THE EFFECT OF INTERVAL DURATION AND WORK-TO-REST RATIO ON ACUTE PHYSIOLOGICAL AND PERCEPTUAL RESPONSES, AND CARDIORESPIRATORY FITNESS FOLLOWING A HOME-BASED HIIT TRAINING INTERVENTION

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A thesis submitted in partial fulfilment of
the requirements of Liverpool John
Moores University for the degree of
Master of Philosophy

May 2021

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1. Abstract

Introduction: Laboratory-based High intensity interval training (HIIT) is an efficacious time-saving exercise modality resulting in similar adaptations to traditional moderate-intensity continuous training. Recently, Home-based HIIT, involving bodyweight exercises, has gained popularity in the literature, as it overcomes additional barriers such as limited access to facilities and appropriate equipment. However, literature in to home-based HIIT is still sparse, and little is known about how manipulating interval duration, interval number and work-to-rest ratio could influence the efficacy and effectiveness of such interventions.

Aims: Two separate but related studies were conducted. The aim of study 1 was to investigate the acute physiological, perceptual, and motivational responses to five home-based HIIT protocols with various work-to-rest ratios (specifically 1:1, 1:2 and 1:4) and interval durations (30s or 60s). The aim of study 2 was to implement and compare two of the HIIT protocols investigated in study one to identify the ideal interval duration for improving cardiorespiratory fitness (CRF) and health in sedentary individuals.

Methods: In Study 1, 10 healthy participants (age = 25±4 yrs, BMI = 22.7±1.4kg.m^2) completed a randomised cross-over study, whereby each participant completed five bodyweight HIIT protocols, four using 30s intervals (30:30x6 (30s interval interspersed with 30s rest, completed 6 times), 30:60x6, 30:120x6 and 30:30x12) and one using 60s intervals (60:60x6). A total of 12 exercises were implemented, examples included burpees, mountain climbers, and jumping jacks. Blood lactate, heart rate (HR), feeling scale (FS), enjoyment and perceived competence were measured in response to each protocol. In Study 2, 28 healthy sedentary participants (age = 29±10 yrs, BMI = 25.3±3.9 kg.m^2) completed a randomised cross-over design, whereby each participant completed 6 weeks of 30:120HIIT (4-8x30s with 120s rest) and 60:60HIIT (6-10x60s with 60s rest). In addition to the 12 exercises implemented in study 1, a further 6 were added in study 2. CRF, body composition (bioimpedance), blood pressure and aortic pulse wave velocity were assessed pre and post each intervention, with a 4-6-week wash-out period between interventions.

Results: Study 1 (acute phase), established that 60:60x6 and 30:30x12 resulted in significantly higher change in blood lactate and HR responses compared to 30:30x6, 30:60x6, and 30:120x6 (P<0.05). 30:120x6 had a significantly higher minimum reported feeling scale score compared to all other protocols (P<0.05). No significant differences were reported for interest/enjoyment or perceived competence between protocols (P>0.05). Study 2 (chronic phase) demonstrated that CRF increased following both 30:120HIIT and 60:60HIIT (P<0.05). There was a significant reduction in aPWV following 30:120HIIT and 60:60HIIT (P<0.05). Systolic BP decreased significantly in 30:120HIIT with no difference in 60:60HIIT (P=0.414). Magnitude of change between protocols was not different for any of the measured variables (P>0.05).

Conclusion: This is the first study to directly compare different home-based HIIT protocols by manipulating interval durations and work-to-rest ratios. Home-based HIIT protocols consisting of 30:120HIIT and 60:60HIIT improved CRF and aPWV after 6 weeks in sedentary individuals, despite 30:120HIIT producing significantly lower lactate and heart rate responses whilst also showing less aversive perceptions during an acute bout of exercise to that of 60:60HIIT.

2. Acknowledgements

Firstly, I wish to acknowledge my supervisors Matthew Cocks, Sam Shepherd, Juliette Strauss, and Anton Wagenmakers for allowing me to carry out research within such a respected research group, and for all your support and guidance throughout. Secondly the rest of Team Anton, with a particular thanks to Katie Hesketh, Jennifer Barrett, Miffy Macey, and Emma Cowley. Thank you for all the help throughout the past 2 years from helping me test when I have had multiple people in to being ‘willing’ volunteers when I have needed to practice cannulating. Thank you to the helpful technicians Gemma Miller, Dean Morrey, and George Savage. Also thank you to everyone in the PGR office, in particular Joe Maxwell for help with FMD’s and Lucy Finnigan for being a reliable drinking partner on Fridays, even if it meant calling in sick to work.

A massive thank you to all my participants as this study would not have been possible without them. Carrying out research you encounter problems on the daily, however some of these have been very out of the ordinary, which I wish never to experience again but they have made my MPhil a memorable one. A special thank you goes to my university flat mates Emma Loughran, Tobi Akinshipo and Bassey for being the most supportive friends I could ask for by enduring months of HIIT training to help with my research.

And finally, a special thanks goes to my nearest and dearest, my sister Laura for travelling up to Liverpool to participate in my project, to my mum, dad, step parents, and my lovely nan Iris for their constant support throughout my entire university experience. A massive thank you to my best buddy Victoria, despite being on the other side of the world, it did not stop you from offering to read through any of my work, and lastly thank you Tom for always being there for me whether I’ve been sobbing over SPSS or needed you to explain anything, but also for constantly reminding me day in day out that you are in fact already are a ‘Master of Science’.

3. Introduction

3.1 Physical inactivity and cardiorespiratory fitness

Physical inactivity has been identified as the fourth leading risk factor for global mortality (WHO, 2010), causing a substantial strain on the NHS with an estimated cost of £1.2 billion per year (BHF, 2017). Conversely, leading a physically active lifestyle can reduce the risk of developing many non-communicable 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). In addition, physically active individuals have been shown to reduce their relative risk of death by approximately 20-35% compared to their inactive counterparts (Warburton 2006) and, a dose response relationship has been demonstrated between physical activity levels and longevity (Arem *et al.,* 2015).

