High intensity interval training: moving away from the laboratory and into the real-world

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Acknowledgments

3…2…1…Go

During my 4 years of research using HIIT interventions I must have said this this phrase more than any other, so I thought it was a fitting start to the thesis. However, this thesis was not done alone, I had *a lot* of help and support from the most delightful people.

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And now 3…2…1…PhDone!

Abstract

Within the laboratory setting, high intensity interval training (HIIT) can elicit physiological adaptations similar to traditional moderate intensity continuous training (MICT) with the important advantage of a reduced total exercise volume and time commitment. However, researchers have argued that HIIT is not a viable public health strategy because it is too demanding to be maintained by non-athletic populations (Biddle and Batterham, 2015). The aim of this thesis was to investigate the effect of real-world HIIT interventions on adherence and cardio-metabolic health risk factors. Furthermore this thesis investigates the feasibility and perceptual responses to home-based whole-body HIIT as a strategy to remove many of the major barriers to exercise.

In **Chapter 3**, 82 previously sedentary males (n=26) and females (n=56) aged 18-65 (28±10 y, BMI 25±3 $kg.m^{-2}$) participated in the study. In a randomised cross-over design, whereby participants completed either 6 weeks of 30HIT (4-8x30s sprint with 120s active recovery) and 6-weeks of 60HIT (6-10x60s sprint with 60s active recovery). Participants then completed a 4-week washout period before completing the alternative intervention. Training sessions were completed on a Wattbike, 3 times per week. VO_{2peak}, body composition (DXA), glycaemic control (oral glucose tolerance test (OGTT) and arterial stiffness (aortic pulse wave velocity (aPWV)) were assessed pre and post each 6-week training phase. VO_{2peak} increased post intervention in 30HIT and 60HIT (P<0.001). Body fat percentage decreased pre to post training in 30HIT and 60HIT (P=0.002). aPWV decreased following 30HIT and 60HIT (P<0.002), and during the OGTT there was a reduction in glucose at 120 min

(P=0.024). No differences between the intervention groups were observed for any variable (P>0.05).

In **Chapter 4,** 154 patients (males: n=88), females: n=66) who were eligible for a UK exercise referral scheme (ERS) (inactive and at least one health risk factor) were recruited. Participants chose either 12-weeks ERS (encouraged to achieve 150min/wk of moderate-intensity exercise, with reduced cost gym membership) or Home-based HIIT (4-9x1min intervals interspersed with 1 min rest, using body weight exercises). Adherence and compliance to the programme were monitored using a heart rate monitor. VO_{2peak}, body composition (DXA), glycaemic control (OGTT) and arterial stiffness (aPWV) was recorded at baseline, post-intervention (12-weeks) and 3-months post-intervention (follow-up). Perceptions of the programme were evaluated using an online interview. 56% (n=87) of eligible participants chose Home-based HIIT in preference to ERS. At baseline Home-based HIIT had a lower VO_{2peak} than ERS (P=0.034). ERS and Home-based HIIT had a similar adherence (HIIT 39%, ERS 53% P=0.298) and compliance to the prescribed programme (HIIT 30%, ERS 47% P=0.331). VO_{2peak} increased post-intervention (P<0.001) in both groups and this was maintained at follow-up (P=0.287). The interview revealed Home-based HIIT was positively received, and the convenience of the programme reduced some of the perceived barriers to exercise.

Finally, in **Chapter 5,** 27 recreationally active (≥1 hr exercise/wk) participants (male/female: n=13/14, age: 22±3y, BMI: 24.3±2.4, VO_{2pea}k: 42.2±7.2 $ml.min^{1}.kg^{-1}$) completed a randomised counter-balanced cross over design. To assess the acute physiological (heart rate and lactate) and perceptual responses (feeling scale, felt arousal scale and rate of perceived exertion) to

four different HIIT protocols (Ergo-60:60: cycling 10x60s at 100%Wmax with 60s rest, BW-60:60: whole-body exercise 10x60s with 60s rest, SM-20:10: following a social media video 20x20s with 10s rest, SM-40:20: following a social media video 15x40s with 20s rest). BW-60:60 resulted in significantly higher interval heart rate peak ($P<0.001$) compared to all other protocols, and a significantly higher change in lactate compared to SM-20:10 ($P<0.001$). No differences were observed between groups when reporting lowest recorded feeling scale ($P=0.292$), but differences in the feeling scale profile during exercise did exist between the protocols used within the research (Ergo-60:60 & BW-60:60) and the social media protocols. Greater post-session enjoyment was reported in BW-60:60 compared to Ergo-60:60 ($P=0.004$) despite using the same work:rest ratio.

In conclusion, this thesis provides strong evidence that sedentary or at risk participants are able to complete HIIT at the correct prescribed intensity to induce health benefits in a free-living environment. Furthermore, Home-based HIIT was an attractive option for at-risk patients referred to an ERS, and had similar adherence to the traditional exercise prescription guidelines. Additionally, body-weight HIIT and social media videos are promising enjoyable options, compared to traditional cycling-based HIIT. Therefore we provide strong evidence that the prescription of HIIT, especially a Home-based HIIT programme using body-weight exercises, is both effective and feasible for a non-athletic population in the real world.

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Abbreviations

AIT – Aerobic interval training

aPWV – Aortic pulse wave velocity

CRF -– Cardiorespiratory fitness

CVD – Cardiovascular disease

ERS – Exercise referral scheme

EU – European Union

FS – Feeling scale

FAS – Felt arousal scale

HDL – High density lipoprotein

HIIT – High intensity interval training

HR – Heart rate

HR_{mean} – Mean heart rate

HRPAS – Heart rate physical activity score

HR_{peak} – Peak heart rate

HR_{max} – Maximum heart rate

IMI – Intrinsic motivation inventory

IPAQ – International physical activity questionnaire

LDL – Low density lipoprotein

LDO – Lifestyle development officer

MICT – Moderate intensity continuous training

NCD – Non-communicable diseases

OGTT – Oral glucose tolerance test

PA – Physical activity

PAS – Physical activity specialist

PO – Power output

PO_{mean} – Mean power output

PO_{peak} – Peak power output

RCT – Randomised control trails

RPE – Rate of perceived exertion

SIT – Sprint interval training

T-ERS – Traditional ERS

TC – Total cholesterol

TG – Triglyceride

VAT – Visceral adipose tissue

VO_{2max} – Maximal oxygen uptake

VO_{2peak} – Peak oxygen consumption

W – Watts

W_{max} – Maximal aerobic power output

WHO – World Health Organisation

Chapter 1. General Introduction

1.1 Long term health conditions

Improvements in hygiene, medical care, living conditions and nutrition at the beginning of the 19th century were followed by improvements in health and life-expectancy. This has led to an ever-growing population, with the global population predicted to reach 10 billion by 2050 (United Nations, 2019). These factors and other trends such as rapid urbanization and lifestyle modifications have contributed to an increase in non-communicable diseases (NCD).

A NCD is a disease that is not transmissible directly from one person to another. The four main NCDs are cardiovascular disease, cancers, diabetes and chronic lung diseases (World Health Organization, 2018). The World Health Organisation (WHO) estimates that 40 million deaths per year, accounting for nearly 70% of deaths worldwide, are caused by NCDs (Martinez et al., 2020). These diseases also pose a substantial financial burden with respect to cardiovascular disease, chronic respiratory disease, cancer, diabetes and mental health. The global economic loss over the next two decades is estimated at £38 trillion (Bloom et al., 2018). The development of NCDs is influenced by a number of risk factors which are often, but not always, in the control of the individual. The most prevalent modifiable risk factors include, overweight and obesity, hypertension, high blood glucose level, alcohol consumption, smoking and poor diet (Department of Health, 2012). In addition, physical inactivity has emerged as an important risk factor for NCDs (Blair et al., 1993, Zhao et al., 2008), with a recent study identifying physical inactivity alone as the fourth leading risk factor for global mortality, resulting in 9% of premature mortality worldwide (totalling 5.3 million deaths in 2008) (Lee et al., 2012). The same researchers used this data to predict that if physical inactivity was improved by 25%, more than 1.3 million deaths could be avoided every year. Furthermore, in 2013 researchers concluded that physical inactivity alone costed health-care organisations £43.8 billion world-wide, and a further £11.1 billion in productivity losses (Ding et al., 2016).

1.2 Physical Activity

The human body has evolved in such a way that most of its tissues and control systems (skeletal, muscle, metabolic and cardiovascular) do not develop and function in an optimum way unless stimulated by frequent physical activity (PA) (Booth et al., 2008). Hence a number of risk factors contributing to an increase in the development of NCDs can be prevented by participation in PA (Alford, 2010). PA is defined as any bodily movement produced by contraction of the skeletal muscles thereby substantially increasing energy expenditure (Caspersen et al., 1985). PA can be categorised in different ways; occupational (e.g. lifting/carrying out work), household based (e.g. cleaning, gardening), recreational activity (e.g. weight lifting, dance, yoga, tai chi), active transport (e.g. walking, cycling) and sport (e.g. football, netball) (Caspersen et al., 1985).

The first research epidemiological study to investigate physical activity was conducted by Morris et al. (1953). The study reported a 30% lower risk of coronary heart disease in conductors of London double-decker buses, who were more active than their sedentary driver counterparts. This initial study focussed on one NCD, but further benefits of PA were highlighted in the subsequent ground-breaking Harvard Alumni study, where PA, and other life-style characteristics, of 16,936 Harvard alumni were related to all-cause mortality. The results showed that even when other risk factors, such as hypertension, cigarette use, weight gain or early parental death, were considered, the survival rates were significantly higher in those alumni who were physically active (Paffenbarger Jr et al., 1986).

Since these ground breaking studies further research has reported that regular PA can reduce the risk of developing and/or improve the management of many diseases and conditions including hypertension, type 2 diabetes, obesity, coronary heart disease, chronic heart failure and chronic obstructive pulmonary disease (Adami et al., 2010, Pedersen and Saltin, 2006). Indeed, the relative risk of death is approximately 20-35% lower in physically active individuals compared to their inactive counterparts (Warburton et al., 2006), equating to approximately 3.5 to 4 years higher life expectancy in physically active individuals (Reimers et al., 2012). Furthermore, Arem et al. (2015) demonstrated a dose response relationship between PA levels and longevity.

Evidence from large cohort studies have demonstrated that PA reduces the risk of mortality in those with type 2 diabetes, and can also prevent or delay the onset of diseases. Epidemiological data has shown that the incidence of type 2 diabetes was inversely related to leisure PA among men in the Harvard Alumni Study (n=5,990) and in US male physicians (n=21,271) and in women from the Nurses' Health Study (n=70,102) (Hu et al., 1999, Manson et al., 1992, Helmrich et al., 1991). These findings are supported by two large randomised control trials; the Finnish Diabetes Prevention Study (Tuomilehto et al., 2001) and the Diabetes Prevention Program Research Group Study (Knowler et al., 2002). In the Finnish Diabetes Prevention Study, 522 middle-aged overweight men and women were randomised to either control (general non-specific behavioural advice) or intervention group (reduced calorie intake and advised to complete moderately intense PA 30 min per day). After a 4-year intervention period the incidence of type 2 diabetes was 11% for the intervention group and 23% for the control group. Those in the intervention group reduced their relative risk of diabetes by 58%. Following this study, Lindström et al. (2006) completed follow up measures, 3 years post intervention, and reported a sustained reduction in relative risk in the intervention group (43%) compared to the control group. To compare the effect of PA to common drug interventions used to treat type 2 diabetes the Diabetes Prevention Program Research Group Study randomly assigned 3234 patients identified with pre-diabetes to either metformin (850mg twice daily) or lifestyle modification (low-calorie diet and 150mins of moderate intensity activity per week). Participants were followed for an average of 2.8 years. Results found lifestyle intervention to be significantly more effective at reducing number of diabetes cases compared to metformin. The lifestyle intervention reduced the incidence of diabetes by 58% compared to placebo, using metformin the incidence was reduced by 31%.

Further to preventing type 2 diabetes, PA has been found to reduce a number of risk factors associated with metabolic syndrome. Metabolic syndrome is characterised by obesity, hypertension, hyper-insulinaemia, low glucose tolerance and dyslipidaemia (Khunti and Davies, 2005). Persons with the syndrome are at twice the risk for developing cardiovascular disease and five times the risk of developing diabetes compared to those without the syndrome (Grundy, 2008). Hypertension is one of the most common risk factors in patients with metabolic syndrome, and is strongly associated with mortality.

Mortality risk doubles for every 20mmHg increase in systolic blood pressure and for every 10mmHg increase about the diastolic blood pressure (Vasan et al., 2001). Mild to moderate intensity exercise interventions (35-80% HR_{max}) have been shown to lead to reductions in blood pressure in individuals with stage 1 hypertension of ~3.4 to 10.5 mm Hg for systolic BP and of 2.4 to 7.6 mm Hg for diastolic blood pressure (Kokkinos and Myers, 2010). Evidence also supports the concept that exercise results in favourable changes to blood lipids. A review of 51 studies, from Leon and Sanchez (2001) found the most common observed change was an increase in high density lipoprotein cholesterol (HDL-C). But reductions to total cholesterol, low density lipoprotein cholesterol (LDL-C) and triglycerides were less frequently observed.

1.3 Cardiorespiratory Fitness

Although any amount of PA can be beneficial (Ekelund et al., 2019), it is well cited that cardiorespiratory fitness (CRF) is associated with decreased mortality in both men and women. Blair et al. (1989) investigated the physical fitness (measured via maximal treadmill exercise test) and risk of all-cause mortality in 10,224 men and 3,120 women. The results of an 8-year follow-up showed a strong inverse relationship between physical fitness and mortality in both men and women. To further quantify this relationship between physical fitness and mortality, Blair et al. (1996) included other personal characteristics that predispose early mortality, such as smoking, elevated blood pressure and cholesterol level. Results showed the protective effect of fitness held for smokers and non-smokers, and for those with or without elevated blood pressure or cholesterol levels. CRF (measured in metabolic equivalents) was also the strongest predictor of the risk of death among both normal subjects (n=2,534) and those with cardiovascular disease (n=3,679) (Myers et al., 2002).

As further evidence for the importance of CRF for decreasing mortality risk, the Aerobic Centre Longitudinal Study followed 40,842 men and 12,943 women to estimate patients' attributable fraction (number of deaths had the risk factor been avoided) to a variety of risk factors to include low CRF, obesity, smoking, hypertension, high cholesterol and diabetes. Within this study low CRF accounted for ~16% of all deaths. This is substantially more than for the other measured risk factors for which the attribution fraction was between 2-8% (Blair, 2009). Church et al. (2005) also demonstrated the importance of physical fitness in a longitudinal study following 2316 men with type 2 diabetes over 15 years. When categorised for BMI (≤24.9 normal weight, ≤29.9 overweight and ≥30 obese), the obese men who were classed as being moderately/highly fit had less than half the mortality risk than their normal weight but unfit counterparts. Therefore, CRF is a strong predictor of mortality even when other risk factors are taken into account.

Interestingly findings also show that changes in CRF levels result in similar changes in mortality risk. Blair et al. (1995) completed two CRF assessments, with an average period of 4.9 years between the two visits, in men (n=9777, aged 20-82 at baseline). Following the second CRF test, these men were followed for an average of 5.1 years for mortality. To reflect previous findings, the men who were unfit at both visits had the highest mortality risk. Conversely the men who were the fittest had the lowest mortality risk. Remarkably, the men who increased their CRF between the first and second test had a lower risk of death than the ‘stayed-unfit’ group. Equally, the men who lowered their CRF at the second visit had increased their risk of death. As such having a high CRF, like high PA levels, is negatively associated with disease risk.

However, other research suggested that achieving a higher CRF is more important for reducing mortality risk, when compared to achieving than meeting the PA guidelines. Lee et al. (2011) examined the relationship between PA and CRF on all-cause mortality in 31,818 men and 10,555 women. The results showed that mortality risk was significantly reduced in men with a high CRF compared to men who had a lower CRF but who met the recommended PA levels (150mins/wk). In the women, there was no significant association between PA levels and mortality, but women in the high CRF category had a 41% lower mortality risk. Previous studies have found similar results when examining the relationship between PA and CRF and mortality, reporting approximately 40-70% lower mortality risk in those with a higher CRF and between 20-50% reduction in mortality in individuals with higher PA levels (Blair et al., 1993, Kampert et al., 1996, Villeneuve et al., 1998, Esophagus, 2000, Arraiz et al., 1992, Hein et al., 1992). Therefore, having a high CRF reduces one’s risk of mortality; the reduction is greater than obtained merely by being physically active. It is important that you explain the underlying physiology. The training response to include the increase in VO2max is massively different between individuals. I suggest that you add a line here on non-responders to exercise. Claude Bouchard is one of the authors on a recent publication I believe with non-responders in the title. Cannot find it now.

Given the importance of CRF for increasing longevity, recommendations of increased PA levels should consider how best to increase CRF, not just PA levels alone. Therefore, all interventions devised by researchers and healthcare workers should include a level of PA or exercise that is sufficient to improve CRF. Yu et al. (2003) found only leisure exercise classified as vigorous was independently associated with reduced risk of premature death from CVD in men. Therefore, vigorous intensity exercise is more effective at increasing CRF than low to moderate intensity exercise. This is also apparent even when the duration of exercise is adjusted to expend the same number of calories (Swain, 2005). The intensity at which the PA is performed is therefore a vital element to the intervention design.

The American diabetes association recommends adults with diabetes should engage in 150 min or more of moderate-to-vigorous intensity activity weekly, spread over at least 3 days/week, with no more than 2 consecutive days without activity (Colberg et al., 2016). Due to the low starting CRF levels of most patients with NCDs most exercise prescriptions employ moderate intensity continuous training (MICT) in order to improve health outcomes. MICT has been found to increase CRF in a variety of populations such as patients with hypertension (Hagberg et al., 2000), obese adults with hypertension (Jurio-Iriarte and Maldonado-Martín, 2019), stroke patients (Pang et al., 2013), patients in cardiac rehabilitation (Mitchell et al., 2019), type 1 diabetics (Seeger et al., 2011), type 2 diabetics (Colberg et al., 2016) and patients with depression (Schuch et al., 2016).

1.4 Exercise Guidelines

Given the advantage of increasing CRF and PA levels on society, the need for policy regarding increasing activity levels has been reinforced by both the

United Nations (United Nations, 2011) and WHO (World Health Organization, 2013). As a result, numerous countries have developed similar exercise guidelines for health improvement. Data from within the European Union (EU), shows 79% of all EU countries have national exercise guidelines (WHO, 2018). The WHO recommends adults aged 18-64 should:

1. Do at least 150 minutes of moderate-intensity aerobic physical activity throughout the week, or do at least 75 minutes of vigorous-intensity aerobic physical activity throughout the week, or an equivalent combination of moderate- and vigorous-intensity activity.
2. Aerobic activity should be performed in bouts of at least 10 minutes duration.
3. For additional health benefits, adults should increase their moderate-intensity aerobic physical activity to 300 minutes per week, or engage in 150 minutes of vigorous-intensity aerobic physical activity per week, or an equivalent combination of moderate- and vigorous-intensity activity.
4. Muscle-strengthening activities should be done involving major muscle groups on 2 or more days a week

1.5 Current Adherence to Exercise Guidelines

Despite a large amount of unequivocal evidence demonstrating the essential role of PA and CRF in maintaining health and preventing disease, only a minority of people meet the minimum recommendations. Globally one third of all adults failed to reach the public health guidelines for exercise (Hallal et al., 2012). This figure was calculated from 122 countries (representing 89% of the population) using a self-report measure known as the International Physical Activity Questionnaire (IPAQ). Large differences between countries were observed, for example the proportion of inactive males and females ranged from 4.7% in Bangladesh to 71.9% in Malta (Hallal et al., 2012).

New technology has resulted in the collection of objective exercise adherence information. Instruments such as accelerometers provide information on frequency, duration and in some cases intensity of exercise. But due to the high costs of this technology only information from high-income countries has been collected globally. Within the UK, the Health Survey for England (2008) collected levels of PA using both IPAQ and accelerometers in 15,000 adults. When using IPAQ, 34% reported PA levels that met current guidelines (in line with the global estimate), but this proportion fell to just 5% when accelerometer data was used (n=4007) (Chaudhury et al., 2009). These figures suggest that factors such as response bias or recall bias, may have contributed to an underestimation in the number of physically inactive people globally.

1.6 Barriers to exercise

In order to drive a change in behaviour and increase exercise levels worldwide, researchers need to identify the factors preventing regular participation. Lack of time is often cited as a common barrier to participation in regular exercise. In an early study from Chinn et al. (1999), among 1070 men and 1305 women who did not exercise regularly, the leading barrier was “lack of time” (cited by 47% of men and 51% of women). Lack of time has since been cited as one of the most common barriers in a variety of populations; inactive but otherwise healthy males and females (Hoare et al., 2017), those with a cardiovascular disease risk factor (Aditama et al., 2015), obese patients with type 2 diabetics

(Egan et al., 2013), and patients with heart disease and/or diabetes (Alharbi et al., 2017).

In addition to time further barriers have been described. These are mostly external factors, such as issues surrounding environment (weather, lack of facilities, cost, intimidating environment, transportation) and support (no knowledge of exercise, no one to exercise with). Common internal factors include lack of motivation, lack of energy, poor body-image and low self-esteem (Trost et al., 2002, Hoare et al., 2017, Reichert et al., 2007).

1.7 Exercise prescription to increase PA/ exercise

As outlined in **Section 1.5**, globally millions of people do not participate in enough PA/exercise to prevent disease. Most governments have recognised that population level physical inactivity is a major concern. In order to address some of the barriers to exercise/PA mentioned in **Section 1.6,** many countries have begun to implement PA interventions within public policy. The primary aim of these schemes is to improve health by increasing PA/exercise levels. Importantly, primary care is seen as a key setting for the promotion of PA/exercise, particularly for sedentary patients with elevated cardiovascular disease risk factors (myocardial infarction, stroke, insulin sensitivity, obesity, hypertension or high cholesterol), to prevent the development of NCD. Consequently, a number of primary care-based interventions have been developed over the past 20 years (Fox et al., 1997). A popular approach is the exercise referral scheme (also known as exercise on prescription), in which a member of the primary care team (in some countries/regions self-referral to such schemes is possible) identifies or refers a patient to a third-party service.

This service then prescribes and monitors an exercise programme tailored to the individual needs of the patient. The details of each ERS will differ depending on the country/region, but in the UK NICE guidelines (National Institute for Clinical Excellence, 2014) suggest an ERS should contain the following components:

1. A personal assessment by a physical activity specialist (PAS) or service to determine what PA programme should be recommended to meet their needs
2. An opportunity to participate in a PA programme.

The duration of schemes varies, but generally last between 10-12 weeks (Morgan et al., 2016). Within ERS there is an increasing understanding that exercise should be personalised to the needs of the individual (Zubin Maslov et al., 2017, Galiuto et al., 2019), therefore the type of activities on offer to the patients is extensive. The research regarding the types of activities offered range from one-to-one supervised gym based exercise sessions (which incorporate both cardiovascular and resistance exercise into one exercise programme), group aerobic classes, swimming, walking groups, and chair based exercise sessions (The British Heart Foundation, 2010).

1.8 Effectiveness of Exercise Referral Schemes

Exercise Referral Scheme (ERS) are becoming increasingly popular; the number of referral schemes in England has increased from 200 to nearly 700 over a 20 year period (Gidlow et al., 2005) and schemes are being established in European countries, including those in Scandinavia, Netherlands, Germany, Belgium, Spain and Portugal, as well as outside Europe in the USA, Canada, New Zealand and Australia (Arsenijevic and Groot, 2017). However, the effectiveness of these schemes for improving clinical health outcomes and increasing PA levels is uncertain. To investigate the effectiveness of ERS on PA levels Morgan (2005) conducted a systematic review including 159 randomised controlled trials (RCTs) from both the UK and internationally. Results showed that ERS appeared to increase PA levels in certain populations, mostly individuals who were active yet not meeting the PA guidelines, but these increases were not maintained over time (Morgan, 2005). This has been supported by other systematic reviews and meta-analyses, such as Williams et al. (2007) who reported a small increase in PA levels following an ERS in sedentary participants. They calculated that 17 sedentary people need to be referred for one to become moderately active. Another systematic review found insufficient evidence to recommend ERS over alternative interventions such as PA advice (Orrow et al., 2012).

However, as discussed in **Section 1.3** increasing PA levels should not be the primary aim of exercise interventions. Very few ERS have the resources to monitor changes in CRF, but most schemes do record some clinical health measurements (e.g. BMI, waist circumference, blood pressure and resting heart rate). In addition to changes in PA, a systematic review from Pavey et al. (2011) reported clinical outcomes to ERS. Results failed to report consistent evidence in favour of ERS in regards to a variety of clinical outcomes; blood pressure, serum lipid levels, indices of obesity, glycaemic control, or respiratory function (forced expiratory volume in 1 second) (Pavey et al., 2011). Within this review three studies had reported CRF, but showed no difference between ERS and usual care (no exercise intervention, patients were only informed of the PA guidelines).

Most studies do not report long-term effects of the ERS, generally because the schemes only last 12 weeks and adherence is generally low. A recent study by Prior et al. (2019) evaluated the long term impact (12 month follow up) of participation in an ERS on self-reported PA and a range of health conditions. They found that for every 11 patients referred 1 went on to report long term PA behaviour changes (>90 mins per week at any intensity), or 19 referrals for 1 participant to become long-term active at moderate to vigorous intensity. For every 8 patients referred 1 patient went on to show long term improvements in at least one health indicator. However, the duration of the scheme was 6-months, double the duration of most ERS, which could have impacted the results at 12 months.

A major limitation when evaluating ERS is the variety of methods used within the schemes (e.g. eligibility, length of scheme, cost, type of PA provided and the evaluation of the programme), making it nearly impossible to compare results between RCTs in systematic reviews or using a meta-analysis. Therefore, academics have argued that an evaluation of ERS using RCT is unrealistic given over 700 schemes are established in the UK alone, and each scheme uses a slightly different intervention (Sowden and Raine, 2008).

1.9 Adherence to Exercise Referral Schemes

It has been suggested that a lack of adherence towards the prescribed programme could explain why ERS are ineffective at improving clinical health outcomes, especially in the long term (Morgan, 2005). However, there is currently no universal method for monitoring adherence during ERS. This could be explained by the wide variety of approaches used to encourage exercise and PA within schemes. Furthermore, studies differ in their definition of 'adherence'. Following the completion of a systematic review on adherence in ERS Pavey et al. (2012) argued that the diverse range of adherence levels may reflect the different methods used to define adherence across studies.

Adherence is currently used in the literature as an umbrella term describing patients' attendance and engagement to the scheme. The phrase 'adherence' is therefore used to describe a variety of different monitoring methods. Currently the literature is using the term adherence, to refer to attendance at the ERS meeting with their Physical Activity Specialist (PAS), prior to and following the completion of the scheme. In an attempt to clarify the adherence within studies, the following definitions will be used throughout this thesis: initial attendance – attendance at the initial ERS meeting with a PAS; final attendance – attendance at the final ERS meeting with a PAS; session attendance – attendance at exercise sessions or classes; prescription compliance – meeting the correct duration and intensity during exercise sessions.

Historically, initial attendance is varied and on a whole, relatively low. A recent systematic review from Shore et al. (2019), including 39 articles, reported initial attendance between 35-85%. Although this number regarding adherence is important to note, currently no study has investigated the characteristics of those who were referred but failed to make contact with the ERS. Research investigating the effects of ERS has traditionally and most commonly used final attendance as a proxy for adherence to the scheme as a whole. When using final attendance, adherence has been reported to be as low as 20% and in some cases as high as 90% (Morgan, 2005). This wide range in final attendance has been explained by the large discrepancies observed between the schemes to include duration of the scheme, exercise modality, level of support and cost of the scheme.

The additional support provided by the PAS is a key element to the scheme's success, therefore most schemes incorporate a meeting with a PAS during the exercise intervention period. Researchers have used attendance at these meetings (mid-attendance) to monitor the rate of dropout (not attending a meeting) during the scheme. In a longer scheme, (6 months) used in Northumberland, UK, Hanson et al. (2013) reported initial attendance, mid-attendance and final attendance of 2233 patients referred across 9 sites. Initial attendance was reported as 81% (n=1811), but 12 weeks later mid-attendance was only 53.5% (n=968), and final attendance was 42.9% (n=777). Therefore, understanding the barriers and facilitators of attendance in the earlier stages would increase sustained engagement with the scheme.

Importantly, these measures of attendance fail to record actual adherence to exercise, but instead only measured the attendance at a meeting with the PAS. The meeting with a PAS are included within the ERS to improve knowledge and encourage exercise participation, yet currently these measures of adherence do not include monitoring of the prescribed exercise. The main aim of a prescribed exercise intervention (as stated in **Section 1.7**) is to improve health as a result of increasing physical activity levels. Furthermore, a common facilitator of long-term exercise participation is a positive change in clinical health outcomes e.g. decrease in blood pressure or BMI and increased self-efficacy or esteem. Therefore within an ERS, researchers need to monitor the adherence to the *exercise* not the adherence to the meeting with a PAS.

As a result, researchers have begun to include session attendance as an indicator of exercise adherence, and often set a ‘minimum number of attended sessions’ to define 'acceptable' adherence. Using this method of adherence, a systematic review from Pavey et al. (2012), comprised of 20 studies, reported a wide range of session attendance (12-93%). Again, this range of adherence levels can be explained by the lack of standardised definition, as studies used different minimum number of attended sessions in their definitions.

Although session attendance can inform researchers, it does not signify that sessions have been completed as prescribed by the PSA (correct duration and intensity of exercise). This is essential in order to determine effectiveness of the various programmes and prevent disease. Completion of exercise sessions as prescribed is defined as compliance. Unfortunately a recent review from Shore et al. (2019) found a lack of reporting on exercise prescription compliance. Not one review reported the type (mode, intensity or duration) of exercise prescribed or the extent to which the participant adhered to the prescription. With no understanding of what is delivered within a programme, from an exercise prescription standpoint, and no reporting on the extent to which individuals adhere to the prescription, no firm conclusions can be drawn about the effectiveness of the scheme. Knowledge of the prescribed exercise ‘dose’ could help to understand if it is too demanding, leading to participant drop out, or insufficiently demanding to engage participants or provide clinical benefit.

1.10 Perceived barriers to exercise referral schemes

In order to understand the low levels of adherence, researchers need to understand the perceived barriers to engaging in ERS. A systematic review from Morgan et al. (2016) reported a number of themes regarding the perceived barriers and facilitators to ERS across 33 studies. A number of themes were not specific to ERS, but mirrored general barriers to PA, as described in **Section 1.6**. The leisure centre or gym environment was frequently discussed for reasons such as; feeling intimidated or uncomfortable in a gym environment; concerns over using gym equipment; unable to control music (volume, type); inconvenient times of the sessions, clashes with work/childcare commitments; the cost of the membership. Difficulties getting to the centre were also reported as an obstruction to participation, due to travel time, long distance to travel or the safety of the location (Morgan et al., 2016). Therefore, due to low levels of adherence within ERS new exercise interventions need to be explored to overcome the reported perceived barriers to participation.

1.11 High Intensity Interval Training

High intensity interval training (HIIT) has recently been used as an alternative intervention to MICT, as it overcomes one of the most commonly cited barriers to exercise, which is “lack of time” (as discussed in **Section 1.6**). For an overall definition, Gillen and Gibala (2013) described HIIT as physical exercise that is characterised by brief intermittent bursts of vigorous activity, interspersed by periods of rest or low intensity exercise.

In the early 2000s researchers from McMaster University began to investigate the effects of repeated Wingate tests, termed sprint interval training (SIT) (a form of HIIT that had traditionally been used to optimise performance in athletes), to improve health and importantly reduce the time requirement of an exercise session. The protocol encompassed four to six 'all-out' bouts of 30s on a cycle ergometer, separated by 4 to 4.5 min of recovery. The protocol was extremely low-volume; just 15 minutes of 'all-out' exercise over 2 weeks was enough to increase skeletal muscle oxidative capacity (Burgomaster et al., 2005). When Wingate SIT (4-6x30s 'all-out' efforts, 3 sessions per week) was compared against MICT (40-60 min of cycling at 65% VO_{2peak}, 5 sessions per week) over 6 weeks, similar improvements were seen in markers of skeletal muscle and cardiovascular adaptations (Burgomaster et al., 2008, Rakobowchuk et al., 2008, Cocks et al., 2013, Shepherd et al., 2013). These improvements were seen despite a 67% lower overall weekly time commitment in the HIIT group (final week 1.5 hours including rest vs 5 hours).

Coinciding this research, academics in Norway established an alternative HIIT protocol designed to optimise health benefits in cardiac rehabilitation. Rather than using a time-saving SIT protocol, they used a method known as aerobic interval training (AIT). This protocol consists of four x 4 minute intervals at 90-95% of maximum heart rate (HR_{max}) interspersed with 3 minutes of active rest at 70% HR_{max}. Researchers used this protocol to measure the effects of AIT and MICT (47min at 70-75% HR_{max}) on CRF in patients with stable post-infarction heart failure (Wisloff et al., 2007). Patients in both groups completed two supervised sessions and one weekly session at home for 12 weeks, the total weekly training time for MICT and HIIT was 150 min and 75 min, respectively. Their findings reported significantly greater increases in VO_{2peak}

with AIT compared to moderate continuous training (46% AIT versus 14% MICT), and AIT was associated with left ventricular remodelling. Following this landmark demonstration, a number of studies investigated AIT as a method to improve health in a variety of at-risk populations. Studies in hypertensive patients (Molmen-Hansen et al., 2012), patients with cardiovascular failure (Wisloff et al., 2007) and metabolic syndrome (Tjonna et al., 2008) have all seen superior increases in CRF following AIT compared to MICT. However these studies used a relatively small samples size (n<100). There the SMART-EX study, a multi-centre trial, recruited 261 patients with left ventricular ejection fraction, to compared 12-weeks of supervised interventions of AIT, MICT or regular exercise recommendations (Ellingsen et al., 2017). Following 12-weeks of supervised exercise similar improvements were seen in left ventricular remodelling and aerobic capacity . After the 12-week supervised intervention, patients were encouraged to continue exercising on their own, and a follow-up assessment was completed at 52-weeks (Ellingsen et al., 2017). None of the positive changes seen following 12-weeks of AIT or MICT were maintained at 52-weeks, suggesting that the feasibility of unsupervised exercise prescription in a clinical population, regardless of intervention, needs to be considered.

