observed between-participant SD was 37.65 across all HR values per session. The set-to-set variance within-participants was 8.54 (95% CI: 7.44, 9.79) beats·min^{-1}. For the CT group, the calculated SDs from the LMM demonstrated an individual variance around the slope of 0.02 beats·min^{-1} (95% CI: 0.01, 0.03). The observed between-participant SD was 30.61 across all HR values per session. The set-to-set variance within-participants was 8.71 (95% CI: 7.34, 10.32) beats·min^{-1}.

6.5. Discussion

Our study aimed to determine the feasibility and fidelity of an 8-week exercise training programme, incorporating HIIT into CT, compared to HIIT alone. The main findings from this study were that all repetitions and intervals were completed in all exercise sessions by all participants and low variability was observed in both the CT and HIIT protocols, indicating the good fidelity and feasibility of both the HIIT and CT training programmes in this population. Low rates of adverse events were observed, though these were higher in CT group, perhaps due to unfamiliarity with resistance exercises. Enjoyment was high in both groups, though greater HIIT intensities were met with greater displeasure when heavier loads were associated with higher enjoyment in the CT group.

6.5.1. Adverse events

The occurrence of adverse events in this study was observed as a low rate across both groups, with the findings of the current study concurring with historical evidence that musculoskeletal injury is the most common type of adverse event (Hootman et al., 2002). The majority of injuries reported by participants were muscular in nature, though no adverse events recorded during-session resulted in the cessation of any exercise session, perhaps highlighting that the severity of reported incidents were acute or minor. The rate of incidence of adverse events were doubled in the CT group despite the lower sample size of this group compared to the HIIT group. The injuries sustained in the CT group may have resulted from participant unfamiliarity of resistance exercises or the triggering of existing chronic injury. Indeed, the types of resistance exercises included in the CT group (e.g., deadlift) were specific weightlifting movements requiring good technique to reduce incidence of injury. Future research should further explore the injuries observed during resistance versus HIIT exercise, including their cause, severity and duration.

6.5.2. Feasibility

All participants completed all exercise repetitions and intervals across both groups, demonstrating that the exercise protocols which incorporated resistance exercises dosed at an individual's 8RM, as well as HIIT intervals at an intensity of 80%Δ, were feasible for completion by sedentary individuals living with overweight and obesity. Moreover, the weekly exercise intensity progression of 5% based on RPE was also successful in terms of the feasibility of completion. Similarly, attendance of exercise sessions was very high, with around one session missed per participant. Attendance was recorded >90% for both groups, well above the 85% threshold cited by the TESTEX (Smart et al., 2015), therefore suggesting that both the HIIT and CT protocols were feasible to complete. However, the findings from this study must be translated to a real-world setting, as well as extended over a longer duration, in order to establish if HIIT and CT programmes are feasible for long-term widespread adoption. Indeed, the total volume of exercise completed in this study equalled 40 minutes per week – only around 50% of 'vigorous-intensity' exercise guidelines (Piercey et al., 2018). As such, adherence to this exercise programme would not result in individuals meeting exercise guidelines, therefore, increased frequency of training programmes could be trialled.

Baseline Tolerance was lower in both groups than Preference of high exercise intensity, a trend also observed in the participant characteristics of the reliability study **(Chapter 5.0.)** However, the reported Tolerance and Preference of higher intensities of exercise increased in both groups after the exercise training intervention. Participants in the HIIT group found larger increases in both Tolerance and Preference compared to the CT group. The greater changes observed in the HIIT group may have occurred as a result of longer durations and higher volumes of high-intensity exercise performed in this group, thus accustoming participants to higher intensities of exercises. This may be a pivotal outcome for long-term maintenance of exercise in population with overweight and obesity s and may be a potential caveat of including small volumes of HIIT in same-session CT protocols, whereby participants do not become conditioned to higher intensities of exercise and continue to tolerate and prefer lower intensities.

A key facet of any feasibility study is to determine its suitability to be upgraded to a large-scale study. An important element of this study was also the recruitment process (detailed at **Chapter 4.3.2.**), which would require careful consideration if adopting this feasibility study into a large-scale research trial. Over a period of 12 months, 41 participants enrolled onto the study, with 19 of these ultimately not commencing the research study. Therefore, it should be considered that around three participants a month can be recruited, but only 46% of these actually start the intervention. This is imperative to understand when planning a large scale study, in order to establish the timeframe that would be required to recruit a sufficient sample size.

6.5.3. Enjoyment and affect

Enjoyment of exercise was generally high across both groups, reaffirming the findings of previous research highlighting the enjoyment of HIIT exercise by individuals with overweight and obesity (Costigan et al., 2016; Oliviera et al., 2018; Eather et al., 2019; Marillier et al., 2022). Both groups observed similar average enjoyment, before diverging around session 7, where HIIT enjoyment was higher to session 12. However, the enjoyment of HIIT sessions declined thereafter to a low after the final session, whereas CT enjoyment peaked at the culmination of the programme. Mean affect in both groups was also positive throughout the programme, remaining above +1, also peaking in the final session for the CT group whilst decreasing for the final sessions in the HIIT group. This reflects the finding by previous research that enjoyment and affect are closely linked in individuals with overweight and obesity (Greene and Petruzzello, 2015). The results of average session-RPE ratings were much more closely linked, with minor fluctuations and no clear trends between-groups. Session-RPE was generally maintained between 40 and 50, highlighting the ‘Heavy’ or ‘Strong’ exertion level participants perceived was required.

Taken together, this may suggest that the increased weight for resistance exercises provided a greater stimulus reflected by greater enjoyment, whereas the highest intensities of HIIT were met with displeasure. Indeed, this would be reflective of dual-mode theory, with reduced enjoyment the further beyond VT^1 participants attained (Ekekkakis et al., 2003). These findings have an important bearing on the long-term continuation of HIIT and further research must establish if the trend of decreasing enjoyment continues with increasing intensity and time-periods of HIIT. If so, the rate at which the intensity of HIIT exercise is progressed may require attenuation.

6.5.4. Fidelity

Linear Mixed Modelling (LMM) was undertaken of HR data within-sessions for both HIIT and CT groups. The LMM was utilised to establish the variability across sessions and within-individuals. The results of the model suggested that each individual varied by 0.03 and 0.02 $beats \cdot min^{-1}$ in the HIIT and CT protocols respectively. This illustrates that the HIIT and CT protocols had low session variance and were therefore well-controlled exercise protocols. The approach of applying a LMM to estimate the variability in exercise protocols has been undertaken previously (Weston et al., 2015), where large variations are presented. Though the findings are promising for the development of a protocol with low variability, in the present study this low variability is likely due to the low number of exercise sessions, short training duration and controlled laboratory environment. The use of LMM to explore the fidelity of CT programmes in individuals with overweight and obesity should therefore be undertaken on future larger exercise training programmes.

6.5.5. Limitations

A key limitation of the measures collected in this study is that they were recorded post-exercise, rather than during exercise when enjoyment is noted to be lower (Niven et al., 2020). The collation of during-session enjoyment and affect scores may be required to establish the feasibility of completing exercise interventions including HIIT long-term, as the supervised exercise sessions in the current study may have increased motivation to complete sessions for participants.

6.5.6. Conclusion

An 8-week exercise training programme, in which sedentary adult males living with overweight and obesity completed either twice-weekly HIIT or CT, proved to be feasible, with all repetitions and intervals in each exercise session completed by all participants with low variation in heart rate both across sessions and within individuals. The prescribed intensities of exercise were therefore appropriate for this cohort and may be applicable to the general sedentary population living with overweight and obesity. There were low rates of adverse events, though incidence of injury within-session were higher in the CT group, perhaps due to unfamiliarity with resistance exercises. Enjoyment was high for both groups, although the progression of training resulted in a greater stimulus and higher enjoyment for the CT group but reduced enjoyment for the HIIT group.

Chapter 7.0. The exploratory effects of an 8-week same-session combined high-intensity interval training (HIIT) and resistance training programme in body composition and cardiometabolic health

In the previous chapter we demonstrated the fidelity and feasibility of an 8-week combined HIIT and RT exercise training programme. However, the capacity of the training programme to provide favourable adaptations to cardiometabolic health must be established, given the principal goal of exercise interventions is to improve obesity-related health.

7.1. Introduction

Cardiovascular Diseases (CVD), such as coronary heart disease or stroke, are the leading cause of deaths worldwide (WHO, 2015). CVDs are rooted by a spectrum of conditions of a 'cardiometabolic' nature, initiated by insulin resistance before progressing to metabolic syndrome, type 2 diabetes mellitus (T2DM) and CVD (Guo et al., 2014). Overweight and obesity – particularly, increased fat mass – are notable risk factors for the development of cardiometabolic and cardiovascular diseases (Vasudevan & Ballantyne, 2005; Ortega et al., 2016), with the addition of sedentarism further increasing risk (Wilmot et al., 2012; Hardgraft et al., 2021). As such, sedentary individuals with overweight or obesity are at a high risk of developing T2DM, Coronary Artery Disease (CAD), stroke, Peripheral Arterial Disease (PAD) and heart failure (Oktay et al., 2017) as well as closely related conditions such as cancer or sarcopenic obesity (WHO, 2000; Roubenoff 2004).

Regular exercise is demonstrated to improve CVD risk factors (Gill and Cooper, 2008) through its ability to reduce adiposity, inflammation and insulin resistance (Nocon et al., 2008; Okay et al., 2009; Church, 2011). Regular cardiovascular-based exercise also facilitates increased cardiorespiratory fitness (CRF), further reducing CVD risk (Lavie et al., 2015). Regular resistance-based exercise can also increase skeletal muscle mass (Yan et al., 2019), improving strength, body composition and metabolic health (Strasser & Schobersberger, 2011). Although reductions in CVD risk are observed by those completing either cardiovascular- or strength-based exercises, those completing both exercise types together present with the greatest reductions in all-cause and CVD mortality risk (Zhao et al., 2020).

However, barriers to completing regular exercise prevent individuals achieving the associated health benefits, with a 'lack of time' commonly cited (Trost et al., 2002; McIntosh et al., 2016). Combining resistance and cardiovascular exercise together into same-session Concurrent Training (CT) may be the most efficient, time-effective and enticing method of exercise training for individuals with overweight and obesity to maximise health benefits.

Furthermore, incorporating High-Intensity Interval Training (HIIT) into CT may further maximise the physiological benefit whilst maintaining time-efficiency (Gibala et al., 2012). A wealth of studies and meta-analyses highlight the ability of HIIT to improve body composition measures in sedentary, individuals with overweight and obesity, particularly Body Mass (BM), Body Fat (BF) and Waist Circumference (WC) (Batacan et al., 2017; Wewege et al., 2017; Andreato et al., 2019). Though, these meta-analyses reveal that training interventions of > 12 weeks in duration are commonly required to observe changes in body composition. Resistance Training (RT) is also demonstrated to increase Fat Free Mass (FFM) and decrease Fat Mass (FM) (Church et al., 2009; Donnelly et al., 2009) through increases in protein fractional synthesis rate and skeletal muscle mass (Evans, 2001; Yan et al., 2019). Combining both exercise types in CT in individuals with overweight and obesity is also shown to reduce BM and BF (Medeiros et al., 2015), though little research examines the effect of incorporating HIIT into CT.

Many health-related benefits can be achieved through exercise independent of weight loss (Johnson, 2009), perhaps most notably increases in CRF (as ascertained by $\dot{V}O_{2peak}$), which reduce mortality rates (Harber et al., 2017). HIIT is well-evidenced to increase CRF (Batacan et al., 2017; Su et al., 2019), to a greater extent than lower intensities of exercise (Helgerud et al., 2007) via greater activation of the AMPK metabolic pathway and its subsequent downstream metabolic effects (Chen et al., 2003; Gibala et al., 2012). CT (in which RT is incorporated) may result in lower CRF improvements compared to HIIT alone, merely through reduced volume of cardiovascular training, though combining HIIT and RT together may attenuate this (Ramirez-Velez et al., 2020) via achieving a greater workload in a condensed time period, facilitated by increased intensity of exercise. Indeed, significant increases in left-ventricular end-diastolic diameters are observed after CT as a result of simultaneous pressure and volume overloads (Hosseini et al., 2012; Amaro-Gahete et al., 2020) positing the role for cardiac adaptations to improve CRF. However, no evidence is provided on the effects of HIIT or CT on cardiac adaptations in a sedentary population living with overweight and obesity.

Regular RT provides individuals with overweight and obesity with increased muscular strength (van Baak et al., 2021), with CT also demonstrated to increase both upper and lower body strength (Duft et al., 2017; Donges et al., 2013; Brunelli et al., 2015). However, the incorporation of cardiovascular-based exercise in CT is suggested to reduce strength gains via the interference effect (Wilson et al., 2012), though evidence does suggest utilising HIIT as the cardiovascular component can ameliorate these reductions (Methenitis et al., 2018; Sabag et al., 2018), with the mechanism for this currently unknown. With regard to metabolic health, both HIIT and RT are effective in improving glycaemic control and lipid metabolism. This is facilitated by increased mitochondrial biogenesis and contraction mediated glucose uptake as a result of HIIT (Little et al., 2011; Gibala et al., 2012) and increased skeletal muscle mass and GLUT4 protein content as a consequence of RT (Tressierras and Balady, 2009). However, the effect of same-session CT on markers of metabolic health is less conclusive (Ho et al., 2012) and under-researched in comparison. Given that combining HIIT and RT together in same-session low-volume CT is a novel approach, we aimed to observe whether a short training duration of 8-weeks would be sufficient to incur improvements in cardiometabolic health.

Therefore, the aim of our study was to determine the feasibility of completing an 8-week same-session concurrent exercise training programme, whilst examining the effects on cardiometabolic health following CT compared to a HIIT intervention. We hypothesised that we would observe differences between groups in body composition measures and CRF though changes in other measures of cardiometabolic health would be negligible.