The above clearly demonstrates the importance of a physically active lifestyle. However, data suggests that high cardiorespiratory fitness (CRF) is superior to physical activity for predicting mortality (Davidson 2018). Supporting the suggestion that where possible the primary aim of interventions should be to increase CRF rather than physical activity alone (Ozemek *et al.,* 2018). Indeed, a major meta-analysis demonstrated that each 1-metabolic-equivalanet (MET) increase in CRF is associated with a 13% reduction in all-cause mortality and a 15% reduction in cardiovascular disease/ coronary events (Kodama 2009). Furthermore, using data generated from the Aerobic Longitudinal Study following more than 14,000 participants, Lee *et al.* (2011) demonstrated that every 1-MET increase in CRF over time (measured through repeated CRF assessments separated by on average more than 6 years) was associated with a 15% and 19% reduction in all-cause and cardiovascular disease mortality, respectively.

Given the well researched dangers of inactivity and the benefits of increasing CRF and physical activity the UK government has developed guidelines which advise adults to partake in ≥150 minutes of moderate intensity activity or ≥75 minutes of vigorous intensity activity a week (GOV.UK, 2019). However, in the UK, approximately 20 million adults are insufficiently active, putting them at a significantly greater risk of type 2 diabetes and cardiovascular disease (BHF, 2017).

3.2 Perceived barriers to exercise

Despite substantial evidence highlighting the benefits of a physically active lifestyle only a minority of people meet the minimum physical activity recommendations. In order to change these trends, it is important to identify the factors preventing regular participation. The most cited barrier for not meeting activity recommendations is a perceived lack of time (Trost *et al.,* 2002), as individuals do not view exercise as a priority when compared to other commitments such as caring for others, working and household jobs (Wolin, 2008, Mullahy and Robert, 2010). Interestingly, parents who spend a lot of time looking after their children (King, Hartson, and Della, 2019) and individuals with less discretionary time are less likely to be active (Wolin, 2008). Other common barriers to activity within the general population include external factors, such as limited access to facilities and appropriate equipment, difficulty with transportation, inadequate financial resources, intimidating environments, and poor weather (Hoare *et al.,* 2017, Reichert *et al.,* 2007). Internal factors such as poor body image and low self-esteem have also been identified (Trost *et al.,* 2002; Reichert *et al.,* 2007; Wolin, 2008). Therefore, strategies to overcome these barriers need to be considered when designing interventions to increase physical activity and CRF. A home-based HIIT approach would overcome the lack of time barrier as well as the external factors listed.

3.3 Defining high intensity interval training

High intensity interval training (HIIT) has emerged as alternative to moderate intensity continuous training (MICT), recommended in activity guidelines, as it is citied to overcome perceived lack of time as an exercise barrier. HIIT involves repeated bouts of high intensity exercise followed by low intensity periods of recovery. Recently HIIT has attracted substantial attention as an efficacious and time-efficient exercise strategy, as it results in equal or greater physiological adaptations to MICT, despite substantially lower training volumes (Gibala, 2007). Additionally, there is evidence that HIIT may be more enjoyable than continuous exercise (Bartlett *et al.,* 2011, Jung *et al.,* 2014). Therefore, it has been hypothesized that HIIT may offer an effective, alternative training strategy to traditional continuous aerobic exercise that has previously been at the centre of the physical activity guidelines (Colberg *et al.,* 2016). Nonetheless, the term 'HIIT' encompasses a diverse range of protocols due to its broad definition, meaning interventions can differ immensely as the intensity and duration of the intervals, and recovery period can be easily manipulated. The endless variety of protocols studied make it difficult for the general population to decipher which HIIT protocol is the most effective approach.

3.4 Sprint interval training

The first studies aiming to overcome 'lack of time' as a barrier used an approach termed sprint interval training (SIT), consisting of as little as 2 minutes of intense exercise in total. The most common approach to SIT used repeated Wingate tests, consisting of 30 second 'all out' cycling efforts, typically repeated four to six times with four minutes of recovery in-between bouts. Repeated Wingate SIT has proved to be a time-efficient strategy for rapid physiological and performance improvements that are comparable to traditional MICT (Burgomaster *et al.,* 2008; Rakobowchuk *et al.,* 2008; Cocks *et al.,* 2013; Shepherd *et al.,* 2013). Burgomaster et al. (2005) found that 6 sessions of SIT over a two-week period, consisting of 15 minutes of high intensity exercise in total, was sufficient to increase skeletal muscle oxidative capacity. Further interventions have compared Wingate SIT to MICT over a four to six-week period. Despite the SIT protocol having a 90% lower weekly training volume and 67% lower time commitment (1.5h vs 4.5 hours per week); SIT has shown similar improvements in markers of skeletal muscle and cardiovascular adaptation as that of the MICT groups (Burgomaster *et al.,* 2008, Shepherd *et al.,* 2013, Cocks *et al.,* 2013). However, Wingate SIT's effectiveness has been criticised by health professionals due to safety concerns arising from the requirement for 'all out' efforts. In addition, the high intensity nature of SIT requires high levels of motivation and sessions can be poorly tolerated, often causing nausea (Gibala *et al.,* 2012). Finally, the time efficiency of Wingate SIT has been questioned as sessions last approximately 30 minutes, due to long rest periods in-between bouts.

3.5 Constant workload approaches

Due to the criticisms of 'all out' approaches using repeated Wingates researchers began investigating alternatives. One such approach used low volume constant workload exercise. Constant workload SIT or HIIT protocols differ from 'all-out' protocols as the workload is maintained at a constant wattage or heart rate throughout all the intervals. Little *et al.* (2010) used a protocol consisting of 10 x 60s work bouts at a constant load eliciting a heart rate above 90% HR_{max}, interspersed with 60s recovery. This protocol used a reduced interval intensity which allowed the rest period and overall session duration to be shorter. It has been hypothesized that the reduced interval intensity would also be better tolerated in sedentary populations. Constant workload approaches have been used and proven to be efficacious in healthy lean (Little *et al.,* 2010) and obese and diseased populations (Little *et al.,* 2011; Cocks *et al.,* 2016). Therefore, indicating that constant load low-volume HIIT protocols are time efficient and efficacious alternate that can induce adaptations beneficial to improving health in both a healthy and a diseased population (Little *et al.,* 2010; Little *et al.,* 2011; and Cocks *et al.,* 2016).