Importantly, the research described above was designed with different objectives, Gibala and colleagues aimed to provide a time-efficient exercise intervention, whereas Wisloff's group aimed to optimise health benefits following training. Although, both of the developed protocols fall under the definition of HIIT they are different in nature due to their different objectives. The difference between these protocols is an important distinction to make, as a number of HIIT systematic reviews and meta-analysis include both AIT and the time efficient SIT protocols. As such results often state that ‘HIIT’ is time efficient protocol that is *more* effective than MICT, when this may not be the case. Even though the duration of AIT was less than MICT in these studies, it is difficult to describe AIT as time saving because the total weekly exercise commitment was approx. 120 minutes. The aim of this thesis is to investigate how HIIT could be used to promote long term adherence to exercise by reducing barriers to exercise. Therefore, the remaining discussion will focus on time-efficient HIIT protocols rather than those with the aim to maximise adaptations.

Although the ‘all out’ Wingate protocol demonstrated that significant improvements in health markers could be made using a time-efficient exercise mode, this protocol has been heavily criticised, even by the researchers themselves. In an invited commentary Gibala (2007) remarked that “the Wingate-based training model requires an extremely high level of subject motivation and that given the extreme nature of the protocol it is doubtful if it is practical for the general population to adopt". There are further criticisms regarding the time-efficiency of this protocol, with a warm-up and 4 min recovery following sprints, the total time commitment is approximately 30 min per training session towards the end of the training programme. The resulting total time commitment (approximately 90 min per week) is greater than the current recommendations for vigorous-intensity continuous exercise of 75 min per week (Vollaard and Metcalfe, 2017).

As a result of these criticisms researchers began to investigate alternatives to Wingate based SIT, with one alternative protocol investigating the use of low-volume constant load exercise. Constant workload SIT or HIIT differ from ‘all-out’ protocols as a constant workload is maintained (in terms of HR or power (W)) throughout the intervals. Gibala’s group designed a practical model of low-volume HIIT that is time efficient and is applicable to different populations, including those with NCDs (Little et al., 2011a). In order to do this the absolute intensity of the work-bouts was decreased but the duration was increased, coupled with a shorter rest interval duration to ensure the protocol was time efficient. The new practical HIIT model consisted of 10 x 60s work bouts at a constant-load intensity that elicits ~90% HRmax, interspersed with 60s of recovery at 50W; a total session time commitment of 20min. Importantly, following 6 sessions over a 2 week period this practical model of HIIT induced skeletal muscle mitochondrial biogenesis, increased GLUT4 content, and improved insulin sensitivity in previously sedentary adults (Hood et al., 2011). Furthermore, following a 2-week intervention, increased markers of skeletal muscle mitochondrial capacity and lowered 24 hour blood glucose excursions were seen in patients with type 2 diabetes (Little et al., 2011).

Subsequently Cocks et al. (2016) developed a SIT protocol designed to maintain the anaerobic nature of ‘all-out’ protocols whilst utilising the accessibility of the constant load modality. The protocol consisted of 4 to 7 x 30 s constant workload intervals at 200% Wmax, interspersed with 2 min rest at 30 W to maintain time-efficiency. Following 6 weeks of this protocol (conducted 3x per week), results showed an improved CRF and whole body insulin response to OGTT in obese men. The increases in CRF were similar in the MICT group who completed 40–60 min cycling at ~65% VO_{2peak}, 5 times per week (Cocks et al., 2016).

More recently there has been a return to ‘all-out’ SIT protocols, to further reduce the time commitment to ≤10 min per session. An approach from Gillen et al. (2014) used a modified Wingate protocol where the workload consisted of 3x20-second ‘all-out’ cycling efforts against 0.05kg/kg body mass (compared to Wingate protocol at 0.075kg/kg body mass), separated by 2 minutes of low-intensity cycling (50W). This very low-volume protocol improved aerobic capacity (12%) when performed 3 times per week for 6 weeks, in overweight/obese participants. Gillen et al. (2016) then directly compared this 3 minute per week SIT protocol to traditional MICT (45 minutes of continuous cycling at ~70% HR_{max}) over 12 weeks. Participants aerobic exercise capacity improved to the same extent as MICT (SIT: 32±7 to 38±8; MICT: 34±6 to 40±8 ml/kg/min), despite a 5-fold lower training volume and total training time. Although this very low volume protocol has been shown to improve CRF to the same extent as MICT, it may not improve all health variables. Using the same two groups (MICT, 45mins cycling or SIT 3 x 20s all out) Shenouda et al. (2017) compared the effect of the protocols on flow-mediated dilation and brachial artery diameter, in sedentary health men. Results showed that MICT was superior to the intense and brief SIT protocol at inducing brachial artery responses. FMD increased by 2.2% after 6 weeks of MICT but did not change following SIT. Equally the largest increase in brachial artery diameter was observed following MICT (8% compared with 0.5% in SIT).

As shown throughout this section there are a number of different HIIT protocols that can improve health and save time. However, the variety of approaches used within the literature has led to a confusing public health message regarding HIIT. In particular, Hardcastle et al. (2014) claimed that "SIT is inappropriate for a largely sedentary population because it is a relatively complex and structured exercise regime" (p.2). It, therefore, is important to simplify HIIT recommendations. The aim of time-saving HIIT protocols should be to increase the feasibility of exercise to a sedentary or at risk population, but the increase in number of complex HIIT protocols has led to unclear guidelines for the public. Furthermore even though an array of options can at first seem appealing, too much choice can actually hamper motivation (Iyengar and Lepper, 2000) and overwhelm the general public with choices that could be detrimental to their adherence. Therefore, rather than creating new protocols, researchers should instead evaluate the efficacy and effectiveness of the existing successful HIIT protocols to clarify recommendations, optimise health outcomes and increase adherence and compliance.

1.12 Real world approaches to high intensity interval training

Although the above demonstrate that HIIT is a time efficient effective intervention a key issue for public health researchers, is that much of the available research has been conducted in a laboratory environment (Hardcastle et al., 2014). This provides an optimal environment for success, as high levels of supervision and specialised equipment are used throughout. HIIT has also been criticised as it is considered unlikely that patients would comply with the strenuous and complex protocols in the real world without supervision (Biddle and Batterham (2015). These commentaries point to a significant limitation of current HIIT research; a lack of interventions performed in real world environments. Therefore, it is unknown if the sedentary population can reach the required intensity to elicit health benefits, without encouragement/reinforcement from an external source. In response to these valid criticisms, researchers are now conducting HIIT in real world environments with the aim of creating a valid public health message.

A number of studies have been carried out in a gym/exercise class setting (Shepherd et al., 2015, Reljic et al., 2018, Giannaki et al., 2016). Shepherd et al. (2015) investigated the effect of HIIT performed as a 10-week gym-based instructor-led group-based spinning class, using 90 inactive volunteers (46 males and 44 females, 42±11 y, 27.7±4.8 $kg.m^{-2}$). Similar improvements in $VO_{2\ peak}$, insulin sensitivity, abdominal fat mass and blood lipids were observed between HIIT (15–60 seconds stationary cycling at >90% HRmax, 3 times per week, all supervised) and MICT (30–45 min per session at ~70% HR_{max}, 5 sessions per week, 2 of which were unsupervised). Reljic et al. (2018) also conducted an 8 -week intervention using spinning bikes in a community-based fitness centre, involving 34 previously sedentary individuals (defined as no specific sports training and engaging in less than 30 min of moderate physical activity three times per week). Two different HIIT protocols were used in a class-based format; either 2x4mins or 5x1min both at 85-95% HR_{max}. When compared to MICT (38mins at 65-75% HR_{max}) these HIIT protocols induced similar improvements in VO_{2max} (2 × 4min-HIIT: 20%, 5 × 1min-HIIT: 27%, MICT: 16%). and Metabolic Syndrome Z-Score.

Interestingly, although differences between HIIT and MICT were not reported for any markers of health, these studies reported higher adherence/reduced drop-out to HIIT than MICT, which is important considering greater adherence to PA may optimize health outcomes if maintained long-term (Miller et al., 2014). Shepherd et al (2015) reported an adherence rate of 83% in HIIT versus 61% for MICT, although the MICT group were asked to perform 5 sessions (3 supervised group-based and 2 at home) a week (in line with WHO guidelines), while the HIIT group completed 3 sessions per week (all supervised group-based). Similarly, Reljic et al. (2018) observed a lower dropout rate in the two HIIT protocols, 17% (2x4min) and 8% (5x1min), respectively, compared to a 30% drop out rate in MICT. This data suggests that practical, non-'all-out' HIIT, when performed in supervised exercise classes resulted in a higher adherence than MICT.

However, all of these sessions were led by experienced fitness instructors and were carried out using specialised equipment, which the general public do not have access to without a gym membership. Negative attitudes towards the gym environment have been reported in overweight and obese gym goers (Schvey et al., 2017), and have also been identified as a key barrier to ERS (as evidenced in **Section 1.10**). Therefore, a further criticism of existing HIIT protocols has been that although they reduce "lack of time" as a barrier to exercise many introduce additional barriers involving equipment and facilities (Korkiakangas et al., 2009). These criticisms have led to the development of alternative HIIT protocols using more accessible exercise modalities, such as walking/running groups and stair climbing. Park-based walking/running programmes are often used by fitness centres and local councils to increase PA in populations with elevated disease risk. In a sedentary population (<2x30min of moderate intensity per week) with a BMI between 28 and 40 kg/m2, Lunt et al. (2014) compared MICT (40mins at 65-75% HR_{max}) to two HIIT protocols (AIT; 4x4mins at 85-95% HR_{max} or SIT; 3-6x30s ‘all-out’). These sessions were supervised at a local park three times per week over 12 weeks (36 sessions in total), the modality of the exercise was walking, jogging or jogging up a slope in order to achieve the prescribed heart rates. Using an intention to treat analysis, the change in VO_{2max} was higher pre to post intervention in AIT (+1.3 ml/min/kg) than that of the MICT group or SIT group (-1.3 and +0.2 ml/min/kg respectfully). Although there was only a small difference in the prescribed duration between AIT and MICT (120 vs 144 minutes per week), the actual time spent exercising in AIT was on average 74 minutes (range: 7-117) compared to 116 minutes (range: 40-144) per week in the MICT group. Additionally, SIT prescribed exercise duration was 90 minutes per week, but actual completed was 45 minutes (range: 0-62) per week. The reported VO_{2max} results are interesting considering the actual time spent exercising, as despite SIT completing 61% less time exercising compared to MICT there was no significant difference between their VO_{2max} change post interventions. Allison et al. (2017) proposed that stair climbing could be used as an accessible form of exercise to offer the benefits of HIIT. Following an acute bout of either cycling (3x20s ‘all-out’) or stair climbing (3x20s ‘all-out’) based SIT, the reported mean HR, blood lactate, and RPE were similar in sedentary women (BMI 23±4 kg/m^2, VO_{2peak} 28.9±3.4ml/kg/min). In the same population, 6 weeks of stair climbing (3x20s ‘all-out’ of continuously ascending stairs, 3 sessions per week), increased cardiorespiratory fitness by 12%, similar to other SIT studies using traditional modalities such as cycling (Gist et al., 2014). Although There, however, is a potential safety issue using ‘all-out’ stair climbing as a form of exercise in an at risk population.

As discussed, the research described above (Shepherd et al. (2015), Allison et al. (2017) and Lunt et al. (2014)) into different modalities of training are a step in the right direction, however all sessions were supervised, either by a gym instructor or a member of the research team. Therefore, it is still difficult to evaluate the real-world applicability of these protocols to the wider at risk population. Furthermore, the results and adherence data cannot yet be translated into a clear public health message, as we still do not know the true adherence in an unsupervised free-living environment. However, these studies do begin to generate evidence that laboratory based HIIT protocols can be successfully translated into simulated real world interventions with potential for use within a public health setting.

Despite advances in intervention development there are a number of other major limitations that need addressing, in addition to the issue of supervision, before HIIT can be implemented into public health recommendations. Firstly, these studies have relatively small sample sizes, the largest being Shepherd et al. (2015) with n=46 and n=44 in the HIIT and MICT groups, respectively. Although the preliminary data obtained from these studies show positive results, further studies with larger cohorts are needed for conclusions that are more substantive. Secondly, these studies are all relatively short intervention periods, 8-12 weeks, therefore the long-term adherence to HIIT protocols remains unclear.

The most complete HIIT study to date addressing many of these concerns is Roy et al. (2018), where 250 overweight/obese individuals chose either 12 months of unsupervised HIIT or MICT. Those who selected MICT were instructed to follow the current guidelines provided to them in a widely available brochure produced by the New Zealand Ministry of Health ("at least 30 min of moderate-intensity PA most if not all days of the week"). The HIIT group were advised to complete HIIT three times per week using home-based exercises, sprinting, hill walking, cycling or exercise machines, with an RPE greater than 8 (10-point scale). For unfit and inexperienced participants, a 10-20s HIIT interval was recommended for 3-5 repetitions. Once adapted participants were encouraged to complete either; 3 repetitions of 30 second maximal intervals, 5-10 one minute intervals at an RPE of 8, or a single 4-minute interval at the highest intensity that could be maintained. It is important to note that when given the choice 42% (n=104) of participants chose HIIT in preference to MICT. Despite the recommendations for duration and intensity of training being markedly different, estimated VO_{2peak} (YMCA submaximal test) and physical activity levels were similar at 12 months. Adherence was measured in the HIIT group only using heart rate monitors for one week at 0, 3, 6, 9 and 12 months. In the HIIT group, the participants were able to perform HIIT (with only RPE provided as a guide) at an adequate intensity (≥80%HRmax). This suggests HIIT can be effectively undertaken by healthy overweight and obese individuals with minimal prior exercise experience and without supervision. However, the proportion of participants who did not provide data increased from 17.6% at baseline to 71.6% at 12 months. So, as with MICT, long-term adherence and compliance to real world HIIT remains a significant challenge.

1.13 Home-based high intensity interval training as a solution

As discussed throughout **Sections 1.11 and 1.12** HIIT interventions are effective at improving clinical markers of health, such as CRF, in addition, the time-saving nature of HIIT removes one of the major barriers to exercise. However, as discussed in **Section 1.6 & 1.10,** there are a number of alternative barriers affecting long term engagement and adherence to exercise. Specifically issues around facilities provide a significant barrier to adherence (cost, travel time, inconvenient scheduling, intimidating gym environment etc.). Therefore, a practical solution could be a modality of exercise performed at home without equipment. Previous studies have successfully used home-based exercise interventions using MICT and have shown that the home-based exercise can increase adherence, even over a supervised training programme (Perri et al., 1997). Consequently, by combining a home-based programme with HIIT, there is the potential to remove multiple barriers to regular exercise participation. To facilitate home-based HIIT the type of exercise needs to be inexpensive, suitable for a range of mobilities and fitness and easy to carry out in a limited space. Whole-body exercises such as burpees, star jumps and running on the spot, have been suggested as a possible modality.

Previous studies have demonstrated that body-weight exercises are a viable option compared to MICT and to traditional lab-based HIIT. Schaun et al. (2018) compared the responses in VO_{2max} following 16 weeks of whole-body

HIIT (8x20s with 10s rest, using burpees mountain climbers, squats, 'all-out' intensity) in healthy men. Results were compared to lab-based HIIT (8x20s running at 130% VO_{2max}, with 10s rest) and MICT (30min running at 90-95% HR_{max}). VO_{2max} increased following all three interventions, this suggests that whole-body HIIT can be utilised as an alternative to traditional training modalities. But these protocols were all completed in a lab setting with "strong verbal encouragement to ensure that a maximum effort was kept during all efforts" (Schaun et al. 2018).

Our research group has recently developed a whole-body HIIT programme that can be completed in any environment, including the home. This training intervention followed the practical, time-saving HIIT protocol as suggested by Little et al. (2011a); 1-min bouts of high-intensity exercise (≥80%HR_{max}) interspersed with 1-min of rest. To fit with the exercise prescription guidelines provided by the American College of Sports Medicine, the number of intervals progress from 4 in week 1, up to 10 intervals by the end of the intervention over a 6 week intervention. Intervals included two consecutive 30 second bouts (1 minute in total) of simple body weight exercises (e.g. star jumps immediately followed by squat jumps), performed straight after each other with no rest in between. The programme included18 different exercises, that required no prior exercise experience (e.g. jogging on the spot), although some exercise contained more coordinated movements which could be selected as confidence/ability increased. All exercises were explained by a member of the research team, and each participant was provided with an information pack which contained pictures and descriptions of the exercises for participants to study prior to exercise. Participants were able to choose which exercises to complete (from those provided in the booklet), according to personal preference. In an obese population with at least one additional CVD risk factor, over a 12 week intervention Scott et al. (2019b) conducted initial work using this Home-HIIT protocol (4-8x1min ≥80%HR_{max}, with 1 min rest), and compared the effect on CRF to supervised laboratory-based HIIT (4-8x1min cycling at 100%W_{max}, with 1 min rest), and unsupervised MICT (~65% HR_{max} 90-150min/wk). This research found the home-based HIIT protocol significantly improved CRF to the same extent as the supervised traditional lab-based HIIT and unsupervised MICT (Home-HIIT: 16% Lab-HIIT: 20% MICT: 12%). Adherence was monitored throughout this study using a novel approach using Bluetooth heart rate monitors that connected to participants smartphones. The monitoring system provided an objective measure of adherence (number of sessions completed) and compliance (whether heart rate thresholds and correct number of intervals were achieved during each session). Adherence was similar and high across all groups (Home-HIIT: 96±3%, MICT: 88±4%, Lab-HIIT 97±1%), as was compliance to the programme (Home-HIIT: 99±1%, MICT: 100±0%, Lab-HIIT 100±0%). Although Home-HIIT and MICT completed all training sessions unsupervised, participants were aware that researchers were monitoring adherence and if participants missed consecutive sessions, a text/email was sent by the researchers to find a specific reason for this. Recently the perceptions towards this home-based HIIT programme has also been explored in individuals with type 1 diabetes (Scott et al., 2019a). Many participants reported an increase in motivation following 6 weeks of this Home-HIIT programme, due to the range of exercises available and the progression in number of intervals.

Furthermore, like previous HIIT protocols participants valued the time efficiency of Home-HIIT but also appreciated the convenience of not having to travel, which in turn added to the time-efficiency.

In conclusion, Home-based HIIT has been well perceived in at risk populations, which has led to high adherence rates in an unsupervised environment. As a result of the high adherence, positive changes to CRF were reported, similar to that of MICT and supervised HIIT conducted on a cycle ergometer. Therefore, the home-based time-saving nature of home-HIIT may help to diminish many of the perceived barriers towards exercise participation within an ERS (such as lack of time, travel time, intimidating gym environment) which in turn will increase adherence and CRF to patients within the ERS.

1.14 Thesis Overview

The overarching aim of this thesis was to investigate the effectiveness of high intensity interval training (HIIT) when applied in a real-world environment, in sedentary and at-risk populations. There is a particular focus within this thesis on examining the feasibility of HIIT as an alternative to the current exercise guidelines, as questions regarding the use of its prescription have been raised. To achieve this three studies are presented, each of which evaluate a range of popular HIIT protocols and modalities including traditional cycling HIIT, body-weight HIIT and HIIT protocols available on social media. Therefore, the aim of this thesis is to generate evidence supporting the incorporation of HIIT into future public health guidelines.

As discussed in **Section 1.11** HIIT is a potential exercise strategy to increase exercise adherence by removing one of the most commonly cited barriers 'lack of time' (Trost et al., 2002). However as **Section 1.12** explains there is limited evidence to highlight how HIIT is performed outside of the laboratory without the supervision and encouragement of researchers. Therefore the aim of **Chapter 3** was to investigate how participants performed self-paced HIIT, in terms of heart rate and power output responses, on a readily available gym bike (Wattbike) without encouragement from the research team. This was achieved, using a randomised cross-over deign, using a 6-week intervention of two HIIT protocols (Burgomaster et al., 2005, Little et al., 2010) commonly cited in recent exercise training research. To compare the efficacy of these popular protocols, changes in cardiorespiratory fitness, body composition, glucose tolerance and arterial stiffness were assessed after 6-weeks of training. Finally, this chapter explored the notion that achieving a higher intensity during the intervals would lead to superior health outcomes, therefore we sought out to compare the changes in CRF between groups achieving different intensities during the intervention period.

Section 1.6 and **1.10** describe the major barriers to exercise that prevent a sedentary population from achieving the current physical activity guidelines, and **Section 1.13** concludes that Home-based HIIT may help to remove these perceived barriers. **Chapter 4** investigates the effects of a Home-based HIIT protocol, developed by our research group (Scott et al., 2019b), as part of a UK exercise referral scheme (ERS). In **Chapter 4** we compare this Home-based HIIT protocol to the current predominately gym-based ERS. During the 12-week intervention a novel heart rate monitoring system was used to remotely monitor adherence and compliance (ability to reach a target duration and heart rate threshold). Changes in VO_{2peak}, glucose tolerance, body composition, cardiovascular and psychological health were assessed to determine the effectiveness of Home-based HIIT in comparison to the traditional ERS. In addition, using a qualitative survey, patients' perception of HIIT and ERS was assessed including barriers to and facilitators of exercise participation. To date no study has combined quantitative and qualitative responses to ERS or a Home-based HIIT protocol, these results therefore provide insight for the prescription of Home-based HIIT within a real-world setting, such as within an ERS.

Finally, in **Chapter 5,** we investigated the acute physiological, perceptual and motivational responses to two HIIT protocols popular on social media, and compared these to two research-based HIIT protocols. As explained in **Section 1.13,** whole-body exercise removed many barriers associated with exercise participation, especially when completed in the home. As a result social media videos using this modality are growing in popularity. Therefore within this study we compared acute physiological responses (heart rate and lactate), perceptual responses (RPE, feeling scale and felt arousal scale), and motivational factors (interest/enjoyment and perceived competence), during and following established protocols described by Little et al. (2010) using a cycle ergometer, Scott et al. (2019b) using body weight exercises and two popular social media HIIT protocols. This was the first study to investigate physiological and perceptual responses to a HIIT protocol from a social media platform.

Over the course of these three studies, the aim was to provide evidence that HIIT can be carried out in the real-world outside of the controlled laboratory environment. This was done by using practical HIIT strategies that can remove many of the major exercise barriers for those at risk of developing a non-communicable disease. Secondly, this thesis aimed to add to the research regarding the prescription of HIIT by evaluating its effectiveness as a public health intervention to reduce the risk of cardio-metabolic disease risk factors.

Chapter 2. General Methods

2.1 Incremental Exercise Test to Determine VO_{2peak} and W_{max}

Throughout this thesis incremental exercise tests to volitional exhaustion were performed using an electromagnetically braked cycle ergometer (Corival, Lode, Groningen, The Netherlands) to determine maximal aerobic power output (Wmax) and VO_{2peak} using an online gas collection system (MOXUS modular oxygen uptake system, AEI technologies, Pittsburgh, PA or METAMAX 3B, Cortex Leipzig, Germany). The test consisted of 3-minute stages starting at 25 W for females and 60W for males. The workload was then increased by 35 W at each stage until subjects could not maintain a cadence of >50rpm or they reached volitional exhaustion. VO_{2peak} was taken as the highest value achieved during a 15-second recording period. Heart rate (HR) was measured throughout the tests using a Polar H7 or H10 HR monitor (Kempele, Finland).

2.2 DXA Scan

Body composition was measured using a fan beam DXA scan (Hologic QDR Series, Discovery A, Bedford, MA, USA) and were analysed using QDR for Windows software version 12:4:3. All scans were performed and analysed by the same trained operator, according to standard operating protocols. Calibration was carried out using an anthropometric spine and step phantom with a subsequent radio-graphic uniformity scan following the Hologic guidelines. The mean coefficient of variation and absolute technical error of measurement in obese men and women have been published previously (LaForgia et al., 2009). Participants lay in a supine position on the scanning bed and were positioned within the scanning area. Arms were placed beside the body with the palmer surface of the hand facing and orientated towards the vastus *lateralis muscle*, fingers were placed together and toes plantar flexed to ensure standard positioning. Duration of the scan was ~2 min, following this the scan was automatically analysed by the software, with the operator confirming regions of interest using point markers. Values were obtained for total mass (kg), lean mass (kg), fat mass (kg), visceral fat (g) and total body fat percentage (%).

2.3 Arterial Stiffness

Aortic pulse wave velocity (aPWV) measurements were made in triplicate (Chapter 1 and 3) using a semi-automated device and software (SphygmoCor, AtCor Medical, Sydney, Australia). Carotid-femoral PWV measurements were performed to characterise aortic stiffness in participants by placing a single high fidelity applanation tonometer at the proximal (carotid) and distal (femoral) pulse, to record sequentially over 10 waveforms. The QRS complex was then measured simultaneously using an ECG. The pulse transit time was calculated by subtracting the time between the R wave of the ECG and the foot of the proximal waveform from the time between the R wave and the foot of the distal waveform. To determine the distance used for PWV, an anthropometric tape measure was used to determine the distance from the carotid measurement site to the suprasternal notch. This was then subtracted from the distance between the femoral measure and suprasternal notch. All measures were completed by the same researcher.

2.4 Blood Analysis

Glucose was measured in response to an oral glucose tolerance test (OGTT) procedure. A cannula was inserted into an antecubital vein and a baseline 10 ml blood sample was taken before consumption of a 25% glucose drink containing 75g of glucose and 225ml of water. Further 10 ml blood samples were collected (in non-additive and EDTA vacutainers) at 30, 60, 90 and 120 minutes after glucose ingestion. Plasma and serum were separated by centrifugation (10 min at 3000 rpm at 4°C). Fasted plasma glucose, cholesterol, high-density lipoprotein (HDL) and low-density lipoprotein (LDL) were analysed using a Randox chemistry analyser (Randox RX Series, the RX DaytonaTM). Glucose was also analysed, using the same methodology, at each time point (30, 60, 90, 120 min).

Chapter 3. Two popular high intensity interval training protocols elicit similar health benefits in a controlled but real world environment.

Abstract

Introduction: High intensity interval training (HIIT) offers a time-efficient alternative to moderate intensity continuous training (MICT), but often HIIT requires expensive specialised cycle ergometers and vigorous encouragement from the researchers.

Aim: To compare the effects of two popular HIIT protocols, performed using readily available cycle ergometers and without encouragement, on cardiorespiratory fitness (CRF), arterial stiffness, glucose tolerance and body composition.

Methods: Eighty-two adults aged 18-65 participated (m/f: 26/56, 28±10 y, BMI 25±3 kg.m-2) in a randomised cross-over design. 6-weeks of 30HIT (4-8x30s sprint with 120s active recovery) or 60HIT (6-10x60s sprint with 60s active recovery) was completed with a 4-week washout period between interventions. Training sessions were completed on a Wattbike, 3 times per week with heart rate (HR) and power output (PO) recorded throughout. Markers of cardio-metabolic health was assessed pre and post each 6-week training phase.

Results: Both interventions increased VO_{2peak} (*P<0.001*) and decreased body fat % (*P*=0.002), aPWV (*P*=0.002) and glucose at 120 mins (*P*=0.024), with no difference between the interventions (*P*>0.005). When HR and PO were grouped into tertiles (n=27, Low, Medium and High) participants achieving a low HR had similar changes to CRF compared to the high HR group in both interventions (*P*>0.005). In 60HIT participants in the high IPO_{peak} group had a

significantly greater change in CRF compared participants producing a low and medium IPO_{peak} (P=0.020).

Conclusion: 6-weeks of 30HIT and 60HIT induce comparable improvements in aerobic capacity, body composition, arterial stiffness and glucose tolerance. Importantly, these favourable improvements were achieved using self-selected exercise intensities and without researcher encouragement. Therefore, this data suggests that either 30 or 60 second interval interventions could be used to improve health outcomes in a sedentary population in the real world**.**

3.1 Introduction

High intensity interval training has been proposed as a time efficient alternative to traditional moderate intensity continuous training (MICT). Specifically, a model of HIIT described as low-volume (≤10 minutes of high intensity work per session), has set out to improve health variables whilst minimising exercise duration (Gibala et al., 2012). The most common model of low-volume HIIT has been based on the Wingate-test (4-6x30s 'all-out' cycling with 4mins recovery). Well controlled laboratory based studies have demonstrated this mode of HIIT improves cardio-metabolic health (Gibala et al., 2006, Burgomaster et al., 2008, Rakobowchuk et al., 2008), despite a considerably lower training volume than MICT. However it has been noted that Wingate-based HIIT is extremely demanding, and may not be safe or tolerable for sedentary individuals (Little et al., 2010). Therefore, Little et al. (2010) developed a practical low-volume HIIT protocol, consisting of 10x60s bouts at 90% HR_{max} (~100% W_{max}) interspersed with 60s recovery. Again using well controlled laboratory based studies this HIIT model has been shown to improve aerobic capacity, glucose tolerance and arterial endothelial function (Little et al., 2014, Hood et al., 2011, Currie et al., 2013) to a similar extent as MICT.

Yet to date, little is known regarding the effectiveness of low-volume HIIT to the wider sedentary population outside of the laboratory. Most studies investigating low volume HIIT have small sample sizes and prescribe exercise intensity using laboratory grade cycle ergometers; which are unobtainable for the general population. Furthermore, most studies have been conducted in a tightly controlled laboratory environment where researchers are present to provide constant encouragement and/or guidance. Consequently, it has been suggested that the application and feasibility of low-volume HIIT in a "real world" environment needs to be investigated further (Gray et al., 2016). Therefore this study compares two popular protocols, 30HIT (4-8x30s intervals interspersed with 2mins rest (Cocks et al., 2016) and 60HIT (6-10x1min intervals interspersed with 1min rest (Hood et al., 2011). Additionally, all sessions were completed on a readily available gym-bike (Wattbike) to replicate the real world environment.

The aim of the study was 1) to investigate the differences in power output and heart rate responses to the different protocols (30HIT or 60HIT), without instruction or encouragement from the research team. 2) To compare the effect of each protocol on maximal aerobic capacity, fasting glucose and glucose tolerance, body composition and arterial stiffness. 3) To explore whether the effort exerted during exercise (in terms of power output and heart rate) influenced the magnitude of the physiological outcomes. We hypothesised that the time course of the changes in power output and heart rate during 30HIT and 60HIT will be different during the 6 weeks of training and that the physiological outcome measures maximal aerobic exercise capacity, insulin sensitivity, body composition and arterial stiffness will be similar for the two interventions following the 6-weeks of training. We also hypothesised that those producing the highest heart rate and power output responses during training would improve their physiological outcomes more so than those with the lowest heart rate and power output.

3.2 Methods

3.2.1 Participants

Eighty-two previously sedentary (defined as performing less than 150 min of moderate intensity exercise per week) males (n=26) aged 18-45 and females (n=56) aged 18-55, with a BMI ≤32 $kg.m^{-2}$, participated in the study (**Table 1**.). Participants were free of diagnosed cardiovascular and metabolic disease and other contraindications to exercise, ascertained through a medical screening process (see Pre-Exercise Screening). Pregnant or breast-feeding participants were excluded. Participants gave written informed consent and all procedures were performed in compliance with the Declaration of Helsinki and were approved by the Coventry and Warwickshire NHS Research Ethics Committee.

Table 3.1. Baseline characteristics

	All (n=82)
Gender (M/F)	56/26
Age (years)	28 ± 10
Height (cm)	167.4 ± 9.2
Weight (kg)	69.9 ± 13.1
BMI ($kg\text{-}m^{-2}$)	24.8 ± 3.4
VO_{2peak} ($ml.kg^{-1}.min^{-1}$)	36.1 ± 7.6
Wattmax (W)	186 ± 51

3.2.2 Pre-exercise screening

To assess cardiovascular risk and participants suitability to undertake the study a Framingham Heart Study Coronary Heart Disease Risk Prediction Score was calculated (Anderson et al., 1991). Briefly, the following information was collected and used to calculate a 5-year risk score: age, systolic blood pressure, total and HDL cholesterol, history of smoking and diabetes. Resting ECG abnormalities were also evaluated through a 12 lead ECG. Participants with a low risk score (<10% risk of developing coronary heart disease in the next 5 years) were deemed eligible to take part in the study, as suggested by the American Heart Association (Gibbons et al., 2002). Participants were also asked to complete the International Physical Activity Questionnaire to assess baseline physical activity levels. If participants achieved more than 150 minutes of moderate intensity exercise per week they were excluded from the study.

3.2.3 Study Overview

The study used a randomised counterbalanced crossover design whereby participants completed two 6-week training interventions, 30HIT (30s high intensity, self-paced cycling efforts interspersed with 120s active recovery) and 60HIT (60s self-paced high intensity cycling efforts interspersed with 60s active recovery), separated by a 4 week wash out period.

Before each intervention (30HIT and 60HIT) participants completed an incremental exercise test to exhaustion on an electromagnetically braked cycle ergometer to determine maximal aerobic power (Wattmax (W_{max})) and VO_{2peak}, using an online gas collection system (MOXUS, AEI technologies, Pittsburgh, PA) as described previously (**Chapter 2.1**).