7.2. Methods

Following ethical approval **(Chapter 4.1)** and protocol pre-registration **(Chapter 4.13)**, 41 participants were recruited from the University and local area **(Chapter 4.3.2)** and were screened against inclusion criteria **(Chapter 4.2.)**. A total of 18 participants completed an 8-week exercise intervention in either a HIIT or CT group **(Chapter 4: Figure 4.1)**, with full details of baseline participant characteristics are presented at **Table 4.2.** Participants in both groups completed either a HIIT or CT twice-weekly 8-week exercise training intervention as outlined in **Chapter 4.13**, with a full study schematic presented at **Figure 4.2.**

During exercise, RPE and HR were collected at the end of each HIIT interval. The CT group completed two sets of four resistance training exercises: barbell deadlift, barbell squat, barbell bench press, machine shoulder press, (Chapter 4.12.). HR was taken at the end of each set, RPE was taken at the end of each exercise. All participants completed baseline testing at Week 1 and repeated testing post-intervention at Week 10 (**Figure 4.2.**). Collection of body composition measures are detailed in **Chapter 4.4.** Body Mass (BM) and height measurements were used to determine Body Mass Index (BMI). Body Fat percentage (BF%) was collected via bioelectrical impedance and both waist and hip circumferences recorded. Assessments of cardiorespiratory health were taken from cardiopulmonary exercise test

(CPET), with Systolic and Diastolic Blood pressure (SBP, DBP), Resting Heart Rate (RHR), Maximum Heart Rate (HRmax), Maximum RPE, Ventilatory Threshold (VT1), Peak Power Output (PPO) and Respiratory Exchange Ratio (RER) recorded as set out in **Chapter 4.9.**

Cardiac measurements were taken from Electrocardiogram (ECG) and standard transthoracic echocardiograph **(Chapter 4.7.)**. Detailed methods for the measurement of Left Ventricular Diameter (LVD), Posterior Wall (PW), Intraventricular Septum (IVS), Left Atrium (LA), Aorta and left-ventricular volumes as well as calculation of Stroke Volume (SV), Ejection Fraction (EF) and LV Mass are presented in **Chapter 4.7.1**. Quality control of the cardiac measurements are presented in **Chapter 4.7.3.** with the majority of measurements exhibiting good to excellent reliability. Metabolic measurements were collected via fingertip capillary blood sampling as detailed in **Chapter 4.8.1**. with lipid profile, plasma glucose concentrations and HbA1C recorded. A 120-minute Oral Glucose Tolerance Test (OGTT) was completed for each participant (**Chapter 4.8.2.**) with the Area Under the Curve (AUC) calculated from glucose concentrations (**Chapter 4.8.3.**). Alterations in diet and physical activity levels were assessed for via baseline 4-day diet diary and accelerometery monitoring, which demonstrated that groups were well-matched with negligible changes in diet and physical activity in all participants for both groups **(Chapter 4.14)**.

Between-group differences in outcome measures were established via one-way ANCOVA analysis **(Chapter 4.15.3)** with pre (baseline) measures used as a covariate to account for regression to the mean (Senn et al., 2006; Vickers, 2009). Background (auxiliary) assumptions for the model were assessed including normal distribution. Descriptive statistics are displayed as mean ± SD unless otherwise stated, the point estimate and 95% confidence (compatibility) intervals are presented.

7.3. Results

A total of 18 participants (CT n = 8, HIIT n = 10) completed the 8-week exercise training programme. Changes in measures of body composition from baseline to post-intervention testing, as well as ANCOVA analysis between-groups are presented in **Table 7.1**. Pre- to post-intervention changes in body composition were generally negligible or slight decreases. Little to no mean differences between-groups were generally observed, with the only notable difference of 2.0 kg between-groups in body mass.

Table 7.1. ANCOVA Analysis of Body Composition Measures.

	Group	Pre	Post	Mean Difference	95% Confidence Intervals		P Value
					Lower Bound	Upper Bound	
Body Mass (kg)	CT	92.7 ± 10.7	90.9 ± 10.5	2.0	-0.7	4.6	0.131
	HIIT	106.6 ± 27.0	106.9 ± 27.5				
BMI ($kg.m^2$)	CT	31.0 ± 2.6	30.4 ± 2.3	0.7	-0.4	1.7	0.182
	HIIT	32.9 ± 6.3	33.0 ± 6.5				
Waist Circumference (cm)	CT	99.3 ± 7.9	97.8 ± 4.7	1.0	-2.2	4.3	0.502
	HIIT	106.4 ± 20.2	105.3 ± 19.4				
Hip Circumference (cm)	CT	98.5 ± 7.5	98.5 ± 7.5	0.0	0.0	0.0	-
	HIIT	103.1 ± 14.0	103.1 ± 14.0				
Waist : Hip	CT	1.0 ± 0.0	1.0 ± 0.0	0.0	0.0	0.0	-
	HIIT	1.0 ± 0.1	1.0 ± 0.0				
Body Fat (%)	CT	30.4 ± 3.5	29.9 ± 3.3	0.1	-1.1	0.9	0.808
	HIIT	34.1 ± 8.0	33.3 ± 7.6				
Lean Body Mass (kg)	CT	64.3 ± 5.0	64.4 ± 5.0	0.3	-0.8	0.2	0.219
	HIIT	68.5 ± 8.3	68.2 ± 8.1				

Figure 7.1 highlights pre- to post-intervention changes in cardiorespiratory fitness, ventilatory threshold and 80% Δ as obtained from CPET. Both groups increased in these measures from baseline at post-intervention testing, with participants in the CT group exhibiting greater increases in cardiorespiratory fitness. Participants in the HIIT group found greater increases in the point of the ventilatory threshold as well as 80% Δ. Low mean differences were observed between-groups in ANCOVA analysis, although there was a 9.2 W difference in the intensity which corresponded to the 80% Δ **(Table 7.2)**.

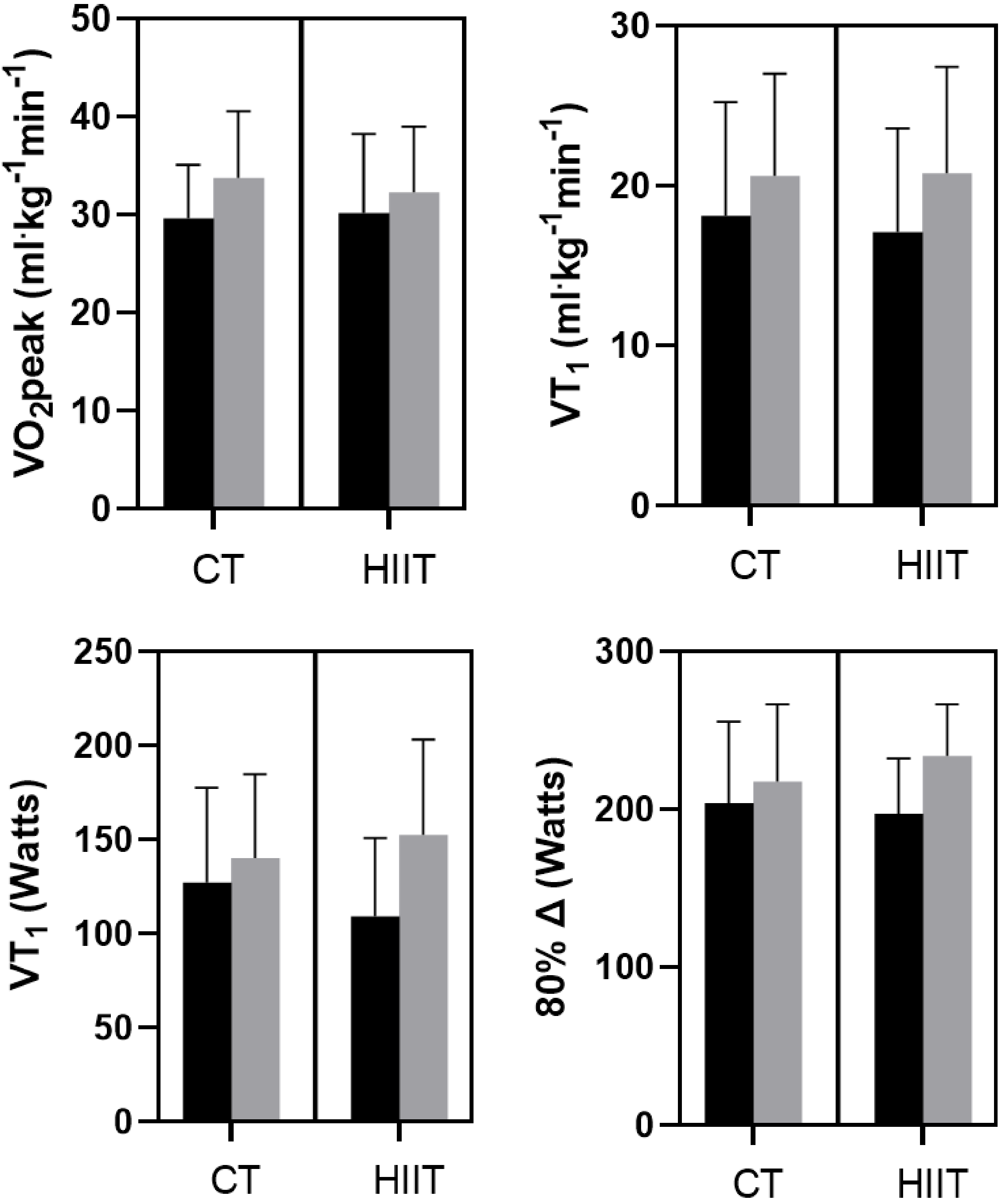

Figure 7.1. Baseline (Black) and post-intervention (Grey) measures (Clockwise from top left; VO_2peak, VT_1 at VO_2, 80% Δ and VT_1 at power output) obtained from Cardiopulmonary Exercise Test. Data presented as Mean plus SD.

Table 7.2. ANCOVA Analysis of CPET Measures.

	Group	Mean Difference	95% Confidence Intervals		P Value
$\dot{V}O_{2peak}$ (ml·kg^{-1}min^{-1})	CT	0.2	-2.1	2.5	0.868
	HIIT				
Ventilatory Threshold (VO_2)	CT	1.4	-1.5	4.3	0.321
	HIIT				
Ventilatory Threshold (W)	CT	7.3	-29.0	14.3	0.481
	HIIT				
80% Δ (W)	CT	9.2	-30.6	12.2	0.375
	HIIT				

The remainder of measures sought from CPET are presented at **Table 7.3**. Peak power output attained at the end of CPET increased from pre- to post-intervention in both groups, as did the peak RER and RPE attained at the cessation of the exercise test. However, no mean differences were observed between-groups in ANCOVA analysis, despite a 10.3 W difference in the power output attained.

Table 7.3. ANCOVA Analysis of Secondary CPET Measures.

	Group	Pre	Post	Mean Difference	95% Confidence Intervals		P Value
					Lower Bound	Upper Bound	
Peak Power Output (W)	CT	240 ± 54	265 ± 42	10.3	-36.5	15.9	0.417
	HIIT	236 ± 38	252 ± 40				
Respiratory Exchange Ratio	CT	1.16 ± 0.04	1.18 ± 0.06	0.03	-0.04	0.09	0.382
	HIIT	1.16 ± 0.08	1.21 ± 0.07				
Peak Rate of Perceived Exertion	CT	18 ± 1	18 ± 1	0.7	-1.7	0.3	0.143
	HIIT	18 ± 1	19 ± 1				
Peak Heart Rate (beats·min^{-1})	CT	162 ± 10	163 ± 10	0.5	-8.6	7.6	0.905
	HIIT	173 ± 10	173 ± 12				

Pre- to post-intervention changes in cardiac outcome measures taken from echocardiography are presented at **Table 7.4.** Measures of resting heart rate, systolic and diastolic blood pressure decreased after the 8-week exercise training programme in both groups. Negligible changes were observed in structural cardiac changes, though stroke volume and two-chamber left-ventricular end diastolic volumes presented with greater differences, with a mean difference observed between-groups for the latter in ANCOVA analysis.

Table 7.4. Pre- to Post-Intervention Changes and Post-Intervention ANCOVA Analysis of Cardiac Measures.

	Group	Pre	Post	Mean Difference	95% Confidence Intervals		P Value
					Lower Bound	Upper Bound	
Resting Heart Rate (beats·min^{-1})	CT	73 ± 12	72 ± 11	0.8	-4.2	2.5	0.604
	HIIT	78 ± 6	76 ± 8				
Systolic Blood Pressure (mmHg)	CT	130 ± 6	127 ± 9	0.2	-6.6	6.1	0.939
	HIIT	133 ± 9	129 ± 9				
Diastolic Blood Pressure (mmHg)	CT	81 ± 6	80 ± 7	0.7	-7.6	6.1	0.820
	HIIT	85 ± 5	82 ± 8				
Aorta (mm)	CT	3.10 ± 0.17	3.07 ± 0.12	0.08	-0.31	0.14	0.447
	HIIT	3.29 ± 0.22	3.14 ± 0.32				
Interventricular Septum (mm)	CT	1.06 ± 0.12	1.07 ± 0.17	0.00	-0.15	0.14	0.959
	HIIT	1.11 ± 0.13	1.10 ± 0.16				
Left Ventricular Diameter (mm)	CT	4.84 ± 0.46	4.73 ± 0.38	0.09	-0.12	0.29	0.378
	HIIT	5.18 ± 0.51	5.06 ± 0.40				
Posterior Wall (mm)	CT	1.04 ± 0.10	1.06 ± 0.10	0.02	-0.13	0.10	0.774
	HIIT	1.10 ± 0.12	1.08 ± 0.15				
Left Atrial Diameter (mm)	CT	3.88 ± 0.55	3.86 ± 0.51	0.09	-0.29	0.12	0.393
	HIIT	3.88 ± 0.32	3.77 ± 0.36				
Two-Chamber Left Ventricular EDV (ml)	CT	88.70 ± 21.70	89.02 ± 24.13	19.48	2.96	36.00	0.024
	HIIT	71.22 ± 23.38	93.15 ± 25.14				
Two-Chamber Left Ventricular ESV (ml)	CT	29.04 ± 13.53	29.03 ± 7.88	4.19	-3.89	12.28	0.287
	HIIT	28.32 ± 12.43	32.84 ± 11.89				
Ejection Fraction (%)	CT	70 ± 9	71 ± 6	0.9	-3.5	5.3	0.666
	HIIT	63 ± 7	67 ± 7				
Stroke Volume (ml)	CT	59.66 ± 14.48	60.62 ± 16.17	10.03	-4.06	24.12	0.150
	HIIT	42.90 ± 18.76	59.31 ± 16.95				
Left Ventricular Mass (g)	CT	187.94 ± 47.11	185.25 ± 51.28	0.21	-33.96	33.54	0.99
	HIIT	222.04 ± 46.64	216.67 ± 54.12				

The greatest changes both pre- to post-intervention and between-groups were observed in four-chamber end diastolic and end systolic volumes from the left ventricle. The four-chamber view highlighted notable increases after HIIT and decreases after CT (**Figure 7.2**), with mean differences observed in ANCOVA analysis **(Table 7.5)**, wherein confidence intervals exceeded 0, demonstrating between-group differences were indeed likely.