3.6 Additional barriers specific to HIIT

HIIT has been shown to be an efficacious training intervention (Cocks *et al.,* 2013, Cocks *et al.,* 2016, Little *et al.,* 2011). However, much of the data comes from highly controlled laboratory-based studies making conclusions regarding its 'real world effectiveness difficult to draw (Weston *et al.,* 2014). Shepherd *et al.* (2015) conducted a more ecologically valid study investigating HIIT performed in a "real world" gym setting (participants attended instructor-led group-based spinning classes 3x per week for 10 weeks). The study found improvements in CRF and psychological health in previously inactive adults after 10 weeks (Shepherd *et al.,* 2015). In addition, adherence was greater in HIIT participants compared to an MICT group who were asked to train 5x per week (30–45 min per session at ~70% HR_{max}, 2 sessions out of the 5 each week were unsupervised). It was hypothesized that adherence to HIIT was increased due to the time commitment being substantially less in the HIIT intervention (55 minutes a week) than in the MICT group (128 minutes a week). This study provides further support for the use of HIIT as a time efficient exercise strategy. However, the intervention still relied on exercise equipment and the sessions were instructor led, where verbal motivation was given throughout. It has been argued by public health researchers, that although HIIT is effective under optimal controlled conditions, performed with high levels of supervision using specialist exercise equipment, it will not be effective when aimed at sedentary populations that are most in need due to the complex and strenuous nature of the protocols (Biddle and Batterham, 2015; and Hardcastle *et al.,* 2014). Although time efficient, laboratory based and current 'real world' HIIT research fails to address additional barriers created by the HIIT protocols employed, such as; limited access to facilities and appropriate equipment, inadequate financial resources and difficulty with transportation (Korkiakangas et al., 2009). Therefore, future studies should focus on practical and feasible forms of HIIT that can be used by the general population.

3.7 Home-HIIT approaches

Since HIIT gained popularity within the research, many have touted HIIT's efficacy and time efficiency in comparison to MICT and as a result, suggested it could increase exercise participation (Gibala *et al.,* 2012, Weston et *al.,* 2014). Nevertheless, a large proportion of the population remain inactive suggesting further research is needed to develop more feasible strategies that can be adopted by most of the population. Home-based HIIT interventions have recently emerged in the literature as an attempt to overcome additional barriers to exercise and have been successfully implemented in various populations (Scott *et al.,* 2019a; Gibala *et al.,* 2020; Blackwell *et al.,* 2017). These home-based interventions, which use simple body-weight exercises, could be very appealing as they combine the time efficient nature of HIIT with the ease and cost effectiveness of home-based interventions, minimising barriers to exercise. Blackwell *et al.* (2017) compared the effectiveness of 4 weeks of an unsupervised home-based HIIT protocol to laboratory based HIIT in middle-aged individuals. Both the home- and laboratory-based protocols consisted of 5x 1-minute intervals interspersed with 90 seconds of rest, 3x per week. However, participants completing the home-based protocol were encouraged to complete as many repetitions as possible of three equipment-free body weight exercises (star-jumps, squat thrusts, and static sprints), while the laboratory-based group trained on a cycle ergometer at a constant load of 95-110% of Wmax. The study reported similar increases in CRF in both groups, suggesting that low-volume home-HIIT could be a practical and tolerable approach in sedentary individuals (Bartlett *et al.* 2011). Although 100% adherence was reported in the home-based HIIT group, adherence was not measured objectively as self-report diaries were used. Moreover, the length of the study was only 4 weeks, and therefore, the study did not assess the long-term efficacy of home-based HIIT.

Scott *et al.,* (2019a) compared 12 weeks of home-based HIIT with laboratory based supervised HIIT and home-based MICT in obese individuals with elevated cardiovascular disease risk. The home-based HIIT protocol used 60s intervals of various body weight exercises, designed for individuals with low fitness and mobility, interspersed with 60s rest. The study showed similar improvements in a range of health-related measures between the 3 exercise modes, including CRF, whole body insulin sensitivity (assessed using an oral glucose tolerance test), body composition and endothelium dependent dilation (assessed using flow mediated dilation). The study also monitored adherence and compliance to the prescribed exercise intensity (achievement of 80% HRmax on one or more intervals) using HR monitors, reporting 96% adherence and 98% compliance to the unsupervised home-based HIIT protocol. Interestingly, the adherence reported was higher than supervised field based HIIT interventions (Shepherd *et al.,* 2015). Importantly, a recent study in people with Type 1 diabetes, using the same home-based HIIT protocol as Scott *et al.* (2019b), showed that qualitative perception of home-based HIIT were positive, supporting that the intervention successfully removed exercise barriers (Scott *et al.,* 2019a).

3.8 Confusing public health message

Numerous laboratory-based HIIT protocols have been established as time-saving alternatives to MICT. Although more studies are emerging, bodyweight HIIT protocols are still sparse in the literature. Importantly, many HIIT studies use different methods in terms of the duration and the intensity of intervals and rest periods, the number of intervals and the work-to-rest ratio, causing an inability to directly compare the literature. The increasing number of HIIT protocols outlined in the research also presents an extremely confusing health message for the public. Evidence of this is illustrated by **Table 1**, outlining the limited, but different 'Home-HIIT' protocols used within the literature.

From the research, 60s bodyweight HIIT protocols have been established as efficacious time efficient protocols i.e. less than 20 minutes, when carried out 3x a week for anywhere between 4 and 12 weeks (Gibala *et al.,* 2020; Scott *et al.,* 2019a, 2019b, Blackwell *et al.,* 2017). However, there are still discrepancies on the effectiveness of bodyweight HIIT protocols with shorter exercise durations. McRae et al. (2012) showed similar improvements in CRF to MICT when bodyweight intervals of 20s, interspersed with 10s rest, were used for 4 weeks, in recreationally active female students. However, Gist *et al.* (2015) found that 30s bodyweight exercises, interspersed with 4 minutes of active recovery, sustained CRF levels but did not improve them over 4 weeks, in army cadets. Additionally, when stair climbing was assessed, improvements in CRF were seen following both 20s and 60s protocols in sedentary women (Alison *et al.,* 2017). Reasons for these inconsistency are unclear but what is apparent is that factors such as intensity and duration of intervals, recovery intensity and duration of the rest periods, as well as the number of intervals and work-to-rest ratio should be considered when prescribing HIIT (Buchheit and Larsen, 2013).