Seventy-two hours after the incremental exercise test participants returned to the laboratory following an overnight fast, having abstained from caffeine, alcohol and vigorous exercise the day before testing. Following 20 minutes of supine rest, blood pressure was measured in triplicate using a sphygmomanometer (Dinamap; GE Pro 300V2, Tampa, Florida). Aortic pulse wave velocity (aPWV) was then measured in triplicate using a SphygmoCor (AtCor Medical, Sydney, Australia) (**Chapter 2.3**). Body composition was analysed using Dual-energy X-ray Absorptiometry (Hologic QDR Series, Discovery A, Bedford, MA, USA). Finally, glucose tolerance was assessed using an oral glucose tolerance test (OGTT). A cannula was inserted into an antecubital vein and a baseline 10 ml blood sample was taken before consumption of a 25% glucose beverage containing 75g of glucose and 225 ml of water. Further 5 ml blood samples were collected 30, 60, 90 and 120 minutes after glucose ingestion (See **Chapter 2.2**. for more detail). Blood samples were stored at -80°C until analysis. Plasma glucose concentrations were analysed using an automated analyser (Randox RX Series, the RX DaytonaTM).

3.2.4 Post-intervention

Following both interventions, an incremental exercise test was performed during the final week of training, instead of one of the scheduled training sessions. Seventy-two hours after the final training session the post-training testing protocol was conducted with procedures, methods and timings identical in all respects to pre-training. During the four-week wash out period participants were instructed to return to their pre-intervention levels of physical activity.

3.2.5 Training Interventions

All training sessions were conducted in the laboratory at Liverpool John Moores University. Participants trained 3 times per week (18 sessions in total), and were withdrawn from the study if <90% (n=16) of sessions were completed during each 6-week intervention, or if they did not attend at least 2 training sessions per week.

All training sessions were conducted on a Wattbike Trainer (Nottingham UK). The Wattbike has been shown to provide accurate data on power output (PO) when compared to the "gold standard" SRM Powermeter (Hopker et al., 2010). The use of the Wattbike allowed participants to manually adjust resistance using an airbrake, thereby controlling the exercise intensity by changing cadence or resistance. Participants were also provided with a HR monitor for all training sessions (Polar H7, Kempele, Finland). HR feedback was provided to allow participants to self-adjust their 'effort' in order to achieve a HR equivalent to >80% of their predicted HR maximum (PHR_{max}, PHR_{max} = 220 – participants age). Only the HR data was made available to participants during sessions. The rest of the data recorded (cadence and PO) was hidden to replicate a real world environment as this feedback is rarely visible on commercially available cycle ergometers.

To further replicate a real-world environment, no encouragement was provided to participants during the training sessions. During the first session a single 'familiarisation interval' was conducted, where the researcher encouraged the participant throughout the interval to help them achieve the appropriate HR response (>80% HR_{max}). Following this, no further encouragement was provided, to imitate the conditions outside of a laboratory. However, to ensure the protocol was conducted correctly, the start and end of each interval and rest period was prompted by the researcher.

Each HIIT training session began with a short warm up (5min) of low intensity (self-selected) cycling, after which participants performed either 30HIT or 60HIT, as described below.

3.2.5.1 30HIT

Participants performed repeated 30-second bouts of high intensity effort interspersed with 2 minutes of active recovery (low-cadence cycling). Participants were instructed to reach >80% HR_{max} during each interval, and to achieve this either by a high cadence or high resistance, but due to the short interval duration an ‘all out’ approach was recommended. Participants completed 4 intervals per session in week 1, 5 in week 2, 6 in weeks 3-4, 7 in week 5 and finally 8 per session in week 6. The total time commitment of each training session during week 6 was 20 minutes (**Table 3.2**).

3.2.5.2 60HIT

Participants performed repeated 60-second bouts of self-paced high intensity effort interspersed with 2 minutes of active recovery (easy cycling). Participants were instructed to reach >80% HR_{max} during each interval, and to achieve this either by using a high cadence or high resistance, but due to the longer interval duration a steady cadence was suggested. Participants completed 6 intervals per session in week 1, 7 in week 2, 8 in weeks 3&4, 9 in week 5 and finally 10 per session in week 6. The total time commitment of each training session at week 6 was 20 minutes (**Table 3.2**).

Table 3.2. Characteristics of both 30HIT and 60HIT training programmes

	30HIT				60HIT			
Week	Number of intervals	Total interval duration (min)	Total rest duration (min)	Total duration (min)	Number of intervals	Total interval duration (min)	Total rest duration (min)	Total duration (min)
1	4	2	8	10	6	6	6	12
2	5	2.5	10	12.5	7	7	7	14
3	6	3	12	15	8	8	8	16
4	6	3	12	15	8	8	8	16
5	7	3.5	14	17.5	9	9	9	18
6	8	4	16	20	10	10	10	20

3.2.6 Training session data analysis

During each training session the Wattbike PowerHub application (version 2.1.0) was used to record time, PO, cadence and HR. The lap counter function was used to mark the start and end of each interval. Following each training session, data was immediately downloaded to the Wattbike cloud-based storage application Wattbike Hub (https://hub.wattbike.com) for offline analysis of each training session (**Figure 1**).

Mean heart rate (HR_{mean}) and power output (PO_{mean}) and peak heart rate (HR_{peak}) and power output (PO_{peak}) were determined for every interval (**Figure 1 and 2**). Mean values for each training session were calculated, and then used to determine mean values over the whole 6-week intervention (IHR_{mean}, IPO_{mean}, IHR_{peak}, IPO_{peak}). It is only these mean values for the whole intervention that are presented in the results section. All HR and PO data were normalised to the participants predicted HR_{max} (220-age) and W_{max} (calculated following the incremental exercise test), respectively. Data from the first training session where verbal encouragement was received was excluded from this analysis. Identical analysis methods were used for 30HIT and 60HIT.

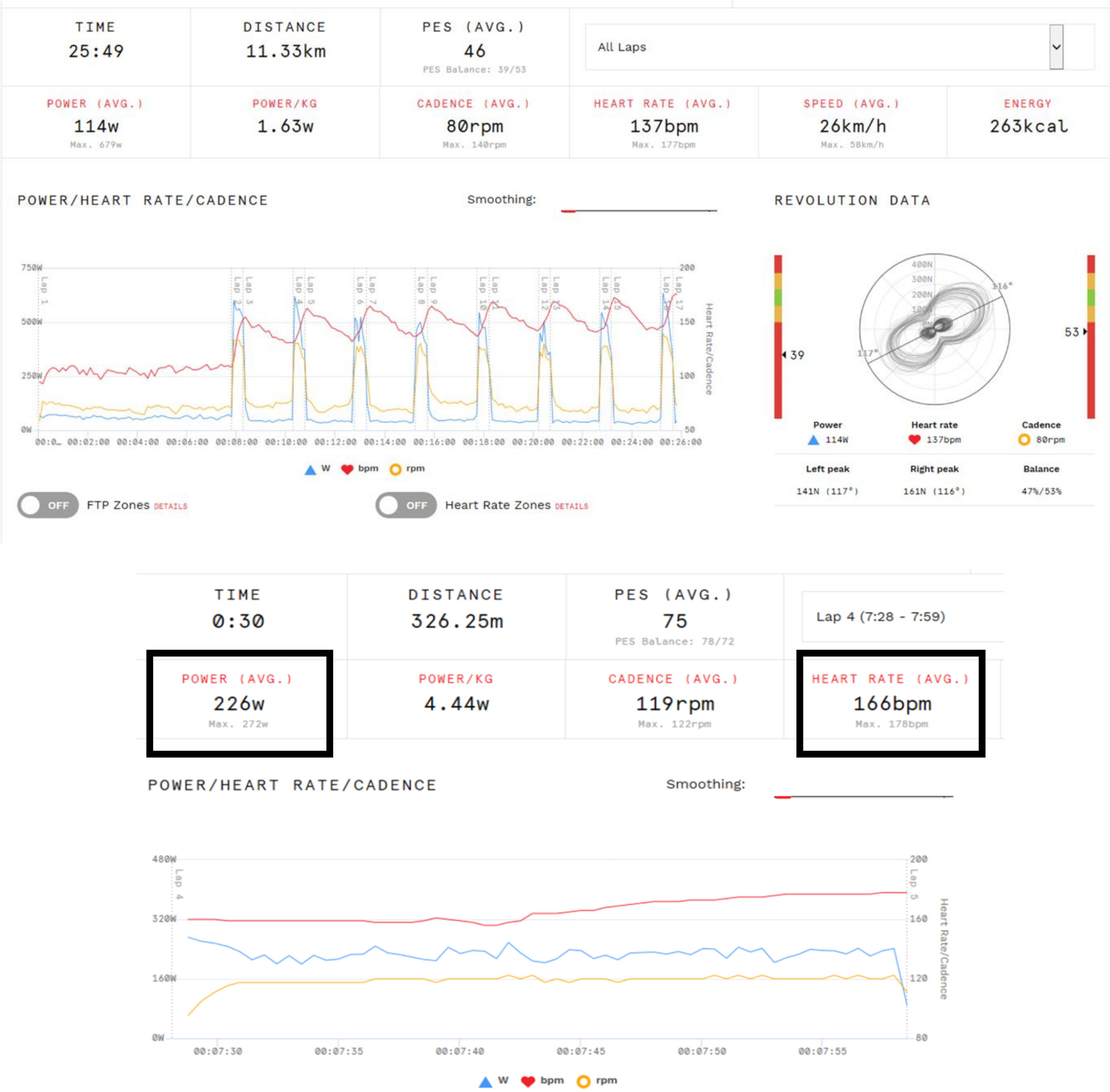

Figure 3.1. Representative screen shot of the online Wattbike PowerHub, during the final week of training. *Depicted is a single training session for an individual participant. Black boxes highlight recorded peak power output, mean power output, peak heart rate and mean heart rate.*

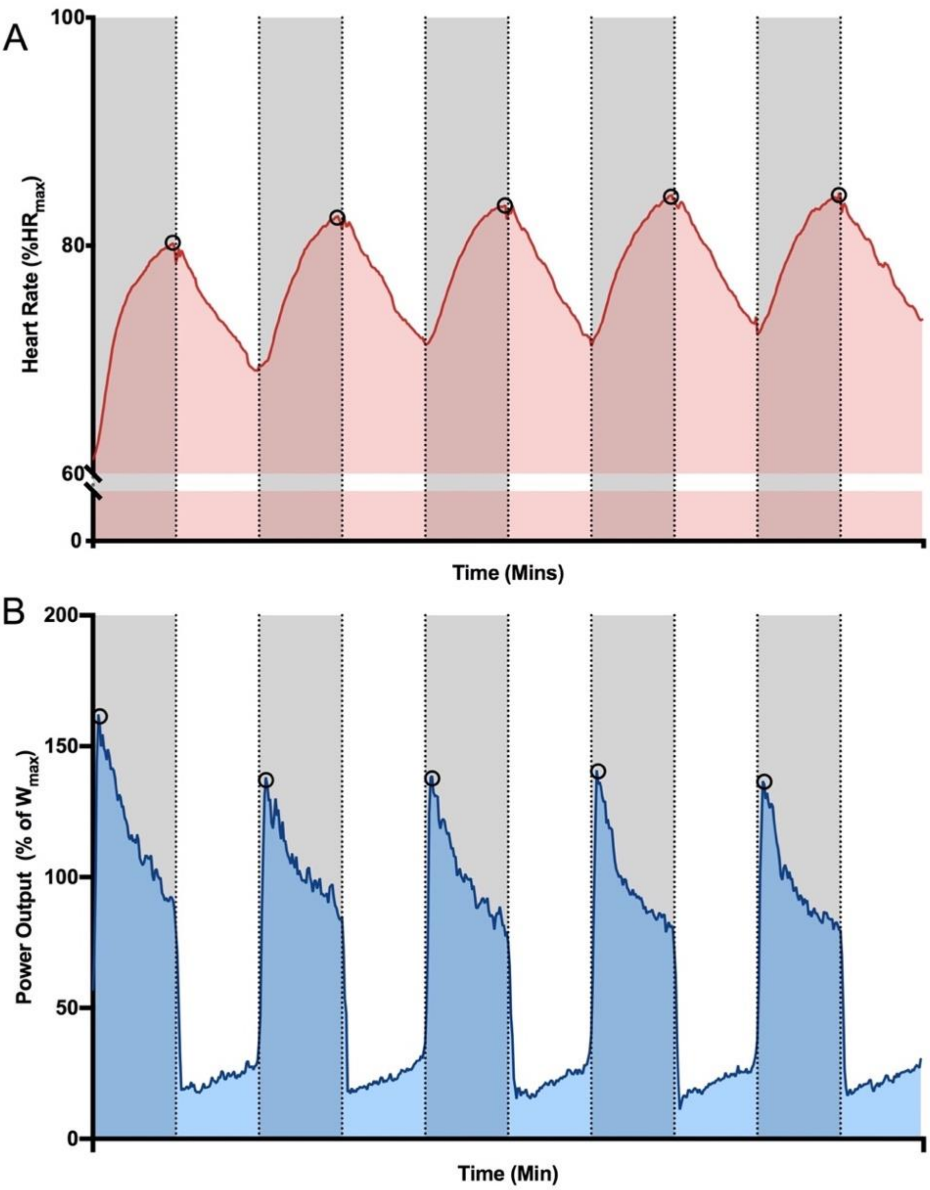

Figure 3.2. Outline of the data analysis conducted on training sessions. ***(A)*** *Example of heart rate data collected during 60HIT. Black circles indicate* IHR_{peak}*. Grey boxes indicate start and end of each interval used to calculate* $IHR_{mean.}$ ***(B)*** *Example of power output data collected during 60HIT. Black circles indicate* IPO_{peak}*. Grey boxes indicate start and end of each interval used to calculate* IPO_{mean}*. Analysis was identical for both 30HIT and 60HIT.*

3.2.7 Statistical analysis

Measures taken pre and post training were analysed using a two-way within subjects ANOVA using the within subject factors training (pre and post) and intervention (30HIT and 60HIT). Difference between the baseline and 3rd visit and differences in HR and PO between training modes were analysed using a paired samples t-test. To evaluate the potential effect of exercise intensity on change in VO_{2peak} patients were divided into 3 groups, and a one-way ANCOVA was completed, with baseline VO2peak as a covariate. The groups were based on exercise intensity, defined by IHR_{peak}, IHR_{mean} or IPO_{peak}, IPO_{mean}. Participants were separated into tertiles (Low, Medium and High) for each of these variables (n=27 in each group, see **Table 3.6** for more details). Plasma glucose responses were only reported for 40 participants, as it was not possible to obtain blood samples from all participants during every time point. All analyses were performed using statistical analysis software (SPSS for windows version 26.0.0.1 (SPSS, Chicago, IL, USA). Significance was set at $P \leq 0.05$. Data are presented as means ± SEM.

3.3 Results

3.3.1 Training Intensity

Figure 3.3. shows average heart rate and power output trace during 30HIT (3A) and 60HIT (3B). A description of the heart rate and power output responses during the interventions are displayed in **Table 3.3.** IHR_{peak} and IHR_{mean} significantly decreased over 6 weeks in both interventions. There were no significant changes in IPO_{peak} or IPO_{mean} over the 6 weeks. (see **Table 3.3.**).

Overall IHR_{peak} was similar in 30HIT and 60HIT (*P*=0.327) (see **Figure 3.4)**. The IHR_{mean} was greater during 60HIT compared to 30HIT (*P*=0.002, see **Figure 3.4**). The IPO_{peak} and IPO_{mean} were significantly higher (p<0.001) during 30HIT compared to 60HIT. **Figure 3.4** contains individual responses to the interventions, and shows the large range of IHR and IPO produced during 30HIT and 60HIT. The percentage of participants achieving an IHR_{peak} and IHR_{mean} greater than 80% HR_{max} (Roy, 2013) can be found in **Table 3.4**. The percentage of participants achieving 200% W_{max} (30HIT (Cocks et al., 2016)) and 100% W_{max} (60HIT, (Little et al., 2010)) are displayed in **Table 3.4**.

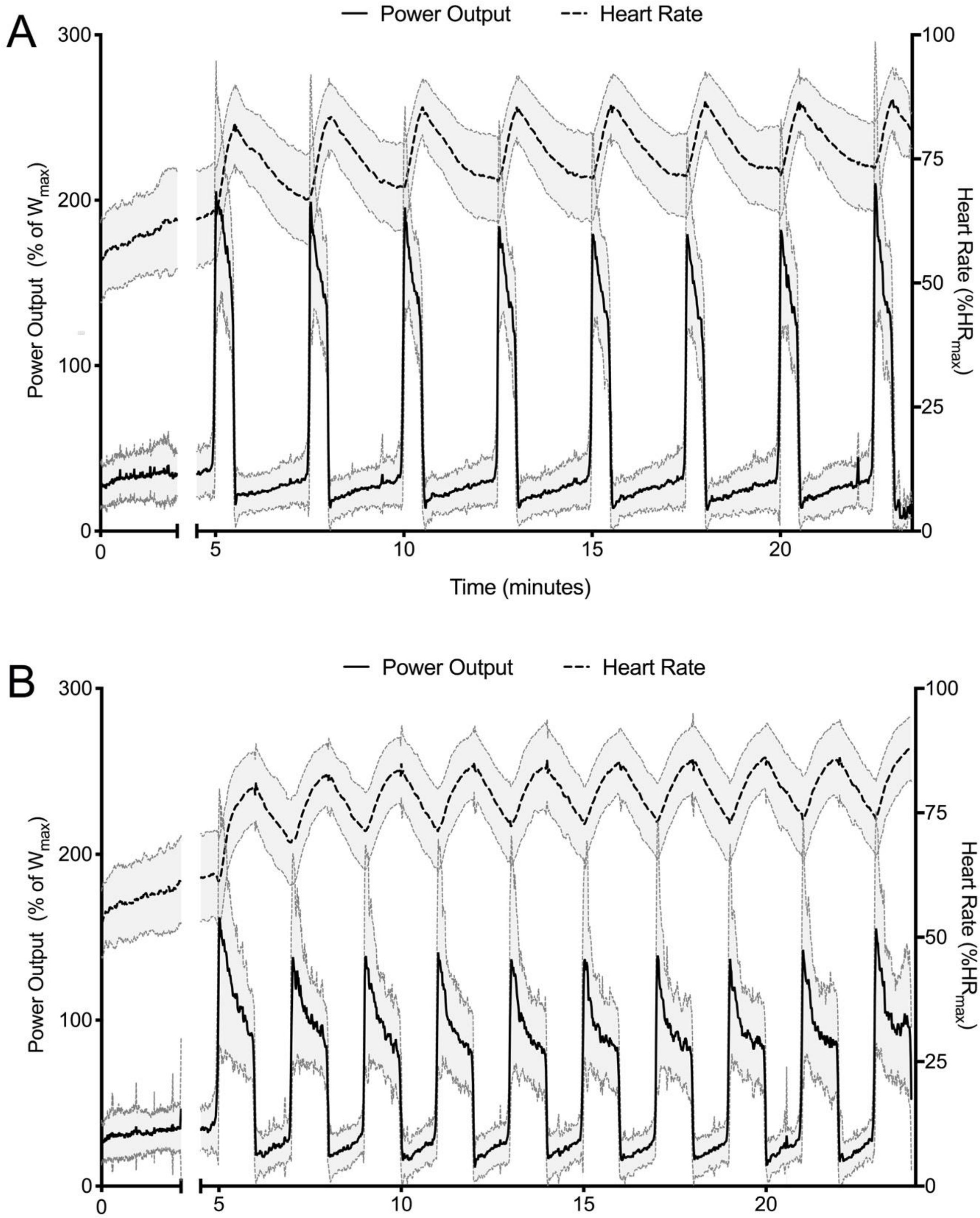

***Figure 3.3. Average heart rate and power output achieved by all participants during the final training session** of 30HIT (A) and 60HIT (B). Data is presented as mean ± SD.*

Table 3.3. Heart rate and power output responses during each week of training, for both 30HIT and 60HIT.

	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	P Value
IHR_{peak} (% HR_{max})							
30HIT	88±7	87±7	86±7	86±6	85±7	85±7	*P*<0.001
60HIT	89±6	88±6	87±6	86±6	84±13	85±7	*P*=0.003
IHR_{mean} (% HR_{max})							
30HIT	81±9	79±8	80±9	78±7	77±7	77±8	*P*<0.001
60HIT	84±6	82±8	82±7	81±7	80±8	79±8	*P*<0.001
IPO_{peak} (% W_{max})							
30HIT	248±56	244±55	244±54	248±68	245±60	245±56	*P*=0.760
60HIT	184±42	189±45	188±53	193±60	189±54	181±59	*P*=0.085
IPO_{mean} (%W_{max})							
30HIT	165±33	162±37	160±25	156±27	158±28	159±26	*P*=0.153
60HIT	106±17	109±19	107±16	108±16	108±19	105±20	*P*=0.230

***IHR_{peak},** interval peak heart rate as a percentage of predicted HR_{max}; **IHR_{mean},** interval mean heart rate as a percentage of predicted HR_{max}; **IPO_{peak}** peak power output as a percentage of W_{max}; **IPO_{mean},** mean power output as a percentage of W_{max}. Values are presented as Mean±SD.*

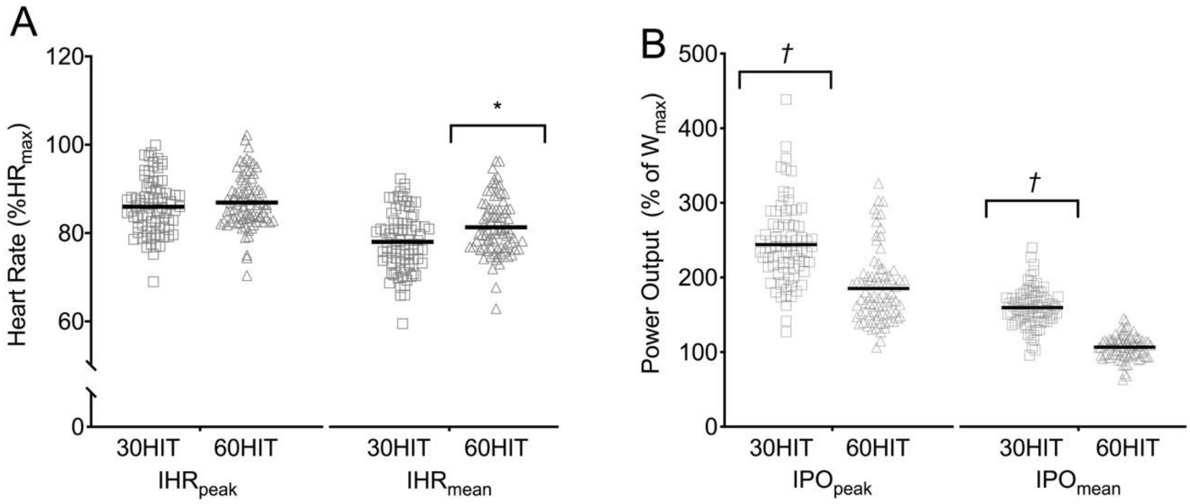

***Figure 3.4. Average interval heart rate (A) and interval power output (B) achieved over the 6-week intervention.** *indicates 60HIT significantly higher than 30HIT. †indicates 30HIT significantly higher than 60HIT.*

Table 3.4. Percentage of participants achieving above the recommended heart rate and power outputs for 30HIT and 60HIT.

	30HIT	60HIT
IHR_{peak}		
≥80% HR_{max}	81%	94%
IHR_{mean}		
≥80% HR_{max}	41%	50%
IPO_{peak}		
≥200% W_{max}	65%	-
≥100% W_{max}	-	100%
IPO_{mean}		
≥200% W_{max}	5%	-
≥100% W_{max}	-	63%

IHR_{peak}* *≥80% HR, *percentage of participants achieving a peak heart rate of above 80% their predicted HR_{max} during the interval;* ***IHR_{mean} ≥80% HR,*** *percentage of participants achieving a mean heart rate of above 80% of their predicted HR_{max} during the interval;* ***IPO_{peak} ≥200%/100% W_{max}*** *percentage of participants achieving a peak power output of above 200% (30HIT) or 100% (60HIT) of their W_{max};* ***IPO_{mean} ≥200/100% W_{max}*** *percentage of participants achieving a mean power output of above 200% (30HIT) or 100% (60HIT) of their W_{max}.*

3.3.2 Training Effects

3.3.2.1 Exercise Capacity and Body Composition

All exercise capacity and body composition data are presented in **Table 3.5,** and **Figure 3.5**. No group differences or interaction effects were detected in any of the variables relating to exercise capacity or body composition (P>0.05). Results revealed a significant main effect of time for VO_{2peak} (P<0.001) and for maximum workload capacity (*P*<0.001), with increases post training (VO_{2peak}: 30HIT 9±1%, 60HIT 8±1%, W_{max}: 30HIT 14±2%, 60HIT 13±2%). Training reduced body mass and BMI (P<0.05) post training, with no difference between the groups (**Table 3.5.**) There was a significant main effect of time for a reduction in whole body absolute fat mass (**Table 3.5.**) and body fat percentage (**Table 3.5 and Figure 3.5**). No difference was observed over time for absolute lean mass (*P*=0.853) or visceral fat mass (VAT) (0.729).

3.3.2.2 Cardiovascular Responses

All cardiovascular responses are reported in **Table 3.5.** No group differences were detected in any of the variables relating to blood pressure, resting heart rate or arterial stiffness (*P*>0.05). Results revealed a significant decrease in systolic blood pressure (*p*<0.018), diastolic blood pressure (*P*=0.054), mean arterial pressure (P=0.014), resting heart rate (*P*=0.004) and aortic pulse wave velocity (*P*=0.002), post intervention. There was no significant main effect for time observed in normalised augmentation index (AIx@75bpm) (*P*=0.219).

Table 3.5. Subject characteristics, body composition, exercise capacity and cardiovascular-related outcomes before and after 30HIT or 60HIT.

	30HIT		60HIT		SPSS Outputs		
	Pre	Post	Pre	Post	Time	Group	Interaction
Exercise Capacity							
VO_{2peak} (l.min^{-1})	2.5 ± 0.7	2.7 ± 0.7*	2.5 ± 0.7	2.7 ± 0.8*	*P*=0.000	*P*=0.417	*P*=0.718
VO_{2peak} (ml.kg^{-1}.min^{-1})	36.3 ± 7.6	39.4 ± 8.0*	36.1 ± 7.7	38.8 ± 8.9*	*P*=0.000	*P*=0.184	*P*=0.406
Wattmax (W)	189 ± 52	215 ± 53*	188 ± 49	212 ± 56*	*P*=0.000	*P*=0.458	*P*=0.598
Body Composition							
Weight (kg)	69.7 ± 13.0	69.3 ± 12.7*	69.8 ± 13.0	69.8 ± 12.9*	*P*=0.040	*P*=0.162	*P*=0.499
BMI (kg-m^{-2})	24.8 ± 3.4	24.7 ± 3.3*	24.8 ± 3.4	24.8 ± 3.4*	*P*=0.047	*P*=0.776	*P*=0.268
Fat Mass (kg)	18.3 ± 7.1	18.1 ± 6.4*	18.6 ± 6.5	18.0 ± 6.8*	*P*=0.029	*P*=0.675	*P*=0.204
Lean Mass (kg)	45.9 ± 10.2	46.2 ± 10.0	46.2 ± 10.3	46.0 ± 11.0	*P*=0.853	*P*=0.921	*P*=0.243
VAT Mass (g)	260.0 ± 149.0	262.1 ± 134.4	264.1 ± 156.2	266.01 ± 158.96	*P*=0.729	*P*=0.512	*P*=0.995
Total Body Fat (%)	27.66 ± 7.53	27.13 ± 7.22*	27.6 ± 7.24	27.16 ± 7.23*	*P*=0.002	*P*=0.276	*P*=0.272
Cardiovascular Characteristics							
Blood Pressure (mmHg)							
Systolic	116 ± 10	115 ± 10*	116 ± 11	114 ± 9*	*P*=0.018	*P*=0.254	*P*=0.585
Diastolic	64 ± 6	64 ± 1*	65 ± 7	63 ± 6*	*P*=0.054	*P*=0.573	*P*=0.680
MAP	82 ± 6	81 ± 7*	82 ± 7	80 ± 7*	*P*=0.014	*P*=0.411	*P*=0.129
Resting Heart Rate (bpm)	66 ± 10	62 ± 10*	64 ± 12	62 ± 9*	*P*=0.004	*P*=0.097	*P*=0.971
PWV (m.s)	6 ± 1	6 ± 1*	6 ± 1	6 ± 1*	*P*=0.002	*P*=0.953	*P*=0.550
AIx @ 75 (%)	1 ± 15	1 ± 15	1 ± 15	0.1 ± 16	*P*=0.219	*P*=0.548	*P*=0.929
Glucose Tolerance							
Fasting Glucose (mmol.L^{-1})	4.4 ±0.9	4.3 ± 1.0	4.5 ± 1.2	4.5 ± 0.8	*P*=0.613	*P*=0.328	*P*=0.967
Glucose at 60min (mmol.L^{-1})	5.9 ± 2.1	5.6 ± 1.0	5.6 ± 2.0	6.0 ± 2.2	*P*=0.669	*P*=0.459	*P*=0.598
Glucose at 120min (mmol.L^{-1})	5.0 ± 1.2	4.6 ± 1.6*	4.6 ± 1.1	4.4 ± 1.6*	*P*=0.024	*P*=0.125	*P*=0.422

*Data reported as mean ± SD. *represents significantly different from Pre.*

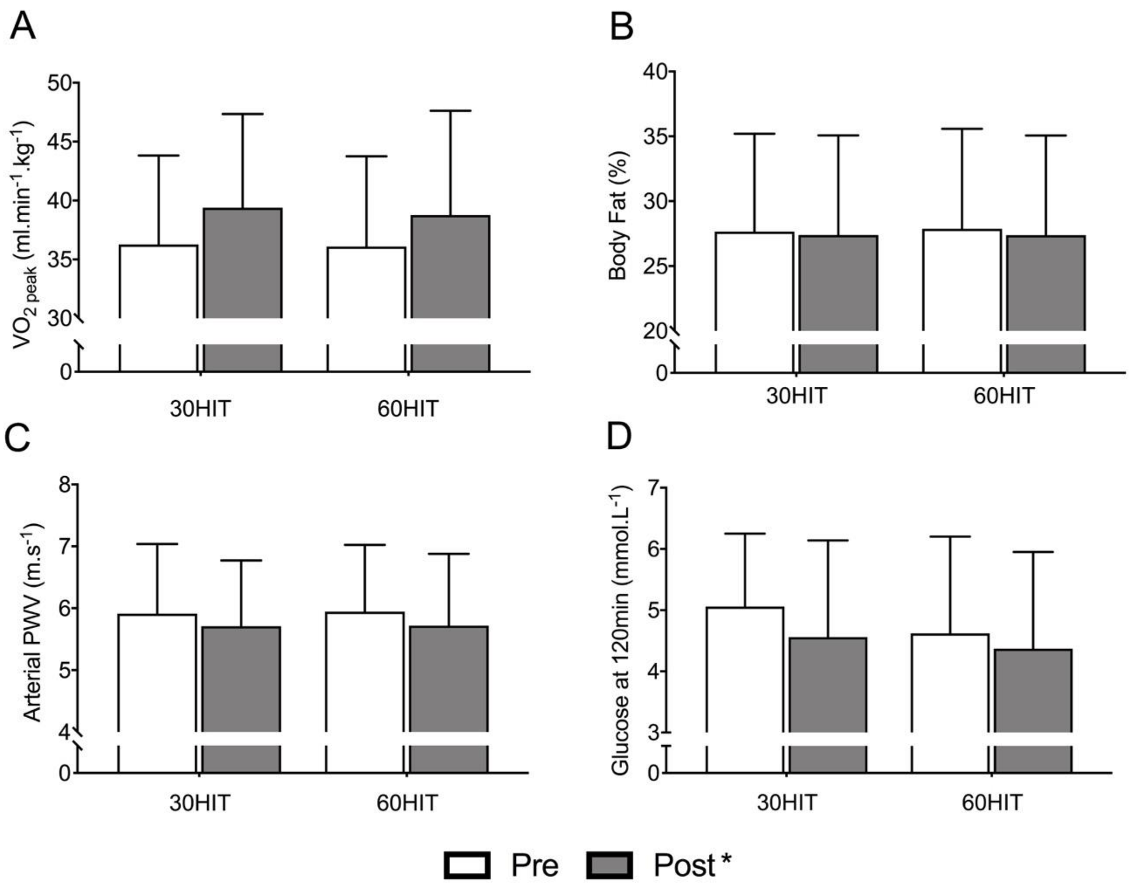

Figure 3.5. Six weeks of 30HIT and 60HIT promote physiological adaptations in A. *VO_{2peak}* ***B.*** *Body fat percentage* ***C.*** *Arterial pulse wave velocity* ***D.*** *Glucose response at 120min during oral glucose tolerance test. Values are presented as means ± SD. *Main training effect (p<0.05).*

3.3.2.3 Glucose Tolerance

There were no significant between group differences or interaction effects in glucose tolerance at any time point of the oral glucose tolerance test (P>0.05, **Table 3.5.**). There was a significant main effect for time for glucose at 120 minutes (P=0.024), glucose at 120 minutes was significantly lower post intervention. No significant main effect over time was found in fasting glucose or at 60 minutes (p>0.05 see **Table 3.5.**)**.**

3.3.2.4 Effect of 4-week wash-out period

Mean arterial pressure (82.2±6.8 vs 80.9±6.7) and fasting glucose (4.6±1.3 vs 4.3±1.0) were significantly higher at baseline compared to pre-testing following the wash-out period (0.043 and 0.025 respectfully). No other variables measured following the wash-out period were different to baseline (P>0.05).