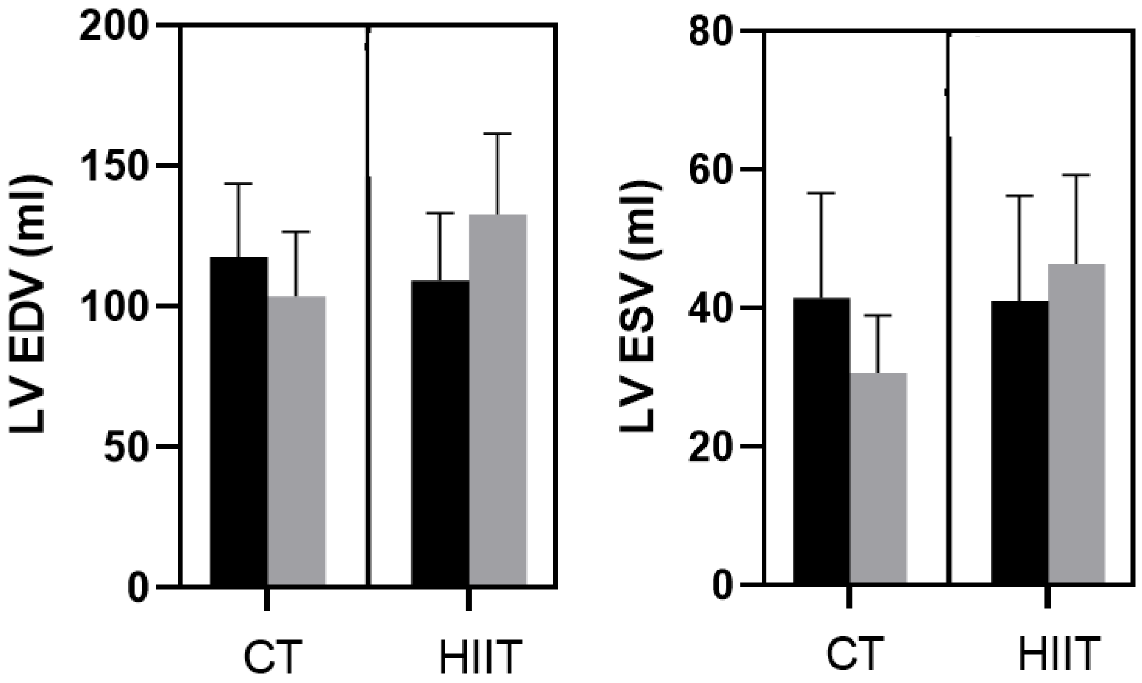

Figure 7.2. Baseline (black) and post-intervention (grey) left ventricular end diastolic volume (left) and end systolic volume (right) obtained from echocardiogram in the four-chamber view.
Data presented as Mean plus SD.

Table 7.5. ANCOVA Analysis of Post-Intervention Four-Chamber View EDV and ESV.

	Group	Mean Difference	95% Confidence Intervals		P Value
Four-Chamber Left Ventricular EDV (ml)	CT	21.55	8.72	34.38	0.003
	HIIT				
Four-Chamber Left Ventricular ESV (ml)	CT	8.03	1.52	14.54	0.019
	HIIT				

Effects of the intervention on strength were determined via baseline and post-intervention testing of 8RM for the four strength exercise movements Squat, Bench Press, Deadlift and Shoulder Press**.** Both groups increased 8RM at post-intervention for Bench Press, Deadlift and Shoulder Press **(Figure 7.3)**. Only participants in the CT group increased Squat 8RM, with a small decrease observed in the HIIT group. ANCOVA analysis is presented at **Table 7.6**, which indicates mean differences between-groups in favour of CT were observed for all exercises, with all confidence intervals >0, though this was not observed for bench press, where there was a smaller mean difference, wide confidence intervals and p-value >0.05. Increases in grip strength were notably less apparent, with no mean differences between groups **(Table 7.7)**.

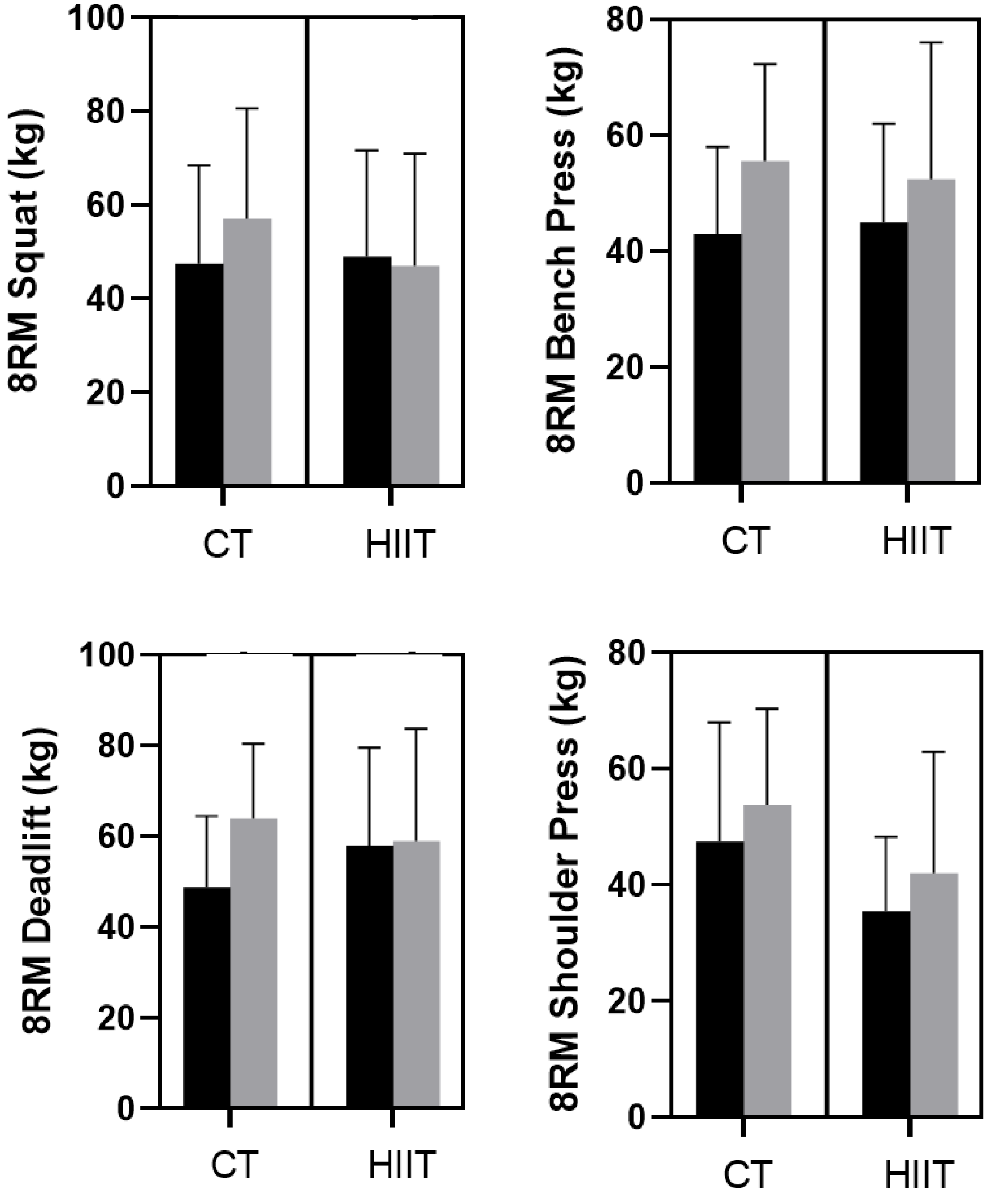

Figure 7.3. Baseline (black) and post-intervention (grey) 8RM for (Clockwise from top left; Squat, Bench Press, Shoulder Press and Deadlift.)
Data presented as Mean plus SD.

Table 7.6. ANCOVA Analysis of Post-Intervention 8RM Testing.

	Group	Mean Difference	95% Confidence Intervals		P Value
8RM Squat (kg)	CT	18.3	13.7	22.9	0.000
	HIIT				
8RM Bench Press (kg)	CT	5.0	-13.3	3.4	0.226
	HIIT				
8RM Deadlift (kg)	CT	12.3	3.4	21.2	0.010
	HIIT				
8RM Shoulder Press (kg)	CT	9.39	2.81	15.97	0.008
	HIIT				

Table 7.7. Pre- to Post-Intervention Changes and Post-Intervention ANCOVA Analysis of Grip Strength.

	Group	Pre	Post	Mean Difference	95% Confidence Intervals		P Value
					Lower Bound	Upper Bound	
Right Grip Strength (kg)	CT	38 ± 9	42 ± 11	1.89	-3.89	7.67	0.497
	HIIT	44 ± 13	47 ± 8				
Left Grip Strength (kg)	CT	37 ± 8	41 ± 9	1.34	-5.45	8.93	0.774
	HIIT	47 ± 8	47 ± 8				

Pre- and post-intervention results for metabolic outcome measures obtained from fingertip capillary blood sampling are presented at **Table 7.8.** Both groups demonstrated reductions in fasting plasma glucose concentrations, lipid profile, HbA1C and OGTT AUC alongside increases in HDL cholesterol, which were greater in the HIIT group, though all confidence intervals surpassed 0, providing uncertainty in determining true differences between-groups.

Table 7.8. Pre- to Post-Intervention Changes and Post-Intervention ANCOVA Analysis of Metabolic Measures.

	Group	Pre	Post	Mean Difference	95% Confidence Intervals		P Value
					Lower Bound	Upper Bound	
Plasma Glucose (mmol/L)	CT	5.1 ± 0.6	5.1 ± 0.2	0.1	-0.3	0.6	0.531
	HIIT	5.4 ± 0.6	5.1 ± 0.6				
LDL (mmol/L)	CT	2.45 ± 0.97	2.42 ± 1.03	0.15	-0.32	0.62	0.515
	HIIT	2.37 ± 1.02	2.21 ± 0.92				
HDL (mmol/L)	CT	1.13 ± 0.20	1.14 ± 0.17	0.05	-0.05	0.14	0.301
	HIIT	1.17 ± 0.38	1.23 ± 0.36				
Total Cholesterol (mmol/L)	CT	4.39 ± 1.10	4.29 ± 0.93	0.05	-0.20	0.30	0.680
	HIIT	4.45 ± 0.96	4.39 ± 0.88				
Triglycerides (mmol/L)	CT	2.38 ± 1.72	2.31 ± 1.74	0.22	-0.22	0.65	0.305
	HIIT	3.29 ± 1.30	2.95 ± 1.23				
HbA1C (mmol/mol)	CT	34.8 ± 1.6	34.5 ± 1.6	0.43	-0.69	1.55	0.423
	HIIT	36.4 ± 3.3	35.4 ± 3.0				
OGTT AUC (mmol/L x minutes)	CT	42.32 ± 4.43	40.98 ± 4.07	0.65	-0.71	1.83	0.516
	HIIT	42.85 ± 5.47	40.84 ± 4.97				

7.5. Discussion

Our study aimed to determine the comparative benefit to cardiometabolic health of completing either an 8-week HIIT or CT intervention in sedentary males with overweight and obesity. The main findings from our study were; 1) neither mode of exercise appeared to improve body composition in 8-weeks of training, with neither group ostensibly superior nor inferior to the other, 2) increases in cardiorespiratory fitness in the CT group were meaningful (4.1 ml·kg^{-1}min^{-1}) and exceeded improvements observed in CT studies without HIIT, 3) left ventricular end diastolic and end systolic volumes were higher for HIIT over CT (MD: 21.55 ml, 95% CI: 8.72, 34.38, p = 0.03; MD: 8.03 ml 95% CI: 1.52, 14.54, p = 0.02) and 4) the CT group had improved gains in strength measures over HIIT for squat (MD: 18.3 kg, 95% CI: 13.7, 22.9, p = 0), deadlift (MD: 12.3 kg, 3.4, 21.2, p = 0.01) and shoulder press (MD: 9.39, 95% CI: 2.81, 15.97, p = 0.01).

7.5.1. Body composition

The findings from our study suggest that 8 weeks of bi-weekly HIIT or CT exercise training is insufficient to result in notable changes in measures of body composition with no mean differences observed between-groups. However, 95% confidence intervals suggest that the true value of the mean difference in body mass (2.0 kg) was between -0.7 and 4.6 kg, which posits a potential for a difference between-groups. Indeed, a ~2.0 kg body mass reduction was observed in the CT group, with a negligible change in the HIIT group. Previous research has highlighted 8-weeks of walking/running and resistance exercises CT in males with overweight and obesity can result in reductions in body mass of 4.2 kg (Atashak et al., 2016), though these reductions were confounded by the lack of dietary control and non-randomised design in this study. As such, the majority of CT studies in this population observe more modest reductions (0.7 – 1.6 kg) in body composition when completed over 12 – 24 weeks (Ho et al., 2012; Brunelli et al., 2015; Duft et al., 2017), though none of these studies included HIIT. Therefore, the reductions in body mass of 2 kg in only 8 weeks observed in the CT group in this study may be a promising result for the use of HIIT in CT. However, the HIIT-only group observed negligible changes in body mass, though, these findings concur with those of Batacan et al. (2017) who determined through meta-analysis that HIIT interventions of less than 12 weeks in duration are not sufficient to provide improvements in measures of body composition.

7.5.2. CPET measures

The primary outcome measure obtained from CPET was cardiorespiratory fitness, determined via assessment of $\dot{V}O_{2peak}$. Although greater average increases were observed after the 8-week training programme in the CT group compared to the HIIT group (4.1 versus 2.1 $ml{\cdot}kg^{-1}min^{-1}$), wide confidence intervals reflected that there were no discernible mean differences observed in ANCOVA analysis (MD: 0.2, 95% CI: -2.1, 2.5, $p = 0.868$). Nonetheless, the average increase in the CT group exceeded the threshold (>3.5 $ml{\cdot}kg^{-1}min^{-1}$) for meaningful benefit to the reduction in all-cause and cardiovascular mortality (Kodama et al., 2009). Moreover, these improvements were similar to previous CT programmes in individuals with overweight and obesity of greater durations (Brunelli et al., 2015; Duft et al., 2017) where improvements of 3.1 and 3.3 $ml{\cdot}kg^{-1}min^{-1}$ were observed, respectively. These studies did not involve HIIT, potentially highlighting the benefit of incorporating HIIT as the cardiovascular component to CT, as greater improvements were sought in a shorter duration. Though it was anticipated that the HIIT group would evoke larger increases in $\dot{V}O_{2peak}$ this was not observed; this may be due to a combination of a higher baseline fitness and a short exercise training programme duration. Nevertheless, these initial results are promising from the perspective of the CT group, with large, meaningful increases in cardiorespiratory fitness in just 8 weeks of training.

Both peak and relative power output (attained at the end of the CPET) increased in both groups, with a slightly larger increase in the HIIT group, despite no significant mean differences between-groups. Though this likely reflects greater exercise capacity, as corroborated by large increases in the equivalent of 80% delta through exercise training, higher peak RER and RPE in the post-intervention CPET may demonstrate that improved performance in this CPET may be due to a greater tolerance of higher intensities of exercise sought from the training programme. The point of the ventilatory threshold also increased in both groups, with reference to both VO_2 and power output. Higher ventilatory thresholds are historically demonstrated to be representative of greater exercise performance (Reybrouck et al., 1986) and are therefore an important adaptation to be sought from exercise training for individuals with overweight and obesity, as they may be more inclined to continue with exercise training should their exercise tolerance improve. However, scrutiny of confidence intervals and point estimates from ANCOVA analysis revealed weak to no evidence of differences in all CPET outcome measures. Further research is required to determine if CT and HIIT elucidate meaningful differences in CPET or if the exercise modes evoke equivalent changes in CRF.