3.9 Enjoyment and perceptions of HIIT

Long term effectiveness and adherence to a training intervention can be influenced by an individuals' perceptual responses during and after exercise (Bauman *et al.,* 2012). These perceptual responses refer to an individual's positive or negative affect (feelings of pleasure or displeasure) along with aspects relating to motivation such as enjoyment and perceived competence (Bauman *et al.,* 2012). Despite the clear importance of perceptual responses to the long-term effectiveness of an intervention very few HIIT studies have investigated these factors. It has been suggested that individuals are likely to avoid exercise if it is found to be aversive, and therefore, HIIT itself could be a potential barrier to exercise participation due to its strenuous nature (Hardcastle *et al.,* 2014). Dual-Mode theory suggests that when exercise is carried out above the individuals ventilatory threshold, the pleasure (affect) experienced whilst exercising declines (Ekkekakis *et al.,* 2011). Importantly, Dual-Mode theory has been established using research based on continuous exercise not HIIT, and as such, its utility within HIIT has been questioned (Biddle & Batterham 2015). However, research comparing laboratory-based HIIT protocols support Dual-Mode theory as findings have shown that lower affective responses are associated with greater physiological strain during HIIT (Boyd *et al.,* 2013; Kilpatrick *et al.,* 2015). Therefore, it is essential to assess the affective response (feelings of pleasure/ displeasure) during bodyweight HIIT, and investigate how manipulating variables within a HIIT protocol can influence perceptions, as negative affect during exercise could act as a deterrent (Garber *et al.,* 2011), but a pleasurable experiences are a determining factor of exercise participation (Williams *et al.,* 2008).

Furthermore, Self-Determination theory suggests that for frequent exercise participation, there needs to be positive emotions associated to the exercise and this can be attained through high levels of enjoyment and perceived competence (feeling physically capable of executing the exercise) (Wienke and Jekauc, 2016). Therefore, if individuals are incapable of demonstrating competence during a HIIT protocol, they are more likely to disengage and not adhere to a programme, as people are intrinsically drawn to engage in behaviours that they feel confident to carry out (McAuley, 1998). In addition, Stork and Martin Ginis (2016) hypothesised that enjoyment can predict attitudes towards HIIT, which can in turn mediate future intentions to participate in exercise. However, the lack of research on this topic limits our current understanding of the psychological responses to HIIT (Stork *et al.,* 2017).

3.10 Aims

Two separate but related studies were conducted, involving one acute exercise comparison, and a subsequent randomised, cross-over study investigating two 6-week training interventions. The aim of the first study was to investigate the acute physiological, perceptual, and motivational responses to five home-based HIIT protocols with various work-to-rest ratios (specifically 1:1, 1:2 and 1:4) and interval durations (30s or 60s). Example exercises included burpees, mountain climbers, and jumping jacks. The aim of the second study was to implement and compare two of the HIIT protocols investigated in study one to identify the ideal interval duration for improving CRF and health in sedentary individuals, when carried out as bodyweight exercises at home, without verbal encouragement or specialised equipment. We tested two main hypotheses: 1) that differences in interval duration, work-to-rest ratio and interval number would elicit contrasting physiological and perceptual responses to exercise, with shorter intervals employing longer work-to-rest ratios eliciting less aversive perceptions but lower physiological responses, and 2) that 6 weeks of a bodyweight HIIT protocol that employs a shorter interval duration and longer work-to-rest ratio would result in significantly lower improvements in CRF to an established 60s bodyweight HIIT protocol.

Table 1. Characteristics of bodyweight HIIT protocols.

Paper	Interval Duration	Rest Duration	Sets	Intensity	Exercises	Intervention Duration	Session Duration (excluding warm up/cool down)
Alison *et al.* (2017)	20s	120s	3	"all-out efforts"	Stair climbing	3d/wk, 6 wks	7.5 mins
	60s	60s	3	"vigorous, relatively intense but not all-out"	Stair climbing (ascending and descending)	3d/wk, 6 wks	6 mins
Blackwell *et al.* (2017)	60s	90s (Active, walking)	5	"maximum number of repetitions possible with good form"	Star jumps, squat thrusts, static sprints	3d/wk, 4 wks	12.5 mins
McRae *et al.* (2012)	20s	10s	8	"As many repetitions as possible"	Burpees, mountain climbers, jumping jacks, & squats and thrusts (using 2.25kg dumbbell).	4d/wk, 4 wks	4 mins
Gist *et al.* (2015)	30s	4 mins (Active, walking)	4 - 7	"All out intensity, achieve maximum repetitions"	Burpees	10-12 sessions, 4 wks	31.5 mins
Scott *et al.* (2019a)	60s	60s	4-8	≥80% PHR_{max}	Mountain climbers, elbow to knee, floor jacks, get ups, squat thrusts, squat touches, split squats, jogging boxers, burpees, squat jumps, jogging on the spot, jogging with high knees, spotty dogs, x jumps, jump overs, jumping jacks, clapping jumping jacks and tuck jumps	3d/wk, 12 wks	16 mins
Scott *et al.* (2019b)	60s	60s	6 - 10	≥80% PHR_{max}	Same exercises used in Scott *et al.,* (2019a)	3d/wk, 6 wks	20 mins
Gibala *et al.* (2020)	60s	60s (Active walking)	5	"Challenging pace"	Burpees, high knees, split squat jumps, squat jumps	3d/wk, 6 wks	10 mins

PHR_{max}; predicted heart rate max.