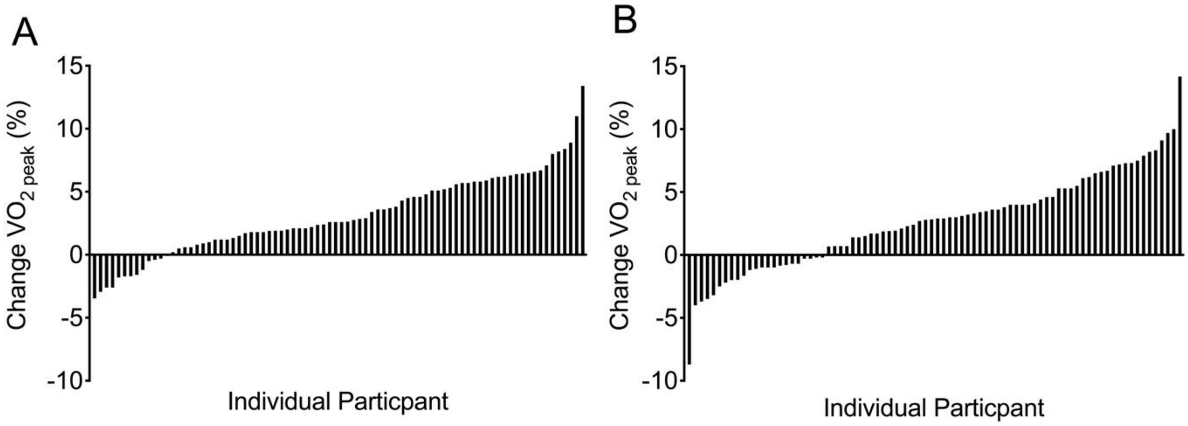

Figure 3.6. Individual changes in VO_{2peak} following 6-week of either 30HIT (A) or 60HIT (B).

3.3.2.5 Relationship between exercise intensity and change in VO_{2peak}

Figure 3.6 displays individual changes in VO_{2peak} from Pre to Post 30HIT and 60HIT. The relationship between exercise intensity (IHR and IPO) and change in VO_{2peak} is displayed in **Figure 3.7**. Three exercise intensity tertiles were used; Low, Medium and High for IHR and IPO (see **Table 3.6**. for mean and ranges). Participants who elicited a greater IHR_{peak} or IHR_{mean} had similar changes in VO_{2peak} compared to those with a lower IHR (see **Figure 3.7A**), in both 30HIT (0.677 IHR_{peak}, 0.535 IHR_{mean}) and 60HIT (0.549 IHR_{peak}, 0.617 IHR_{mean}).

In 60HIT, participants in the High IPO_{peak} group had a significantly greater change in VO_{2peak} compared participants producing a Low and Medium IPO_{peak} (0.020, Low 1.8±4.1 Medium 1.8±3.2 and High 4.2±3.6 $mL \cdot kg^{-1} \cdot min^{-1}$). Change in VO_{2peak} was not significantly different between participants producing a Low, Medium or High IPO_{peak} during 30HIT (*P*=0.886) (**Figure 3.7B**). In 60HIT, there was a strong trend (0.074) towards participants with a Medium and High IPO_{mean}, having a greater change in VO_{2peak}, compared to the Low group. There was no significant difference between the Low, Medium and High IPO_{mean} groups in 30HIT (*P*=0.398) (**Figure 3.7B**).

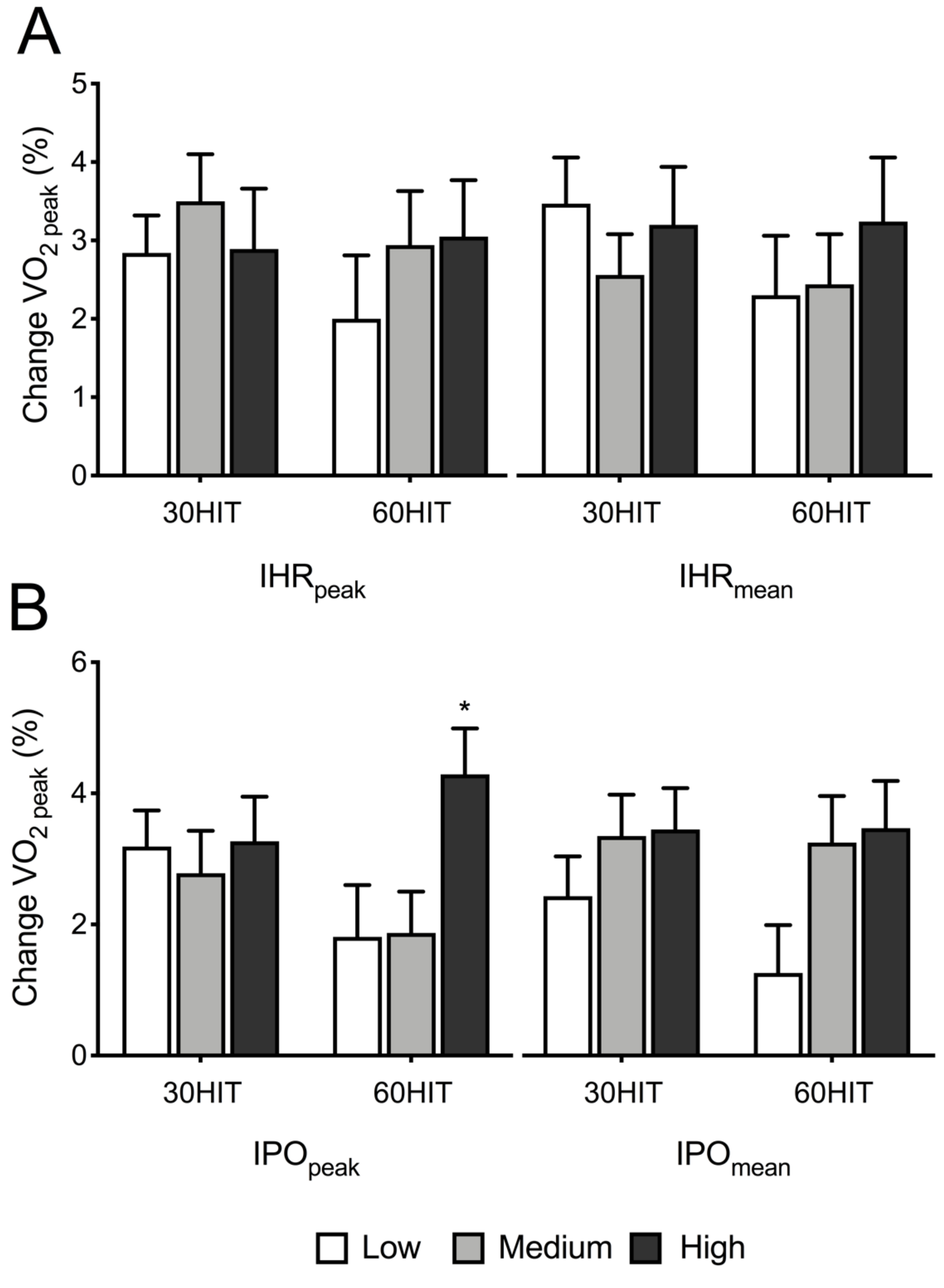

Figure 3.7. Relationship between exercise intensity and change in $VO2_{peak}$. (A) *Changes in $VO2_{peak}$ categorised by heart rate peak (HR_{peak}) or heart rate mean (HR_{mean}). (**B)** Changes in $VO2_{peak}$ categorised by peak power output (PPO) or mean power output (MPO). * indicates significantly higher than low and medium IPO_{peak} during 60HIT.*

Table 3.6 Characteristics of groups based on exercise intensity.

	30HIT		60HIT	
	Mean ± SD	Range	Mean ± SD	Range
IHR_{peak} (% HR_{max})				
Low	80 ± 3	69 – 82.9	81.2 ± 3.2	70.4 – 83.8
Medium	85.7 ± 1.6	83.0 – 87.9	86.1 ± 1.5	83.8 – 88.9
High	92.8 ± 2.8	88.0 – 99.9	93.5 ± 3.7	89.1 – 102.2
IHR_{mean} (% HR_{max})				
Low	70.7 ± 3.3	59.5 – 74.3	74.9 ± 3.2	62.9 – 77.9
Medium	77.8 ± 2.0	74.5 – 80.8	80.5 ± 1.8	78.2 – 83.6
High	85.5 ± 3.4	80.9 – 92.3	88.5 ± 3.7	83.6 – 96.3
IPO_{peak} (% W_{max})				
Low	192.6 ± 23.5	127.1 – 220.2	141.1 ± 11.9	106.3 – 154.6
Medium	237.7 ± 10.0	220.5 – 253.7	176.9 ± 11.8	161.2 – 193.7
High	302.0 ± 42.7	254.1 – 438.6	237.5 ± 41.0	196.2 – 326.2
IPO_{mean} (% W_{max})				
Low	132.9 ± 14.6	95.7 – 149.4	89.8 ± 9.3	63.0 – 98.0
Medium	159.3 ± 5.7	150.6 – 169.9	107.4 ± 4.6	98.2 – 113.5
High	187.1 ± 18.2	170.0 – 239.8	122.3 ± 8.7	114.0 – 145.3

IHR_{peak}, interval peak heart rate as a percentage of predicted HR_{max}; IHR_{mean}, interval mean heart rate as a percentage of predicted HR_{max}; IPO_{peak} peak power output as a percentage of W_{max}; IPO_{mean}, mean power output as a percentage of W_{max}. N=27 in all groups.

3.4 Discussion

This was the first study to employ a randomised cross-over design to investigate two popular HIIT protocols using readily available gym equipment, without provision of verbal encouragement. We found that during self-paced HIIT participants could achieve the prescribed HR (>80%HRmax) during both 30HIT and 60HIT and 6-weeks of training resulted in similar cardiovascular and metabolic adaptations in response to both protocols. Despite all participants being given the same intensity target (>80%HRmax during the intervals), a large range of individual HR and PO responses were observed. Interestingly, this study found similar increases in VO_{2peak} regardless of HR achieved during 30HIT or 60HIT. However, larger increases in VO_{2peak} were observed in participants who elicited a higher IPO_{peak} but only in 60HIT.

3.4.1 Comparison of cardiometabolic health responses following 30HIT and 60HIT

HIIT has recently been advertised as an effective and time-efficient exercise option for improving cardiometabolic health (Batacan et al., 2017, Campbell et al., 2019). However, previous studies using HIIT have included a diverse range of protocols, which in the future is likely to lead to confusion when prescribing low-volume HIIT to the general public. Interestingly, despite large differences between protocols, as seen in the heart rate and power output profiles (**Figure 3.3**), 6-weeks of self-paced 30HIT or 60HIT resulted in similar positive adaptations to cardio-metabolic health.

In previous meta-analysis, laboratory-based low-volume HIIT reported a 4-10% increase in VO_{2peak} (Weston et al., 2014), in the current study similar improvements were found following 30HIT (8.6%) and 60HIT (7.4%), with no differences between the groups. This finding has importance given that CRF is strong predictor of mortality (Blair et al., 1989), and improvements in VO_{2peak} are associated with a reduction in all-cause mortality (Blair et al., 1995). Previous epidemiological studies report an 8-17% reduction in all-cause mortality for each 1-MET increase (~3.5 $ml.min^{-1}.kg^{-1}$) in CRF (Myers et al., 2002). Therefore, either 30HIT or 60HIT could be prescribed within a gym environment with the aim to increase CRF. Additionally, results from the current study showed modest but significant changes in body composition, with 0.5% decrease following 30HIT or 60HIT. This is less than the -1.5% reported in a recent meta-analysis from Viana et al. (2019). However the meta-analysis included studies with longer intervention periods (≥12 weeks), overweight/obese participants and walking/running/jogging as the form exercise, which have been shown to have a larger effect on body composition (Viana et al., 2019). Furthermore, the meta-analysis of Maillard et al (2018) showed that intensities above 90% HR_{max} are more effective than lower intensities in reducing whole-body adiposity. Therefore, the smaller change in body fat percentage observed in the current study, compared to Viana et al. (2019)**,** could be explained by the lower IHR_{mean} observed in both 30HIT (78%HR_{max}) and 60HIT (81%HR_{max}).

Both 30HIT and 60HIT resulted in a decrease in MAP (30HIT: -1.5mmHg; 60HIT: -2mmHg) and resting heart rate (30HIT: -2.8bpm; 60HIT: -2.4bpm). Although these results were not clinically significant (MAP >10mmHg (Ettehad et al., 2016)), improvements were similar to a previous gym-based study from Shepherd et al. (2015) using a varied low-volume HIIT protocol (15-60s intervals). Finally, the current study found similar improvements, regardless of intervention, in glucose response following a 2h OGTT. It has been suggested that the 2h response following an OGTT is a stronger predictor of mortality than fasting glucose (DECODE Study Group, 2003, Metter et al., 2008). Taken together these results suggest that either 30HIT or 60HIT can be successful at improving cardio-metabolic health, even when completed outside of the laboratory environment without constant encouragement.

3.4.2 Effect of intensity on cardiorespiratory fitness

This is the first study to investigate the effect of intensity on CRF using low-volume HIIT and surprisingly, the current research found similar improvements in VO_{2peak} regardless of the peak or mean HR achieved during intervals in either 30HIT or 60HIT. MacInnis and Gibala (2017) suggest that the prescribed training intensity is an essential component of an exercise intervention, as it has been shown to influence the physiological response to chronic exercise training. In patients with coronary heart disease (CHD), Moholdt et al. (2014) demonstrated that there was a dose-response relationship even when participants performed interval exercise in the 85-95%HRmax intensity zone. Following 12-weeks of AIT a greater improvement in VO_{2peak} (~2ml.kg-1.min-1) was observed when patients HR exceeded 92%HRmax, compared to <92%HRmax. This conflicting result could be explained by the interval duration, as the protocol used in the work from Moholdt et al. (2014) consisted of longer intervals (4mins). Additionally, it has previously been argued that HR achieved during intervals may not be suitable for prescription of low-volume HIIT (<30s), as HR lag at exercise onset results in a slower response to exercise intensity compared to a VO_2 response (Cerretelli and Di Prampero, 1971, Buchheit and Laursen, 2013). In response to this, Moholdt et al. (2014) removed the first 2 minutes of the interval to allow time for participants to reach a HR >80%HRmax. Therefore, using IHR_{peak} or IHR_{mean} to analyse low-volume HIIT intervals (<60s) may not be appropriate, and so the use of alternative analysis methods, e.g. time spent above 80%HR_{max}, and its effect on CRF should be investigated in low-volume HIIT.

Although HR did not predict changes in CRF, HR is still a useful and accessible prescription tool for a sedentary population. In the current study, the prescribed HR (>80%HRmax) was achieved by the majority of participants during each interval, and this intensity was enough to elicit clinically significant improvements in CRF (~2ml.kg^{-1}.min^{-1}) even when participants were classed in the low intensity HR group. This has important practical implications as public health researchers have previously questioned whether sedentary participants would be able to achieve the required intensity to elicit health benefits when exercise was performed without encouragement (Hardcastle et al., 2014, Biddle and Batterham, 2015).

This study was the first to use a readily available gym bike which allowed collection of power output data during self-paced HIIT (Wattbike), therefore individual PO could also be used to assess the impact of exercise intensity on CRF. When exploring the effect of PO on changes in CRF following 60HIT, the results of this study show participants producing a High IPO_{peak} induced greater VO_{2peak} advances compared to their Low or Medium counterparts. However, surprisingly, changes in CRF failed to reach significance when grouped based upon IPO_{mean}. One possible explanation for this is that although participants in the current study achieved similar IPO_{mean} compared to previous lab-based research (100%W_{max}), it has to be noted that the 'power profile' for 60HIT differed from earlier studies (Little et al., 2010). Previous research has traditionally used a constant load approach during 60 second intervals, whereby the same power is applied throughout based on %VO_{2peak} or %HR_{max}. However, in the current study, with the freedom to perform the intervals using self-pacing, our participants' power profile during 60HIT was similar to that seen in a Wingate (with a large initial peak in PO), rather than mimicking the constant load approach. Importantly, although significant differences in CRF existed between the IPO_{peak} tertiles for 60 HIIT, participants in all groups achieved clinically significant improvements in CRF (Low: 1.8 $ml.kg^{-1}.min^{-1}$, Medium: 1.9$ml.kg^{-1}.min^{-1}$ High:2.3 $ml.kg^{-1}.min^{-1}$).

In contrast to 60HIT, it appears there was no relationship between changes in CRF and PO intensity during 30HIT, despite large variation in PO responses (Low:193% Medium:237% High:302% W_{max}). It has been established that intensity of exercise is important for many key physiological adaptations, and that an increasing exercise intensity can mediate responses to training e.g. VO_{2peak} and mitochondrial adaptations (MacInnis and Gibala, 2017). Therefore, when studying low-volume HIIT protocols (using intervals <30s), the methods used in the current study (HR and PO) may not be encompassing the changes in exercise intensity that impact adaptations to exercise. A recent study from Fiorenza et al. (2018) found the PGC-1α mRNA response to low-volume HIIT (18 × 5 s "all-out" sprints with 30s rest vs 6 × 20 s "all-out" sprints) was greater when exercise induced the highest muscle lactate accumulation, the greatest drop in muscle pH, and the highest plasma adrenaline levels. Therefore, in order to improve HIIT prescription, future research should investigate further the effects of exercise intensity on health outcomes such as CRF and utilise these alternative intensity measurements.

3.4.3 Limitations

There are some limitations that should be considered when interpreting the results and designing future interventions. Firstly, sedentary but otherwise healthy participants were recruited, therefore we cannot generalise these results to populations with cardiovascular or metabolic disease. However, in laboratory environments, the traditional protocols used in 30HIT and 60HIT (i.e. using specialist equipment and verbal encouragement) have been successful at improving markers of health in overweight/obese populations (Cocks et al., 2016), coronary artery disease (Currie et al., 2013) and type 2 diabetes (Little et al., 2011a). Secondly, this was a relatively short intervention (6-weeks), therefore we do not know the long term effects of self-paced HIIT, nor the compliance to the prescribed programme and intensity over a longer intervention period. Due to the nature of this study design, it was not possible to assess adherence in a free-living environment, however participants received no encouragement from the researchers to attend training; only a weekly invitation via email which allowed them to select their training slot. Finally, due to a large number of participants completing the intervention simultaneously, and a lack of resources, it was not possible to assess habitual physical activity levels. Although all participants were sedentary prior to the study (based upon IPAQ questionnaire) and were instructed to maintain similar physical activity and dietary habit throughout the study.

3.4.4 Conclusions

In summary, this study demonstrates that 6-weeks of either 30HIT or 60HIT result in similar improvements to cardiometabolic health, suggesting either 30HIT or 60HIT can be successfully prescribed to a sedentary or at-risk population to improve cardio-metabolic health. Additionally, this study found similar increases in VO_{2peak} regardless of HR achieved during the intervals. Interestingly, larger increases in VO_{2peak} were observed in participants who elicited a higher IPO_{peak} but only in 60HIT. Importantly, even participants in the low HR or PO categories showed significant improvements in CRF, therefore >80%HRmax is an effective intensity prescription for HIIT that stimulates positive health adaptations.

Chapter 4. Home-based high intensity interval training is effective in a primary care setting for at-risk individuals: A multidisciplinary approach evaluating health and perceived barriers to exercise.

Abstract

Introduction: Within primary care, the exercise referral scheme (ERS) is a common approach to promote physical activity (PA). However, adherence to ERS is often poor, and its effect on health is unclear. High-intensity interval training (HIIT) performed at home (Home-HIIT), could be an alternative prescription within ERS.

Aim: To evaluate a Home-HIIT intervention embedded within an ERS using a mixed method multidisciplinary approach.

Methods: 154 patients (age 48±10.1y; BMI 30.5±6.1kg/m2; VO_{2peak} 25.5±7.6ml.kg.min) enrolled in a 12-week ERS (sedentary with ≥1 CVD risk factor) chose either traditional ERS prescription (150min/wk at 50-70% HRmax) or Home-HIIT (4-9x1min intervals at ≥80% of HRmax). Programme adherence was monitored using heart rate monitors. Cardiorespiratory fitness (VO_{2peak}), blood pressure, body composition (DXA) and glucose tolerance were measured at baseline, post-intervention (12-weeks) and 3-months post-intervention (follow-up). An online survey was completed post intervention, using open ended questions explored feasibility and acceptability of Home-HIIT.

Results: 56% (n=87) of patients chose Home-HIIT in preference to ERS (n=67), and Home-HIIT had a lower VO_{2peak} at baseline (P=0.029). Excluding initial drop out (Home-HIIT n=17 vs ERS n=6), adherence to the prescribed number of sessions (Home-HIIT 38.9±36.3% vs ERS 53.2±42.0%; *P*=0.298), and compliance to the prescribed session intensity and duration (Home-HIIT

30.1±34.3% vs ERS 46.9±39.8%; P=0.331) were similar. Training increased VO_{2peak} (Home-HIIT 13% vs ERS 16%; *P*<0.001), and was maintained at follow up (*P*<0.001). Only ERS resulted in decreased fat mass (*P*=0.010), and improved mean arterial pressure at follow up (*P*=0.001). Qualitative perceptions of Home-HIIT were generally positive, especially its convenience. Interestingly, the perceived barriers to ERS and Home-HIIT were similar.

Conclusion: This is the first study to evaluate Home-HIIT in individuals with elevated CVD risk in a primary care setting. Although adherence to Home-HIIT was low it was similar to traditional ERS. Importantly Home-HIIT improved VO_{2peak} and was perceived positively. We provide evidence that Home-HIIT could be adopted as an alternative form of exercise within primary care based ERS.

4.1 Introduction

Physical inactivity causes 5.3 million deaths from non-communicable disease (e.g. CVD) worldwide (Lee et al., 2012), and conservative estimates placed the economic burden on international health-care systems as $53.8 billion worldwide, in 2013 (Ding et al., 2016). As such, the World Health Organisation (World Health Organization, 2013) and national governments have prioritised the promotion of regular physical activity (PA) as part of a coordinated approach to reduce non-communicable diseases. Primary care has been identified as a key setting for the promotion of PA, often in sedentary individuals with elevated cardiovascular disease (CVD) risk (Williams, 2011). Consequently a number of primary care-based interventions have been implemented internationally to promote PA (Arsenijevic and Groot, 2017). A common approach are exercise referral/physical activity on prescription schemes (ERS). Many countries have developed ERS, resulting in significant variation, but most follow a similar structure; initial meeting with an exercise specialist followed by the prescription of a personalised training programme (Morgan et al., 2016).

Although ERS are becoming increasingly popular, there is little evidence supporting their efficacy to improve markers of health (Pavey et al., 2011, Prior et al., 2019). Factors such as uptake and adherence to the prescribed exercise programme, have a significant impact on health outcomes during ERS (Marcus et al., 2000). Yet uptake and adherence have often been shown to be poor within an ERS setting (Morgan, 2005, Pavey et al., 2012). Importantly, exercise prescription for ERS is often based on traditional guidelines, recommending patients strive to achieve 150 minutes of moderate-intensity exercise per week. However, many studies have shown that traditional exercise guidelines create significant barriers to exercise (Korkiakangas et al., 2009), which could be contributing to poor uptake and adherence of ERS (Morgan et al., 2016).

High-intensity interval training (HIIT) could be a useful additional exercise prescription for ERS, as HIIT has been shown to be an effective training mode (Gibala, 2007), that reduces one of the major barriers to PA in ERS, “lack of time” (Morgan et al., 2016). Recently our group successfully modified a traditional HIIT protocol (Little et al., 2010) by using simple body weight exercises to allow training to be completed at home without equipment (Scott et al., 2019b). This home-based HIIT approach further reduced barriers to ERS, including feeling intimidated or uncomfortable in a gym environment, concerns over using gym equipment, inconvenient times of the sessions, clashes with work/childcare commitments and the cost of the gym membership (Scott et al., 2019a). However, whether HIIT can form a viable public health strategy for use within primary care has been questioned by public health researchers, due to the strenuous nature of the exercise and complex protocols creating additional barriers to PA (Hardcastle et al., 2014, Biddle and Batterham, 2015). Hence it is unclear whether home-based HIIT could form a viable exercise choice for use within ERS.

We therefore used a multi-disciplinary approach to evaluate a Home-based HIIT intervention embedded within an ERS, comparing adherence and physiological responses to traditional ERS prescription. In addition, an online qualitative survey was used to explore participant experiences of home-based HIIT. It was hypothesised that Home-based HIIT would 1) have higher uptake and adherence than ERS, 2) improve markers of cardio-metabolic disease risk to the same extent as ERS, and 3) reduce perceived barriers to PA.

4.1 Methods

4.1.1 Ethical Approval

All participants provided written informed consent, and the study was approved by the Liverpool Central NHS Research Ethics Committee (approval reference no. 17/NW/0042) and conformed to the Declaration of Helsinki.

4.1.2 Study Location and Participants

The study followed the process in place for the Active Lifestyles ERS within the Metropolitan Borough of Sefton, in the North West of England, funded by Sefton Clinical Commissioning Group (CCG). Patients were either referred to the Active Lifestyles ERS by their GP or self-referred to the programme, following advertisement of the trial in the local area. Following an initial statement of interest, eligibility to the Active Lifestyles ERS and the trial was assessed by the research team (**Table 4.1** for specific inclusion exclusion criteria). Once eligibility had been confirmed 154 patients (**Table 4.3.** for patient characteristics) attended an initial meeting with an Active Lifestyles Lifestyle Development Officer (LDO) or member of the research team who acted as the patients LDO.

4.1.3 Intervention and group allocation

Once eligibility had been established all patients followed the Active Lifestyles ERS process. The support provided to the two groups was the same, only the exercise prescription; traditional ERS or home-based HIIT, was different between groups. In line with UK National Institute for Clinical Excellence

(NICE) guidance for ERS the Active Lifestyle ERS contained, 1) a personal assessment by a physical activity specialist (LDO) to determine what physical activity programme should be recommended to meet their needs, and 2) an opportunity to participate in a 12-week physical activity programme (NICE, 14). Specific details for the Active Lifestyle ERS are as follows:

4.1.3.1 Initial meeting and group allocation

All patients attended an initial meeting with their LDO. Briefly, the patient and LDO explored the patient's barriers and motivation to exercise. Once this review had been completed patients were given information on the two exercise prescriptions (traditional ERS or Home-based HIIT) and were asked to choose a prescription to follow. Patients who chose the traditional ERS developed a personalised exercise prescription with their LDO. Patients who chose Home-based HIIT had the programme explained to them by a member of the research team. See exercise prescription for details (**Table 4.1**.). To minimise potential allocation bias recruitment to the groups was not restricted at any point; i.e. groups were left open for recruitment until appropriate participant numbers were achieved in both groups. Self-selection of the exercise prescription was chosen to increase the real-world translation of the findings.

4.1.3.2 Mid-intervention (6-week) meeting

All patients were invited to attend a mid-intervention meeting (face-to-face or telephone depending on patient preference) with their LDO. Briefly, the patient and LDO explored the patient's progress with their exercise prescription and any barriers they faced.

4.1.3.3 Exit (12-weeks) meeting

All patients were invited to an exit meeting with their LDO. Briefly, the patient and LDO explored the patient's progress with their exercise prescription. Exit routes and strategies to maintain physical activity were then discussed. All meetings with LDO's were free conversation, questions were not standardised between participants but generally meetings involved a review of goals and sign post towards future activity routes.

4.1.3.4 Exercise prescriptions

Patients in both the traditional ERS and home-based HIIT groups completed a 12-week exercise programme. All patients were provided with a HR monitor which connected via Bluetooth to their smart phone (Polar Beat; www.polar.com/beat/uken), allowing patients to view their HR during exercise. Provision of HR monitors is not normal practise within the Active Lifestyle ERS, but HR was used in the prescription of exercise intensity in the home-based HIIT group, and was essential for providing information on adherence and compliance to the prescriptions, outline below.

Table 4.1. Inclusion and exclusion criteria.

	Inclusion	Exclusion

Criteria	One or more of the following:
	
	• Referred to Active Lifestyles Exercise Referral Scheme by a GP
	• High blood pressure
	• Angina (treated and stable)
	• Mental Health issues (anxiety/ stress/ depression)
	• Arthritis
	• Previous Heart attack or heart surgery (not under current investigation)
	• Impaired glucose tolerance
	• Overweight/ obese (BMI >25)
	• Aged 18-65
	• Dyslipidaemia (total cholesterol >5 mmol/L)
		• Aged <18 or >65
		• Cardiac rehab patient
		• Blood pressure >180/100 and/or uncontrolled or poorly controlled hypertension
		• Currently prescribed Beta-blockers
		• Cardiomyopathy
		• Uncontrolled tachycardia
		• Cardiac arrhythmia
		• Valvular heart disease
		• Aneurysms
		• Uncontrolled (drug resistant) epilepsy - failed to become (and stay) seizure free following trials of two seizure medications.
		• History of falls or dizzy spells in the last 12 months
		• Excessive or unexplained breathlessness on exertion
		• Uncontrolled or poorly controlled asthma (severe COPD) - Limitation in performing day-to-day activities, weekly nocturnal symptoms and awakening, more need for rescue medications, lung function (FEV1) < 80%, three or more asthma attacks per year
		• Pregnant or breast feeding or becomes pregnant during the study
		• End stage renal disease
		• Awaiting medical investigation
		• Severe mental health condition
		• Diabetes and 1 of the following
		  – Aged >35
		  – Type 2 diabetes mellitus >10 y duration
		  – Type 1 diabetes mellitus >15 y duration
		  – Hypercholesterolemia (total cholesterol >6.2 mmol/l)
		  – Hypertension (systolic blood pressure >140 or diastolic >90 mm Hg)
		  – Smoking
		  – Family history of coronary artery disease (CAD) in first-degree relative <60 y
		  – Presence of microvascular disease
		  – Peripheral vascular disease
		  – Autonomic neuropathy

4.1.3.5 Traditional ERS

All exercise programmes were personalised to some extent based on discussions from the initial meeting. However, all prescriptions were based on completion of moderate intensity exercise (50-70% HR_{max}). Patients were encouraged to train at least 3 times per week, totalling 45 minutes per week during the first 2 weeks and increasing to 135 minutes per week by the end of the intervention (**Table 4.2**). Patients were given a choice of exercise modes depending on their preference, current fitness levels and health considerations. In general the exercise prescription included use of gym equipment (treadmill running, stationary cycling, cross-training, rowing etc.), attending exercise classes or exercise in patients local environment (e.g. walking groups). All participants attended their local gym or leisure centre for an induction with a staff member. Access to gyms/exercise classes was provided for free or at a heavily reduced rate (£3 per session) depending on the local leisure centre. This reduced rate was discontinued at the end of the 12-week ERS.

4.1.3.6 Home-based HIIT

Patients were encouraged to train 3 times per week. The sessions prescribed repeated 1-minute bouts of exercise interspersed with 1-minute of rest. Patients were advised to achieve ≥80% of predicted heart rate maximum (HRmax; 220–age) during the intervals. The 1-minute intervals were composed of two different 30-second bodyweight exercises with no rest in between. During the first two weeks of the intervention patients were advised to complete 4 intervals, which increased by one interval each fortnight up to a maximum of 9 intervals. This prescription was the same for all patients.

However, patients were free to choose the specific body-weight exercises performed. Patients were provided with an exercise pack (**appendix 1.**) containing 9 exercise pairs and 18 total individual exercises. The exercises ranged from simple low-impact exercises to complex movements with higher impact. This allowed participants to modify exercise sessions, choosing exercises that elicited the desired HR response (≥80% of predicted heart rate maximum during the intervals), but were suitable for their level of mobility and fitness.

4.1.4 Experimental protocol

4.1.4.1 Pre-intervention assessment

Following the initial meeting and before the start of their exercise programme all patients attended the laboratory at Liverpool John Moores University. Patients attended the laboratory following an overnight fast, having abstained from caffeine, alcohol and vigorous exercise the day before testing. Following 15 minutes of supine rest brachial artery blood pressure and aortic pulse wave velocity (aPWV) were measured in triplicate using a sphygmomanometer (Dianamap; GE Pro 300V2, Tampa, Florida) and SphygmoCor (AtCor Medical, Sydney, Australia), respectively (**Chapter 3**). A resting blood sample was then obtained and an oral glucose tolerance test (OGTT) was performed (**Chapter 3**). Body composition was analysed using Dual-energy X-ray Absorptiometry (DXA Hologic QDR Series, Discovery A, Bedford, MA, USA) (**Chapter 3**). Finally, an incremental exercise test to exhaustion on an electromagnetically braked cycle ergometer was administrated. Briefly, patients started cycling at 25W for females or 65W for males for 3 min, following this the workload was increased by 35 W every 3 mins until volitional fatigue (described in detail in

Chapter 3). VO_{2peak} was determined using an online gas collection system (Moxus modular oxygen uptake system, AEI technologies, Pittsburgh, PA). VO_{2peak} was defined as the highest VO_2 achieved over a 15 second recording period.

4.1.4.2 Post-intervention and follow-up assessment

At least 72 hours after the final training session participants reported to the laboratory for post-intervention testing. Subsequently, at least 3-months following the exit meeting patients reported to the laboratory for follow-up testing. Post-intervention and follow-up assessments were conducted with procedures, methods and timings identical in all respects to pre-training. Participants also completed a post-intervention survey (described in **4.2.6**).

4.1.5 Blood analysis

Plasma glucose during the OGTT (fasting, 60 and 120min) and fasting triglyceride (TG), total cholesterol (TC), LDL-cholesterol (LDL-C) and HDL-cholesterol (HDL-C) concentrations were analysed using an automated analyser (Randox RX Series, the RX DaytonaTM).

4.1.6 Qualitative survey

Following post-intervention testing, while alone in a quiet space, participants completed an anonymous online qualitative survey (www.googleforms.co.uk). The survey asked patients about their barriers and facilitators to exercise before the ERS, their experiences of their exercise intervention, and their intentions to exercise in the future (**Appendix 4**). Questions were developed, piloted within, and revised by the research team using appropriate literature (Kinnafick et al., 2018).