7.5.3. Cardiac measures

Previous research has highlighted the role of HIIT for providing cardiac changes, particularly in the structure and volume of the left ventricle (Hosseini et al., 2012; Wilson et al., 2019; Amaro-Gahete et al., 2020). Indeed, the present study identified a large increase in four-chamber view end-diastolic and systolic volumes in the HIIT group compared to the CT group (MD: 21.55 ml, 95% CI: 8.72, 34.38, $p = 0.03$; MD: 8.03 ml 95% CI: 1.52, 14.54, $p = 0.02$). These findings concur with previous research which established significant increases in left-ventricular end-diastolic volumes in sedentary men after 8 weeks of HIIT (Ahmadzadeh et al., 2019). However, these changes were not mirrored in the CT group (who performed only 50% of the HIIT intervals in comparison), perhaps highlighting that the volume of HIIT is an important factor in establishing cardiac changes. These volume increases were also reflected in increases in stroke volume in the HIIT group, with little change observed in the CT group, though no clear mean differences were detected by ANCOVA. Previous research has posited the role of endurance exercise training in increasing stroke volume as a result of increases in end-diastolic volume (Vogelsang et al., 2008) and this has also been demonstrated in T2DM patients after 8 months of HIIT (Wilson et al., 2019). However, the greater changes in stroke volume in the HIIT group did not correspond to greater increases in cardiorespiratory fitness compared to the CT group in the present study. Though, the HIIT group presented with a higher baseline fitness, therefore training programmes of greater duration in more evenly baseline-matched groups may be required to examine if the observed differences in cardiac measures are reflected in concomitant cardiorespiratory fitness changes between-groups.

In terms of meaningful cardiac changes to the benefit of cardiorespiratory fitness, measures of resting heart rate, systolic and diastolic blood pressure were all observed to decrease in both groups, with mostly similar changes of around 5 bests·min^{-1} and 4 mmHg. Though these changes could logically be linked to the observed changes in stroke volume, there were no differences between-groups as with stroke volume. Inspection of ANCOVA analysis revealed no notable differences between-groups for any structural cardiac measures, with no obvious trends in increases or decreases in measurements for either group, perhaps exhibiting that 8-weeks of exercise training were insufficient to incur any structural changes.

7.5.4. Strength

Only participants in the CT group performed strength-based exercises, therefore unsurprisingly, mean differences with confidence intervals > 0 and p-values < 0.05 were observed in post-intervention strength for the CT group compared to HIIT for squat (MD: 18.3 kg, 95% CI: 13.7, 22.9, p = 0), deadlift (MD: 12.3 kg, 3.4, 21.2, p = 0.01) and shoulder press (MD: 9.39, 95% CI: 2.81, 15.97, p = 0.01). However, this was not the case for bench press. Research highlights that only resistance type training can provide increases in skeletal muscle mass (Yan et al., 2019), but evidence points to the fact that the interference effect can reduces strength gains from CT (Donges et al., 2013; Wilson et al., 2019). Despite other research not measuring changes in strength over the same four exercises as the present study, generally improvements in strength of around 17 – 19% are sought across upper/lower body (Brunelli et al., 2015; Duft et al., 2017), which is reflected in this study (average 17.4% increase across four exercises), though massively inferior to RT only groups in this population, who are reported to increase strength by 68 – 99% (Donges et al., 2013). However, all of these previous studies included a greater volume and duration of exercise training, perhaps highlighting the superiority of the present CT protocol due to its short training duration. An important caveat with the present study is that the exercises utilised to measure strength (e.g., deadlift) were also more specialised weightlifting movements which require an element of technique and familiarity to maximise the amount of weight lifted.

Therefore, further research may wish to examine the effect on a variety of resistance-type exercises.

Intriguingly, the HIIT group also observed increases in strength from baseline. This may be further evidence to suggest that when HIIT is included as the cardiovascular component of CT the interference effect is ameliorated (Methenitis et al., 2018; Sabag et al., 2018), though, the mechanism for this is yet to be understood. The HIIT group may have observed such increases in strength due to their sedentary basis and unfamiliarity with resistance type exercises. Indeed, previous research in sedentary individuals with obesity has observed increases in strength in those completing only aerobic exercise training (Donges et al., 2013). Taken together, the evidence suggests that although CT was more beneficial for increasing strength gains, even 8-weeks of HIIT exercises may be sufficient to increase performance in weightlifting movements in sedentary males with overweight and obesity.

7.5.5. Metabolic measures

Generally, reductions were observed for both groups in both fasting plasma glucose and lipid profile, though no mean differences were established between-groups. These improvements are key markers of cardiometabolic health (Fisher et al., 2015; Kessler et al., 2012) and the observed decreases in the present study are notable for the improvement of obesity-related health, due to the close relationship between obesity and the metabolic syndrome (Jung and Choi, 2014). Both HIIT and RT have previously been demonstrated to improve metabolic health, due to the key metabolic pathways the two exercise types distinctly activate. Namely, the increased GLUT4 protein content and skeletal muscle oxidative capacity incurred from both HIIT and RT act to the betterment of metabolic health (Tresierras and Balady, 2009; Hood et al., 2011; Little et al., 2014). Indeed, improvements in markers of metabolic health have also previously been evidenced after CT in population with overweight and obesity s (Brunelli et al., 2015; Duft et al., 2017). There were also small decreases in glucose AUC and Hb_{A1C} which are historically well-evidenced to occur as a result of HIIT and RT (Durak et al., 1990; Jelleyman et al., 2015). Though, 8-weeks of training may have been insufficient to incur more notable changes in markers of metabolic health, and training programmes of greater durations may wish to explore this further.

7.5.6. Limitations

A number of limitations with the present study may have impacted on the findings. Groups were not evenly matched at baseline, so that even when one group was superior for a particular outcome measure, ANCOVA analysis determining non-significant differences between-groups. Although ANCOVA analysis was utilised to mitigate this, any patterns or trends may have been easier to elucidate with more well-matched groups. Moreover, the present study included just twice-weekly exercise sessions for 8-weeks, which is cumulatively lower than exercise guidelines (Piercey et al., 2018). The small sample size in this study also increases the likelihood of type II error, with difficulty interpreting statistical tests with certainty. The small cross-section of the population that was recruited also means that applying the results of this study to the sedentary population living with overweight and obesity as a whole, particularly women, may be imprecise. Dietary changes were self-reported and physical activity levels were only monitored at baseline and week 10 rather than throughout the study **(Chapter 4.0)**, therefore behavioural changes in diet and physical activity cannot be ruled out as contributing factors to changes in outcome measures. Measures of bioelectrical impedance were used to determine changes in body fat and lean body mass, however, whilst fluid intake was standardised, ensuring that all participants voided before measurement was not. This should be incorporated into future research expanding this feasibility study into a large scale research trial.

7.5.7. Conclusion

Completing either 8-weeks of twice-weekly HIIT or CT resulted in improvements to markers of cardiometabolic health in males with overweight and obesity. 8-weeks ultimately proved insufficient stimulus to incur notable changes in body composition, though a preliminary trend of superior reductions in the CT group may be present, with the body mass losses that were observed comparable the previous research but in a shorter time period. Both groups improved cardiorespiratory fitness though the CT group found greater improvements, though wide confidence intervals around the mean difference suggested uncertainty in its interpretation. Nonetheless, these changes were clinically meaningful in the CT group and exceeded improvements observed by previous research in longer durations of training. A large increase in end diastolic and systolic volumes were observed in the HIIT group, which facilitated a greater increase in stroke volume compared to the CT group. Both groups increased strength, though CT was far superior in this regard.

Taken together, the results suggest that both HIIT and CT are valuable to improve cardiometabolic health in previously sedentary adult males with overweight and obesity. Although twice-weekly training for 8-weeks was insufficient to greatly impact on measures of body composition and structural cardiac changes, improvements were sought in cardiorespiratory fitness and strength in both groups, which were comparable to research of greater training durations. Results in the CT group were superior in a number of outcome measures in comparison to other CT research not including HIIT. Ultimately, the findings from this feasibility study highlight the potential role of both HIIT and CT inclusive of HIIT to improve cardiometabolic health in males with overweight and obesity, with further research required to elucidate both the long-term effect on cardiometabolic health and between-group differences.

Chapter 8.0. General Discussion

8.1. Summary of Thesis Context

8.1.1. Background

The incidence of obesity has tripled worldwide within the last 50 years (World Health Organisation, 2018), with the majority of adults in England classified as living with overweight or obesity (Health Survey for England, 2017), highlighting the issue as a major public health crisis. Sedentary behaviour is identified as a major contributor to the development of overweight and obesity (Hardgraft et al., 2021), positing a role for regular exercise in the fight against obesity-related ill health. Indeed, regular aerobic/cardiovascular based exercise and strength/resistance-based exercise exhibit a number of positive health-related outcomes (Gill and Cooper, 2008; Strasser and Schobersberger, 2011). As such, exercise guidelines advocated by the American College of Sports Medicine include both exercise types (Piercey et al., 2018), with the maximum benefit to a variety of health outcomes observed only when both exercise types are completed (Zhao et al., 2020).

Individuals with overweight and obesity are historically noted not to achieve exercise guidelines (Tudor-Locke et al., 2010), with a 'lack of time' posited as a key barrier to regular exercise participation (Trost et al., 2002). High-Intensity Interval Training (HIIT) is proposed as a time-efficient modality of exercise, in which higher loads of exercise are condensed and broken up into smaller, manageable chunks. HIIT is postulated to evoke a greater physiological stimulus, culminating in superior adaptations to lower intensities of exercise (Gibala et al., 2012). Nonetheless, strength-based exercise is still required in order to maximise health benefits (Zhao et al., 2020), therefore, combining HIIT and strength-based exercises together in same-session concurrent exercise training may be the most efficacious and efficient exercise type for completion by individuals with overweight and obesity.

8.1.2. Thesis aims

The primary aims of this thesis were to:

- Synthesise the current evidence-base on the utility and effect of CT as an exercise mode for individuals with obesity, particularly including the use of HIIT and the common methodologies employed.
- Determine the efficacy, reliability and feasibility of using individualised HIIT designs, for more accurate prescription of HIIT for individuals with obesity.

- Establish the feasibility and evaluate the intervention fidelity of completing combined HIIT and RT exercise training programmes in individuals living with overweight and obesity.
- Determine the use and effectiveness of CT compared to HIIT on improving cardiometabolic outcomes in individuals with obesity.

8.2. Themes arising from review of literature

A key limitation of the current evidence base was minimal evidence and poor quality of studies examining the effect of same-session CT incorporating HIIT in an population with overweight and obesity . Through a wide-scoping general review on HIIT and CT **(Chapter 2.0)** and a systematic review and meta-analysis **(Chapter 3.0)** of training programmes in an population with overweight and obesity several key themes were highlighted to be addressed by this thesis; Fidelity, Feasibility, and Changes in Body Composition and Cardiometabolic Health.

8.2.1. Fidelity

A myriad of HIIT protocols exist in the published literature, with no definitive characterisation of what a 'HIIT session' consists of. Nonetheless, the general consensus is that HIIT intervals are generally those above the lactate threshold (Laursen and Buchheit, 2019), though the duration and number of intervals can vary widely, with protocols of 4 x 4 minutes (Selmi et al., 2017) to 15 x 15 seconds (Dupont et al., 2004) employed in the literature. HIIT is often prescribed using maximal anchors (e.g., VO_2peak), resulting in a dissimilar actual intensity of exercise achieved by each relative individual (Jamnick et al., 2020) resulting in large between-subject variances in intensity. Consequently, this impacts on the outcome of exercise training studies, as larger sample sizes are required in order to detect effects (Weston et al., 2015). As such, it is vital to quantify fidelity and individual variability in exercise protocols. The 'delta' method of exercise prescription is proposed to reduce this heterogeneity by prescribing intensity based on the ventilatory threshold (Lansley et al., 2011). However, limited research (Granata et al., 2016; Bossi et al., 2019) has been undertaken on the use of the delta method in intermittent exercise, with those which have conducted such studies having recruited healthy or athletic populations. It appeared therefore imperative for the present study to establish a HIIT protocol design using the 'delta' method for intensity prescription and to determine its fidelity in order to accurately assess its impact on other outcome measures.

8.2.2. Feasibility

The feasibility of exercise interventions is vital for widespread long-term adoption by the population with overweight and obesity . Interventions must be feasible for same-session CT incorporating HIIT to play a role in the solution to overweight and obesity. The successful completion of HIIT and RT appear closely linked to enjoyment and adverse events, with the evidence base proposing mixed results on these outcome measures.

8.2.3. Measures of body composition and cardiometabolic health

The existing literature base highlighted the capacity of both HIIT and RT exercises to improve a number of markers of cardiometabolic health (Batacan et al., 2017; Strasser and Schobersberger, 2011). Furthermore, studies undertaking CT interventions in population with overweight and obesity s also present the benefit to cardiometabolic health (Johannsen et al., 2016). The most commonly investigated outcome measures relate to body composition, with rapid weight loss often sought by individuals (Sears and Santon, 2001; Dansinger et al., 2005). However, the majority of CT studies in overweight and obesity **(Chapter 3.0)** observe modest reductions in body mass below the threshold of 5% understood to equate to positive health outcomes (Williamson et al., 2015). Indeed, a number of markers independent of weight loss are of more value when observing the effect of CT interventions. The reduction in body fat and waist circumference were two key measures, with meta-analysis of CT studies revealing meaningful improvements in these measures versus control. The importance of increases in fat free mass (FFM) was also established, with increases in mass of the pivotal metabolic tissue skeletal muscle observed, suggesting the importance of assessing measures such as FFM rather than body mass loss in isolation. As a strong predictor of CVD and all-cause mortality, cardiorespiratory fitness (CRF) was an important factor obtained in CT studies, with previously sedentary individuals observing large increases in CRF. In the systematic review, HIIT alone was superior to CT, likely due to greater duration of cardiovascular-based exercise, though this was not established in well-matched groups with protocols of similar volumes. Large increases in strength were recorded in RT groups, with increases from baseline in CT groups, but inferior to RT alone, postulating the influence of the interference effect, though the effect of incorporating HIIT into CT on strength was not determined. Inconclusive results regarding metabolic health were presented, with measures such as fasting plasma glucose and insulin concentrations assessed

8.3. Synthesis of Key Themes

8.3.1. HIIT Protocol Development

In the literature the term HIIT has been used to describe a very heterogeneous range of exercise protocols, as demonstrated by **Figure 8.1**.