4. Methods

4.1 Overview: Two separate studies were conducted, one involving an acute exercise comparison and one involving a subsequent randomised, cross-over study with two 6-week training interventions, separated by a 4-6-week wash-out period. In study 1, the acute physiological, perceptual, and motivational responses to five home-based HIIT protocols, using different interval durations and work-to-rest ratios, were compared. After evaluating acute responses, study 2 compared two home-based HIIT protocols ((60s intervals interspersed with 60s rest (60:60HIIT), and 30s intervals interspersed with 120s rest (30:120HIIT)) after recruiting a separate group of participants to assess indices of cardiometabolic health before and after 6-weeks of both training programmes. The rationale for the protocol selection for study 2 was that although 30:120HIIT resulted in lower heart rate responses and change in blood lactate than 60:60HIIT in study 1 (a training protocol that was previously shown to enhance CRF when participants trained 3x/week for 4-weeks (Blackwell *et al.,* 2017)), 30:120HIIT still resulted in a HRmax above the criterion recommended by the ACSM for HIIT (Roy, 2013). However, the lowest recorded value on the Feeling Scale during the protocol was significantly higher during 30:120 HIIT than all other protocols investigated in study 1. As perceptual responses during exercise (positive/ negative affect) are linked to long term adherence (Bauman *et al.,* 2012) the higher lowest reported score on the Feeling Scale during 30:120HIIT could increase adherence. However, it is unclear if the lower physiological responses observed during exercise may reduce the efficacy of the 30:120HIIT protocol to enhance cardiorespiratory fitness and other clinical outcomes.

For ease of presentation the studies have been ordered as study 1, acute responses, and study 2, chronic responses, however study 2 was completed before 1.

4.2 Participants

Two separate groups of healthy individuals were recruited for both the acute (**Table 2**) and chronic phase (**Table 3**). In study 1, participants were recruited irrespective of their habitual physical activity and exercise levels; however, in study 2 only sedentary individuals were recruited. Participants were considered sedentary based on a self-report of <150 minutes of structured physical activity per week using the International Physical Activity Questionnaire (IPAQ). Both studies were conducted at Liverpool John Moores University and were approved by the Liverpool John Moores University Ethics Committee (North West, UK) conforming to the Declaration of Helsinki. The experimental procedures and associated risks were explained to all subjects before their participation, and all participants provided written informed consent.

Table 2. Study 1 participant characteristics

	All (n=10)
Gender (M/F)	(5/5)
Age (y)	25 ± 4
Height (cm)	170.0 ± 9.8
Weight (kg)	65.7 ± 7.9
BMI (kg.m^2)	22.7 ± 1.4

Values are means ± SD

Table 3. Study 2 Descriptive statistics of participants' pre-interventions.

Variables	Baseline (n=28)	Pre-Training 30:120HIIT (n=23)	Pre-Training 60:60HIIT (n=21)
Gender (M/F)	11/17	7/12	4/5
Age (y)	29 ± 10	30 ± 10	30 ± 11
Height (cm)	168.5 ± 9.4	169.0 ± 10.0	169.8 ± 8.4
Weight (kg)	72.8 ± 16.4	72.6 ± 16.2	72.6 ± 15.0
BMI ($kg.m^2$)	25.3 ± 3.9	25.2 ± 3.4	25.1 ± 3.7
VO_{2peak} ($l.min^{-1}$)	2.4 ± 0.9	2.3 ± 0.9	2.4 ± 0.9
VO_{2peak} ($ml.kg^{-1}.min^{-1}$)	32.4 ± 9.6	31.3 ± 9.9	32.6 ± 8.6
Fat Mass (kg)	21.1 ± 9.0	21.2 ± 8.3	21.1 ± 8.1
Fat Mass (%)	28.3 ± 8.9	29.0 ± 8.5	28.6 ± 8.8
Muscle Mass (kg)	25.0 ± 7.1	24.7 ± 7.1	25.0 ± 6.6
aPWV (m.s)	6.2 ± 0.9	6.2 ± 0.7	5.5 ± 0.9
Systolic BP (mmHg)	114.2 ± 9.0	113.2 ± 9.4	111.4 ± 10.8
Diastolic BP (mmHg)	68.4 ± 11.3	68.0 ± 11.6	66.0 ± 7.3

Values are Means ± SD

4.3 Pre-exercise screening

In study 1, participants completed the Physical Activity Readiness Questionnaire (PAR-Q+) before taking part. In study 2 only, participant's cardiovascular risk and their suitability to undertake the study was assessed using the Framingham risk score as suggested by the American Heart Association (Gibbons *et al.,* 2002). 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, diabetes and resting ECG abnormalities were 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.

4.4. Study 1: Acute phase.

4.4.1 Experimental design

A randomised crossover design was implemented to compare acute responses to five different Home-based HIIT protocols. Details of the exercise protocols and body weight exercises performed can be found in Table 4. Participants reported to the laboratory on five separate occasions, with each visit separated by at least 48h. All experimental visits were identical except for the HIIT protocol performed, for which the order was randomised. 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 also introduced to the Feeling Scale (Hardy & Rejeski, 1989) and Rate of Perceived Exertion (RPE) scale (Modified Borg Dyspnoea Scale). Scores on each scale were recorded immediately after each interval. HR was recorded continuously throughout the exercise protocols (Polar H10, Warwick, England). Each exercise protocol involved a 2-minute warm-up of jogging on the spot. During the interval's participants were instructed to complete as many repetitions of the body weight exercises as possible in the time period. HR feedback was also provided allowing participants to self-adjust their 'effort' in subsequent intervals in order to achieve a heart rate equivalent to ≥80% predicted HRmax (PHRmax), calculated using the equation 80% HRmax = (220 – participants age) x 0.8. The recovery periods involved walking at a self-selected pace. 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. Following completion of the protocols (within 1min), a post exercise blood sample was collected for analysis of lactate. Finally, participants were asked to complete the Intrinsic Motivation Inventory (IMI) (Ryan, 1982).

Table 4. *Acute Home-HIIT protocols*

Protocol	Work duration (s)	Number of Intervals	Rest Duration (s)	Work-Rest Ratio	Exercises
60:60x6	60	6	60	1:1	1. SD + X 2. JO + JJ 3. B + J 4. HK + SJ 5. MC + STo 6. STh + EK
30:120x6	30	6	120	1:4	1. SD 2. X 3. JO 4. JJ 5. B 6. J
30:60x6	30	6	60	1:2	
30:30x6	30	6	30	1:1	
30:30x12	30	12	30	1:1	1. SD 2. X 3. JO 4. JJ 5. B 6.J 7. HK 8. SJ 9. MC 10. STo 11. STh 12. EK

Exercise abbreviations: B – burpees, EK – elbow to knee, HK – jogging high knees, J – jogging on the spot, JJ – jumping jacks, JO – jump overs, MC – mountain climbers, SD - spotty dogs, SJ – squat jumps, STh – squat thrusts, STo – squat touches, X – x jumps. Selection of these exercises are based on previous literature by Scott et al. (2019a).