4.1.7 Qualitative analysis

Answers from the qualitative survey were analysed using a framework approach (Ritchie and Spencer, 2002). This is a flexible approach appropriate for multi-disciplinary research teams (Gale et al., 2013). The analytical process was guided by Gale and colleagues' 7 stages of analysis (given that responses were already transcribed, the process started at stage 2) (Gale et al., 2013). The stages included; familiarisation with the interview, coding of the responses, developing an analytical framework to group and discuss codes (three of the researchers discussed this on two occasions); applying the analytical framework where agreed groups of codes were applied to the transcript; charting data to the framework where quotes were aligned to an appropriate group of codes; and finally interpreting the data where researchers discussed the meaning of quotes, consulted notes collected by F.K. during the analytical process and agreed on how they would be presented

4.1.8 Training session analysis

Patients were encouraged to wear the HR monitor (Polar H10) for all exercise sessions performed during the 12-week Active Lifestyle ERS. Following each training session HR data was automatically uploaded to a cloud storage site (www.flow.polar.com), available to the research team. For each training session in the ERS group exercise duration and mean HR over the whole session were derived. For each training session in the home-based HIIT group, number of intervals completed, peak heart rate on each interval, % of intervals achieving a HR >80% HR_{max}, and time spent above 80% HR_{max} were derived. HR variables were all expressed as % of the individuals predicted HR_{max} (220-age). The rationale for predicted HR_{max} over actual HR_{max}

(obtained on the incremental exercise test) was to increase the real world translation of the study, as the research team do not envisage, or deem it feasible, that all individuals engaging in home-based training should complete a maximal exercise test before commencing training. Descriptive training session analysis used intention to treat and per protocol principles, as recommended for evaluation of exercise training intervention fidelity (Taylor et al., 2015). For intention to treat analysis all consented patients were included, and it was assumed that missing HR data represented a missed training session. As such, values of 0 (session duration and number of intervals) or 40% HR_{max} were imputed where HR monitor data was not available. A value of 40% HR_{max} to represent missing data has been proposed by Taylor et al. (2015), as 40% HR_{max} represents no additional physiological loading (e.g. approx. 80 beats.min). For the per protocol analysis only data for completed training sessions was presented.

4.1.9 Training drop-off, adherence and compliance to exercise prescriptions

Training drop-off is defined as the week patients no longer completed any training sessions. (i.e. a patient who trained regularly, but then completed no training sessions from week 6 onwards would have a training drop-off of week 6). Patients who did not complete any training sessions were described as no exercise uptake.

Adherence refers to completing the prescribed number of sessions. In both groups full adherence was defined as 3 sessions per week for 12 weeks, totalling 36 sessions. Due to the effect of drop-off, and patients completing more than the prescribed number of sessions in some week's, adherence was presented in two forms, programme adherence and weekly adherence. Programme adherence described the total number of sessions completed as a percentage of 36. Weekly adherence used 3 sessions as the maximum that could be executed in a week (i.e. 3 or 4 sessions would both = 100% adherence), the mean weekly adherence was then calculated. Using these distinctions, a participant that completed 36 sessions but did not train past week 6 (i.e. 6 sessions per week for the first 6 weeks (drop-off week 7)) would have a programme adherence of 100%, but a weekly adherence of 50%. Intention to treat and per protocol principles were also used for assessment of adherence. It was again assumed that missing HR data represented a missed training session. For intention to treat analysis all consented patients were included. For the per protocol analysis, initial dropouts (i.e. had an adherence of 0%) were excluded, but all other consented patients were included.

Compliance refers to achieving the prescribed duration/ number of intervals and the correct exercise intensity during each session. Details of the basic prescription for each intervention can be found in **Table 4.2**, where the prescription differed from this the individual patients programme was used. Due to the different nature of the ERS and HIIT programmes compliance was calculated differently between the two interventions.

For ERS duration (min) was adjusted for the exercise intensity (%HR_{max}) to produce a heart rate physical activity score (HRPAS = min*%HR_{max}) for each session, as suggested by Miller et al. (2014). The session HRPAS was then compared to a prescribed-HRPAS, based on the minimum prescribed duration and exercise intensity (**Table 4.2.**). If the session HRPAS was equal to or greater than the prescribed-HRPAS the session was compliant. For HIIT compliance was defined as achieving a HR ≥80% HR_{max} during the session and performing the prescribed number of intervals (**Table 4.2.**). Intention to treat and per protocol principles were used for assessment of compliance. Intention to treat analysis was conducted as above for adherence. For the per protocol analysis, only recorded sessions were analysed.

Table 4.2. Prescribed exercise for home based high intensity interval training (Home-based HIIT) and exercise referral scheme group.

	Home-HIT					Exercise Referral Scheme			
Week	Total time per session (min)	Number of intervals per session	Interval intensity (%HR_{max})	Sessions per week	Weekly time commitment (min)	Total time per week (min)	Intensity (%HR_{max})	Sessions per week	Weekly time commitment (min)
1	8	4	≥80	3	24	15	50-70	3	45
2	8	4			24	15			45
3	10	5			30	15			45
4	10	5			30	15			45
5	12	6			36	15			45
6	12	6			36	30			90
7	14	7			42	30			90
8	14	7			42	30			90
9	16	8			48	30			90
10	16	8			48	30			90
11	18	9			54	30			90
12	18	9			54	45			135

Total time per session and total time per week not including warm up and cool down. %HRmax percentage of predicted heart rate maximum, when heart rate maximum is calculated using 200-age.

4.1.10 Statistical analysis

The study was powered to detect a difference in cardiorespiratory fitness (CRF) between ERS and home-based HIIT. Power analysis indicated that 64 patients per group would be required to detect a 1.5ml/kg/min difference in VO_{2peak} with a power of 80% and alpha of 0.05, assuming a standard deviation for change in VO_{2peak} of 3ml/kg/min (Scott et al., 2019b, Lunt et al., 2014). All physiological outcomes were analysed using intention to treat principles, where all patients who consented, regardless of adherence, compliance, or attendance at testing sessions were included in the analysis. A linear mixed model was used to assess the change in outcomes at post-intervention and follow-up (relative to baseline) within and between each treatment group. The analysis considered the change in the measurements between the follow-up visits and baseline as the outcome. Time was considered as a categorical variable and an unstructured covariance matrix, which was allowed to differ by treatment group, was used to model the correlation over time. Descriptive training session data and adherence and compliance were analysed using intention to treat and per protocol principles, as suggested by Taylor et al. (2015). See "training session analysis" (**4.2.8**) and "training drop-off and adherence and compliance to exercise prescriptions" (**4.2.9**) for assumptions used for analysis of these variable. Descriptive training session data, adherence and compliance were then assessed using an independent samples t-Test. All analyses were performed using SPSS Statistics for Windows, Version 26.0 (IBM, Armonk, NY, USA). Significance was set at $P \leq 0.05$ and data are presented as mean ± SD.

4.2 Results

4.2.1 Participant characteristics

Baseline characteristic of 154 patients who chose either T-ERS (n=68) or Home-based HIIT (n=86) are reported in **Table 4.2**. (P>0.05). See **Figure 4.1** for consort participant flow diagram. Cardiorespiratory fitness (CRF) (relative VO_{2peak}) was significantly lower in Home-based HIIT compared to T-ERS (*P*=0.038) at baseline. All other baseline characteristics between groups were similar.

Table 4.6 and 4.7 show the linear mixed model results examining within- and between-group mean change from baseline to post intervention and 3-months post intervention (follow-up) (with associated 95% confidence interval and *p*-values). See **Appendix 3** for group level descriptive statistics across the study (mean ± SD).

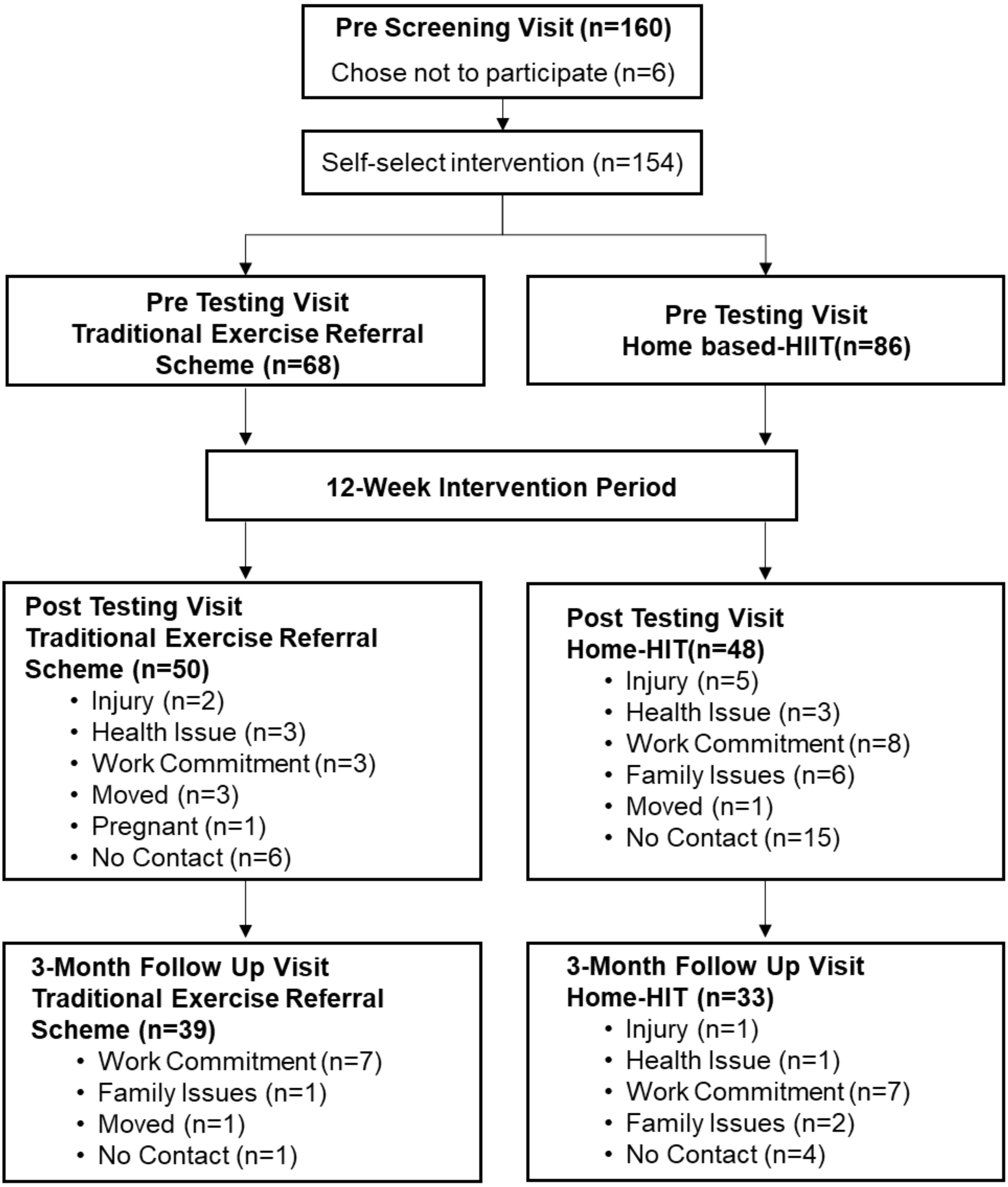

Figure 4.1. Consort participant flow diagram.

Table 4.3. Descriptive statistics for individuals that took part in the intervention.

Variable	Intervention		
	All (n=154)	T-ERS (n=67)	Home based-HIIT (n=87)
Age (years)	48±10	48±11	49±10
Sex (male/female)	88/66	41/27	47/39
Height (cm)	171.0±8.7	170.9±8.8	171.3±8.6
Weight (kg)	89.1±17.7	89.5±18.3	88.8±17.4
BMI ($kg.m^2$)	30.5±6.1	30.7±6.3	30.3±6.0
VO_{2peak} ($l.min^{-1}$)	2.2±0.7	2.3±0.7	2.2±0.7
VO_{2peak} (ml. min-1.kg-1)	25.6±7.6	26.7±8.4	24.6±6.9*
Health Condition (n=)			
Anxiety	3	2	1
Arthritis	12	7	5
Asthma	13	5	8
Bronchiectasis	1	0	1
Chronic Kidney Disease	3	0	3
Depression	8	3	5
Dyslipidemia	74	31	43
Fibromyalgia	1	0	1
Hypertension	34	17	27
Impaired Fasting Glucose	5	3	2
Impaired Glucose Tolerance	16	10	6
Kidney Stones	1	1	0
Obesity	69	27	42
Polycystic Ovary Syndrome	2	0	2
Sedentary	139	59	80
Sleep Apnoea	2	2	0
Thyroid Condition	5	0	5
Mean number of risk factors per participant	3±1	3±1	3±1
Range of Risk Factors	1-7	1-6	1-7

* indicates a significant value.

4.2.2 Intervention Characteristics, adherence and compliance

Table 4.4. Mean training session duration and heart rate responses during 3-month exercise referral or Home-based HIIT.

Variable	Traditional Exercise Referral Scheme
Duration (min:sec)	
Intention to Treat	24:27±22:03
Per Protocol	50:36±20:25
HR_{mean} (% HR_{max})	
Intention to Treat	55±13
Per Protocol	73±8
Variable	**Home Based-HIIT**
Duration (min:sec)	
Intention to Treat	4:14±5:10
Per Protocol	10:10±2:00
HR_{peak} (% HR_{max})	
Intention to Treat	58±20
Per Protocol	91±7
Time above ≥80%HR_{max} (min:sec)	
Intention to Treat	2:40±5:42
Per Protocol	7:45±16:17
% of Intervals Above 80%HR_{max}	
Intention to Treat	22±31
Per Protocol	75±25

***Intention to Treat:** all consented patients were included.* ***Per Protocol:** initial dropouts (i.e. had an adherence of 0%) were excluded, but all other consented patients were included.*

The mean training session duration and heart rate responses can be found in **Table 4.4.** Drop-off from training is displayed as number of patients per week in **Figure 4.2**. 32% of patients completed the 12-week intervention. Although total drop-off was greater in Home-based HIIT (Home-based HIIT n=66, T-ERS n=38) much of this was made up of patients who did not train at all (initial dropout) or stopped training after week-1 of the intervention (Home HIIT n=27 patients accounting for 41% of total Home-based HIIT drop-off, T-ERS n=8 patients accounting for 21% of total T-ERS drop-off). Once training drop-off in this period was accounted for the difference in group size observed at baseline was eliminated (Home-based HIIT n=60 after week-1 of training, T-ERS n=59 after week-1 of training). Following this initial phase, drop-off was similar between groups (Home-based HIIT n=39, T-ERS n=30), leaving the final number of patients training at the end of the intervention similar between groups (Home-based HIIT n=21, T-ERS n=29).

Adherence and compliance data for the 3-month intervention period is presented in **Table 4.7**. There were no significant between-group differences for adherence or compliance, when using intention-to-treat or per protocol analysis ($P>0.05$).

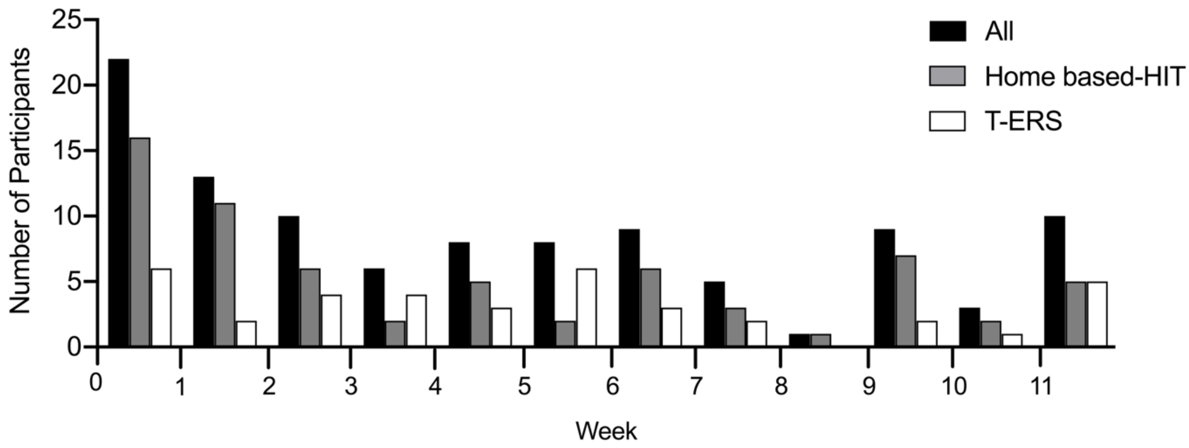

Figure 4.2. Training drop-off over the 12-week intervention period.

Table 4.5. Adherence and compliance to the exercise referral and Home-based HIIT interventions.

	Traditional Exercise Referral Scheme	Home-based HIT	P Value
Intention to Treat			
Sessions per week (n)	1.5±1.3	1.1±1.1	*P*=0.114
Programme Adherence (%)	53.2±42.0	38.9±36.3	*P=0.298*
Weekly Adherence (%)	48.0±34.7	38.9±36.3	*P=0.772*
Compliance (%)	46.9±39.8	30.1±34.3	*P=0.331*
Per Protocol			
Sessions per week (n)	1.7±1.2	1.3±1.1	*P*=0.352
Programme Adherence (%)	58.4±40.4	47.1±34.8	*P*=0.402
Weekly Adherence (%)	53.6±32.3	41.1±34.8	*P*=0.528
Compliance (%)	88.4±22.5	81.9±23.4	*P=0.104*

Values presented as mean±SD. ***Intention to treat*** *analysis for all variables included all consented patients.* ***Per protocol*** *analysis for adherence variables excluded initial dropouts (i.e. had an adherence of 0%).* ***Per protocol*** *analysis for compliance included only recorded sessions.* ***Programme adherence:*** *the total number of sessions completed as a percentage of 36.* ***Weekly adherence:*** *mean number of sessions per week, using 3 sessions as the maximum (i.e. 3 or 4 sessions per week would both = 100% adherence).*

4.2.3 Cardiorespiratory Fitness

Figure 4.3 shows changes in CRF from baseline to post intervention and 3-month follow up. Compared to baseline, both groups significantly improved their CRF (absolute and relative VO_{2peak}) at both time points (P<0.001). There were no significant between-group differences at either time point (Post 0.130, Follow Up 0.208).

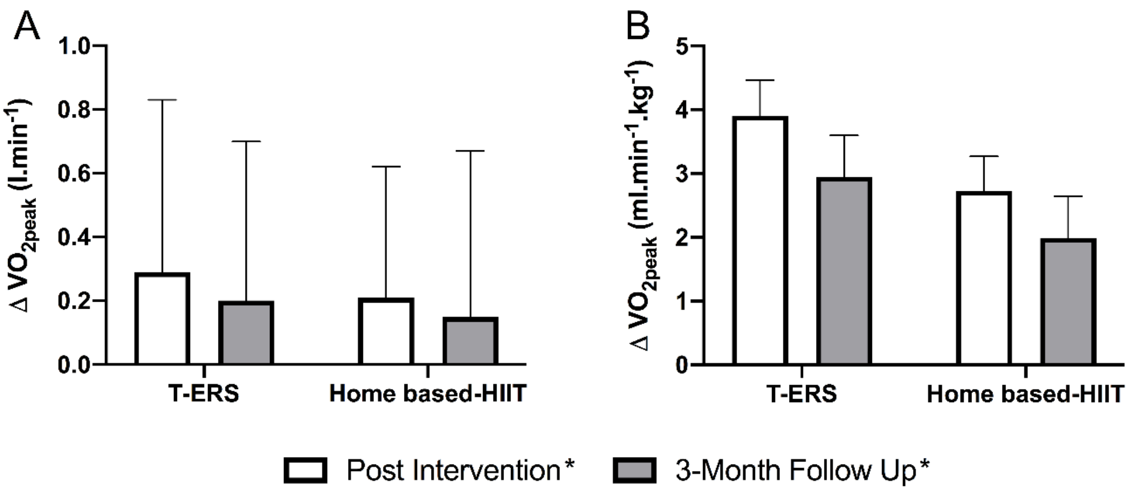

Figure 4.3. Mean change in cardiorespiratory fitness from baseline to post intervention and 3-months follow up in T-ERS and Home-based HIIT groups. *A) absolute change in VO_{2peak}, B) relative change in VO_{2peak}. T-ERS, Exercise Referral Scheme. Home-based HIIT, Home-based high intensity interval training. Data presented as mean + SD. *indicates significance from baseline.*

4.2.4 Body Composition

Compared to baseline there was a significant reduction in body mass and BMI post intervention, however, only T-ERS maintained these reductions at follow-up (see **Table 4.6.).** In addition, post intervention there was a significant between group difference in BMI, and a trend towards a between group difference in body mass (P=0.057), with T-ERS reducing both more than

Home-based HIIT. At follow up there was a significant between group difference for both BMI and body mass.

There were significant reductions in fat mass and muscle mass post intervention in T-ERS only compared to baseline, however, these reductions were not maintained at follow up (See **Table 4.6.**). The differences in fat mass and muscle mass between T-ERS and Home-based HIIT were reflected in significant between group differences post intervention, but not at follow up. There were no significant between or within group differences in body fat percentage observed throughout the study.

4.2.5 Cardiovascular responses

Compared to baseline, there were no significant changes in blood pressure post-intervention, however, at follow-up patients in T-ERS had significantly reduced systolic (P<0.001), diastolic (P=0.049) and mean arterial pressure (P=0.001), with no improvements in Home-based HIIT. There was a significant between group difference in diastolic blood pressure post intervention, with T-ERS significantly lower than Home-based HIIT. No other between group differences in blood pressure (systolic or mean arterial pressure) were observed post intervention. There were significant between-group differences in all measures of blood pressure at follow up, with T-ERS significantly reducing all measures compared to Home-based HIIT. There were no significant between- or within-group differences in pulse wave velocity observed throughout the study.

4.2.6 Glucose tolerance and blood lipids

Fasting plasma glucose and 60- and 120-minute glucose concentrations were not improved at any time point in either group, compared to baseline. There were no significant between-group differences post intervention for any of the glucose measures (0, 60 or 120 minutes during OGTT), however, at follow up there were significant between-group differences for glucose concentrations at 60 and 120 minutes, with T-ERS having lower glucose values compared to Home-based HIIT. There were no significant between- or within-group differences in any blood lipid markers throughout the study.

Table 4.6. Changes to body composition and exercise capacity post intervention and at 3-month follow up.

Variable	Time	T-ERS	*P Value*	Home based-HIIT	*P Value*	Between group differences	*P Value*
Exercise Capacity							
VO_{2peak} (l.min)	Post	0.29 (0.19, 0.39)	*P<0.001**	0.21 (0.12, 0.31)	*P<0.001**	0.07 (-0.07, 0.21)	*P=0.304*
	Follow Up	0.20 (0.09, 0.32)	*P=0.007**	0.15 (0.04, 0.27)	*P=0.047**	0.05 (-0.12, 0.21)	*P=0.573*
VO_{2peak} ($ml.kg^{-1}.min^{-1}$)	Post	3.91 (2.81, 5.00)	*P<0.001**	2.73 (1.67, 3.79)	*P<0.001**	1.18 (-0.35, 2.70)	*P=0.130*
	Follow Up	2.95 (1.67, 4.23)	*P<0.001**	1.99 (0.71, 3.27)	*P=0.015**	0.96 (-0.85, 2.77)	*P=0.298*
Body Composition							
Body Mass (kg)	Post	-1.73 (-2.28, -1.17)	*P<0.001**	-0.97 (-1.52, -0.42)	*P=0.008**	0.76 (-0.02, 1.54)	*P=0.057*
	Follow Up	-1.92 (-2.55, -1.30)	*P<0.001**	-0.38 (-1.04, -0.28)	*P=0.871*	1.54 (0.64, 2.25)	*P=0.001**
BMI ($kg.m^2$)	Post	-0.59 (-0.78, -0.39)	*P<0.001**	-.032 (-0.51, -0.12)	*P=0.013**	0.27 (0.001, 0.54)	*P=0.050**
	Follow Up	-0.65 (-0.87, 0.44)	*P<0.001**	-0.12 (-0.35, 0.11)	*P=0.978*	0.53 (0.22, 0.84)	*P=0.001**
Muscle Mass (kg)	Post	-1.92 (-2.91, -0.93)	*P=0.011**	-0.74 (-1.73, 0.25)	*P=0.712*	1.19 (-0.21, 2.58)	*P=0.096*
	Follow Up	-1.01 (-2.13, 0.11)	*P=0.459*	-0.44 (-1.63, 0.75)	*P=1.000*	0.57 (-1.06, 2.21)	*P=0.490*
Fat Mass (kg)	Post	-1.57 (-2.45, -0.69)	*P=0.010**	-0.19 (-1.07, 0.68)	*P=1.000*	1.37 (0.13, 2.61)	*P=0.030**
	Follow Up	-0.60 (-1.55, 0.43)	*P=0.684*	-0.84 (-1.13, 0.96)	*P=1.000*	0.46 (-0.96, 1.91)	*P=0.516*
VAT Mass (g)	Post	-30.33 (-58.74, -1.91)	*P=0.158*	19.74 (-8.61, 48.10)	*P=0.654*	50.07 (9.92, 90.21)	*P=0.015**
	Follow Up	-26.51 (-58.65, 5.62)	*P=0.340*	29.52 (-4.34, 63.39)	*P=0.342*	56.03 (9.36, 102.71)	*P=0.019**
Body Fat (%)	Post	0.51 (-0.80, 1.8)	*P=1.000*	0.07 (-1.25, 1.38)	*P=1.000*	0.45 (-1.41, 2.30)	*P=0.637*
	Follow Up	0.22 (-1.26, 1.71)	*P=1.000*	0.01 (-1.56, 1.58)	*P=1.000*	0.21 (-1.95, 2.37)	*P=0.846*

*Change compared to baseline and IQR and p-value are presented. * indicates a significant value.*

Table 4.7. Changes to cardiovascular responses, glucose tolerance and blood lipid responses post intervention and at 3-month follow up.

Variable	Time	T-ERS	*P Value*	Home based-HIIT	*P Value*	Between group differences	*P Value*
Cardiovascular Responses							
Systolic Blood Pressure (mmHg)	Post	-1.68 (-3.52, 0.156)	*P=0.570*	-0.57 (-2.40, 1.26)	*P=1.000*	1.11 (-1.49, 3.70)	*P=0.402*
	Follow Up	-5.54 (-7.61, -3.47)	*P<0.001**	0.74 (-1.45, 2.92)	*P=1.000*	6.28 (3.27, 9.29)	*P<0.001**
Diastolic Blood Pressure (mmHg)	Post	-0.63 (-2.26, 1.02)	*P=1.000*	1.68 (0.51, 3.31)	*P=0.351*	2.31 (0.002, 4.62)	*P=0.050**
	Follow Up	-2.89 (-4.74, -1.04)	*P=0.049**	2.44 (0.49, 4.40)	*P=0.127*	5.33 (2.64, 8.03)	*P<0.001**
Mean Arterial Pressure (mmHg)	Post	-0.96 (-2.37, 0.45)	*P=1.000*	0.92 (-0.49, 2.32)	*P=1.000*	1.88 (-0.11, 3.87)	*P=0.064*
	Follow Up	-3.78 (-5.38, -2.19)	*P=0.001**	1.86 (0.18, 3.55)	*P=0.216*	5.65 (3.33, 7.97)	*P<0.001**
Pulse Wave Velocity (m.s)	Post	-0.01 (-0.36, 0.34)	*P=1.000*	-0.11 (-0.45, 0.23)	*P=1.000*	0.10 (-0.38, 0.59)	*P=0.682*
	Follow Up	-0.08 (-0.47, 0.31)	*P=1.000*	0.41 (-0.07, 0.89)	*P=0.386*	0.49 (-0.13, 1.10)	*P=0.120*
Glucose Tolerance							
Fasting Glucose (mmol.L^{-1})	Post	0.03 (-0.14, 021)	*P=1.000*	0.10 (-0.08, 0.27)	*P=1.000*	0.06 (-0.19, 0.31)	*P=0.628*
	Follow Up	-0.04 (-0.25, 0.16)	*P=1.000*	-0.05 (-0.27, 0.17)	*P=1.000*	0.01 (-0.29, 0.31)	*P=0.963*
Glucose at 60 min (mmol.L^{-1})	Post	-0.14 (-0.65, 0.38)	*P=1.000*	-0.20 (-0.70, 0.30)	*P=1.000*	0.07 (-0.65,0.78)	*P=0.856*
	Follow Up	-0.28 (-0.88, 0.33)	*P=1.000*	0.69 (0.07, 1.31)	*P=0.144*	0.96 (-0.10,1.83)	*P=0.029**
Glucose at 120 min (mmol.L^{-1})	Post	-0.17 (-0.56, 0.24)	*P=1.000*	0.06 (-0.34, 0.46)	*P=1.000*	0.23 (-0.35, 0.81)	*P=0.431*
	Follow Up	-0.18 (0.65, 0.29)	*P=1.000*	0.59 (0.10, 1.08)	*P=0.096*	0.77 (0.09, 1.45)	*P=0.026**
Blood Lipids							
Triglycerides (mmol.L^{-1})	Post	-0.10 (-0.23, 0.02)	*P=1.000*	-0.11 (-0.23, 0.02)	*P=0.423*	0.004 (-0.17, 0.18)	*P=0.962*
	Follow Up	-0.18 (-0.32, -0.04)	*P=0.303*	-0.04 (-0.19, 0.11)	*P=1.000*	0.14 (-0.07, 0.35)	*P=0.177*
Cholesterol (mmol.L^{-1})	Post	0.10 (-0.05, 0.26)	*P=0.941*	-0.01 (-0.16, 0.15)	*P=1.000*	0.11 (-0.11, 0.33)	*P=0.339*
	Follow Up	-0.11 (-0.30, 0.07)	*P=0.942*	-0.10 (-0.29, 0.09)	*P=1.000*	0.02 (-0.25, 0.28)	*P=0.909*
HDL-Cholesterol (mmol.L^{-1})	Post	0.03 (-0.02, 0.08)	*P=1.000*	-0.01 (-0.01, 0.04)	*P=1.000*	0.04 (-0.04, 0.10)	*P=0.289*
	Follow Up	-0.01 (-0.07, 0.05)	*P=1.000*	0.04 (-0.02, 0.10)	*P=0.506*	0.05 (-0.03, 0.13)	*P=0.211*
LDL-Cholesterol (mmol.L^{-1})	Post	0.05 (-0.09, 0.18)	*P=1.000*	0.06 (-0.07, 0.20)	*P=1.000*	0.02 (-0.17, 0.21)	*P=0.857*
	Follow Up	-0.03 (-0.19, 0.12)	*P=1.000*	-0.07 (-0.23, 0.09)	*P=1.000*	0.04 (-0.19, 0.26)	*P=0.737*

Change compared to baseline and IQR and p-value are presented.

4.2.7 Participant perception of exercise barriers and motivation to take part in the study

Based on the qualitative survey responses (Total n=79, T-ERS n=34, Home-based HIIT n=45) the main barrier to previous exercise participation in both groups was motivation (n=23). Patients in the Home-based HIIT group frequently mentioned lack of time and work/family life to be significant barriers to exercise participation (see **Table 4.8.**), whereas T-ERS patients commented on a lack of motivation or ill-health. Improved health and fitness was a key motivator behind taking part in the programme, regardless of intervention group. Patients also saw participation in a research study as additional motivation to exercise (n=12).

Reasons for choosing Home-based HIIT stemmed around the convenience or time-saving nature of the programme. Patients also cited reasons such as no means to travel or having the flexibility to complete a HIIT session when the moment presented itself. T-ERS patients mentioned that they were already a member at a gym as a key reason for their choice. Patients also mentioned that they would need an alternative environment than their home for exercise (mostly due to motivation or too many distractions in their home-life).

4.2.8 Participant feelings towards the intervention

Based on the survey responses, three key themes, and further subthemes were developed: 1) *Health*, with two subthemes, i) motivation to start the programme and ii) responses to the programme 2) *Convenience* with two subthemes, i) motivation for intervention choice and ii) adherence throughout the programme and 3) *Motivation*, with three subthemes, i) social support during the programme, ii) personalised health and exercise monitoring and iii) achievement or satisfaction during/following the programme. **Table 4.9** shows the frequency of participants responses to each theme.

4.2.8.1 Theme 1: Health

Nearly all participants mentioned the concept of health. It was noted as a motivator to take part in the programme, continuing with the programme during the intervention period, and as an important concern in their lives as they age.

Motivation to start the programme

Both Home-based HIIT and T-ERS participants were motivated to engage in the programme to achieve health benefits (physical and mental) and both groups felt those benefits, with only a couple of exceptions. The ability to monitor their health and receive feedback throughout the programme was mentioned by nineteen patients.

Responses to the programme

Patients reported positive health changes, in terms of both physical and mental health, following both interventions. Patients from both groups experienced injuries or periods of ill health. These included old injuries or new injuries (sometimes as a result of the exercise) which inhibited participation or forced participants to either miss exercise sessions or change the exercises they were doing. Both groups expressed frustration/annoyance at having to alter or miss sessions because of injury or ill health.

4.2.8.2 Theme 2: Convenience

Phrases related to convenience were mentioned throughout the responses (both positive and negative).

Motivation for intervention choice

For T-ERS, people with existing gym memberships that were not being used found it more convenient to enter the T-ERS programme. For Home-based HIIT it was perceived as convenient to fit around busy work/family commitments, due to the short time commitment and it could be completed at home.

Adherence throughout the programme

Convenience was subsequently a facilitator or barrier for adherence throughout the programme. T-ERS commented on how they enjoyed following a structured programme, including timings and which exercises to complete. Whereas Home-based HIIT patients commented on how they could do the sessions anytime to fit around life commitments. T-ERS participants mentioned having to miss sessions during busy work/life periods. Despite time being cited as a facilitator for some, a number of patients still reported lack of time as a barrier to adherence.