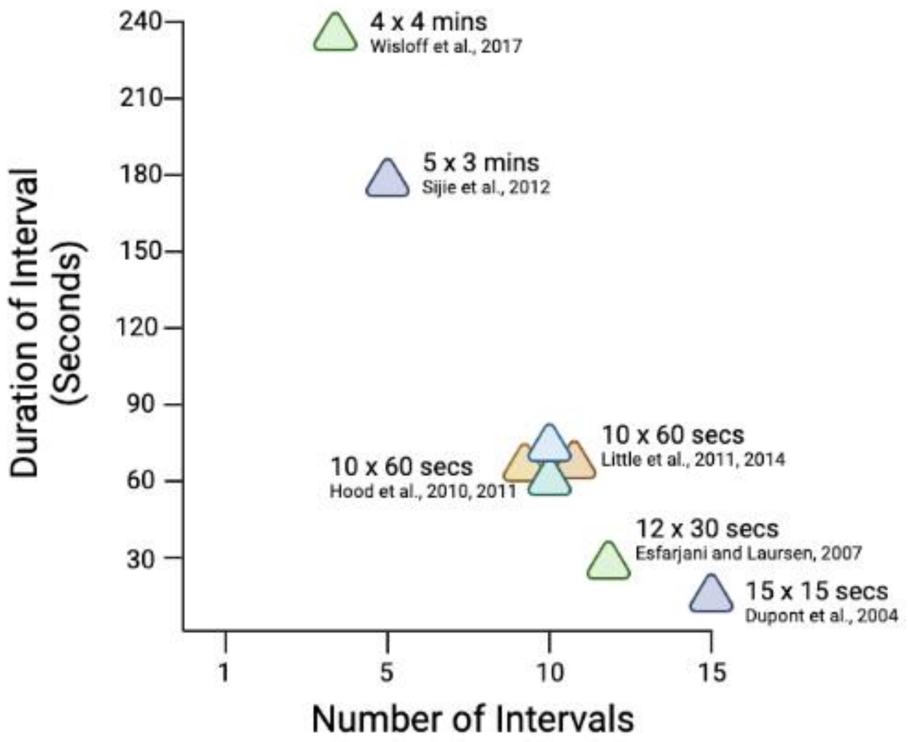

Figure 8.1. HIIT Protocol Designs.

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Given that a 10 x 60 s design was the most frequently adopted protocol as well as a 'middle ground' of the potential protocols and has been used effectively in previously sedentary clinical populations with little prior experience of HIIT (Little et al., 2011; Hood et al., 2011; Little et al., 2014; Stoa et al., 2017), this was selected as the HIIT design. This design incorporated a simple 1:1 work to rest ratio, with a shortened interval length and short total session duration. This design was deemed to be to the benefit of an population with overweight and obesity with low tolerance of exercise and a 'lack of time' to complete such exercise. The intensity of exercise was prescribed using the 'delta' method in order to reduce inter-subject heterogeneity of actual intensities of exercise achieved (Lansley et al., 2011; Jamnick et al., 2020) from a graded exercise test. Use of the delta method during HIIT is limited, though previous studies ranged from 30 – 80% Δ in a variety of designs in healthy and trained populations (Granata et al., 2016; Bossi et al., 2019). Lansley et al. (2011) proposed that 80% Δ corresponded to 'severe-intensity' during continuous exercise, and given the short intervals associated with the 10 x 60 s design and lack of any prior precedent set in the literature for this population, 80% was set as the desired intensity.

In order to establish the reliability of this design, the test-retest reliability study was conducted **(Chapter 5.0)**. Reliability analysis indicated that a 10 x 60 s HIIT protocol dosed at 80% Δ corresponded to 'vigorous' intensity exercise, which was aligned with respect to internal physiological load. Moreover, all participants were able to complete each interval and full protocol, proposing that this was a feasible HIIT design for completion by previously sedentary individuals with overweight and obesity. Though, this did not establish the feasibility of the protocol over a longer period or address the addition of a form of progressive overload with regard to the intensity of exercise.

8.3.2. Fidelity of training programme

Linear Mixed Modelling of HR data was undertaken of HR data measured during HIIT and CT exercise protocols during the exercise training programme **(Chapter 6.0)** to establish the within-participant variability in internal physiological load, in line with previous fidelity research in HIIT (Weston et al., 2015). The model demonstrated that both the HIIT and CT protocols were well-controlled, with low session variance in HR of around 0.02 – 0.03 beats per minute, though it was acknowledged this fidelity would need to be replicated in larger samples over greater durations of exercise training.

8.3.3. Feasibility

Feasibility was shown to be closely linked to widespread adoption of exercise training programmes. The prescription of exercise in a sedentary, population with overweight and obesity is somewhat of a balancing act which must be precise. Importantly, (particularly when considering HIIT) this previously sedentary population have a low functional capacity and consequently, a low tolerance and preference of higher intensities of exercise **(Chapter 5.0; Chapter 6.0).** As such, exercise interventions must strive to be enjoyable, well adhered to and promote low rates of adverse events **(Chapter 2.0)**, but there remains a scarcity of studies determining these factors in CT interventions in this population **(Chapter 3.0)**.

Tolerance and Preference of high intensities of exercise as assessed by the PRETIE-Q increased after a CT intervention **(Chapter 6.0)**, with HIIT increasing Tolerance and Preference to an even greater extent. This cements the rationale for the inclusion of HIIT in CT in order to accustom participants to higher intensities of exercise and improve their functional capacity, providing an important adaptation to improve health-related quality of life and prepare for future exercise. CT is noted to be highly enjoyable **(Chapter 6.0)** as assessed by PACES, which was demonstrated to be a reliable measure of enjoyment of HIIT in this population **(Chapter 5.0)**. HIIT-only training may result in displeasure as exercise sessions become more difficult with increasing intensities **(Chapter 6.0)**. This is a key consideration for CT programmes incorporating HIIT, and it may be pertinent to implement a slower rate of progression of intensity to avoid reduced rates of enjoyment. Nonetheless, in the CT training programme undertaken in **Chapter 6.0**, enjoyment remained high, indicating that completing only 50% of HIIT intervals and the inclusion of resistance exercises can attenuate the increased displeasure observed during HIIT-only.

8.3.4. Cardiometabolic Health

The key aim of exercise interventions in population with overweight and obesity s is to improve many of the cardiometabolic factors affected as a result of obesity-related ill health. Measures of body composition, particularly body mass, were the key outcome measures obtained. A number of secondary outcome measures related to cardiometabolic health were also determined.

8.3.4.1. Body composition

The three most commonly assessed measures of body composition were body mass, body fat and waist circumference in the literature. The pooled mean reduction for body mass observed in a meta-analysis of CT programmes in overweight and obesity **(Chapter 3.0)** was -1.7 kg (95% CI: -3.6, 0.1, $p = 0.07$), highlighting the small range of changes observed in the literature. As a result of the wide confidence intervals observed there is no certainty that CT does indeed incur body mass reductions and a greater sample size is required to confirm this. Nonetheless, In the exercise training programme **(Chapter 7.0)** a reduction of 1.8 kg (~2%) was also observed. However, this reduction was achieved in a much shorter time period (8-weeks) than the studies included in the systematic review (12–24 weeks), perhaps highlighting the capacity of the low-volume combined HIIT and CT protocol to provide improvements in shorter time periods. Though, the observed reduction remained well below the 5% threshold for positive health benefits stated in the literature (Williamson et al., 2015). Therefore, although reductions in body mass are observed after CT, it may be apparent that measures independent of body mass (and, incidentally, BMI) are of greater importance to focus on as a result of exercise interventions in this population. Indeed, factors including diet, sedentary time and habitual physical activity levels may play a greater role in instigating weight-loss. As such, given that BMI is the definitive characteristic pertaining to overweight and obesity, some thought may be warranted to looking beyond BMI alone when both exploring obesity-related ill-health and the betterments that exercise training can provide.

Meta-analysis **(Chapter 3.0)** of existing CT exercise programme studies revealed a reduction in body fat (-3.7%, 95% CI: -6.4, -1.1, $p < 0.01$) and waist circumference (-2.8 cm 95% CI: -4.0, -1.7, $p < 0.01$) with confidence intervals below zero, providing more certainty that CT can evoke changes in these measures than for body mass. However, the CT group in the training study **(Chapter 7.0)** identified reductions of only 0.5% and 1.5cm respectively, falling outside of the range of confidence intervals identified in the meta-analysis. This suggests an 8-week bi-weekly exercise training programme is insufficient to incur body composition changes in males with overweight and obesity. However, future research may wish to explore the effects on body fat through various methodologies, as a wide range were utilised by studies in the literature. Indeed, the use of bioelectrical impedance in the present study was not without its own limitations (Mialich et al., 2014), which may be exacerbated by the relatively high amounts of extracellular and total body water in individuals with obesity, resulting in overestimations of fat free mass and underestimations of fat mass (Coppini et al., 2005).

When comparing CT to HIIT in the training study, wide confidence intervals reflected uncertainty around any true mean differences between groups, though there were greater reductions in body mass after CT compared to HIIT, which may warrant further investigation. It may be that the inclusion of resistance exercises resulted in greater increases in skeletal muscle mass and consequently resting metabolic rate to result in greater reductions in body mass (Alexander, 2002).

8.3.4.2. Cardiorespiratory fitness

The superior exercise types for adaptations to the benefit of cardiorespiratory fitness (CRF) are cardiovascular-based, due to the upregulation of AMPK and its subsequent downstream metabolic effects in improving oxidative capacity. HIIT was evidenced to provide greater activation of AMPK in comparison to lower intensities of exercise **(Chapter 2.0)** and therefore larger relative increases in CRF. The inclusion of RT in CT may evoke an ‘interference effect’ which can diminish these adaptations. CT was demonstrated to be effective in improving CRF in overweight and adults with obesity, with a systematic review of the literature **(Chapter 3.0)** demonstrating that duration of training programme was the most important facet, with those over 12 weeks observing increases in CRF of clinical significance (~ 3.5 $mL{\cdot}kg^{-1}min^{-1}$). Promisingly, the inclusion of HIIT in CT resulted in the greatest increases in CRF. Generally, in the literature, improvements in CRF after CT were partly attributed to concomitant cardiac volume and pressure overloads which increase end diastolic diameter.

In the training programme study **(Chapter 7.0)**, both the HIIT and CT groups increased CRF from baseline in previously sedentary males with overweight and obesity. However, these adaptations were lower than anticipated, with the short duration of training (8 weeks) the primary justification for this. Nonetheless, both groups increased by similar amounts, therefore longer durations of training may be required to elucidate if CT including HIIT is inferior to HIIT alone in increasing CRF as hypothesised. It is likely that the low baseline fitness in the previously sedentary participants provided a large scope for increases in CRF and any divergence in groups may be observed after longer durations of training. With regard to the mechanism behind these adaptations, echocardiography revealed large increases in left-ventricular end diastolic volumes, though only in the HIIT group. Intriguingly, a slight decrease was observed in the CT group, though they completed half of the volume of HIIT in this group. It may be that this poses a potential mechanism by which sufficient volumes of HIIT can increase CRF, though further research is warranted.

8.3.4.3. Strength

Resistance exercises were identified as the essential component for increasing strength, via activation of the mTORC1 signalling complex, subsequent muscular hypertrophy and thereafter, strength **(Chapter 2.0)**. However, the addition of cardiovascular-based training in same-session CT can result in an interference effect, inhibiting some strength adaptations. Though, the use of HIIT as the cardiovascular component is proposed to ameliorate this effect **(Chapter 2.0)**. A systematic review of the literature revealed that groups of participants performing solely RT found the greatest increases in strength, compared to CT groups **(Chapter 3.0)**. CT was superior to aerobic training or a non-exercise control, though the influence of the interference effect clearly contributed to inferior strength adaptations to RT alone.

In the exercise training programme **(Chapter 7.0)**, CT provided greater increases in strength compared to the HIIT group, with confidence intervals > 0 for the mean difference between-groups for all exercise but Bench Press. However, a training arm performing just RT was not included, which would have provided an interesting comparator group, given they would have likely observed even greater improvements. Despite inferior strength gains, the HIIT group also increased from baseline. This may demonstrate the sedentary nature of participants at baseline, as even HIIT was able to improve strength, those this could be attributed to a number of factors such as psychology and familiarity, rather than purely muscular strength per se. It would be anticipated that longer exercise training durations would result in a plateau in the relationship between HIIT and strength, with only CT being able to continually provide increases in strength with a progressive overload of exercise loads.

8.4. Reflection, Strengths and Limitations

8.4.1. Reflection and General Strengths

Over the course of producing this PhD thesis there are a number of key strengths and limitations that have become evident. Overall, the process has highlighted that although the PhD project may have been devised into a range of several studies, the thesis knits those together to tell a cohesive story. This project involved numerous strengths which maximise the value of the findings, discussion and practical application of the work. The thesis as a whole involved a clear process of establishing the background literature, performing a systematic review to understand the gaps in the knowledgebase and the undertaking of reliability study prior to the implementation in a training programme. This approach was also very transparent, with the methodology well established prior to completion, which is well-evidenced by the pre-registration of both the systematic review and feasibility training study.

8.4.2. Sample Size

Each of the meta-analysis, reliability and training studies involved small sample sizes. This resulted in difficulty in confidently interpreting results and increasing the likelihood of a type II error. This also impacted the generalisability of the findings to the population living with overweight and obesity as a whole, particularly to women. As a result of this small sample size, there remains uncertainty in the interpretation of many of the statistical tests undertaken in this thesis. As such, an approach to focus on mean differences and confidence intervals rather than statistical significance per se was employed. To that end, any inferences on cardiometabolic outcome measures cannot be categorically established, and instead provide exploratory outcomes which warrant further investigation.

8.4.3. Covid-19 pandemic

The unprecedented Covid-19 global pandemic began during the midst of the reliability study, influencing both recruitment and completion of the study as well as adding a confounding variable for the future studies. Thus, the reliability study culminated in a sample of 10 participants, when 20 were aimed for based on previous reliability studies and analyses. Thereafter, during recruitment for the training programme, individuals who had tested positive for Covid-19 were excluded from the study due to the unknown effects of the virus and any potential long-lasting symptoms. Regular testing was introduced to the training study, with participants requested to return two negative tests before commencing the study and completing weekly testing for the duration of the study, though these results were self-reported.

As a result of the pandemic, the PhD project was ultimately put on hold for a 12-month period in which no data collection could take place. This was a very uncertain time, given the end-date of the pandemic and when data collection would be able to resume was impossible to determine. The longer the pandemic continued for, the greater impact this had on the time remaining for the project and therefore the ability to recruit sufficient participants and collect data. Consequently, the project was greatly impacted upon by the pandemic. The initial plans for the feasibility training study were to undertake a four-arm study over a 12-week training period. The four arms of the study were to include a CT, HIIT, RT and control group. As we emerged from the pandemic and were able to collect data within the University again, it became apparent that there would be insufficient time to recruit and undertake such a study. Therefore, the study was narrowed to include an 8-week training period and two experimental groups, with the CT and HIIT groups selected as the most pivotal in terms of relevance to the study and for comparative purposes when exploring the prospective cardiometabolic effects.