4.5 Study 2: Chronic phase

4.5.1 Experimental design

The study used a randomised counterbalanced crossover design whereby participants completed two 6-wk training interventions, 30:120HIIT (30s high intensity efforts interspersed with 120s active recovery) and 60:60HIIT (60s high intensity efforts interspersed with 60s active recovery), separated by a 4-6-wk washout period. Before each intervention period participants completed pre-training testing. Participants attended the laboratory after an overnight fast (>10 hours), having abstained from caffeine, alcohol and vigorous exercise the day before testing. During the visit participants blood pressure, aortic pulse wave velocity, body composition and cardiorespiratory fitness were assessed. Blood samples obtained through an oral glucose tolerance test (OGTT), and flow mediated dilation (FMD) measurements were conducted pre and post intervention, however due to Covid-19 restrictions, analysis of these measures was not completed (Appendix 2).

Participants were then randomised to either 6-wks of 30:120HIIT or 60:60HIIT and began training approx. 48h following pre-training testing. On completion of training, participants returned for post-training testing at least 72h after the final training session, all procedures were identical and completed at the same time of day (±0-3 h) as the baseline measures taken on participant’s first visit. Participants then underwent a 4-6-wk washout period, during which they were instructed to return to their pre intervention levels of physical activity. After the washout period participants began a second experimental period identical in all respects to the first, except the alternative training intervention was conducted (Figure 1).

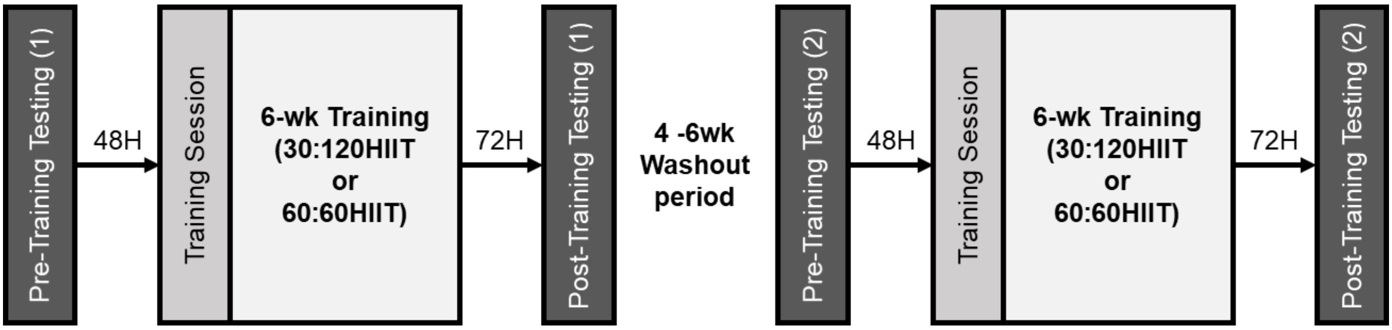

Figure 1. *Chronic Phase, Protocol Overview*

4.5.2 Home-HIIT Interventions

During both interventions’ participants trained 3x/wk (18 sessions in total). To be eligible to complete the study participants had to complete ≥80% of training sessions during each intervention and could not miss more than one training session in a week. All ‘Home-HIIT’ training sessions were performed in a place of the participants choosing, without supervision from the research team. Each HIIT session began with a two-minute warm up consisting of jogging on the spot. Participants were given a training booklet for each intervention which contained 18 different bodyweight exercises that participants could freely select themselves. 60:60HIIT intervals were composed of two different 30s bodyweight exercises with no rest in between. To facilitate this suggested exercise pairs were also detailed in the 60:60HIIT training booklet. Participants were provided with a HR monitor (Polar H10, Warwick, England) and were requested to wear the monitor for all exercise sessions. During both interventions' participants were advised to achieve ≥80% of PHRmax during the intervals. During the 30:120HIIT intervention participants completed four intervals during week 1, five intervals in week 2, six intervals in weeks 3 and 4, seven intervals in week 5 and eight intervals in week 6 (**Table 5**). During the 60:60HIIT intervention participants completed six intervals during week 1, seven intervals in week 2, eight intervals in weeks 3 and 4, nine intervals in week 5 and ten intervals in week 6 (**Table 6**). The increase of intervals each week were in keeping with previous literature (Scott *et al.,* 2019a). During study 2, RPE, Feeling Scale and IMI measurements were not recorded. This is because we had assessed these measurements in study 1 and our main objective in study 2 was to assess physiologically if 30:120HIIT and 60:60HIIT would be effective at improving CRF.

Table 5. Characteristics of 30:120HIIT

Week	Number of Intervals	Total Interval Duration (mins)	Total Rest Duration (mins)	Total Time (mins)
1	**4**	**2**	**8**	**12**
2	**5**	**2.5**	**10**	**14.5**
3	**6**	**3**	**12**	**17**
4	**6**	**3**	**12**	**17**
5	**7**	**3.5**	**14**	**19.5**
6	**8**	**4**	**16**	**22**

Table 6. Characteristics of 60:60HIIT

Week	Number of Intervals	Total Interval Duration (mins)	Total Rest Duration (mins)	Total Time (mins)
1	**6**	**6**	**6**	**14**
2	**7**	**7**	**7**	**16**
3	**8**	**8**	**8**	**18**
4	**8**	**8**	**8**	**18**
5	**9**	**9**	**9**	**20**
6	**10**	**10**	**10**	**22**

4.6 Measurements

4.6.1 Perceptual responses during and motivational responses following acute exercise

4.6.1.1 Rate of Perceived exertion

Whole-body rate of perceived exertion was assessed 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 of 10 indicated the highest sustainable exercise intensity (maximal).

4.6.1.2 Feeling 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 participants were asked their score based on their feelings at the time of completing the scale.

4.6.1.3 Motivation

The Intrinsic Motivation Inventory (IMI) is a multidimensional measurement device, which includes two subscales to assess both interest/enjoyment and perceived competence (Ryan, 1982). 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.