4.2.8.3 Theme 3: Motivation

Both motivation and lack of motivation was discussed by the majority of the participants, regardless of intervention group.

Social support during the programme

Both cohorts mentioned how social support helped them to keep motivated throughout the programme (e.g. friends/family/researchers). Friends and family were particularly important to those doing Home-based HIIT, whereas a ‘gym-buddy’ helped to keep T-ERS participants motivated. Although some patients in both groups reported they did not have any social support during the intervention period, and relied on self-motivation.

Personalised health and exercise monitoring

Monitoring of progression, heart rate monitors, health related results and being part of a wider research study all contributed to motivation. HIIT participants were particularly motivated by the instant feedback of the HR monitors, and T-ERS were motivated by the end results and perception of progression through exercises/fitness. Both groups found connection issues with the HR monitor caused frustration and sometimes demotivation to participate.

Achievement or satisfaction during/following the programme

Finally, having a sense of achievement appeared to be important for continued motivation. Feelings of satisfaction following the end of a Home-based HIIT sessions facilitated motivation for participants. Whereas seeing health and fitness improvements, and increased competence increased motivation for ERS participants. Feeling tired and not having enough time to exercise caused demotivation in both groups.

Table 4.8. Perceived barriers to previous exercise participation, motivation behind participation and motivation for intervention choice.

	Traditional -ERS	Home-based HIIT
Perceived barriers to previous exercise participation	Motivation (11), Physical health (7), Time (4), Work/Family life (4), Cost/accessibility (4), Mental health (2), Perceived exercise as boring (1)	Time (12), Motivation (9), Work/family life (7), Physical health (4), Confidence (3), Knowledge (2), Cost/accessibility (2), Mental health (1), Perceived exercise as boring (1)
	"I'm just not motivated to exercise"	*"Time, two young children and then a busy work life meant the 'luxury' of going for a run/the gym was not very time productive"*
Motivation to participate	Improve health (15), Improve fitness (11), Monitor health (9), For motivation (3), Interested in research (4)	Improve health (22), Improve fitness (16), Monitor health (13), For motivation (9), Interested in research (7)
	"The opportunity to make a positive change in relation to my health and lifestyle"	*"To assist with the study and also gain a greater in depth knowledge of my own health and how exercise can help improve it."*
Motivation for intervention choice	Already a member (9), Alternative environment (6), Use of the equipment (3), Social (2), Advice from staff (1)	Convenience (13) To save time (12), Freedom/flexibility (4), Home-based (4), No travel (3), HIIT (2), Social (1)
	"I felt I would like to use gym equipment and have access to trained staff for help and advice."	*"(I have) previously been a gym member but struggled with consistency of going. Though HIIT at home would be more convenient and easier to stick to"*

Table 4.9. Summary of participant responses in qualitative survey.

Theme	Subtheme	Traditional Exercise Referral Scheme		Home-based HIIT	
		Positive Responses	Negative Responses	Positive Responses	Negative Responses
Health (173)	Motivation to start the programme (89)	Improve health/fitness (28), Monitor Health/Fitness (6)		Improve Health/Fitness (42), Monitor Health/Fitness (13)	
		"Lose weight, improve my fitness, and overall health in the long term"		*"I wanted to gain a greater in depth knowledge of my own health and hope exercise can help improve it"*	
	Response to the programme (84)	Physical health benefits (25), Mental health benefits (5)	Illness or Injury – Missed sessions (4), Needed to adapt exercises because of injury or illness (3)	Physical health benefits (15), Mental health benefits (5)	Illness or Injury – Missed sessions (18), Need to adapt exercises because of injury or illness (9)
		"Made me feel more energetic, younger, less baggage to carry and feel better overall with loads more energy"	*"My swimming pool has been closed for 6 weeks which has affected my ability to exercise when my knee won't let me do load bearing exercises".*	*"I noticed that I was improving my overall stamina and recovering from exercise more quickly."*	*"I was injured near the last few weeks, which was annoying"*
Convenience (93)	Motivation for intervention choice (38)	Already a member of a gym (13)		To fit around busy work/family commitments (25)	
		"I chose the gym as had membership wasn't using it"		*"I work shifts so choose the exercise at home programme to fit them in around work"*	
	Adherence throughout the programme (55)	Structured programme (6)	Missed sessions due to lack of time (10), Waiting for other people on the machines (2).	Quick to complete (11), Home setting (6), Ability to chose exercises (5), Flexibility of time (5)	Lack of time (6), Tired (2), Distractions in the house (2)
		"I liked the structured approach, doing 30 minutes 3 times a week and having a program to follow"	*"It is harder to continue the gym when I work more. Finishing an 8 hour shift would make me want to just go home and not go the gym."*	*"I could tailor the exercises to suit which part of the body I wanted to work on. I enjoyed the versatility and being able to work at my own pace."*	*"Sometimes it was difficult to find time to fit 20 minutes of exercise into a daily routine."*

Motivation (243)	Social Support during the programme(69)	Friends/Family (8), Gym buddy (7), Researcher (5)	No Social Support (11)	Family or Friends (19), Others on the programme (8), Exercise Buddy (2), Researcher (2)	No Social Support (10)
		"Training with a colleague massively helped. More with just getting me to the gym than the actual exercise"		*"My wife, we exercise together; my daughter - watches me and encourages me and occasionally gets involved"*	
	Personalised health and exercise monitoring (59)	Post testing (12), Live feedback (10), Monitored remotely by researcher (1), Session tracking (1)	Connection issues with HR monitor (3), Fell off during swimming (2), Forgot to take HR monitor sometimes (1),	Live feedback (14), Monitored remotely by researcher (4), Session tracking (3), Post testing (2)	Connection issues with HR monitor (6)
		"The assessments (motivated me), as this helped me to measure changes"	*"(Whilst swimming) as you push off from the wall the rush of water can move the HR monitor. So I often had to stop to tighten it"*	*"(The monitor) helps push you because you want to see your heart rate going up into Red zones"*	*"The heart monitor didn't always work well and it took quite a while to connect"*
	Achievement or satisfaction during and following the programme (115)	Health improvements (15), Felt positive during a session (3), Completing a session (3), Reaching target HR (3)	Lack of time (15), Tiredness (4), Not completing 3 sessions per week (4), Slow health improvements (2)	Completing a session (17), Health improvements (14), Reaching target HR (8), Completing target number of sessions (2), increasing intervals (2)	Not completing 3 sessions per week (5), Not enough time (5), Tiredness (5), Lack of motivation (4), Struggled to reach target HR (3), Not able to do the exercises (1)
		"Running for a train and realising that I no longer get out of breath. That motivated me to continue"	*"Sometimes struggle for time to exercise which has frustrated me"*	*"I felt positive and more energetic at the end of each exercise as it made me feel good that I achieved something (when usually sat down or have been eating junk) knowing the outcomes of exercising for my health"*	*"When I feet too tired or busy to undertake a session - I felt guilty"*

4.3 Discussion

This is the first study to examine the effectiveness of incorporating a HIIT intervention within a primary care based ERS. The study illustrates that when compared to a traditional UK based ERS the novel Home-based HIIT programme was chosen by over half of the patients. Furthermore, most patients were able to complete the HIIT sessions as prescribed, with no difference in compliance to traditional ERS prescription. However, adherence to both Home-HIIT and traditional ERS was poor, despite Home-HIIT reducing many of the traditional barriers to exercise. Despite the low adherence patients were able to improve cardiorespiratory fitness and sustain these improvements 3-months after the intervention in both groups. However, neither intervention improved fasting glucose or glucose tolerance, and the traditional ERS was more effective at improving body composition and blood pressure than Home-HIIT. Overall findings suggest that unsupervised home-based HIIT and T-ERS can be completed as prescribed, and can promote long-term improvements in cardiorespiratory fitness. But adherence to ERS, regardless of exercise prescription, needs to be improved.

4.3.1 Free-living adherence and compliance to Home-based HIIT and traditional exercise referral schemes

Very few studies have investigated adherence to HIIT in a free-living environment, and no previous studies have examined adherence to HIIT when incorporated as part of an ERS. The sparsity of real-world data has led public health experts to suggest that HIIT’s reach and adoption by sedentary individuals is likely to be very poor. Like the current study, Roy et al. (2018) used a non-randomised design where overweight/obese individuals self-selected either a 12-month HIIT or moderate intensity continuous training (MICT) intervention. The study demonstrated that 42% of participants chose to complete HIIT over MICT. Similarly, we report more than half of patients referred (55% vs 45%) opted to complete the Home-based HIIT intervention over the traditional gym-based ERS. Interestingly, the Home-based HIIT group had a significantly lower baseline VO_{2peak} than traditional ERS, suggesting that in contrast to the prevailing view individuals with lower fitness were more likely try a Home-based HIIT programme than one based on traditional guidelines using moderate intensity exercise. As hypothesised, the survey responses suggest that Home-based HIIT was attractive to this population due to its time efficiency. The convenience of not having to travel to exercise facilities added to the time efficiency of Home-based HIIT. In addition, patients liked the convenience of carrying out exercise in their own homes, at a time of their choosing in between work/life commitments. Although the demand for Home-based HIIT was greater than the traditional ERS, the number of patients who did not record a training session or stopped training after week 1 was high. This is the first study to assess drop out continually throughout either a HIIT intervention or ERS, and due to the non-randomised design it is difficult to assess if this high initial drop-out was due to the participants selecting HIIT or the demands of HIIT intervention. Interestingly, if initial drop-outs were removed from the analysis, the difference in baseline group size was eliminated and drop-out during the remining period was similar.

It has been suggested that sedentary/non-athletic populations, such as patients on an ERS, would not be able to successfully perform HIIT without supervision (Hardcastle et al., 2014, Ekkekakis et al., 2016). To assess this claim, heart rate monitors were used to evaluate compliance to the prescribed exercise intensity of every session throughout the 3-month intervention period. The per protocol compliance data shows that the majority of participants were able to perform Home-based HIIT at the correct intensity (80% of sessions were completed as prescribed). As such, the current data supports Roy et al. (2018) who also demonstrated previously sedentary overweight/obese individuals were able to perform unsupervised HIIT at an adequate intensity. However, the current study adds important depth to this observation as exercise intensity was recorded during all sessions, rather than a 1-week period every 3-months.

Although compliance to both Home-based HIIT and traditional ERS was high, adherence in both groups was low, 39% and 48%, respectively, and when compliant sessions only were considered this dropped further to 30% and 46%, respectively. Previous studies investigating adherence during free-living exercise interventions have also found adherence to be a challenge (Jung et al., 2020, Roy et al., 2018). Roy et al. (2018) demonstrated that approx. 40% of participants were still engaged in HIIT after 3 months, with adherence dropping to approx. 20% at 12-months, although no comparison was made between traditional exercise prescription and HIIT. Like the current study, Jung et al (2020) showed approx. 35-40% of participants were engaged in the prescribed number of exercise minutes per week (as assessed by accelerometer) at 3-months and 13-20% at 12-months, with no difference between HIIT or MICT groups. Due to the variability within reporting methods for adherence in studies assessing UK based ERS it is difficult to compare with the current work. However, Taylor et al. (1998) showed that the mean attendance rate was approximately 45% during a 10-week gym-based ERS, however patients were only prescribed 2 sessions per week. Taken together this research suggests that it is not only adherence towards HIIT that is low, but adherence towards unsupervised free-living exercise programmes. This conclusion was echoed in our survey responses where barriers such as tiredness, lack of motivation and work/life commitments were cited in both groups.

4.3.2 Changes in cardiorespiratory fitness and cardiometabolic health

Despite low adherence to the scheme, sustained improvements in absolute and relative VO_{2peak} were observed following both Home-based HIIT and traditional ERS, with no difference between the prescriptions. This suggests that both interventions were effective for improving CRF across a 6-month period in patients on an ERS. These findings are supported by Jung et al. (2020) who also demonstrated significant and sustained (12-months) increases in VO_{2peak} in overweight/obese individuals, following a brief evidence-based behaviour change counselling intervention, with no differences between patients randomised to HIIT or MICT prescriptions. Together these studies suggest prescription of free-living exercise in the form of HIIT or traditional MICT can result in a clinically meaningful increase in VO_{2peak}, as previous work has suggested that a 1 $ml.kg^{-1}.min^{-1}$ increase in CRF was associated with a 10% reduction in cardiovascular mortality risk (Kavanagh et al., 2002, Kavanagh et al., 2003) and a 45-day increase in longevity (Clausen et al., 2018). The importance of increasing CRF within the ERS patient population was also highlighted by the survey responses, with a number of patients reporting a desire to “improve fitness” as a key motivation to starting the exercise programme. Furthermore, patients also saw improvements in CRF as a motivator to continue with the programme in the long-term.

In addition to CRF previous studies have demonstrated HIIT to be effective at improving a number of other cardiometabolic risk factors (Batacan et al., 2017). However in the current study, only patients in the traditional ERS group reduced their systolic, diastolic and mean arterial blood pressure at 6-months. In addition, when comparing changes in body composition, a significant decrease in fat mass was only demonstrated following 3-months of traditional ERS, though this reduction in fat mass was not maintained at 6-months. These findings are in contrast to recent meta-analyses of supervised trials that have reported similar, or superior, improvements in blood pressure (Costa et al., 2018) and reductions in fat mass (Viana et al., 2019) following HIIT interventions compared to MICT. A potential reason for the discrepancy is that the low adherence to HIIT resulted in a very low weekly training volume (per protocol weekly training volume approximately 10min). In contrast although adherence was also low in the traditional ERS group patients had a higher weekly training volume (per protocol weekly training volume approximately 50min) which may have been enough to induce changes in these variables. Finally, neither Home-based HIIT or traditional ERS resulted in significant improvements in blood lipids, fasting glucose, or glucose tolerance. Again these findings are in contrast to a recent meta-analysis of supervised trials that reported similar improvements in blood lipids (Wood et al., 2019) following HIIT and MICT, suggesting adherence to both Home-based HIIT and traditional ERS needed to be higher to induce changes in these outcomes.

4.3.3 Strengths and limitations

The decision not to include an untrained control group was informed by the research question, which aimed to investigate the effectiveness of incorporating a Home-based HIIT prescription into a UK ERS. The research question also led to the decision to allow patients to self-allocate intervention groups. Previous reports have questioned the potential attraction of HIIT for sedentary patients (Biddle and Batterham, 2015, Hardcastle et al., 2014), as such, we aimed to investigate patient preference for Home-based HIIT and traditional ERS prescription. Therefore, self-allocation was essential and improved the real-world translation of the findings. Interestingly, our data suggested that initial drop-out was higher in Home-based HIIT than traditional ERS but using the current design it was not possible to assess if this was due to the intervention or differences in the populations at baseline. Although self-selection was essential to answer the research question in the current study, future work should also employ a traditional randomised approach to answer this question.

Patients in both groups were given HR monitors which provided live feedback during the exercise session. In addition, although data from the HR monitors was not used to provide weekly feedback to patients, as has been used in previous studies from our group (Scott et al., 2019a, Scott et al., 2019b) all patients were aware the recordings could be seen by the research team. The provision of HR monitors is not normal within ERS, and data from the survey suggested that patients found the feedback from the monitor an important source of motivation. As such, the provision of HR monitors could have influenced the data, with patients in the Home-based HIIT group in particular noting the feedback the HR monitor provided as a motivator. Although the monitors could have influenced the intervention outcomes there is a need for additional information regarding adherence and compliance during prescribed exercise programmes. HR monitors were chosen as HR is the most personalised objective reflection of the body's response to exercise, regardless of the modality, as it directly parallels metabolic rate (Zisko et al., 2017). Although other technology such as accelerometers would have allowed blinding of participants to the data collected the advantages of HR monitoring outlined above were felt to outweigh this limitation. In addition, the use of HR monitors also enabled data to be collected from all exercise sessions across the 3-month intervention, which has not previously been possible with accelerometers (Jung et al., 2020). New technology has made it possible to use HR monitors blinded, but future studies should investigate patient adherence to such monitors, which need to be worn for each exercise session. Finally, we do not present HR data from the follow-up period. It was our aim to present such data, but adherence to wearing the monitor was low in this period and it was not felt the data was a true reflection of patient adherence to exercise.

4.3.4 Conclusion

This study provides novel evidence that Home-based HIIT was a popular option to patients on an ERS, which patients were able to complete at the prescribed intensity in an unsupervised free-living environment. However, adherence to both Home-based HIIT and traditional ERS prescription was poor. Despite the poor adherence levels, Home-based HIIT and traditional ERS both led to clinically relevant increases in CRF, which were maintained

3-months after participation in the ERS. Although the low adherence did not affect CRF other measures of cardiometabolic health may have been affected, with Home-based HIIT being shown to be less effective than traditional ERS at improving blood pressure or body composition, although improvements in body composition with traditional ERS were not maintained after 3-months. Furthermore, neither intervention improved blood lipids, fasting glucose or glucose tolerance. Together the data suggests that Home-based HIIT is a viable option that should be included within ERS to increase patient choice. However, future studies need to address the poor adherence to ERS, regardless of exercise mode, investigating strategies to improve long term adherence and prevent patient drop-out.

Chapter 5. Are high intensity interval training (HIIT) protocols promoted via social media platforms similar to those used in a research setting: acute physiological and perceptual responses to a single bout of HIIT.

Abstract

Introduction: High intensity interval training (HIIT) has regularly topped the ACSM Worldwide Fitness Trends list since 2014, due in part to promotion by social media influencers and videos available on social media platforms. However, little is known regarding acute physiological and perceptual responses to these online protocols compared to HIIT protocols used within research to date.

Aim: To investigate the acute physiological, perceptual and motivational responses to two HIIT protocols popular on social media, and compare these to two research-based HIIT interventions.

Methods: Twenty-seven recreationally active (>1 hour of structured exercise per week) participants aged 18-35 years, with a BMI <32kg.m^{-2}, completed the study (male/female n=13/14, 22±3 y, 42.2±7.2 ml.min^{-1}.kg^{-1}). A randomised cross-over design was used, whereby each participant completed Ergo-60:60 (cycling 10x60s at 100%W_{max} with 60s rest), BW-60:60 (body-weight exercises 10x60s with 60s rest), SM-20:10 (social media video, 20x20s with 10s rest) and SM-40:20 (social media video, 15x40s with 20s rest) sessions. Lactate, heart rate (HR), rate of perceived exertion (RPE), feeling scale (FS), felt arousal scale (FSA), enjoyment and perceived competence responses were measured to each protocol.

Results: HR and change in lactate were higher in BW-60:60 compared to SM-20:10 (P=0.001). No differences were observed in lowest reported FS between protocols (P=0.292). Throughout the protocol FS decreased linearly in Ergo-60:60 and BW-60:60 (first *vs.* last interval P<0.05), but not in SM-20:10 or SM-

40:20 ($P>0.05$). Enjoyment was higher upon completion of BW-60:60 compared to Ergo-60:60 ($P=0.004$) and SM-40:20 ($P=0.017$).

Conclusions: HIIT protocols using body-weight exercise are a promising additional option to traditional cycling-based HIIT. Furthermore, HIIT protocols available on social media offer an interesting and accessible real-world alternative, which appear to result in less adverse affect during exercise and therefore have the potential to increase long-term adherence.

5.1 Introduction

It is well established that high intensity interval training (HIIT) is an effective time efficient means of training, resulting in equal or superior physiological adaptations to traditional moderate-intensity continuous training (MICT), despite substantially lower training volumes Gibala (2007). Following the positive reporting of this research through established media outlets, HIIT topped the American College of Sports Medicine's (ACSM) Worldwide Fitness Trends list for the first time in 2014, and has remained in the top three since then returning to first place in 2018 (Thompson, 2013, Thompson, 2017, Thompson, 2019). In addition to the promotion of HIIT through the established media, its popularity has grown through endorsements by social media influencers and the availability of fitness videos on media sharing sites. For example, one of the most popular HIIT exercise videos available on YouTube has over 15 million views. These social media influencers provide interesting opportunities to engage with audiences on a personal level, and can assist in the delivery of health improvement interventions (Lutkenhaus et al., 2019). Although social media outlets have helped establish HIIT as a popular training method, there is no research comparing the protocols used in these fitness videos to those within the research.

Recent work has suggested that the acute physiological response to HIIT may influence its long-term effectiveness. Importantly, Fiorenza et al. (2018) demonstrated that metabolic stress is a key mediator of the acute molecular response to HIIT in endurance trained cyclists (Fiorenza et al., 2018). In mice, Hoshino et al. (2015) suggested that repeated lactate accumulation during

HIIT may be associated with training-induced mitochondrial adaptation. Through the pharmacological blunting of lactate accumulation, the metabolic adaptations to HIIT (10x1 min high intensity running with 1 min rest, 3 days/week in week 1 and 5 days/week in weeks 2–4) were attenuated. Furthermore Moholdt et al. (2014), demonstrated that the mean heart rate achieved during HIIT interval is central to long term increases in VO2peak achieved following training, in patients with coronary heart disease. Here following 12-weeks of treadmill training (4x4min at 85-95% HR_{max} with 3 mins rest at 60-70% HR_{max}), increases in VO_{2peak} were significantly higher when exercise was performed at >92% of maximal heart rate (HR_{max}) (+5.2 $ml.kg^{-1}.min^{-1}$) compared to <88% HR_{max} or 88-92% HR_{max} (+3.1 and +3.6 $ml.kg^{-1}.min^{-1}$, respectively).

Although acute physiological responses are an important determinant of long-term adaptation, perceptual responses (positive/negative affect) during exercise and factors related to motivation (enjoyment and perceived competence) during and following exercise also influence the long term effectiveness of a training programme, as these factors can predict exercise adherence (Bauman et al., 2012). As such, assessing the acute psychological responses (i.e. how one is feeling during a HIIT session (affect)) to different HIIT protocols may provide important information regarding future effectiveness. It has been hypothesised that the strenuous nature of HIIT may be a barrier to participation, as individuals are likely to avoid exercise if it is found to be aversive (Hardcastle et al., 2014). This assumption is based upon Dual-mode theory proposed by Ekkekakis (2003), which argues pleasure (affect) experienced during exercise declines when individuals exercise above ventilatory threshold. Therefore, assessing the affective response (feelings of pleasure/ displeasure) to HIIT protocols is important, as negative affect during exercise can act as a deterrent (Garber et al., 2011), while pleasurable experience is a determinant of exercise participation (Williams et al., 2008). In addition, self-determination theory suggests that high levels of perceived competence/self-efficacy (feeling physically capable of executing the exercise) are often combined with positive emotions, which are needed for regular exercise participation (Wienke and Jekauc, 2016). As such, if individuals are unable to demonstrate competence during a HIIT protocol, they are more likely to disengage and not adhere to a programme. Finally, Stork and Martin Ginis (2017) hypothesised that enjoyment predicts attitudes towards HIIT, which in turn mediate future intentions to participate.

Therefore, the aim of this study was to investigate the acute physiological, perceptual and motivational responses to two HIIT protocols popular on social media (SM-20:10, SM-40:20), and compare these to two research based HIIT interventions. Both social media HIIT protocols use simple body weight exercises, therefore, one of the research based intervention comparisons was based on the protocol developed by Scott et al., (2019b), which also uses whole-body exercises and no equipment (BW-60:60). The final research based intervention comparison was based on the laboratory-based protocol developed by Little et al., (2011a) (Ergo-60:60), conducted on a cycle ergometer.

5.2 Methods

5.2.1 Participants

Twenty-seven recreationally active (defined as at least 1 hour of structured exercise per week) participants (male/female: n=13/14, age: 22±3y, height: 1.70±0.09m, weight: 70.4±11.2kg, BMI: 24.3±2.4, VO_{2peak}: 42.2±7.2 $ml.min^{-1}.kg^{-1}$) aged between 18-35 years, with a BMI < $32kg.m^{-2}$, completed the study. Exclusion criteria were those with a known cardiovascular or metabolic disease, pregnant or breastfeeding women, and those currently carrying an injury. The study was approved by the Liverpool John Moores Research Ethics Committee, and all participants gave written informed consent to the protocol which conformed to the Declaration of Helsinki.

5.2.2 Study design

The study used a randomized, counter-balanced crossover design to investigate the four HIIT protocols. Participants attended an initial experimental visit followed by 4 experimental trials to assess the acute physiological and psychological responses to the HIIT protocols. All visits were separated by at least 48 hours.

5.2.3 Initial experimental visit

Prior to the experimental trials participants completed an incremental exercise test to exhaustion on an electronically braked cycle ergometer (Lode Corival, Holland), to determine VO_{2peak}, maximum heart rate and maximal aerobic power output (W_{max}*).* The method is described fully in Chapter 3, but briefly, participants began cycling at 25 W for females and 60 W for males for 3 min;

following this the workload was increased by 35 W every 3 min until volitional fatigue. VO_{2peak} was assessed using an online gas collection system (Metamax 3B, Cortex, Germany) and was defined as the highest value achieved over a 15 second recording period. Heart rate was monitored throughout the test (Polar H10, Kempele, Finland).

5.2.4 Experimental visits

All experimental visits were identical except for the HIIT protocol performed. Prior to exercise a capillary blood sample was obtained from a fingertip for an immediate assessment of blood lactate (Biosen, EKD diagnostics, UK). Participants were introduced to the Feeling Scale (Williams et al., 2008), Felt Arousal Scale (Russell, 1980) and the adapted Borg Rating of Perceived Exertion Scale (0-10) (RPE). Scores on each scale were recorded immediately before and after each interval to indicate responses during the interval and at rest. Before starting the protocols all participants completed a 2-minute warm up; either 25W on a cycle ergometer (Ergo-60:60) or jogging on the spot (BW-60:60, SM-20:10 and SM-40:20). Participants were given no encouragement by the research team during the protocols, but if an exercise was being conducted incorrectly the researcher would advise/demonstrate to ensure consistency and minimise injury risk. Heart rate (HR) was measured continuously throughout the exercise protocols (Polar H10). Following completion of the protocols (within ~1min) a post exercise blood lactate was collected. Finally, participants were asked to complete the Intrinsic Motivation Inventory (IMI) (Ryan, 1982).

5.2.5 Training Protocols

5.2.5.1 Ergometer laboratory based HIIT (Ergo-60:60)

The laboratory-based HIIT protocol was completed on a cycle ergometer (Lode Corival), and consisted of repeated 60 second efforts of high intensity cycling at 100% W_{max} (Little et al., 2010). These intervals were interspersed by 60 seconds of cycling at a low intensity (50 W). Subjects completed ten high-intensity intervals. The total time commitment for the protocol (excluding warm-up) was 20 minutes.

5.2.5.2 Home-based body weight HIIT (BW-60:60)

The established body weight exercise protocol was identical to that used in Ergo-60:60, 10 repeated 60 second bouts of high intensity exercise, interspersed with 60 seconds of rest (Scott et al., 2019b). The 60 second intervals were comprised of two different bodyweight exercises performed for 30 seconds each, with no rest in between. Prior to the protocol participants were given 10 exercise pairs, which were verbally explained and demonstrated by the research team. All participants completed the same exercise pairs, 9 pairs were used with one pair completed twice (see **Table 5.1** and **appendix 1.**). Participants were asked to complete as many repetitions as possible in 60 seconds. The total time commitment for the protocol (excluding warm-up) was 20 minutes.

5.2.5.3 Social Media HIIT 1 (SM-20:10)

Participants followed the YouTube video https://www.youtube.com/watch?v=VhdXXqcoco0. The video was shown on a television screen with the volume on. The protocol consisted of 5 sets of exercise. Each set used a different exercise and was made up of 4x20s intervals, separated by 10 seconds of rest (see **Table 5.1.**). Each set was then separated by 20s of rest. The total time commitment for the protocol (excluding warm-up) was 11.5 minutes.

Table 5.1 Summary of protocols used to measure acute responses to HIIT.

	Number of intervals	Intensity of intervals	Interval duration (seconds)	Rest duration (seconds)	Total duration (minutes)	Exercise
Ergo-60:60	10	100% Wmax	60	60	20	Cycling
BW-60:60	10	As many repetitions as possible	60	60	20	**1)** mountain climbers + lateral jumps **2)** floor jacks + get ups **3)** squat thrusts + elbow to knee **4)** split squats + jogging boxers **5)** burpees + jogging on the spot **6)** jogging with high knees + squat jumps **7)** spotty dogs + X jumps **8)** jump overs + jumping jacks **9)** tuck jumps + clapping jacks **10)** mountain climbers + lateral jumps
SM-20:10	20	Guided by exercise video	20	10 (20s between sets)	11.5	**1)** Broad jumps x2 jumping jacks **2)** pop squats **3)** burpees with a kick **4)** 3 jumps and lunge **5)** squat jump slides
SM-40:20	15	Guided by exercise video	40	20	15	**1)** walkout press-up with shoulder taps **2)** squat with knee to elbow *left* **3)** 8 high knees and burpee **4)** squat with knee to elbow *right* **5)** kick through **6)** knee to elbow plank **7)** 90°squat jump **8)** staggered stance push up *right* **9)** jogging with punches **10)** staggered stance push up *left* **11)** side lunge *right* **12)** bear crawl **13)** side lunge *left* **14)** narrow push up with arm lift **15)** 180∘ burpee

Ergo-60:60 10x60s on a cycle ergometer, with 60s rest. BW-60:60 10x 60s body weight exercises, with 60s rest. SM-20:10 20x 10s with 20s rest, exercises provided from a social media video. SM-40:20 15x 40s with 10s rest, exercises provided from a social media video.

5.2.5.4 Social Media 2 (SM-40:20)

Participants followed the YouTube video https://www.youtube.com/watch?v=yz59KggOtb0. The video was shown on a television screen with the volume on. The protocol involved 15x40s intervals, separated by 20 seconds rest, a different exercise was used for every interval (15 exercises in total, see **Table 5.1.**). The total time commitment for the protocol (excluding warm-up) was 15 minutes.

5.2.6 Assessment of heart rate during exercise

HR was assessed continuously throughout each exercise session (Polar H10). The time of the start and end of each interval were written down and used to mark the start and end of each interval for analysis. Following each exercise session, data was immediately downloaded to excel for offline analysis. Mean HR for the whole session (session HR_{mean}), and the highest HR achieved during each session were determined (session HR_{peak}). Mean and peak HR (HR_{mean} and HR_{peak}) were also determined for every interval. Mean values for each exercise session were then calculated and used to determine the interval HR_{peak} and interval HR_{mean}. The ACSM suggests that HIIT should be performed at a HR above 80% of an individual's HR_{max} (Roy, 2013). As such, we determined the proportion of intervals meeting the high-intensity criterion (HR >80% of max) and time spent above the criterion HR, as suggested by Taylor et al. (2015).

5.2.7 Perceptual responses during exercise

5.2.7.1 Rate of Perceived Exertion

Whole-body rate of perceived exertion was assessed immediately before and after each interval using the adapted Borg RPE (0-10) scale (Borg, 1998). The Borg CR-10 scale was used as ratio scales provide more accurate insights into perceptual processes during exercise than the 6–20 RPE scale (Borg and Kaijser, 2006, Oliveira et al., 2013). The meaning of perceived exertion was explained as ‘the subjective intensity of effort, strain and/or fatigue’ (Robertson and Noble, 1997). A rating of 0 was assigned to the lowest exercise intensity (nothing at all, just noticeable), while a rating for 10 indicated the highest sustainable exercise intensity (maximal).

5.2.7.2 Feeling Scale and Felt Arousal Scale

The Feeling Scale is an 11-point scale ranging from +5 to -5 (Hardy and Rejeski, 1989) and is commonly used to measure affect responses (pleasure/displeasure) during exercise (Williams et al., 2008, Garber et al., 2011). The scale presents the following verbal anchors: -5 = very bad; -3 = bad; -1 = fairly bad; 0 = neutral; +1 fairly good; +3 = good; and +5 = very good. The Felt Arousal Scale measures perceived activation along a 6-point scale ranging from low arousal (1) to high arousal (6). Verbal anchors were provided with high arousal described by states such as excitement, anxiety and anger and low arousal described as states such as relation, calmness and boredom. The participants were asked their score on each of the scales, based on their feelings at the time of completion.

5.2.8 Motivation

5.2.8.1 Intrinsic Motivation Inventory

The Intrinsic Motivation Inventory (IMI) is a multidimensional measurement device, which includes two subscales to assess both interest/enjoyment and perceived competence. Interest/enjoyment and perceived competence are self-report and behavioural measures of intrinsic motivation. All participants were asked to read the phrases in the two subscales (13 in total), and were asked to rate them on a scale from 0 (not true at all) to 7 (very true). The two subscale scores were then calculated by averaging across all the items on the subscale.

5.2.9 Data Analysis

Data is expressed as means ± SD and was analysed using SPSS Version 26.0 (Chicago, IL, USA). Two subjects were not able to finish the Ergo-60:60 protocol due to fatigue, therefore, the data from these participants was removed during analysis (n=25). A repeated measures ANOVA was used to investigate differences between protocols for heart rate responses during exercise, change in lactate, change in RPE, lowest recorded score on the Feeling Scale and responses to the IMI (interest/enjoyment and perceived competence). A one-way ANOVA was also used to assess responses to the Feeling Scale and RPE over time within each HIIT protocol. The data from the Feeling Scale and Felt Arousal Scale were also represented in a circumplex model, which described the affective state with respect to activation (high and low) and valence (positive and negative). A Bonferroni post-hoc test was applied where appropriate. Significance was set at $P \leq 0.05$.