8.4.4. Diet & physical activity monitoring

Though diet and physical activity were controlled for during the exercise training programme, monitoring took place over a representative three-day period during baseline (Week 1) and post-testing (Week 10). Therefore, it is realistic to assume that habitual dietary intake and physical activity levels could have differed during the training programme (Weeks 2 – 9) providing confounding factors to exploratory outcome measures such as body composition. Diet was also assessed via self-reported diet diary, although participants were briefed prior to completion. Self-reported diet diaries have long been established to require caution when interpreting due to imprecision and bias (Schoeller, 1995). The use of actigraphy and its precision in determining energy expenditure accurately is also questioned in the literature (Reilly et al., 2006; Gusmer et al., 2014). Though, physical activity levels were only determined as controlling factors rather than outcome measures. Notwithstanding, the role of diet and habitual physical activity and the influence of the CT exercise training programme on these factors are an intriguing avenue for future research, particularly when considering the ‘meaningful’ impact of the programme for individuals with overweight and obesity.

8.4.5. Capillary Blood Sampling

Capillary blood sampling was selected over venous sampling to determine a number of markers of metabolic health due to its less invasive nature, requirement for a lower blood sample volume and ease (Krleza et al., 2015). However, a poor sampling protocol or when capillary sampling is carried out incorrectly, can result in a high variability in sample quality, with the selected puncture site and technique key factors (Plebani, 2006; Crabtree et al., 2014). Nevertheless, capillary sampling was undertaken in accordance with the World Health Organisation's guidelines on drawing blood (WHO, 2016), by the same researcher in an attempt to reduce the impact of this variation. A number of markers of metabolic health were also determined via indirect measures, with factors such as insulin sensitivity determined by oral glucose tolerance test, for example. Though, these were included as exploratory outcomes to be expanded upon with further research. Thus, the importance of direct measures and the method of blood sampling may be of greater consequence in future larger-scale training studies.

8.4.6. Progression of exercise intensity

The intensity of exercise set for the training programmes progressed by 5% on a weekly basis with a noted drop in the rate of perceived exertion (RPE). However, the reliability study **(Chapter 5.0)** determined that subjective measures of load (inclusive of RPE) were less reliable than internal measures. As such, heart rate changes were included to corroborate changes in RPE. However, measurement of VO_2 in each exercise session was not determined, which would have been the most direct method of assessing when participants required a progression of intensity. Despite the potential value of this, it should be noted that a long-term exercise training programme in which participants are required to undergo on-line gas-analysis during each session may well affect a plethora of additional factors such as enjoyment and may influence desire to complete such an intervention. Therefore, including a mid-intervention CPET may be a beneficial compromise to reassess each participants 'delta' and confirm the intensities of exercise being achieved during exercise sessions.

8.5. Practical Applications and Future Research

A wide range of HIIT protocol designs are on offer for practitioners and the general population living with overweight and obesity, including the manner in which the intensity of these protocols are set. We establish that a 10 x 60 s protocol design is time-effective, feasible and enjoyable in this population, with good reliability in internal physiological load. We also demonstrate that use of the delta method to prescribe exercise intensity is effective in this population, with an initial intensity of 80% Δ a feasible starting intensity, equating to 'vigorous' intensity exercise, though this can be manipulated and progressed. However, the general population living with overweight, and obesity may not have access to the resources required to establish the delta method. We established that 80%Δ equated to around 80% of maximum heart rate, with good reliability, which could be established by gym-based heart-rate monitoring machines or smart wristwatches. Moreover, the use of CR100 RPE was feasible for progression of intensity both for HIIT and resistance exercise in this population. This gives confidence to practitioners when using RPE in this population as well as a simple tool for the general population living with overweight and obesity to use when progressing their own CT programmes.

The training study was an important exercise to establish the feasibility of conducted a larger scale trial, which would be acceptable to complete with minor modifications. The exercise protocols and frequency of training were well-adhered to by participants, though the duration of training was insufficient to truly explore cardiometabolic effects, with > 12 weeks typically required. The addition of further training arms may also be included, with non-exercise control, RT only and conventional CT (without HIIT) all interesting concepts for comparison with a CT programme including HIIT. A key focus for future research should also be to undertake this CT programme in a female population to establish if the findings around fidelity, feasibility and improvement in cardiometabolic health are comparable to male population included in this study. Additional outcome measures may also be included, with different methodologies for the measurement of body composition trialled, the assessment of blood lactate and further exploration of echocardiography (particularly the apparent relationship between HIIT and left-ventricular end diastolic volumes) all intriguing avenues of further research. Indeed, the further exploration of the feeling scale and the timepoints during exercise in which this can be employed is warranted, with the measurement of participant enjoyment throughout exercise protocols an interesting prospective. The initial findings from this study establish a good protocol design to follow and highlight potential trends in the associated changes in cardiometabolic health. The findings also findings can also be utilised in power calculations to determine an appropriate sample size for determining true effects.

Results from the training programme indicated that 8 weeks of exercise training culminated in modest body mass loss, with the wider evidence base suggesting even longer-term CT does not result in larger scale body mass reductions. This is not to say that no body *fat* is lost per se, rather that increases in lean body mass mask these changes for participants 'on the scales'. Given that the majority of individuals living with overweight and obesity cease exercise interventions due to unmet weight loss demands, it is apparent that a shift in focus from weight loss is required. Indeed, a plethora of favourable health outcomes are attainable through CT independent of body mass loss. Individuals living with overweight and obesity must be supported to focus on these additional factors, with a reduced emphasis on body mass and BMI changes and this must be encouraged by practitioners. It may encourage individuals with overweight and obesity to continue engagement with exercise interventions were they to be given a greater understanding of the positive effects they cannot physically 'see', such as quality of life, cardiorespiratory fitness and metabolic health. Moreover, a lot of focus in the literature resides on p values and statistical significance of findings, whereas we demonstrate very few outcome measures with statistical significance. It may be more pertinent for researchers to focus on the value of changes in outcome measures, rather than prioritising the importance of statistical significance over what is clinically relevant and meaningful for participants.

The findings of this thesis have provided a wide range of potential practical applications as outlined above, however, in order to ensure that this work enters the knowledgebase of the literature, as well as to practitioners and individuals, it must be disseminated correctly and with an awareness of the platforms via which this is undertaken. Therefore, whilst some of the research in this thesis can be published in academic journals, in order to engage a larger audience posters, infographics and other short-form pieces will be promoted using online and social media platforms.

8.6. Conclusion

This thesis aimed to address three primary objectives through a general and systematic review of the literature, a test-retest reliability study and an exercise training intervention which is summarised in **Figure 8.2**. In conclusion, the summative findings from this thesis address the primary aims as follows:

- Synthesise the current evidence-base on the utility and effect of CT as an exercise mode for individuals with obesity, particularly including the use of HIIT and the common methodologies employed.

CT has been used in an population with overweight and obesity to the benefit of a wide range of outcome measures, though the use of HIIT in same-session CT is much less well-researched. There also exists a vast amount of variation in the design of HIIT protocols, with the majority using maximal anchors to prescribe intensities, which is fraught with the risk of introducing heterogeneity in the actual intensities achieved by individuals.

- Determine the efficacy, reliability and feasibility of using individualised HIIT designs, for more accurate prescription of HIIT for individuals with obesity.

The delta method of exercise prescription is proposed to reduce inter-subject heterogeneity. Using the delta method to prescribe HIIT protocols at an intensity of 80% equates to vigorous intensity exercise, has reliable and repeatable internal physiological load and is feasible for completion by previously individuals with overweight and obesity. A weekly progression of 5% of the delta, rounded to the nearest Watt, was an appropriate rate of progression for completion by this population based on a fall in RPE and corroborated by heart rate data.

- Establish the feasibility and evaluate the intervention fidelity of completing combined HIIT and RT exercise training programmes in individuals with overweight and obesity.
- Determine the use and effectiveness of CT compared to HIIT on improving cardiometabolic outcomes in individuals with obesity.

An 8-week exercise training programme consisting of twice-weekly CT exercise sessions of 30 minutes in duration was feasible for completion by sedentary males living with overweight and obesity. The protocol is acceptable with minor modifications to be upgraded to a larger-scale training study. Few differences were determined between the CT intervention and the HIIT intervention, with longer training programme durations required to elucidate any divergence in groups. However, exploratory outcome measures highlighted areas of interest for future research, which include the impact on cardiorespiratory fitness and the mechanisms behind these adaptations, with left-ventricular end diastolic volumes to be further examined in relation to this.

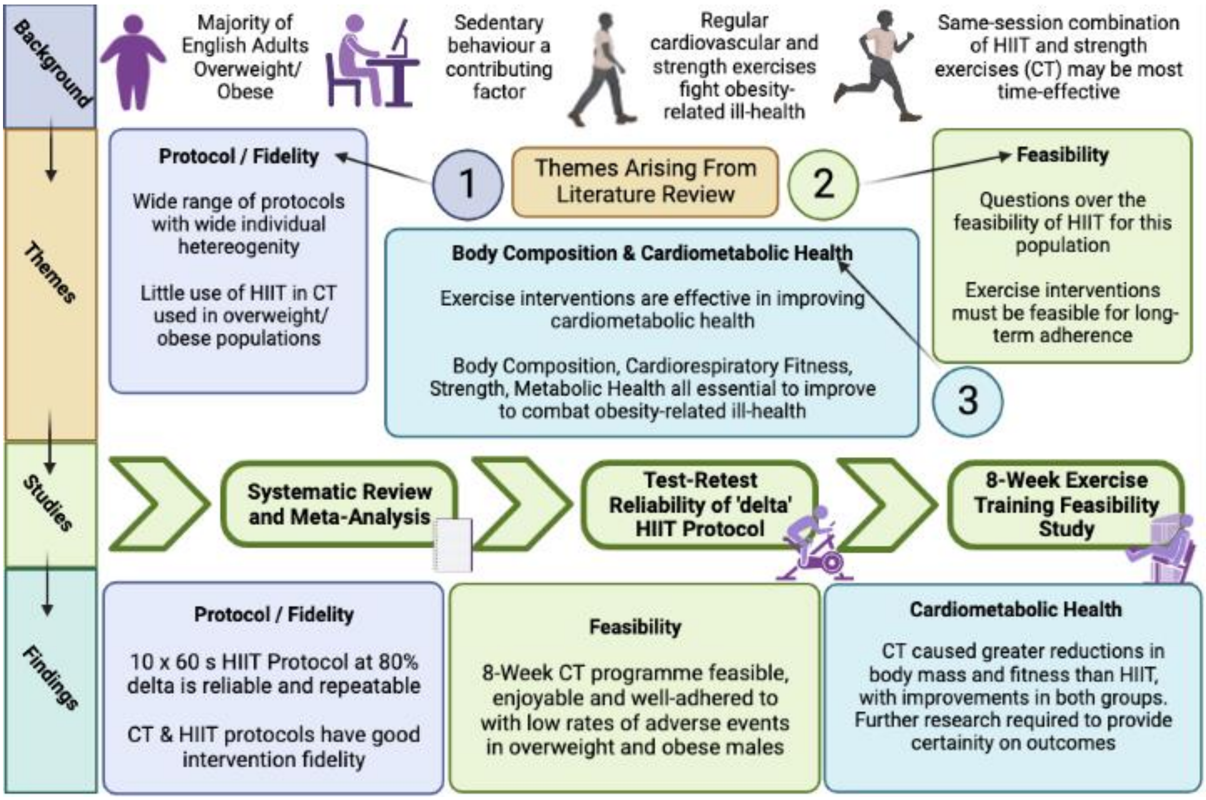

Figure 8.2. Thesis Schematic.
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Appendix

Appendix A
Ethical Approval

Downloaded: 27/05/2022
Approved: 12/07/2019

Jordan Bell
School of Nursing and Health Sciences
Programme: PhD

Dear Jordan

PROJECT TITLE: Establishing the test-retest reliability of an individualised high-intensity interval training (HIIT) protocol and measures of cardiometabolic health.
APPLICATION: Reference Number 004492

On behalf of the University ethics reviewers who reviewed your project, I am pleased to inform you that on 12/07/2019 the above-named project was **approved** on ethics grounds, on the basis that you will adhere to the following documentation that you submitted for ethics review:

- University research ethics application form 004492 (form submission date: 10/07/2019); (expected project end date: 01/12/2019).
- Participant information sheet 1008838 version 3 (10/07/2019).
- Participant consent form 1008842 version 1 (08/07/2019).

The following optional amendments were suggested:

Recommend that the deadline for retroactive data withdrawal is provided, as it is in PI Sheet

If during the course of the project you need to deviate significantly from the above-approved documentation please email ethics.review@sunderland.ac.uk

For more information please visit: https://www.sunderland.ac.uk/research/governance/researchethics/

Yours sincerely

Dr John Fulton
Ethics Administrator
University of Sunderland

University of Sunderland

Downloaded: 27/05/2022
Approved: 03/06/2021

Jordan Bell
School of Nursing and Health Sciences

Dear Jordan

PROJECT TITLE: The feasibility of an 8-week randomised controlled same-session concurrent exercise training programme, and the prospective effect on cardiometabolic health, in overweight and obese males.
APPLICATION: Reference Number 009112

On behalf of the University ethics reviewers who reviewed your project, I am pleased to inform you that on 03/06/2021 the above-named project was **approved** on ethics grounds, on the basis that you will adhere to the following documentation that you submitted for ethics review:

- University research ethics application form 009112 (form submission date: 24/05/2021); (expected project end date: 30/04/2022).
- Participant information sheet 1015622 version 3 (24/05/2021).
- Participant consent form 1015623 version 2 (24/05/2021).

If during the course of the project you need to deviate significantly from the above-approved documentation please email ethics.review@sunderland.ac.uk

For more information please visit: https://www.sunderland.ac.uk/research/governance/researchethics/

Yours sincerely

Veronique Laniel
Ethics Administrator
University of Sunderland

Appendix B
Informed Consent Forms

Consent Form

Establishing the test-retest reliability of an individualised high-intensity interval training (HIIT) protocol and measures of cardiometabolic health.

Participant code: _______________

I am over the age of 18	
I have read and understood the attached study information and, by signing below, I consent to participate in this study	
I understand that I have the right to withdraw from the study without giving a reason at any time during the study itself.	
I understand that I also have the right to change my mind about participating in the study for a short period after the study has concluded.	

Signed: ____

Print name: ____

(Your name, along with your participant code is important to help match your data from two questionnaires. It will not be used for any purpose other than this.)