4.6.2 Assessment of heart rate during acute exercise

HR was assessed continuously throughout each protocol (Polar H10). 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 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). All heart rate data was normalised to participants PHR_{max}.

4.6.3 Pre- and Post-Intervention Testing Measures

4.6.3.1 Body composition

Participant's body composition was assessed using SECA Bio-Impedance Scales (SECA mBCA 515) (Birmingham, UK). The device was used to assess body mass, fat mass, body fat percentage and muscle mass.

4.6.3.2 Blood Pressure and aortic Pulse Wave Velocity

Following 20 minutes of supine rest, brachial artery blood pressure measurements were made in triplicate using an automated sphygmomanometer (Dianamap; GE Pro 300V2, Tampa, FL, USA). Aortic (carotid-femoral) pulse wave velocity (aPWV) was assessed using a semi-automated device and software (SphygmoCor, AtCor Medical, Sydney, Australia). A single high fidelity applanation tonometer was used to obtain a proximal (carotid artery) and distal (femoral artery) pulse, recorded sequentially over 10 waveforms. Simultaneously the QRS complex was measured using electrocardiography (ECG).

4.6.3.3 Cardiorespiratory fitness

A progressive exercise test to exhaustion was performed on an electronically braked cycle ergometer (Lode BV, Groningen, Netherlands) to determine peak oxygen consumption (VO_{2peak}), using an on-line gas collection system (Moxus modular oxygen uptake system, AEI technologies, Pittsburgh, PA) , as described previously (Scott et al., 2018). The test consisted of initially cycling at 25W for females and 60W for males, followed by consecutive increases of 35W every 3min until the participants could no longer cycle, or their cadence dropped below 50 rpm, at which point the test was terminated. VO_{2peak} was defined as the highest VO_2 achieved over a 15s recording period. Participants were fitted with a heart rate monitor (Polar H10, Warwick, England) to determine maximum HR.

4.6.4 Assessment of Heart Rate during training

Following each training session HR data was automatically uploaded to a cloud storage site (www.flow.polar.com). Using the method described above (4.6.2), session HRmean and HRpeak, interval HRmean and HRpeak, proportion of intervals meeting the high-intensity criterion (HR >80% of max) and time spent above the criterion HR were calculated for each training session. The values derived from each session over the 6-wks were then used to create an intervention mean. Descriptive training session analysis used per protocol principles, where only data for completed training sessions was presented.

4.7 Statistical analysis

All analyses were performed using statistical analysis software (IBM SPSS for windows version 26 (SPSS, Chicago, IL, USA)). Significance was set at $P \leq 0.05$. Results are expressed as means ± SD.

4.7.1 Study 1: Acute phase

A one-way within subjects 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). An LSD post-hoc test was applied where appropriate.

4.7.2 Study 2: Chronic phase

Before the start of the study, it was calculated that 26 participants were needed to reach a power of 80% to detect a true difference of $1.5ml.kg^{-1}.min^{-1}$ in CRF, which was the primary outcome parameter. For these calculations a two-sided alpha of 0.05 and a standard deviation for change in CRF of $2.6ml.kg^{-1}.min^{-1}$ (unpublished data from the research group) were used. Response to training was assessed as post minus pre for 30:120HIIT and 60:60HIIT. Differences in HR responses to the interventions and the effect of the interventions on health outcomes were assessed using a linear mixed model which adjusted for pre-training values. Carry-over and order effects were also assessed using a linear mixed model.

5. Results

5.1 Study 1: *Acute phase.*

5.1.1 Participants

Ten healthy participants (male/female: n=5/5) meeting the inclusion criteria; aged between 18-35 years, with a BMI < 32kg.m^{-2}, completed the study (**Table 2**).

5.1.2 Acute Physiological Responses to Exercise

5.1.2.1 Heart Rate

Mean HR traces for each protocol are shown in **Figure 2**. There was a significant effect of protocol for all HR variables considered (P<0.05; **Table 7**). Session HR_{mean} and HR_{peak} were both significantly higher during 30:30x12 than all other protocols (P<0.05). 60:60x6 also resulted in a significantly higher session HR_{mean} than 30:120x6 (P=0.004) and HR_{peak} than 30:30x6 (P=0.02), 30:60x6 (P=0.02) and 30:120x6 (P=0.02).

Interval HR_{mean} and HR_{peak} were significantly higher during 30:30x12 than all other protocols (P<0.05), and 30:60x6 (P=0.02) and 30:120x6 (P=0.01), respectively. 60:60x6 also resulted in significantly higher interval HR_{mean} than 30:60x 6 (P=0.01) and 30:120x6 (P<0.001) and HR_{peak} than 30:30x6 (P=0.04), 30:60x6 (P=0.05) and 30:120x6 (P=0.01).

Time spent (in minutes) above the criterion HR (HR ≥80% of max) was significantly higher during 60:60x6 and 30:30x12, compared to 30:30x6, 30:60x6 and 30:120x6 (P<0.05). Finally, the criterion HR (HR >80% of max) was achieved more regularly during 60:60x6 and 30:30x12, than 30:30x6 and 30:120x6 (P<0.05).