5.3 Results

5.3.1 Physiological responses to exercise

5.3.1.1 Heart Rate

Mean HR traces for each protocol are shown in **Figure 5.1**. There was a significant effect of protocol on interval HR_{peak} (*P*=0.001), with BW-60:60 resulting in a significantly higher interval HR_{peak} than SM-20:10 (*P*=0.002), but no other differences between HIIT protocols (*P*>0.05). Interval HR_{mean} was not different between protocols (*P*=0.202). There was also no difference between HIIT protocols for session HR_{peak} (P=0.353) or session HR_{mean} (*P*=0.734). There was a significant effect of protocol on the proportion of intervals meeting the ACSM high-intensity exercise criterion (HR >80% of predicted max HR) (P=0.008), with the criterion being achieved more regularly during BW-60:60 than SM-20:10 (*P*=0.026), but no further differences observed during Ergo-60:60 or SM-40:20. There was also a significant effect of protocol on time spent above the criterion HR (HR >80% of max) (*P*=0.002), with participants spending significantly less time above 80% of HR_{max} in SM-20:10 than all other protocols (Ergo-60:60: *P*=0.034, BW-60:60: *P*=0.006, SM-40:20: *P*=0.006), but no further differences between protocols. Data is presented in **Table 5.2.**

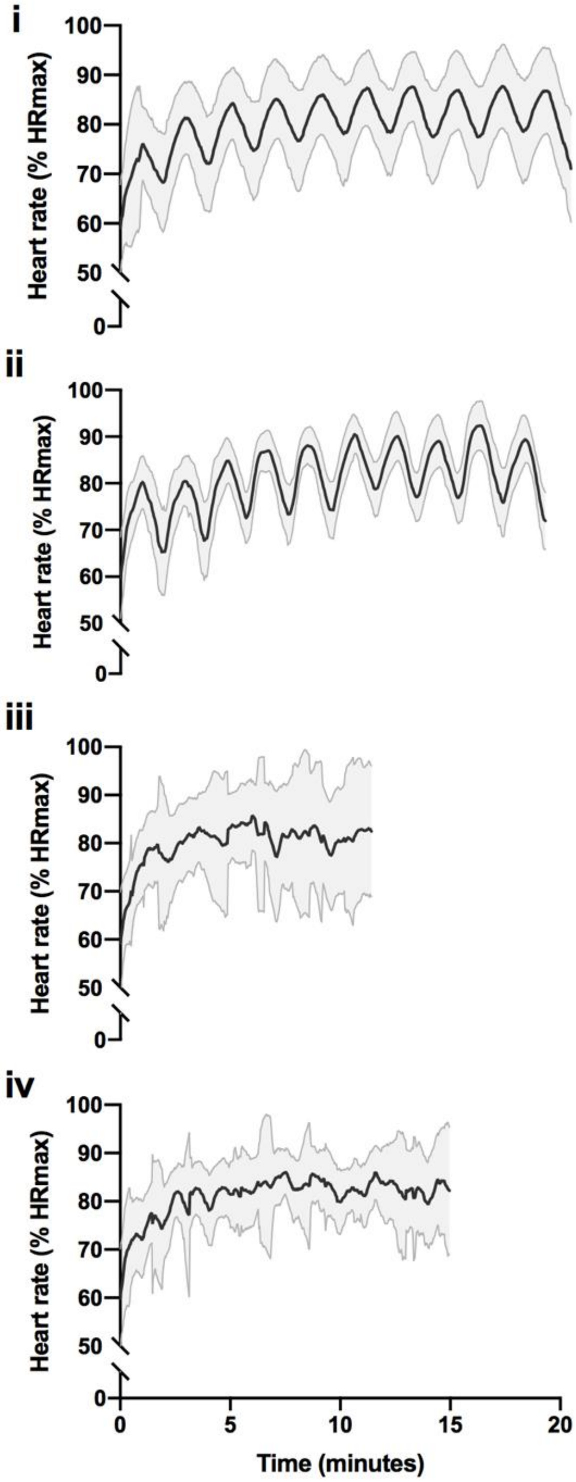

Figure 5.1 Heart rate responses to the protocols. *Mean ± SD heart rate traces during (i) Ergometer-60:60 (Ergo-60:60; 10x1min with 1min recovery on a cycle ergometer), (ii) Body weight-60:60 (BW-60:60; 10x1min with 1min recovery, using whole-body exercises), (iii) Social Media-20:10 (SM-20:10; 5* sets of 4x20s with 10s rest.) and (iv) Social Media-40:20 (SM-40:20; 15x40s interval with 20s rest).

Table 5.2 Heart rate (HR) responses to the HIIT protocols

	Ergo-60:60	BW-60:60	SM-20:10	SM-40:20	P Value
Session HR_{peak} (%)	92.2±5.0	93.1±4.5	91.0±6.2	91.8±4.7	P=0.353
Session HR_{mean} (%)	77.8±3.3	81.1±0.9	80.7±1.9	81.8±1.1	P=0.734
Interval HR_{peak} (%)	86.6±6.2	87.6±3.8*	81.4±6.5	84.3±4.9	P=0.001
Interval HR_{mean} (%)	82.3±6.6	81.4±3.6	78.3±8.2	81.5±5.5	P=0.202
HR ≥80% max (min)	12.5±6.0*	12.8±3.9*	7.4±3.4	11.7±2.4*	P=0.002
Proportion of intervals meeting a HR ≥80% max (%)	78.8±27.5	90.0±10.3*	62.2±32.5	77.1±26.6	P=0.008

*Values are mean ± SD. *Represents significant difference from SM-20:10 (P<0.05). Session HR_{peak}: maximum heart rate achieved during the whole exercise session. Session HR_{mean}: mean heart rate achieved during the whole exercise session. Interval HR_{peak}: average maximum heart rate achieved during each of the intervals only. Interval HR_{mean}: average mean heart rate achieved during each of the intervals only. HR ≥ 80% max: time spent above or equal to the high-intensity criterion (80% of predicted maximum heart rate (220-age)). Proportion of intervals meeting a HR ≥ 80% max, proportion of the intervals meeting the high-intensity criterion (≥80% of maximum heart rate).*

5.3.1.2 Blood Lactate

SM-20:10 resulted in a significantly lower change in blood lactate concentration compared to Ergo-60:60 and BW-60:60 (*P*=0.003 and *P*=0.001 respectively). There were no further differences between protocols (*P*>0.05; **Figure 5.2)**.

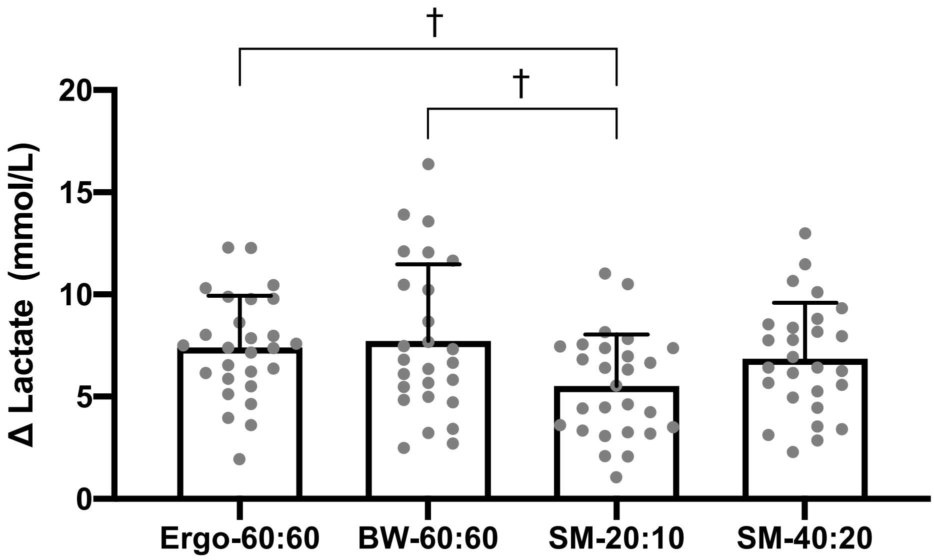

Figure 5.2. *Change in lactate during the HIIT protocols. † Represents significant difference from Social-Media-1 (SM-20:10) (P<0.05).*

5.3.2 Perceptual responses during exercise

5.3.2.1 RPE

There was a significant effect of protocol on change in RPE (*P*=0.001). Change in RPE was lower during SM-20:10 than all other protocols (Ergo-60:60 *P*=0.001, BW-60:60: *P*=0.041, SM-40:20: p<0.001; **Figure 5.3A**). Change in RPE was also lower during BW-60:60 than Ergo-60:60 (*P*=0.008) and SM-40:20 (*P*=0.021). Detailed information regarding RPE over time for each protocol is presented in **Figure 5.3B**, importantly the markings on the figures represent occasions where the change in RPE was *not significantly* different compared to the following interval. RPE immediately before the interval is also presented in **Figure 5.3B**. Generally, RPE increased in a linear fashion between interval 1 and 6 in Ergo-60:60 and BW-60:60, although this pattern was more disrupted in BW-60:60 (**Figure 5.3Bi and 5.3Bii**). Such a linear relationship was not seen in SM-20:10 and SM-40:20, with large variations apparent (**Figure 5.3Biii and 5.3Biv**).

5.3.2.2 Feeling Scale

The minimum reported Feeling Scale score was similar across all protocols (*P*=0.292; **Figure 5.4A**). Detailed information regarding Feeling Scale scores over time for each protocol is presented in **Figure 5.4B**, importantly markings on the figure represent ***significant*** changes compared to the following intervals. Feeling Scale scores immediately before the interval are also presented in **Figure 5.4B**. The Feeling Scale scores decreased in a linear manner after interval 5 during Ergo-60:60 and interval 6 during BW-60:60 (**Figure 5.4Bi** and **5.4Bii**. The response to SM-20:10 and SM-40:20 was more complex with large variations present (**Figure 5.4Biii** and **5.4Biv**).

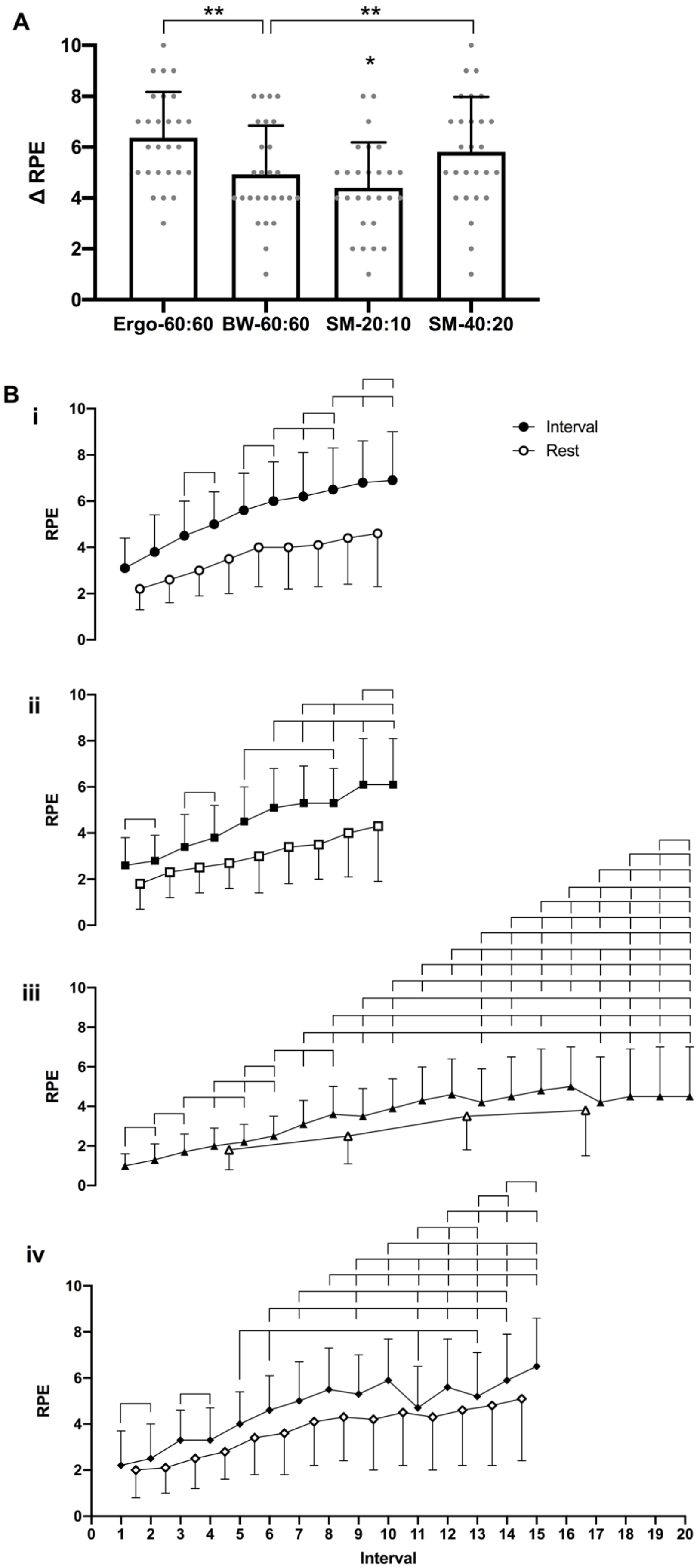
A
**
**
*
Δ RPE
10
8
6
4
2
0
Ergo-60:60
BW-60:60
SM-20:10
SM-40:20
B
i
ii
iii
iv
Interval
Rest
RPE
Interval

Figure 5.3. Rate of perceived exertion (RPE) responses to the protocols. *A. Change in RPE over the duration of the four protocols. B. RPE over time during (i) Ergometer-60:60 (Ergo-60:60), (ii) Body weight-60:60(BW-60:60), (iii) Social Media-20:10 -1 (SM-20:10) and (iv) Social Media-40:20 (SM-40:20). Closed icons represent RPE recorded at the end of each interval, open icons represent RPE recorded at the end of the rest period. *represents significant difference from all other protocols (P<0.05). **represents significant difference from BW-60:60 (P<0.05). To simplify the figure the markings in Figure 3B, represent non-significant differences in RPE immediately after the interval compared to the following intervals (P>0.05).*

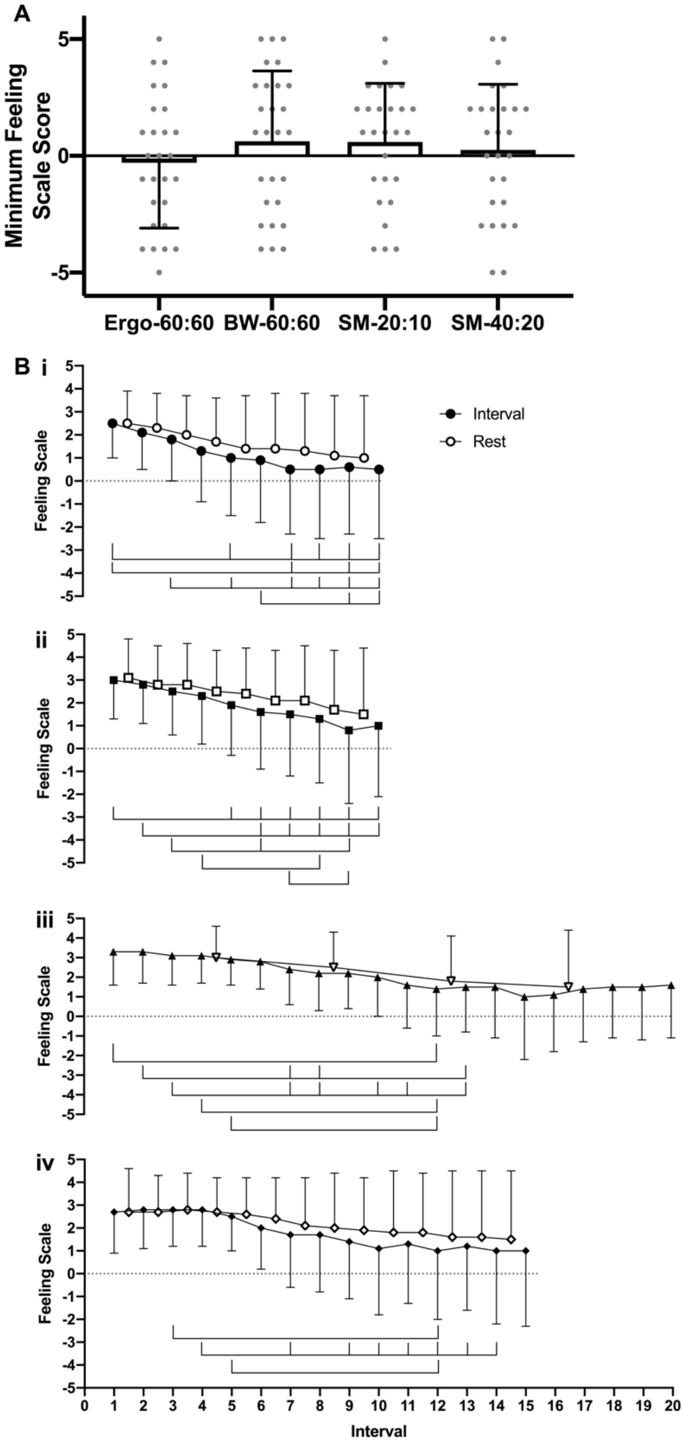

Figure 5.4. Feeling scale (FS) responses to the protocols. A. *Minimum recorded Feeling Scale score* ***B.*** *Feeling Score over time during (i) Ergo-60:60, (ii) BW-60:60, (iii) SM-20:10 and (iv) SM-40:20. Closed icons represent FS recorded at the end of each interval, open icons represent FS recorded at the end of the rest period. The markings above Figure 4B represent significance differences in Feeling Scale score immediately after the interval compared to the following intervals (P<0.05)*

5.3.2.3 Circumplex Model

In order to investigate the nature and the magnitude of affect changes that occur in response to acute exercise stimuli a circumplex model was used. In a circumplex model of affect the horizontal axis represents affective valence (negative to positive) and the vertical axis represents the degree of perceived activation (low to high). Based on visual inspection, the patterning of Feeling Scale and Felt Arousal Scale values between Ergo-60:60 and BW-60:60 was similar within the circumplex model depicted in **Figure 5.5A and B**. During Ergo-60:60 and BW-60:60 the Feeling Scale shifted left toward greater displeasure after each interval, and Felt Arousal Scale shifted up towards a high arousal during the protocols, but only reached the 'energy' quadrant after the 9th interval. SM-20:10 and SM-40:20 initially followed this pattern, however past interval 11 in SM-20:10 and the 9th interval in SM-40:20 the results fluctuate (**Figure 5.5C and D**). Unlike all other protocols, SM-20:10 remains in the 'calmness' quadrant throughout the session.

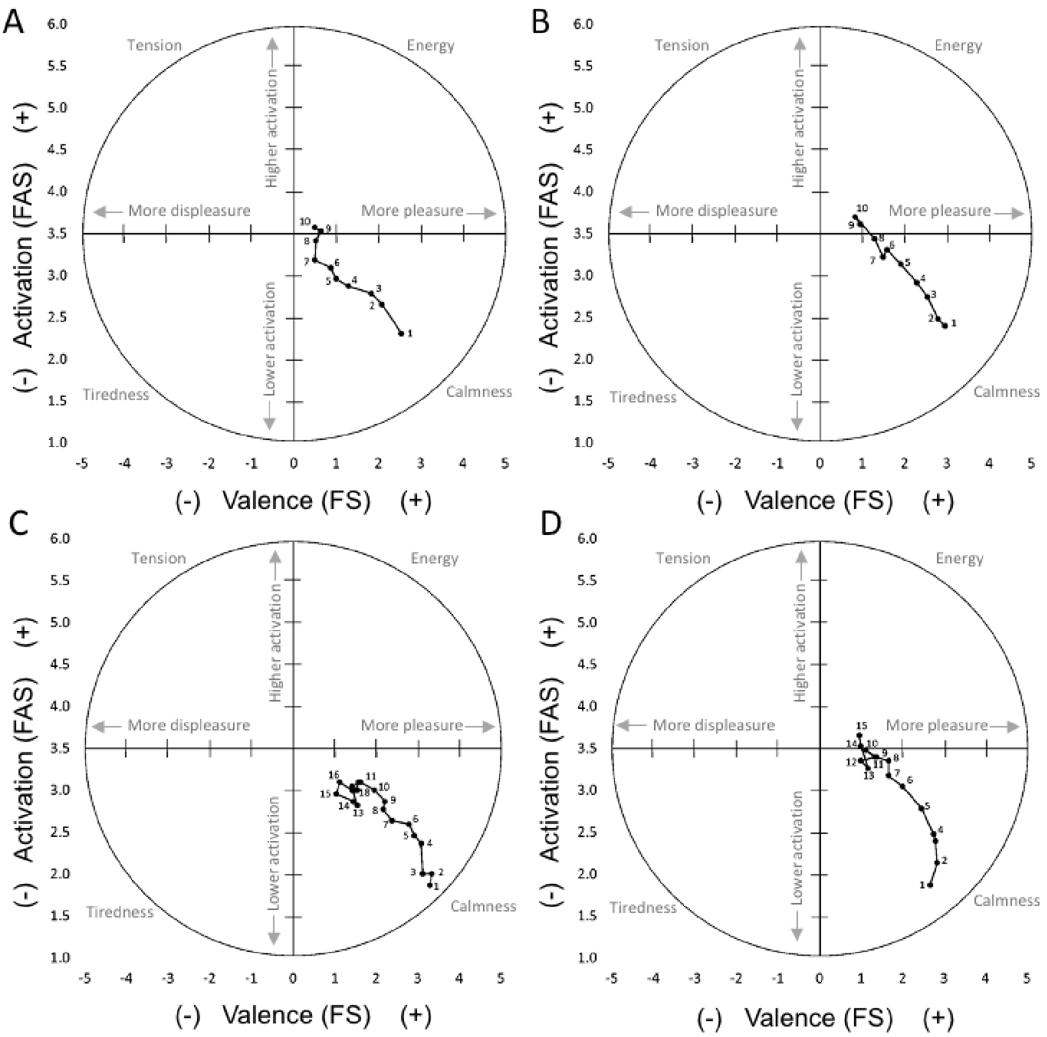

***Figure 5.5. Circumplex model to representing Feeling Scale (FS) and Felt Arousal Scale (FAS) responses to the protocols. A**. Ergo-60:60 **B.** BW-60:60 **C.** SM-20:10 **D.** SM-40:20. Values on the line represent the interval number when measurement was taken.*

5.3.3 Motivational responses to exercise

5.3.3.1 Intrinsic Motivation Inventory

BW-60:60 reported significantly higher scores on the interest/enjoyment subscale compared to Ergo-60:60 (*P*=0.004) and SM-40:20 (*P*=0.017), with no other significant differences between the protocols (*P*>0.05; **Figure 5.6A**). BW-60:60 and SM-20:10 reported significantly higher scores on the perceived competence subscale compared to SM-40:20 (*P*=0.005 and *P*=0.001

respectively), with no other significant differences between the protocols (*P*>0.05; **Figure 5.6B)**.

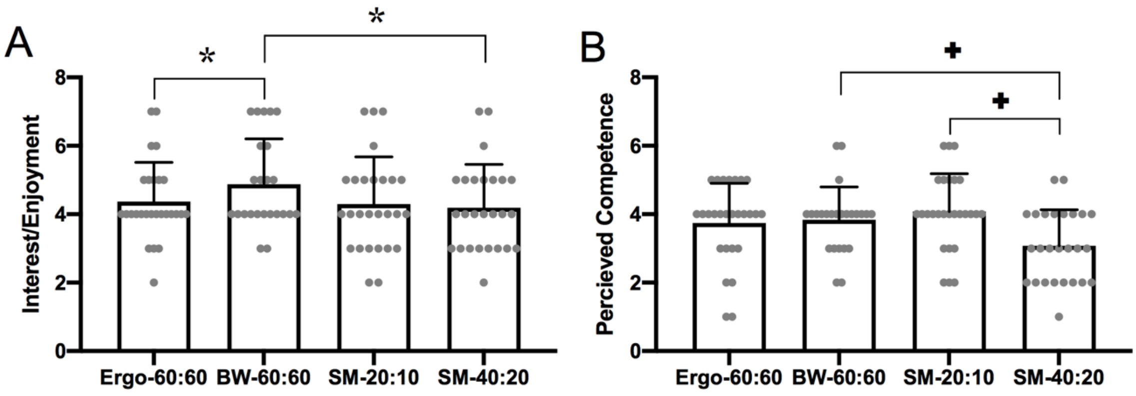

Figure 5.6. Intrinsic motivation inventory responses to the HIIT protocols. ** represents significant difference from BW-60:60 (P<0.05). + represent significant difference to SM-40:20 (P<0.05).*

5.4 Discussion

The main finding of the present study is that important acute physiological, perceptual and motivational differences exist between HIIT protocols developed for social media platforms and those shown to be effective in academic literature. In addition, our data suggests higher physiological responses experienced during HIIT are not a key determinant of post-exercise enjoyment or feelings of competence. Finally, in contrast to traditional HIIT protocols performed on a cycle ergometer, protocols performed using body-weight exercises result in more complex perceptual responses during exercise, which do not correlate with HR responses. Therefore, application of traditional models (e.g. Dual-theory) may not be appropriate to describe the perceptual responses to body-weight HIIT. Future research should seek to investigate the physiological and perceptual responses to exercise throughout a body-weight HIIT intervention to determine long-term feasibility and effectiveness within a real world setting.

5.4.1 Physiological Responses to Exercise

This is the first study to compare the physiological responses to popular HIIT workouts found on social media with established research based protocols (Scott et al., 2019b, Little et al., 2010). Social media workouts are an attractive and popular alternative to traditional forms of HIIT, SM-20:10 and SM-40:20 have over 6 million views on YouTube, but research into their effectiveness is lacking. Recent work (Moholdt et al., 2014, Fiorenza et al., 2018, Hoshino et al., 2015) suggests that acute physiological responses may dictate long-term training outcomes to HIIT. Therefore, a comparison of these social media protocols to those already established as effective in a research setting provides important information for consumers and fitness professionals.

Interestingly, similar heart rate and blood lactate responses were seen when comparing the two established protocols (Ergo-60:60 and BW-60:60), despite the different modalities of exercise (cycle ergometer vs body-weight). Furthermore, despite considerable differences in the mean HR traces (Figure 2) there were no acute physiological differences between the established protocols and SM-40:20. In contrast a number of significant differences were observed between SM-20:10 and the established protocols. Moholdt et al. (2014) reported greater increases in VO_{2peak} in patients who achieved a higher HR_{mean} during HIIT intervals (12 weeks, 4x4min at 85-95% HRmax with 3 mins rest at 60-70% HRmax), in patients with coronary heart disease. In addition, recent studies have suggested that lactate accumulation during HIIT is linked to the magnitude of the physiological adaptations. Hoshino et al. (2015) administered mice with dichloroacetate (DCA), a pyruvate dehydrogenase activator which reduces muscle and blood lactate concentrations during and after exercise, over a 4 week HIIT training period (10x60s high intensity treadmill running with a 1 min rest). Chronic DCA administration attenuated exercise-induced metabolic adaptations, including increases in mitochondrial enzyme activity (CS and b-HAD) and protein content (COXIV) compared to control animals (saline), suggesting that repeated lactate accumulation during HIIT is important for training–induced mitochondrial adaptations. Furthermore, Fiorenza et al. (2018) found that speed endurance exercise (18x5s “all-out” efforts interspersed with 30s of passive recovery) increased PGC-1α mRNA response compared to work matched repeated-sprint exercise (6x20 s “all-out” with 120 s of passive recovery). Importantly, speed endurance exercise was associated with higher muscle lactate accumulation and lower muscle pH, suggesting that that greater metabolic perturbations with high lactate accumulation contributed to the enhanced PGC-1α mRNA response. As such, it is hypothesised that the lower time spent above the criterion HR (>80% of max) and change in lactate observed with SM-20:10 compared to the other protocols will reduce its long-term effectiveness. However, the data would suggest that body-weight exercises can be used as an effective HIIT modality, capable of eliciting similar acute physiological responses to HIIT performed on a laboratory ergometer. Furthermore, protocols available via social media platforms can mimic acute physiological responses, but fitness professionals need to proceed with caution when prescribing these protocols as they are not all equal. Interestingly, the lower lactate responses observed following SM-20:10 may have been due to the reduced interval duration as previous research in regional-level cyclists reported higher blood lactate responses after longer intervals (90s and 130s) compared to shorter 10s interval (Warr-di Piero et al., 2018).

5.4.2 Perceptual Responses to Exercise

Dual-Mode theory suggests affect experienced during exercise is influenced, in part, by the metabolic demand associated with the exercise (Ekkekakis, 2003). However, in the current study the lowest recorded value on the feeling scale was not different between the protocols, despite significant differences in the physiological responses. This data contrasts with previous comparisons of HIIT protocols where findings have shown greater physiological strain is associated with lower affective responses (Boyd et al., 2013, Kilpatrick et al., 2015), supporting the application of Dual-Mode theory for HIIT. Although the exercise intensity was different between HIIT protocols the same interval duration and work-to-rest ratios were employed in these earlier studies (Boyd et al., 2013, Kilpatrick et al., 2015). This contrasts with the current study where work-to-rest ratio and interval duration were different between the protocols. The potential importance of interval duration and work-to-rest ratio in determining affective response to HIIT is supported by recent research (Wood et al., 2016, Martinez et al., 2015). Martinez et al. (2015) demonstrated that shorter intervals (30 and 60 seconds) had similar affective responses, but longer intervals were perceived as more aversive (120 seconds). Wood et al. (2016), showed no difference in affect when comparing a HIIT and SIT protocol, despite significantly greater lactate accumulation experienced during SIT. Importantly, the work-to-rest ratio and interval duration used in the HIIT and SIT protocols were again different (60 second intervals and a 1:1 work-rest-ratio in HIIT; and 30 second intervals and a 1:3 work-to-rest ratio in SIT). Together these studies may suggest that work-to-rest ratio and interval duration could influence affective response to HIIT, and that manipulating these factors could interfere with the utility of Dual-Mode theory for HIIT.

As well as the magnitude of the peak negative or positive affect, Decker and Ekkekakis (2017) suggests that the rate of change in affect occurring during the exercise is also important. Previous studies employing cycling (Wood et al., 2016, Astorino et al., 2016, Tucker et al., 2015, Jung et al., 2014) or running (Frazão et al., 2016, Oliveira et al., 2013) have consistently reported that affect becomes less positive during exercise in response to acute HIIT. This finding was echoed in a scoping review of the literature by Stork et al. (2017), who noted that nearly all of the studies assessing in-task affect have shown a significant decline during HIIT. This profile is shown in both Ergo-60:60 and BW-60:60, where in-task affect shows a significant decline from interval 5 onwards. In contrast, SM-20:10 and SM-40:20 do not show a significant fall in affect from the first to last interval and changes in affect show no obvious pattern. The circumplex model, which incorporates affective valence and perceived activation to give a more complete view of affective responses during exercise (Ekkekakis, 2008), also highlights the difference in affect responses when using the two social media videos. It is unclear what is causing this difference between the protocols, however the social connection within social media HIIT (e.g. led by an influencer) may have altered the enjoyment or perception of the unpleasant exercise (Kinnafick et al., 2018). Therefore, future studies should look to investigate the influence of exercise videos, interval duration work-to-rest ratio and the use of body-weight exercises on in-task affect.

5.4.3 Motivation

This is the first study to compare post-exercise enjoyment of HIIT protocols employing different exercise modalities. In their scoping review Stork et al. (2017) cautioned that people's experiences during one form of interval exercise may not be the same as another. Our data provides novel evidence supporting this argument, identifying that participants reported greater enjoyment when HIIT was performed using body-weight exercises (BW-60:60) compared to a cycle ergometer (Ergo-60:60). Importantly, BW-60:60 and Ergo-60:60 (matched for interval duration and work-to-rest ratio) produced similar heart rate traces and overall physiological responses, suggesting that the exercise mode could be an important factor in the differential enjoyment. Interestingly, BW-60:60 was also more enjoyable than SM-40:20, despite body-weight exercises being employed during both protocols. The greater enjoyment experienced could have been influenced by the lower confidence for completing SM:40:20 compared to BW-60:60. It is possible that the specific exercises employed during BW-60:60 and SM-20:10 were responsible for the greater perceived competence following these protocols compared to SM-40:20. Unlike BW-60:60 and SM-20:10 which used entirely whole-body exercise, SM-40:20 employed a combination of whole-body and upper body exercise. This observation may prove important to exercise professionals when designing HIIT protocols, as people are inherently drawn to engage in behaviours that they feel confident to carry out (McAuley, 1998).

5.4.4 Limitations

It is important to note that the current study was conducted in recreationally active participants. As such, we are unable to generalise our findings to sedentary individuals. However, the work still represents an important step forward in our understanding of HIIT, as it is the first study to explore the differences between established research protocols and workouts with millions of views on social media. Given the importance of social influencers for impacting health (Lutkenhaus et al., 2019) and the popularity of HIIT on social media it is important that future research continues to consider the potential effects of such protocols.

5.4.5 Conclusion

Overall this study provides preliminary evidence that that HIIT protocols employing body-weight exercises are a promising additional option to traditional cycling-based HIIT. In addition, the data suggests that HIIT protocols available on social media offer an interesting real-world alternative for promoting exercise participation. As such, this study highlights the potential utility of body-weight HIIT and social media videos for use by the general public, and we encourage future studies to continue to look at these highly popular and practical HIIT protocols, investigating a range of physiological and psychological responses to fully understand their potential impact.

Chapter 6. General Discussion

Recent figures suggest that physical inactivity is one of the leading risk factors for global mortality and leads to more than 5 million premature deaths worldwide (World Health Organization, 2011; Lee et al., 2012). The cost of prevention and treatment of chronic diseases resulting from inactivity in the UK has been estimated at a staggering £8.2 billion per year (both direct treatment and indirect costs e.g. sickness absence), placing an enormous financial burden on the economy (Allender et al., 2007). As such, current public health guidelines suggest adults should engage in a minimum of 150 minutes of moderate intensity physical activity (PA) per week to maintain cardiorespiratory fitness and improve health outcomes (World Health Organization, 2011). In line with PA guidelines, prescription of moderate intensity continuous training (MICT) is an important first line strategy for the management of non-communicable diseases (NCD) (Ismail et al., 2013). However, despite overwhelming evidence showing improved health outcomes with physical activity (Warburton et al., 2006), 25% of adults (globally) are not sufficiently active to prevent disease (World Health Organization, 2011).