Date: _________________________

Witnessed by: ____

Print name: ____

Date: _____________________

Consent Form

The feasibility of an 8-week randomised controlled same-session concurrent exercise training programme, and the prospective effect on cardiometabolic health, in overweight and obese males

Participant code: ______________

I am over the age of 18	
I have read and understood the attached study information and, by signing below, I consent to participate in this study	
I understand that I have the right to withdraw from the study without giving a reason at any time during the study itself, but that if I withdraw after 1st June 2022 my data will still be used	
I understand that I also have the right to change my mind about participating in the study and my data being used, up to the 1st June 2022	
I understand that whilst every precaution has been made to prevent transmission, my participation in this study may increase the risk of contracting COVID-19	
I give permission that should any abnormality be identified in my ECG trace or echocardiogram; this data may be forwarded to a cardiologist and/or my General Practitioner (GP) as required	

Signed: ____

Print name: ____

(Your name, along with your participant code is important to help match your data from two questionnaires. It will not be used for any purpose other than this.)

Date: ______________________

Witnessed by: ____

Print name: ____

Date: ____________

Appendix C
Participant Information Sheets

INFORMATION FOR PARTICIPANTS

Title of the study

Establishing the test-retest reliability of an individualised high-intensity interval training (HIIT) protocol and measures of cardiometabolic health.

Introduction

You are invited to take part in a PhD research project. Before you decide whether you would like to take part, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully. Please ask if there is anything that is unclear, or if you would like more information (contact details can be found at the end of this information sheet). This study follows the ethical guidelines of the University of Sunderland.

Background and purpose of the study

HIIT is a time-effective approach to exercise which has been demonstrated to be effective in reducing weight and improving fitness as well as a whole host of other beneficial health outcome measures in a wide range of populations. However, there are many different HIIT protocol designs and it is difficult to determine the 'optimal' HIIT protocol. This study will be testing the reliability of a series of health outcome measures in a HIIT protocol designed using individualised exercise prescription.

Am I a suitable participant for this study?

This study is looking for adult (18-65 years) male and female participants who have a body mass index (BMI) of over 25 and do not regularly achieve 150 minutes of physical activity a week. If you are willing, we would be very pleased for you to participate in this study.

Do I have to take part?

No, participation is entirely voluntary, it is your decision whether or not to take part. If you decide to take part, you will be given this information sheet to keep and be asked to sign separate consent and health screening forms. If you decide that you do not wish to participate then please appropriately discard this information sheet. Regardless of your decision, I thank you for your time.

What happens if I want to withdraw from the study?

If you agree to participate you can withdraw your participation at any time without reason or penalty. However, if you withdraw after 31st December 2019 your data will still be used in a PhD thesis and possible academic publication, but will be subsequently destroyed. If you do not wish for your data to be used you must withdraw before 31st December 2019.

What will happen if I take part?

If you choose to take part you will attend the laboratory at the University of Sunderland on three separate occasions. The first visit will be for a baseline VO_2peak test. You will be required to attend having consumed a light carbohydrate-containing meal 2 hours prior. You will be asked to sign screening forms and undergo measures of anthropometry, heart rate and blood pressure. The VO_2peak test will consist of a warm-up, a maximal cycling protocol that will last 8-12 minutes and a cool down. You will be asked to provide a saliva sample before and after the exercise, an ECG and gas analysis will be performed throughout. The entire visit should last no longer than one hour.

The following two visits will be for the test-retest reliability of a HIIT protocol. You will be required to attend having fasted for 12 hours prior. You will undergo a warm-up, 20 minute HIIT protocol and cool down. You will be asked to provide a saliva sample before and after the HIIT protocol and complete some questionnaires around enjoyment and perceived exertion. The entire visit should last no longer than one hour. Each of the two visits will be exactly the same, separated by one week and undertaken at the same time of day.

What are the benefits of taking part?

If you take part in this study you will receive measures of aerobic fitness (VO_2peak), measures of body composition and heart health. You will also take part in two supervised HIIT workouts and will be contributing to the continued development of HIIT protocols for clinical use.

What happens if something goes wrong?

All of the experimental procedures that will be used in this study have been rigorously tested to ensure that they meet health and safety standards. These tests are all commonplace within clinical exercise testing. In the unlikely event of you experiencing any problems that may be caused by this study you should inform the lead researcher immediately (contact details are at the end of this sheet) and any issues will be addressed.

Will taking part in this study be kept confidential?

All information collected about you will be kept strictly confidential, other than to the principal researcher who is undertaking the study. Data will be stored safely and securely and held for the duration of the research project, after which it will be destroyed, in line with the Data Protection Act 2018. At no time will information be disclosed or the data used for other purposes than those described here. Data will be retained electronically for ten years on a password protected computer. Any information that leaves the University of Sunderland will have your personal details removed so that you cannot be recognised. Each participant will be identified and recorded as a unique code for the duration of the study and will therefore not be identifiable in any way. The data will never be presented with the use of real names.

What will happen to the results from this study?

Once the study has been completed the study will be written up as part of a PhD thesis and potentially an academic publication. The overall study findings will also be made available to you if desired. After analysis, your files will be deleted from the machines (although you may have a copy to keep if you wish). It will not be possible for anyone to see your individual results or identify that you participated.

Contact for further information

If you require any information about the study, or at any time during participation, you may contact lead researcher Jordan Bell or supervisor Dr David Archer.

Address: Faculty of Health Sciences and Wellbeing, University of Sunderland, City Campus, Chester Road, Sunderland, SR1 3SD.
Name: Jordan Bell **(PhD Student)**
Email: bh48mz@research.sunderland.ac.uk
Name: Dr David Archer **(Supervisor)**
Email: david.archer-1@sunderland.ac.uk

If you have any concerns about the study or would like any independent advice please contact **Doctor John Fulton** (Chair of the University of Sunderland Research Ethics Group, University of Sunderland)

Email: john.fulton@sunderland.ac.uk
Phone: 0191 515 2529

Thank you for considering your participation in this study. Please retain this information letter for your records.

INFORMATION FOR PARTICIPANTS

Title of the study

The feasibility of an 8-week randomised controlled same-session concurrent exercise training programme, and the prospective effect on cardiometabolic health, in overweight and obese males

Introduction

You are invited to take part in a PhD research project. Before you decide whether you would like to take part, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully. Please ask if there is anything that is unclear, or if you would like more information (contact details can be found at the end of this information sheet). This study follows the ethical guidelines of the University of Sunderland.

Background and purpose of the study

64% of all adults in England are classified as overweight. Exercise and physical activity have the potential to reduce incidence of overweight and obesity, as well as improve obesity-related ill health. Both aerobic and strength-based exercises are beneficial, with both being included in exercises guidelines. However, many individuals do not achieve exercise guidelines, with a commonly cited barrier being a 'lack of time'. A time-efficient method of completing both aerobic and strength-based exercise is same-session concurrent exercise training. We would like to determine the feasibility and benefits of completing concurrent exercise training, in comparison to other training types.

Am I a suitable participant for this study?

This study is looking for adult (18 – 66 years) male participants who have a body mass index (BMI) of over 25 and do not regularly achieve 150 minutes of physical activity, or 2 strength training exercise sessions per week. If you are willing, we would be very pleased for you to participate in this study.

Do I have to take part?

No, participation is entirely voluntary, it is your decision whether or not to take part. If you decide to take part, you will be given this information sheet to keep and be asked to sign separate consent and health screening forms. If you decide that you do not wish to participate then please appropriately discard this information sheet. Regardless of your decision, I thank you for your time.

What happens if I want to withdraw from the study?

If you agree to participate you can withdraw your participation at any time without reason or penalty. However, if you withdraw after 28th February 2022 your data will still be used in a PhD thesis and possible academic publication but will be subsequently destroyed. If you do not wish for your data to be used, you must withdraw before 28th February 2022.

What will happen if I take part?

If you choose to take part, you will attend the University of Sunderland across 10 weeks. There will be two visits per week. In the first and final weeks (1 & 10) you will undergo a series of exercise and health tests, including fitness, strength, heart echocardiography, blood pressure, anthropometry, questionnaires and a short interview about yourself and exercise. If there are any abnormalities identified in your ECG trace or on your echocardiogram, your data will be shared (with your consent) with a cardiologist and/or your general practitioner (GP) as required. You will also have an assessment of your diet, and the amount of exercise you usually perform in a typical day. Fingertip blood samples will also need to be collected in this visit. The visits for the middle 8 weeks (2 – 9) will depend on which group you are randomised into. You will either be completing twice-weekly HIIT cycling sessions, or a combined strength and HIIT cycling session. The exercise sessions will be 20 minutes in length and each visit should last around 45 minutes.

What are the benefits of taking part?

If you take part in this study you will receive measures of aerobic fitness (VO_2peak), strength, body composition, heart health, dietary assessment, physical activity levels and metabolic health (e.g. blood glucose).

What happens if something goes wrong?

All of the experimental procedures that will be used in this study have been rigorously tested to ensure that they meet health and safety standards. These tests are all commonplace within clinical exercise testing. In the unlikely event of you experiencing any problems that may be caused by this study you should inform the lead researcher immediately (contact details are at the end of this sheet) and any issues will be addressed.

Are precautions in place due to COVID-19?

Yes, precautions are in place to maximise the safety of volunteers, researchers, staff and students at the University. Social distancing will be maintained where possible between researchers and yourself, but where this is not possible researchers will wear appropriate personal protective equipment. Disposable gloves, apron and mask or visor will be worn by researchers when coming into close contact with you such as when fitting any equipment. You will be asked to sanitise your hands upon entry and exit of the laboratory or gym. Any equipment you use (such as the cycle ergometer, heart rate monitor or resistance exercise machine) will be thoroughly cleaned and disinfected after use. You will attend the laboratory alone, and no two participants will be scheduled into the laboratory for the same time. We will also advise you to complete regular lateral flow tests throughout the study duration.

Will taking part in this study be kept confidential?

All information collected about you will be kept strictly confidential, other than to the principal researcher who is undertaking the study. Data will be stored safely and securely and held for the duration of the research project, after which it will be destroyed, in line with the Data Protection Act 2018. At no time will information be disclosed or the data used for other purposes than those described here. Data will be retained on a password protected computer. Any information that leaves the University of Sunderland will have your personal details removed so that you cannot be recognised. Each participant will be identified and recorded as a unique code for the duration of the study and will therefore not be identifiable in any way. The data will never be presented with the use of real names.

What will happen to the results from this study?

Once the study has been completed the study will be written up as part of a PhD thesis and potentially an academic publication. The overall study findings will also be made available to you if desired. After analysis, your files will be deleted after the duration of the study (although you may have a copy to keep if you wish). It will not be possible for anyone to see your individual results or identify that you participated.

Contact for further information

If you require any information about the study, or at any time during participation, you may contact lead researcher **Jordan Bell** or supervisor **Dr David Archer**.

Address: Faculty of Health Sciences and Wellbeing, University of Sunderland, City Campus, Chester Road, Sunderland, SR1 3SD.

Name: Jordan Bell **(PhD Student, Lead Researcher)**

Email: jordan.bell@research.sunderland.ac.uk

Name: Dr David Archer **(Supervisor)**
Email: david.archer-1@sunderland.ac.uk
If you have any concerns about the study or would like any independent advice please contact **Doctor John Fulton** (Chair of the University of Sunderland Research Ethics Group, University of Sunderland)
Email: john.fulton@sunderland.ac.uk
Phone: 0191 515 2529

Thank you for considering your participation in this study. Please retain this information letter for your records.

Appendix D
Pre-Exercise Screening Form

University of Sunderland

Exercise Participation Health Screening Questionnaire

This information will be treated as confidential and only members of staff employed by the University of Sunderland, Sport and Exercise Science will have access.

Your safety during your participation in this Practical session/ research study is of paramount importance to us. We ask you to complete the following pre-participation medical screening questionnaire. Please answer the questions honestly and thoroughly.

Personal Information

NAME: ....………….......... **Date of Birth:** ....

Medical Conditions

If you tick 'Yes' to any of the following questions please provide further details and list medications.

1. Have you had to consult your Doctor within the last six months? Yes ☐ No ☐

2. Do you have diabetes? Yes ☐ No ☐

   Insulin Dependent Diabetes Mellitus (IDDM) ☐
   Non-insulin dependent diabetes mellitus (NIDDM) ☐

   How long have you had diabetes? …………………. Years

3. Do you have asthma? Yes ☐ No ☐

   Do you have an asthma inhaler? Yes ☐ No ☐

4. Do you have a chronic obstructive pulmonary disease, x= interstitial lung disease or cystic fibrosis? Yes ☐ No ☐

5. Has your doctor ever told you that you have heart trouble? Yes ☐ No ☐

6. Has your doctor ever told you that you have a heart murmur? Yes ☐ No ☐

7. Has your doctor ever told you that you have circulation problems Yes ☐ No ☐

8. Do you have, or have you ever had, high blood pressure? Yes ☐ No ☐

9. Have you ever had a stroke? Yes ☐ No ☐

10. Is there a history of heart disease in your family? Yes ☐ No ☐

11. Do you have, or have you ever had, seizures or epilepsy? Yes ☐ No ☐

12. Do you have, or have you ever had, any form of illness or injury to the head? Yes ☐ No ☐

13. Do you have, or have you had, any form of liver disorder? Yes ☐ No ☐

14. Do you have, or have you had, any form of kidney disorder? Yes ☐ No ☐

15. Do you have, or have you had, any form of thyroid disorder? Yes ☐ No ☐

16. Do you have, or have you had, any form of cancer? Yes ☐ No ☐

17. Do you have osteoporosis? Yes ☐ No ☐

18. Do you have any form of arthritis? Yes ☐ No ☐

19. Are you, or do you have reason to believe, you may be pregnant? Yes ☐ No ☐

20. Do you currently have any form of muscle, ligament or joint injury? Yes ☐ No ☐

Signs and Symptoms

21. Do you ever have pains in your chest or surrounding areas, especially during exercise? Yes ☐ No ☐

22. Do you ever get the feeling that your heart is beating abnormally, racing, or skipping beats, either at rest or during exercise? Yes ☐ No ☐

23. Do you ever get pains in your calves, buttocks or at the backs of your legs during exercise which is not due to fatigue or stiffness? Yes ☐ No ☐

24. Do you ever feel faint or have spells of severe dizziness, particularly with exercise Yes ☐ No ☐

25. Do you ever experience swelling or accumulation of fluid around the ankles? Yes ☐ No ☐

26. Do you ever experience unusual fatigue or shortness of breath at rest or with mild exertion? Yes ☐ No ☐

27. Have you ever had an attack of shortness of breath that came on after you stopped exercising? Yes ☐ No ☐

28. Have you been awakened in the night by shortness of breath? Yes ☐ No ☐

29. Do you ever have chest tightness when not exercising? Yes ☐ No ☐

30. Have you ever had chest tightness, cough or wheezing which Yes ☐ No ☐ made it difficult for you to perform in sports?

31. Have you ever been treated/ hospitalized for asthma? Yes ☐ No ☐

32. Have you ever been told to give up sports because of health problems? Yes ☐ No ☐

33. Have you ever been told you have high blood pressure? Yes ☐ No ☐

34. Have you ever been told you have high cholesterol? Yes ☐ No ☐

35. Do you have trouble breathing or do you cough during or after activity? Yes ☐
No ☐

36. Have you in the last 6 months had an ECG or 24 Hour heart rate trace taken? Yes ☐
No ☐

University of Sunderland

Physical Activity & Lifestyle

Physical Activity Definitions

Sedentary No physical activity sessions of 30 minutes duration or longer per week

Low Some physical activity on 1-2 days per week but activity sessions are generally less than 30 minutes.

Moderate Regular physical activity sessions of 30 minutes or more on 3-5 days per week

High Regular physical activity sessions of at least 30 minutes on 6-7 days per week

37. Using the definitions above, how would you describe your present level of physical activity?

Sedentary Low Moderately active Highly active

38. How would you describe your present level of fitness?

Very Unfit Unfit Moderately fit Very fit Elite fitness

39. How would you describe your present body weight?

Underweight Ideal weight Overweight

40. Do you smoke ? Yes ☐ No ☐

If No, please go to question 35

41. How many cigarettes do you smoke, *on average,* per day ? …………..

42. How long have you smoked? …………..years …………..months

43. Do you drink alcohol? Yes ☐
No ☐
If No, please go to question 38

44. How many units of alcohol, *on average*, do you drink per day during the week? …………..

45. Have you drank any alcohol in the last 24 hours? Yes ☐
No ☐

46. Have you ingested any substances in the last 48/72 hours? Yes ☐ No ☐

Medications

Are you currently taking any form of medications? Yes ☐ No ☐

(if Yes, please list all current medications, doses and purpose below)

Name of medication	Dose	Purpose

I confirm that :-

(a) I am willing to take part in the as a volunteer subject.

(b) I have had no significant illness since my last medical examination.

I understand that :-

(a) The member of staff will explain the nature and purpose of each practical session and will inform me of any foreseeable risk to my health as a result of my participation.

(c) I agree to terminate any practical activity if the member of staff in charge feels it is advisable to do so.

(d) I have/will inform the member of staff in charge of any permanent and/or temporary medical condition from which I am suffering or have suffered recently, which might be made worse by physical activity participation.

I authorise the member of staff in charge to inform my general practitioner should he/she feel that any significant untoward event occurs during or after the practical session, which might be a result of my participation.

Name (Participant): ……………………………..... ………….

Name(Staff/Researcher)..……………………

Signature: …………………………………………… ……………………………………….

Signature:………

Date: ……………………………………………..…… ……..:……………………………………………

Date:

GP Contact:

GP Name:
…………………………………………

GP Contact address:
…………………………………….
………………………………………
………………………………………
………………………………………
Contact Telephone:
………………………………………

Emergency contact:

Name:
…………………………………………

Contact Address:…………………..
………………………………………..
………………………………………..
………………………………………..

Contact Telephone :
………………………………………..

Appendix E
Study Posters

Volunteers Required

We're looking for volunteers to exercise on 3 days

HIIT

Adults (18 - 65) with a BMI above 25 who exercise less than 150 minutes a week

BMI = Weight (kg) / Height (m)^2

Visit One

Eat 2 hours before the visit. Complete a maximal exercise test with ECG. Provide saliva samples.

Visit Two/Three

Arrive fasted at the same time of day one week apart. Complete a 20 minute HIIT workout. Provide saliva samples.

You will receive

- A VO_2max test
- Body composition measures
- Measures of fitness and heart health
- 2 supervised HIIT exercise workouts

Contact

For more information contact lead researcher **Jordan Bell**

jordan.bell@research.sunderland.ac.uk

University of Sunderland


Volunteers Required
FREE 8-Week Exercise Training Programme
RECEIVE…
• 8-week exercise programme
• Fitness Test
• Strength Test
• Measures of body composition
• Assessment of heart health
• Assessment of your diet
• Measures of metabolic health
ARE YOU:
• Adult (18-66 years)
• Male
• Sedentary
(complete less than 150 minutes exercise per week)
• Have a BMI over 25
(BMI = weight/height^2)
COMPLETE:
A series of tests and measurements, questionnaires and a short interview.
8-weeks of either*: HIIT exercises, or concurrent HIIT and strength exercises
(*allocation randomised)
University of Sunderland
For more information, and to register your interest, please contact:
University of Sunderland
Jordan Bell (Lead Researcher) Jordan.bell@research.sunderland.ac.uk

Appendix F
PrEference and Tolerance of Intensity of Exercise Questionnaire (PRETIE-Q)

APPENDIX: Preference for and Tolerance of the Intensity of Exercise Questionnaire

Inventory of Exercise Habits

Please, read each of the following statements and then use the response scale below to indicate whether you agree or disagree with it. There are no right or wrong answers. Work quickly and mark the answer that best describes what you believe and how you feel. Make sure that you respond to all the questions.

1 = I totally disagree *2 = I disagree* *3 = I neither agree nor disagree* *4 = I agree* *5 = I totally agree*

1.	Feeling tired during exercise is my signal to slow down or stop.	1	2	3	4	5
2.	I would rather work out at low intensity levels for a long duration than at high-intensity levels for a short duration.	1	2	3	4	5
3.	During exercise, if my muscles begin to burn excessively or if I find myself breathing very hard, it is time for me to ease off.	1	2	3	4	5
4.	I'd rather go slow during my workout, even if that means taking more time.	1	2	3	4	5
5.	While exercising, I try to keep going even after I feel exhausted.	1	2	3	4	5
6.	I would rather have a short, intense workout than a long, low-intensity workout.	1	2	3	4	5
7.	I block out the feeling of fatigue when exercising.	1	2	3	4	5
8.	When I exercise, I usually prefer a slow, steady pace.	1	2	3	4	5
9.	I'd rather slow down or stop when a workout starts to get too tough.	1	2	3	4	5
10.	Exercising at a low intensity does not appeal to me at all.	1	2	3	4	5
11.	Fatigue is the last thing that affects when I stop a workout; I have a goal and stop only when I reach it.	1	2	3	4	5
12.	While exercising, I prefer activities that are slow-paced and do not require much exertion.	1	2	3	4	5
13.	When my muscles start burning during exercise, I usually ease off some.	1	2	3	4	5
14.	The faster and harder the workout, the more pleasant I feel.	1	2	3	4	5
15.	I always push through muscle soreness and fatigue when working out.	1	2	3	4	5
16.	Low-intensity exercise is boring.	1	2	3	4	5

PRETIE-Q

Appendix G
Rate of Perceived Exertion (RPE) Scales

6	No exertion at all
7	Extremely light
8	
9	Very light
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard (heavy)
16	
17	Very hard
18	
19	Extremely hard
20	Maximal exertion

●	Absolute maximum	
120		
110		
100	"Max" (almost maximal)	
95		
90	Extremely strong	
85		
80		
75		
70	Very strong	
65		
60		
55		
50	Strong	Heavy
45		
40		
35	Somewhat strong	
30		
25	Moderate	
20		
15		
13		
	Weak	Light
10		
7		
	Very weak	
5		
3	Extremely weak	
2	Minimal	
1		
0	Nothing at all	

The Physical Activity Enjoyment Scale (PACES)

Please rate how you feel *at the moment* about the physical activity you have been doing.

1	2	3	4	5	6	7
I enjoy it						I hate it

1	2	3	4	5	6	7
I feel bored						I feel interested

1	2	3	4	5	6	7
I dislike it						I like it

1	2	3	4	5	6	7
I find it pleasurable						I find it unpleasurable

1	2	3	4	5	6	7
I am very absorbed in this activity						I am not at all absorbed in this activity

1	2	3	4	5	6	7
It’s no fun at all						It’s a lot of fun

1	2	3	4	5	6	7
I find it energising						I find it tiring

1	2	3	4	5	6	7
It makes me depressed						it makes me happy

1	2	3	4	5	6	7
It’s very pleasant						it’s very unpleasant

1	2	3	4	5	6	7
I feel good physically while doing it						I feel bad physically while doing it

1	2	3	4	5	6	7
It's very invigorating						it's not at all invigorating

1	2	3	4	5	6	7
I'm very frustrated by it						I'm not at all frustrated by it

1	2	3	4	5	6	7
It's very gratifying						it's not at all gratifying

1	2	3	4	5	6	7
It's very exhilarating						it's not at all exhilarating

1	2	3	4	5	6	7
It's not at all stimulating						it's very stimulating

1	2	3	4	5	6	7
It gives me a strong sense of accomplishment						It does not give me any sense of accomplishment

1	2	3	4	5	6	7
It's very refreshing						it's not at all refreshing

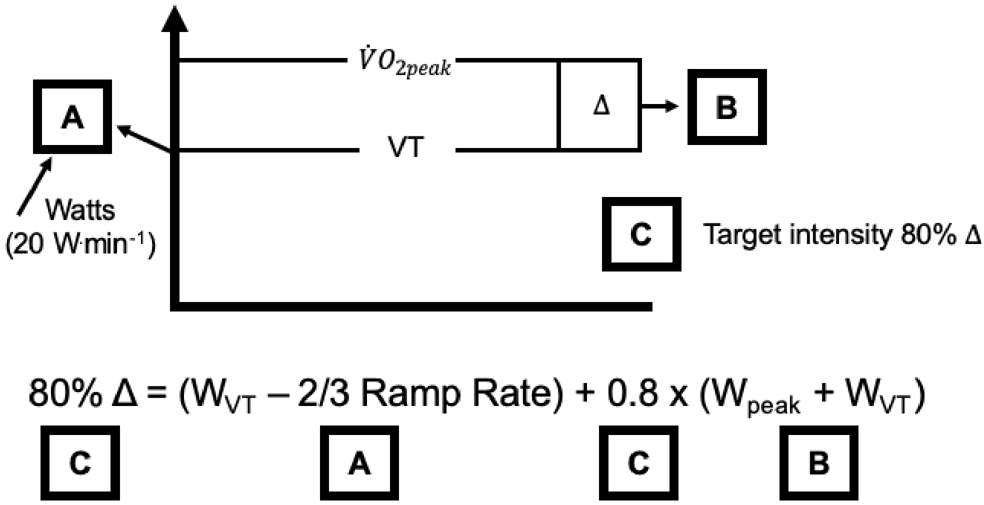
1	2	3	4	5	6	7
I feel as though I would rather be doing doing something else						I feel as though there is nothing else I would rather be doing

Appendix I
The Feeling Scale

FEELING SCALE

+5	Very Good
+4	
+3	Good
+2	
+1	Fairly Good
0	Neutral
-1	Fairly Bad
-2	
-3	Bad
-4	
-5	Very Bad

Appendix J
The Delta Method



Supplementary Figure 1. Prescription of the delta method for exercise intensity.

A schematic representation of the delta method of exercise prescription is provided in **Supplementary Figure 1**. As such, if a participant reached $\dot{V}O_{2peak}$ at 285 W and had reached VT at 135 W, in order to work out the intensity that would correspond to 80% of their Δ (80Δ):

$$80\%\ \Delta = (135 - 13.4) + 0.8 \times (285 - 135),$$

$$= \ 241.6.$$

This value was rounded to the nearest Watt. Therefore, in this example the participant would have their HIIT intervals set at a workload of 242 W.

Appendix K

Diet Diary

Diet Diary
Participant Code _______

	Weekday 1	Weekday 2	Saturday	Sunday
Breakfast				
Lunch				
Tea				
Snacks				
Drinks				

Appendix L

TESTEX Scores

Study	TESTEX Scale Component												Total (study quality / study reporting)
	1	2	3	4	5	6	7	8	9	10	11	12	
Atashak et al., 2016	1	0	0	1	0	2	0	2	1	0	0	1	**8** (2/6)
Duft et al., 2017	1	0	0	1	0	1	0	2	1	0	1	1	**8** (2/6)
Ho et al., 2012	1	1	0	1	0	1	0	2	1	0	0	1	**8** (3/5)
Brunelli et al., 2015	1	0	0	1	0	1	0	2	1	0	0	1	**7** (2/5)
Donges et al., 2013	1	0	0	1	0	2	0	2	1	0	1	1	**9** (2/7)
Ramirez-Velez et al., 2020	1	1	0	1	0	2	0	2	1	0	0	1	**9** (3/6)

TESTEX methodological quality

TESTEX Criteria (with points possible):

1. Eligibility criteria specified (1)
2. Randomisation specified (1)
3. Allocation concealment (1)
4. Groups similar at baseline (1)
5. Blinding of assessor (1)
   Total possible points for **study quality** 5
6. Outcome measures assessed in 85% of patients (3)
7. Intention-to-treat analysis (1)
8. Between-group statistical comparisons reported (2)
9. Point measures and measures of variability reported for all outcome measures (1)
10. Activity monitoring in control groups (1)
11. Relative exercise intensity remained constant (1)
12. Exercise volume and energy expenditure (1)
    Total possible points for **study reporting** 10
    Total possible points 15

Appendix M

PubMed Search Strategy

Search terms are individually searched and combined together using Boolean operators. Number of results per search term are provided in brackets.

#1: ‘adult’ (7289474)
#2: ‘obese OR obesity OR overweight’ (347925)
#3: 1 AND 2 (152833)
#4: 1 AND 2 NOT ‘trained’ (151835)
#5: ‘concurrent exercise’ OR ‘concurrent training’ OR ‘concurrent physical activity’ (9891)
#6: ‘multi-component exercise’ OR ‘multi-component training’ OR ‘multi-component physical activity’ (1053)
#7: ‘multi-modal exercise’ OR ‘multi-modal training’ OR ‘multi-modal physical activity’ (553)
#8: ‘same-session exercise’ OR ‘same-session training’ OR ‘same-session physical activity’ (196)
#9: ‘combined exercise’ OR ‘combined training’ OR ‘combined physical activity’ (59927)
#10: 5 OR 6 OR 7 OR 8 OR 9 (70706)
#11: ‘strength training’ OR ‘weight training’ OR ‘resistance training’ (54086)
#12: ‘HIIT’ OR ‘HIT’ OR ‘HIIE’ OR ‘High-intensity’ OR ‘interval training’ OR ‘intermittent training’ OR ‘sprint training’ (98854)
#13: ‘moderate-intensity’ OR ‘endurance’ OR ‘continuous exercise’ OR ‘aerobic exercise’ OR ‘control’ (4135923)
#14: 11 OR 12 OR 13 (4214491)
#15: 4 AND 10 AND 14 (1901)

Final search string:
((((((Adult) AND ((obese OR obesity OR overweight)))) NOT trained)) AND (((((((concurrent training OR concurrent exercise OR concurrent physical activity))) OR ((same-session exercise OR same-session training OR same-session physical activity))) OR ((multi-component exercise OR multi-component training OR multi-component physical activity))) OR ((multi-modal exercise OR multi-modal training OR multi-modal physical activity))) OR ((combined exercise OR combined training OR combined physical activity)))) AND (((((HIIT OR HIT OR HIIE OR high-intensity OR interval training OR intermittent training OR sprint training))) OR ((moderate-intensity OR endurance OR continuous exercise OR aerobic exercise OR control))) OR ((strength training OR weight training OR resistance training)))