A number of perceived barriers to physical activity participation have been cited, such as limited access to facilities, lack of appropriate equipment, difficulties with transportation or limited financial resources (Korkiakangas et al. 2009). One of the most commonly cited barriers to physical activity engagement for both men and women is a “lack of time” (Trost et al., 2002). High intensity interval training (HIIT) has recently been suggested as an alternative to MICT to overcome ‘lack of time’ as a barrier and improve health (Gibala, 2007).

HIIT refers to as vigorous exercise performed at a high intensity for a brief period of time interposed with period of rest or recovery. There are several variable components that contribute to a HIIT session (e.g. interval and rest modality, duration and intensity). Due to this variability, a number of HIIT protocols which aim to tackle 'lack of time' as a barrier have been developed. Clear improvements in cardiometabolic risk factors have been observed using a variety of laboratory-based HIIT programmes (Cassidy et al., 2017, Costa et al., 2018, Gibala and McGee, 2008, Gist et al., 2014, Jelleyman et al., 2015, Weston et al., 2014). However, two key questions surface as a result of these laboratory studies;

i) Which of these protocols should we prescribe to the general public to improve health?

ii) Can these protocols successfully be carried out in a real-world environment without the supervision of researchers?

The applicability and feasibility of some of these laboratory based HIIT protocols, have been questioned by public health researchers (Hardcastle et al., 2014, Biddle and Batterham, 2015), who cite the strenuous nature and complex protocols used in HIIT as major barriers to sedentary or exercise-naïve individuals. Therefore, despite research suggesting HIIT is a time-efficient exercise strategy to improve health, the real-world application of HIIT is yet to be confirmed.

The overall aim of this thesis was to provide evidence for the application of HIIT in a real-world environment in a sedentary or at-risk population, to improve health and reduce the risk of non-communicable disease. To achieve this aim three studies were conducted to investigate the effect of different HIIT protocols and modalities in a ‘real world’ setting. Chapter 3 aimed to examine how two different HIIT protocols (commonly used within research to improve health), were carried out when self-paced on a commercially available gym bike without encouragement from the researchers. This chapter also aimed to further develop the prescription of HIIT in a real world environment by assessing the impact of interval intensity on health outcomes in a sedentary population. The purpose of Chapter 4 was to assess the use of home-based HIIT in the real-world, by incorporating a home-based HIIT programme into a 12-week UK exercise referral scheme. Using one of the largest trials in the field (n=154), we assessed aerobic capacity, CVD risk factors and body composition pre-, post-, and 3 months post- intervention. Additionally, this was the first study to evaluate an ERS or a home-based HIIT programme using a qualitive survey. Finally, Chapter 5 examined the acute physiological and perceptual responses, and motivation factors, towards established evidence-based HIIT protocols (in the form of ergometer cycling and whole-body exercises), as well as two HIIT protocols from social media videos using whole-body exercises.

6.1 Mechanisms and adaptations following HIIT

Throughout the literature, and within this thesis, HIIT has proved successful at inducing the typical adaptations that are normally associated with high-volume endurance training, despite a considerable reduction in total training volume. Previous literature suggests that exercise intensity is a key factor influencing peroxisome-proliferator activated receptor γ coactivator (PGC)-1α (Egan and

Zierath, 2013), the master regulator of mitochondrial biogenesis in muscle (Wu et al., 2002). Acute low-volume Wingate-based HIIT has been shown to cause similar increases in PGC-1α mRNA to that seen following a continuous bout of endurance-type exercise (Egan et al., 2010). Similar to endurance training (Wright et al., 2007, Little et al., 2011b), acute Wingate-based HIT may activate PGC-1α by increasing its nuclear translocation (Little et al., 2011b), which coincides with increased mRNA expression of several mitochondrial genes (Little et al., 2011b).

It is not fully understood what actives PGC-1α and mitochondrial biogenesis in response to low-volume HIIT, although it seems to be the high level of muscle fibre recruitment and cellular stress, particularly in type II fibres ((Godin et al., 2010)). As such the upstream signals activating PGC-1α probably relate to changes in intramuscular ATP:ADP/AMP ratio following exercise (Chen et al., 2000), and other metabolic stressors such as calcium concentration, reactive oxygen species, glycogen depletion, lactate production (Holloszy, 2008). These changes to the cell, as a result of intense exercise, activate a variety of intracellular signalling protein kinases, such as 5'-adenosine monophosphate-activated protein kinase (AMPK), p38 mitogen-activated protein kinase (MAPK) and Ca2+/calmodulin-dependent protein kinase (CaMK). Following a period of low-volume HIIT these signalling cascades can lead to alterations in PGC-1α gene expression, via elevated levels of PGC-1 protein. Six-weeks of Winagte-based HIIT increased the protein content of PGC-1 by ~100% in young, healthy individuals (Burgomaster et al., 2008) and 2 weeks of 10 x 1min HIIT results in a ~25% increase in nuclear PGC-1 protein (Little et al., 2010). Given the positive effects that a modest increase in muscle

PGC-1 α appears to have on oxidative capacity, anti-oxidant defence and glucose uptake (Sandri et al., 2006, Benton et al., 2008, Wenz et al., 2009), the increase in PGC-1α following low-volume HIIT may highlight potential widespread health benefits for this type of exercise.

6.1 Real-world HIIT – the effect on cardiometabolic health

Chapter 3 examined whether six-weeks of self-paced HIIT could improve markers of cardiometabolic health, including cardiorespiratory fitness, glucose tolerance during an OGTT, body composition and arterial stiffness. During this intervention, participants were only provided with a heart rate (HR) monitor and a target HR (>80%HRmax). Sessions were self-paced and completed on a cycle ergometer found in most gym facilities which uses a combination of air and magnetic resistance. No encouragement or further guidance was provided by the researchers throughout the intervention, thereby providing a simulated real-world gym environment for the participants. The findings from this chapter show that, even without a controlled laboratory environment, 6-weeks HIIT training can lead to significant improvements in cardiorespiratory fitness, body fat percentage, aortic pulse wave velocity and glucose tolerance. These improvements in cardiometabolic health risk factors were similar between the two HIIT protocols (30HIT: 4-8x30s with 2mins rest and 60HIT: 6-10x60s with 60s rest), suggesting either could be completed in a gym environment to obtain health benefits.

Chapter 3 was conducted in a simulated gym environment. Commonly, commercial gyms are associated with additional barriers to exercise participation such as the dislike of the gym environment, lack of access to facilities, and the cost of membership (Morgan et al., 2016). In order to bridge the gap between the findings of laboratory based studies and development of future public health policy, previous research has called for interventions that are low cost, easily accessible and effective at improving health in the real-world (Gray et al., 2016). In Chapter 4 we therefore used an equipment-free whole-body HIIT protocol which could be completed at a location of the participants' choosing (e.g. the home or local community centre). When included within an exercise referral scheme, this home-based HIIT protocol improved cardiorespiratory fitness by ~3 $ml.min^{-1}.kg^{-1}$ after 12-weeks, and this increase was maintained at 3-months follow up. This improvement in cardiorespiratory fitness (CRF) is clinically significant given that every $1ml.kg^{-1}.min^{-1}$ improvement in VO_{2peak} is associated with a 10% reduction in cardiovascular mortality risk in men and women (Kavanagh et al., 2002, Kavanagh et al., 2003). Interestingly, this increase in CRF was similar to 12-weeks of gym-based exercise referral care, supporting the use of HIIT in a real-world exercise prescription setting. In Chapter 4 we also presented fasting blood lipid profiles, glucose tolerance and body composition assessed via DXA. This comprehensive approach provided a full physiological assessment of a home-based HIIT programme when included as an alternative option in an ERS. Despite previous lab-based research showing HIIT is just as, if not more, successful at improving these health outcomes compared to MICT (Cassidy et al., 2017, Costa et al., 2018, Gibala and McGee, 2008, Gist et al., 2014, Jelleyman et al., 2015, Weston et al., 2014), after 12-weeks, the ERS group had additional health improvements such as decreases in blood pressure and body composition, compared to the Home-based HIIT group. To date, this is the only study to include home-based HIIT within a real-world exercise prescription setting, and adherence to both exercise interventions were relatively low. If the aim of exercise prescription is to reduce health risk factors, higher adherence may be needed than observed in Chapter 4.

6.2 Prescription of HIIT in the real world – Adherence and compliance

Previous research using supervised HIIT interventions have reported similar health improvements compared to MICT in healthy populations (Milanović et al., 2015, Bacon et al., 2013), and superior improvements in CRF in patients with lifestyle-induced cardiometabolic disease (Weston et al., 2014, Ramos et al., 2015, Wisloff et al., 2007). However, questions have been raised regarding the feasibility of HIIT in a public health setting (Hardcastle et al., 2014, Biddle and Batterham, 2015). Specifically, whether a sedentary, at-risk population can perform HIIT to the correct intensity outside of a laboratory environment without encouragement and supervision. Although the efficacy of HIIT for improving health is well evidenced (Gibala, 2007)) there is a clear need to demonstrate application of HIIT in free-living environments, particular in those at risk of developing or with chronic diseases.

In Chapter 3, we sought to investigate how sedentary participants approached two evidence-based HIIT protocols (Burgomaster et al., 2005, Little et al., 2010) in a self-paced manner and without encouragement from the research team, using readily available gym-bikes. This study found the majority of previously sedentary participants were capable of achieving an average interval peak HR >80%HRmax over a 6-week intervention, irrespective of the protocol used (30HIT or 60HIT). Furthermore, when body-weight HIIT was carried out in the home environment for 12-weeks, data from Chapter 4 reveals high compliance (achieving target HR and number of intervals during training) rates during HIIT (82±3%), similar to that seen in the ERS group (88±23%). This provides support for the work of Roy et al (2018), who also monitored compliance with prescribed intensity during HIIT in a free-living environment, and found participants to be capable of achieving HRs >80% HR max. Moreover, Chapter 4 found that patients who chose to complete the Home-HIIT intervention had a lower baseline cardiorespiratory fitness level than those in the ERS group. Taken together these results provide strong evidence that sedentary participants are able to perform HIIT successfully outside of the controlled laboratory environment, and (as a result of its convenience) Home-HIIT could be the preferred option for an unfit population.

From these studies, it is clear that a sedentary population can carry out HIIT successfully in the real world, although questions regarding the intensity of the prescribed HIIT remain. In terms of intensity, most researchers would agree, that the intensity during a high intensity interval should exceed vigorous (i.e. 6 METS or >80%HRmax), which is in line with the current HIIT recommendations from ACSM (Roy, 2013). However, to many researchers, fitness professionals and clinicians this advice raises more questions than it answers. For example, it is currently unknown if a participant needs to maintain >80%HRmax for the whole interval duration, or if can they reach 80%HRmax in the final seconds of the interval? Additionally, does the participant need to achieve this target HR on just one interval, some of the intervals, or on every interval in the session? Currently these questions are difficult to answer, due to the limited detail provided regarding the compliance to interventions (and indeed single training sessions) made available within published research studies. In Chapters 3, 4 and 5 we used comprehensive methods to record and report exercise intensity, including average interval HR peak (IHR_{peak}) and interval HR mean (IHR_{mean}). In Chapter 3 this novel approach was also applied to power output, therefore interval power output peak (IPO_{peak}) and interval power output mean (IPO_{mean}) were also reported. In Chapter 3, we discovered that most participants reached a IHR_{peak} >80%HRmax (81% of participants in 30HIT, and 94% of participants in 60HIT).

It is currently unknown which of these intensity variables is more representative of physiological stress, and therefore long-term adaptations (Fiorenza et al., 2018). Even within the prescription of >80% HRmax individuals could respond very differently within a HIIT session, for example one participant working at 80%HRmax and another at 95%HRmax. These seemingly small variations on the exercise prescription could have meaningful implications on adaptations over time. A study from Moholdt et al. (2014) found after a 12-week intervention, those performing HIIT above 92% HRpeak had a 2ml.min-1.kg-1 greater increase in VO_{2peak} compared to patients exercising below 92%. Data from Chapter 3 did not support this finding, however, as changes in CRF were similar between groups achieving a Low Medium or High HR (n=27 in each group) during the intervention. This observed difference between the studies could be due to differences in study populations (coronary artery disease vs healthy), interval durations (4mins vs 60s or 30s), or methodology of heart rate analysis. It is clear however that intensity is an important factor, as following 60HIT (Chapter 3) when grouping participants based on their PO (tertiles, n=27 in each group), we found similar results to those of Moholdt et al. (2014) as the higher exercise PO induced greater improvements in VO_{2peak}.

Despite compliance to HIIT being relatively high in Chapters 3 and 4, it remains clear that adherence is still a challenge when prescribing HIIT to ERS patients. This may not be surprising given that even in rigorously controlled clinical trials specifically aimed to increase physical activity levels, many individuals fail to adhere to the recommended amount of activity (Martin and Sinden 2001). Previous studies conducted in an ERS setting have reported an adherence rate of approximately 45% during a 10-week gym-based ERS (Taylor et al., 1998). In Chapter 4, the drop off from training was high, with only 32% of patients still training at the end of the 12-week intervention. Furthermore, weekly adherence was less than 40% (prescribed session n=36). It is noteworthy, however, that similar drop off and adherence was observed in the traditional ERS group, with only 43% of patients still exercising at week 12 of the intervention and adherence to the programme was less than 50%. The multidisciplinary approach used in Chapter 4 allows for the combination of objective quantitative data and qualitative survey responses to aid in the explanation and understanding of differing adherence levels. The responses from those who choose Home-based HIIT show that the time-saving nature, and the ability to complete the exercise in their home without equipment, was a facilitator for exercise participation. Interestingly, the barriers to participation were similar between the HIIT and ERS groups, which reflected common barriers to exercise participation mentioned in Section 1.6 e.g. lack of motivation, lack of time and tiredness. Therefore, it is reasonable to say that by changing the exercise intervention this could help remove barriers for some participants, but not for all. Now researchers have developed a wide range of effective interventions, future research should investigate the delivery of the exercise prescription and develop strategies to adjust participant's priorities to include exercise.

6.3 Prescription of HIIT in the real world – Whole-body HIIT as a modality

The overall aim of Chapter 4 was to assess the physiological effectiveness of a home-based HIIT programme, which included body-weight exercise that can be performed in participants' own home without equipment, compared to a current exercise referral scheme. As described in Section 6.1, Home-based HIIT increased CRF to the same extent as the ERS group, representing a low cost and accessible exercise intervention that removes many of the perceived barriers to exercise. This was highlighted in the qualitative survey responses used in Chapter 4, as reasons for choosing the Home-based HIIT intervention stemmed around the convenience or time-saving nature of the programme. Participants also cited reasons such as no travel or having the flexibility to complete a HIIT session when the moment presented itself. Furthermore, the convenience of Home-based HIIT, was cited as a facilitator for adherence to the programme, with participants commenting on how they could do the sessions anywhere/anytime to fit around life commitments. Future programmes for public health promotion should therefore create exercise interventions that are convenient, as well as effective.

To help increase exercise adherence rates it is important for academics to consider the affect (feelings of pleasure/displeasure) experienced during the activity, which has been shown to predict future engagement (Williams et al., 2008, Williams, 2011). Within the context of adherence, hedonic theory suggests that how one feels during exercise, or the affect response to exercise may predict their future exercise behaviours (Ekkekakis et al., 2016). Within Chapter 5, we analysed perceptual responses and motivational factors towards exercise. We found that participants reported greater post-exercise enjoyment when HIIT was performed using body-weight exercises (BW-60:60, 10x60s with 60s rest) compared to a cycle ergometer (Ergo-60:60, 10x60s with 60s rest). Importantly, BW-60:60 and Ergo-60:60 were matched for interval duration, work-to-rest ratio and produced similar HR traces and overall physiological responses, suggesting that the exercise mode was the important factor.

Moreover, this study was the first to assess acute responses to HIIT protocols promoted via social media. HIIT protocols on social media are time saving, and by using whole-body exercises (often with no specialist equipment) they are easily accessible, but they also provide the additional feeling of attending a fitness class lead by an instructor. As a result, HIIT has grown in popularity on social media over the past decade, with some videos reaching >10 million views. Interestingly, when considering change in affect during the exercise, results from Chapter 5 show the feeling towards these social media protocols may differ during the exercise compared to the protocols used within the research. In Chapter 5, Ergo-60:60 and BW-60:60 show in-task affect declining from interval 5 onwards. In contrast, the two social media based protocols (SM-20:10 and SM-40:20) did not show a significant fall in affect from the first to the last interval; indeed the changes in affect show no obvious pattern. Therefore, work-to-rest ratio, interval duration and body-weight exercise choice could influence affective response to HIIT, and in turn adherence.

6.4 Future work in prescription of HIIT

Without a clear template for the prescription of HIIT, it is not feasible to be adopted as a public health strategy (Biddle and Batterham, 2015). Future research should seek to deduce key factors within a HIIT protocol needed for optimal health benefits, as without this knowledge we cannot accurately prescribe and measure compliance to HIIT interventions. All protocols, under the umbrella of HIIT, can vary greatly in work to rest ratio (1:1, 2:1, 1:4 etc), mode of exercise (cycling, treadmill or body-weight), prescribed intensity (100% W_{max}, 80% HR_{max}, all-out) and duration. A variety of different protocols and modalities have been used within this thesis, each resulting in vastly different acute and chronic physiological and perceptual responses. Figure 3.2 and Figure 5.2 clearly highlight that manipulating these factors can influence physiological responses. However, the difference in these responses is only evident due to the depth of analysis and reporting used within the current work. Previous HIIT research, whereby only session average intensity is reported, fails to account for individual differences between protocols and participants. It is therefore prescient that all future HIIT research should record compliance with throughout the intervention, using an individualised objective measure such as HR. Furthermore, average and peak data for each of the work and rest intervals and, where possible, individual responses to an intervention should be reported. Without knowing all the information about how the intervention was carried out, and the changes to health and adherence as a result, we cannot optimise HIIT prescription.

Additionally, more research needs to be carried out to understand the psychological responses to HIIT. Firstly, a number of researchers have argued that low affect during exercise leads to low adherence (Ekkekakis et al., 2016, Greene et al., 2018), although there is evidence to support this in MICT, confirmation from HIIT intervention studies is lacking. A study from Martinez et al. (2015) reported that affect (feeling scale) at the completion of exercise trials was more positive in protocols using shorter interval durations (30s and 60s compared to 120s), furthermore enjoyment was lower following 120s interval protocol. Therefore, to investigate the effects of these acute perceptual responses on long-term adherence, a randomised control trial should be conducted using an intervention of either 60s or 120s intervals in a free-living environment.

Finally, the use of HIIT protocols that are low-cost, easily accessible and replicate the effects of the lab-based protocols should be investigated further. One potential approach is the use of workout videos on social media platforms, as this allows participants to choose short, and often, vigorous workouts, which could be customized to individual abilities and interests. When delivered via social media, there is great potential for a HIIT intervention to contribute to increasing exercise participation and in turn a reduction of health risk factors contributing to the development of NCDs. Future work should, therefore, look to investigate the effect of the popular social media HIIT modes on health risk factors and long-term adherence to exercise.

6.5 Conclusions

The work conducted over the course of this thesis provides strong evidence for the use of HIIT, particularly whole-body home-based HIIT, as a strategy to improve health in sedentary or at-risk populations within the real world. Chapter 3 provides evidence that the traditional HIIT protocols used within the laboratory can be completed correctly by non-athletic populations, even when self-paced and unsupervised. The novel methodology used to assess intensity within this study, and the other chapters within this thesis, provides further detail regarding the implementation of HIIT outside the laboratory, aiding the future prescription of HIIT. Chapter 4 demonstrates that a whole-body home-based HIIT protocol is an effective strategy which improves CRF to the same extent as a traditional ERS, and is able to remove some of the reported perceived barriers to exercise. Additionally Chapter 5 demonstrates the delivery of HIIT using social media may be a potential avenue for researchers to explore, as it resulted in similar physiological responses to traditional ergometer cycling HIIT but reported less adverse affect responses during the exercise session. In conclusion, this thesis has generated evidence that HIIT can be a successful strategy when taken out of the laboratory and into the real-world. Effective validated HIIT protocols should, therefore, be incorporated as an alternative exercise mode in exercise prescription schemes. In this thesis we have demonstrated that HIIT is effective and feasible for use in public health and therefore HIIT should be considered viable for inclusion in future world-wide public health policies and recommendations by scientific organisations and health authorities.

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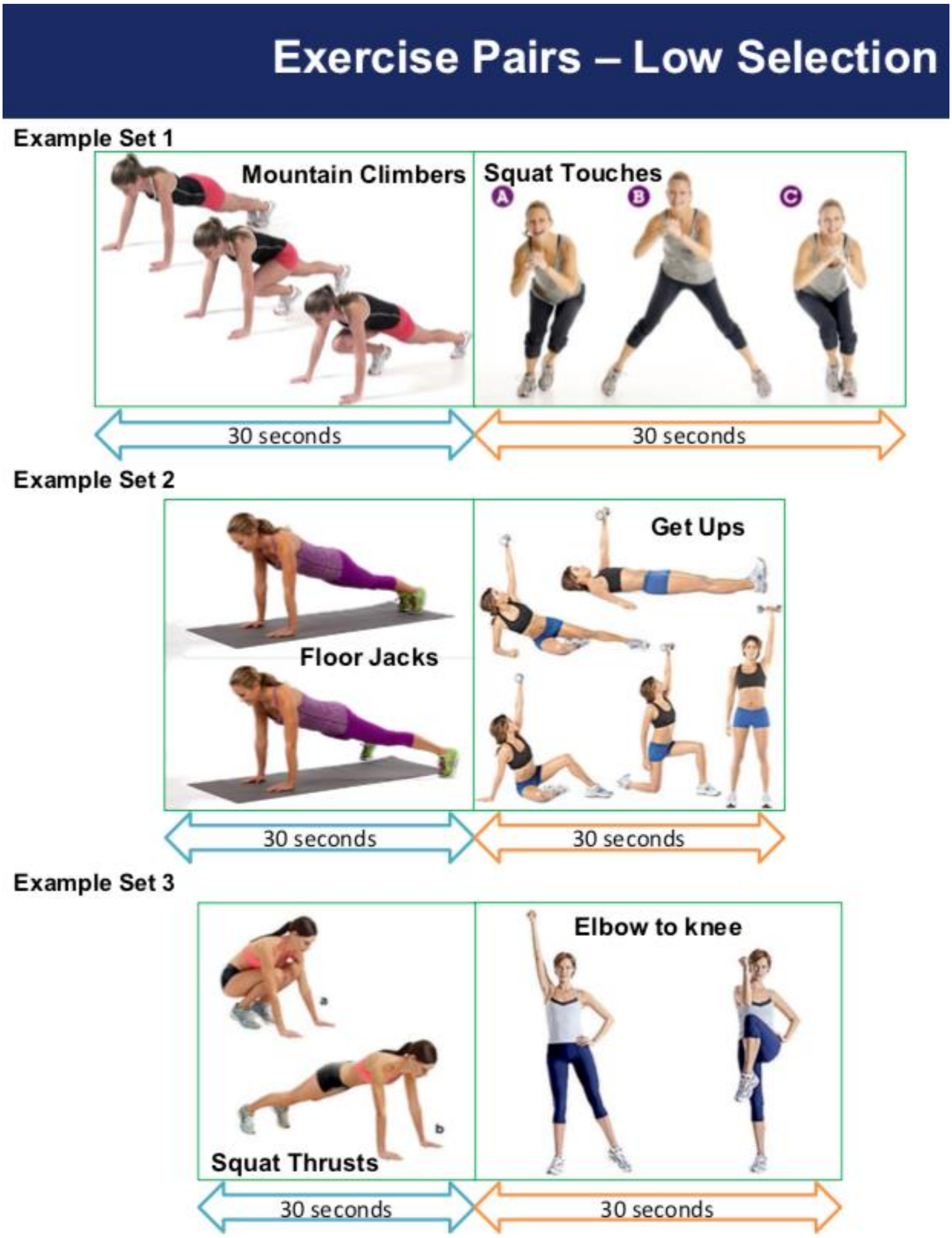
Appendix

Appendix 1. Exercise pack for Home-based HIIT

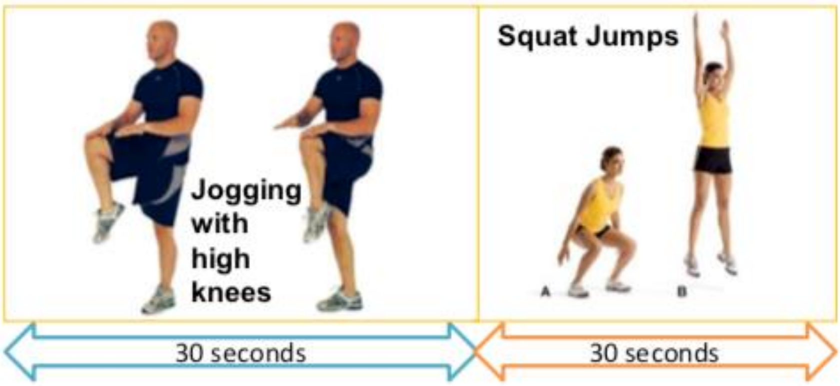


Exercise Pairs – Medium Selection

Example Set 4

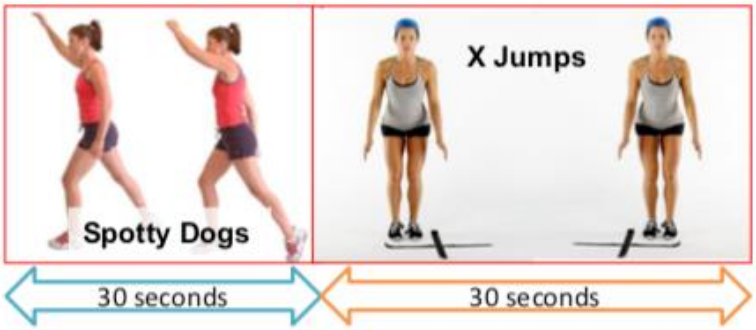
Example Set 5

Example Set 6

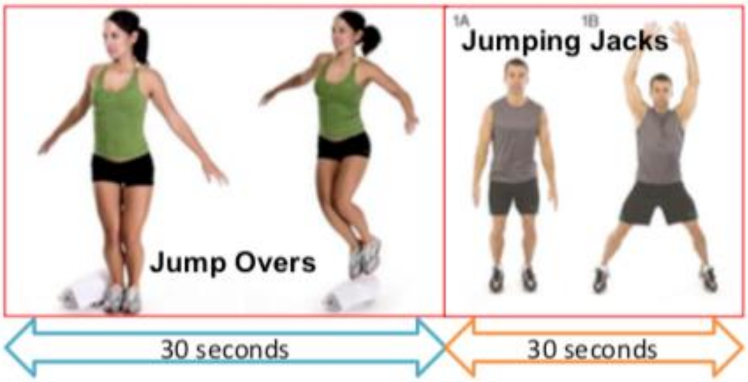


Exercise Pairs – High Selection

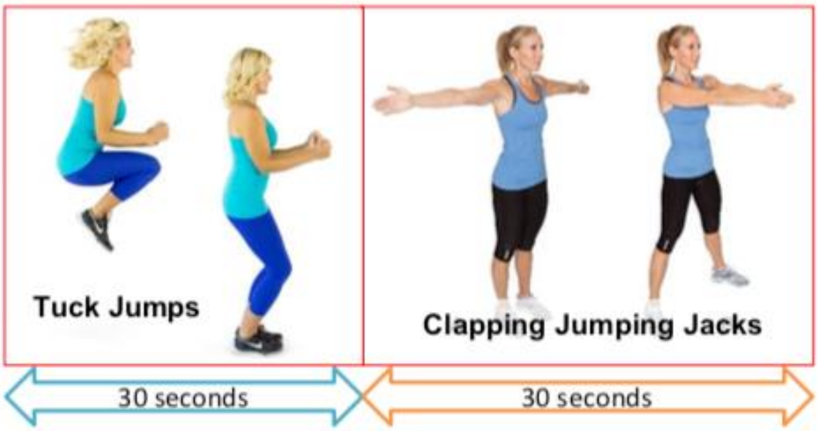
Example Set 7



Example Set 8



Example Set 9



Appendix 2. Example of exercise referral scheme programme.

Session 1

Exercise	Warm Up	
Mobility exercises	**Intensity:** 50–60%	Head turns, shoulder circles/shrugs, side bends, trunk twists
Upright Bike	**Intensity:** 60–70%	5-10 minutes at a steady pace.

Exercise	Cardio Workout	
Treadmill	**Intensity** 70–80% Keep an eye on your heart rate, if it is lower than 70% increase the speed/resistance. If your heart rate is greater than 80% decrease the speed/resistance.	5 minutes to 15 minutes on each exercise. Start at 5 and add more time as it starts to feel easier to complete.
Rowing Machine		At the start: 5 minutes 6 weeks: 10 minutes 12 weeks: 15 minutes
X Trainer		At the start: 5 minutes 6 weeks: 10 minutes 12 weeks: 15 minutes

Exercise	Resistance Workout	
Leg Press	**Intensity** 70–80%	• 2 x 12-15 repetitions • Make sure the weight is a challenge you should be struggling on the last repetition • It should be a slow and controlled movement. • As the weeks go on increase the weight or increase to 3-4 sets if you have time. • If you feel any pain or discomfort please stop.
Lat Pull Down	**Intensity** 70–80%	
Leg Extension	**Intensity** 70–80%	
Chest Press	**Intensity** 70–80%	
Sitting Twists	**Intensity** 70–80%	

Exercise	Cool Down	
Upright Bike	**Intensity:** 60–70%	5-10 minutes at a steady pace.
Stretches	**Intensity:** 50–60%	Hold each stretch for 10-20 seconds.

Appendix 3. Physiological responses to T-ERS and Home-based HIIT.

Variable	T-ERS			Home-HIIT		
	Pre	Post	Follow Up	Pre	Post	Follow Up
Exercise Capacity						
VO_{2peak} (l.min)	2.3±0.7	2.7±0.8	2.7±0.9	2.2±0.7	2.5±0.8	2.5±0.9
VO_{2peak} (ml.kg^{-1}.min^{-1})	26.8±8.4	32.5±9.0	32.6±8.9	24.7±6.9	28.8±8.0	28.7±9.8
Body Composition						
Body Mass (kg)	89.5±18.3	85.5±16.3	85.0±15.7	88.8±17.4	87.3±15.5	87.2±16.6
BMI (kg.m^2)	30.7±6.3	29.2±5.5	28.8±5.1	30.3±6.1	29.8±4.5	29.8±4.5
Muscle Mass (kg)	58.7±11.1	57.8±11.0	58.1±11.4	58.2±11.2	58.4±12.1	58.2±13.0
Fat Mass (kg)	29.3±11.7	26.0±10.0	25.6±8.8	31.1±21.3	27.7±8.5	27.5±8.2
VAT Mass (g)	634.6±265.7	568.2±233.8	547.8±221.0	584.0±235.3	623.0±237.2	604.4±207.6
Body Fat (%)	31.8±7.9	31.5±11.4	29.5±7.5	32.0±7.9	31.2±7.2	31.2±7.4
Cardiovascular Responses						
Systolic Blood Pressure (mmHg)	127.7±11.7	126.4±13.0	124.0±12.7	130.0±14.9	129.2±11.4	130.2±12.8
Diastolic Blood Pressure (mmHg)	73.4±9.4	72.5±8.7	70.7±13.4	74.6±12.0	76.7±8.9	76.9±9.1
Mean Arterial Pressure (mmHg)	91.5±9.3	90.5±9.3	88.5±11.6	93.1±11.6	94.2±8.9	94..7±9.2
Pulse Wave Velocity (m.s)	7.6±1.5	7..3±1.7	7.4±2.0	7.7±1.9	7.8±2.2	8.3±2.8
Glucose Tolerance						
Fasting Glucose (mmol.L^{-1})	5.3±0.9	5.3±0.7	5.3±0.7	5.4±0.8	5.5±0.8	5.4±0.6
Glucose at 60min (mmol.L^{-1})	8.0±2.5	7.9±2.4	7.7±3.0	7.9±2.8	7.5±2.1	8.6±2.5
Glucose at 120min (mmol.L^{-1})	5.9±2.1	5.7±2.0	5.9±1.8	5.5±1.9	5.4±1.4	5.8±1.7
Blood Lipids						
Triglycerides (mmol.L^{-1})	1.2±0.6	1.1±0.5	1.0±0.5	1.3±1.1	1.3±0.7	1.0±0.5
Cholesterol (mmol.L^{-1})	5.2±1.0	5.3±0.9	5.1±0.9	5.2±1.1	5.3±1.0	5.1±0.8
HDL-Cholesterol (mmol.L^{-1})	1.4±0.4	1.4±0.3	1.4±0.3	1.3±0.4	1.4±0.3	1.4±0.3
LDL-Cholesterol (mmol.L^{-1})	3.2±1.0	3.2±0.8	3.1±0.8	3.2±1.0	3.2±1.0	3.1±0.7

Appendix 4. Qualitative survey questions.

Qualitative Survey Questions
What attracted you to take part in this study?
What has prevented you from exercising in the past?
Which intervention did you choose, and why did you choose it?
Has the exercise programme met your expectations? If so why? If not, why not?
What did you like about the programme?
What didn't you like about the programme?
Can you give an example of a situation when you felt positive during the programme?
Can you give an example of a situation when you felt negative during the programme?
Is there anything, within the programme, that could have been done different?
How has the programme impacted your life overall?
Have you experienced any barriers when completing the exercise programme?
Were you able to overcome these barriers? If so how?
Is there anything we can change or provide to help you overcome any barriers?
Who has helped you become more active during the programme? If so, how have they helped?
What are your intentions regarding exercise and physical activity going forward? What type of exercise do you intend to do? Who with?