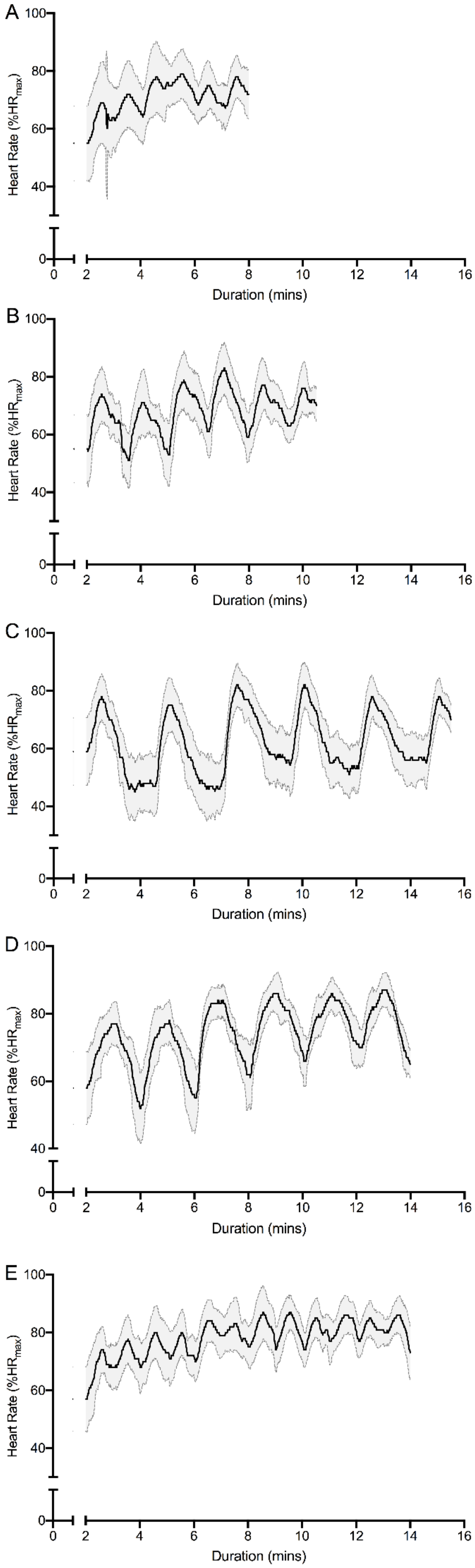

Figure 2. Heart rate responses to the acute HIIT protocols. *Mean ± SD heart rate traces during (A) 30:30x6 (30s exercise x6 with, 30s rest in-between), (B) 30:60x6 (30s exercise x6 with, 60s rest in-between), (C) 30:120x6 (30s exercise x6 with, 120s rest in-between), (D) 60:60x6 (60s exercise x6 with, 60s rest in-between), and (E) 30:30x12 (30s exercise x12 with, 30s rest in-between).*

Table 7. Heart Rate (HR) responses to the Acute HIIT protocols

	30:30x6	30:60x6	30:120x6	60:60x6	30:30x12	P Value
Session HR_{mean} (%)	71 ± 8*	63 ± 6*	58 ± 14*#	73 ± 4*	79 ± 6	*P*=0.017
Session HR_{peak} (%)	85 ± 8*#	85 ± 8*#	84 ± 7*#	89 ± 5*	92 ± 6	*P*<0.001
Interval HR_{mean} (%)	69 ± 8*	68 ± 7*#	63 ± 7*#	73 ± 4*	77 ± 7	*P*=0.001
Interval HR_{peak} (%)	75 ± 10	78 ± 8*	76 ± 8*	83 ± 5	83 ± 7	*P*=0.025
HR ≥80% max (min)	1.5 ± 1.7*#	1.8 ± 1.5*#	1.5 ± 2.0*#	3.9 ± 1.8	6.4 ± 3.7	*P*=0.001
Proportion of Intervals meeting a HR ≥80% max (%)	40 ± 42*#	54 ± 42	38 ± 48*#	69 ± 31	72 ± 32	*P*=0.026

*Values are mean ± SD. *Represents significant difference from 30:30x12 (P<0.05). #Represents significant difference from 60:60x6 (P<0.05). Session HR_{mean}: mean heart rate achieved during the whole exercise session. Session HR_{peak}: maximum heart rate achieved during the whole exercise session. Interval HR_{mean}: average mean heart rate achieved during each of the intervals only. Interval HR_{peak}: average maximum 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)) during the entire session. Proportion of intervals meeting a HR ≥ 80% max, proportion of the intervals meeting the high-intensity criterion (≥80% of maximum heart rate).*

5.1.2.2 Blood Lactate

There were no significant differences in baseline lactate between the HIIT protocols (30:30x6 1.56±0.56, 30:60x6 1.21±0.30, 30:120x6 1.49±0.60, 60:60x6 1.66±0.60, and 30:30x12 1.89±0.76mmol/L; P=0.141). 60:60x6 and 30:30x12 resulted in significantly greater change in blood lactate concentration compared to 30:30x6, 30:60x6, and 30:120x6 (P<0.05). There were no further differences between protocols (P>0.05; **Figure 3**).

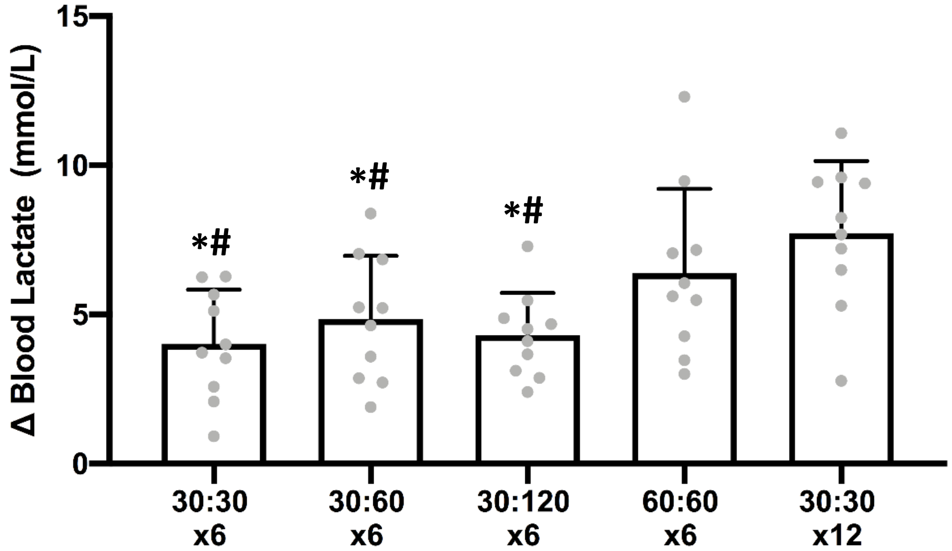

Figure 3. *Changes in blood lactate during the acute HIIT protocols. Values are means ± SD. * Significant difference from 30:30x12, # Significant difference from 60:60x6 (P<0.05).*

5.1.3 Acute Perceptual Responses during Exercise

5.1.3.1 RPE

There were no significant differences in baseline RPE between the HIIT protocols (30:30x6 2.30±1.06, 30:60x6 2.80±1.48, 30:120x6 2.60±1.07, 60:60x6 3.50±1.35, and 30:30x12 3.00±0.82 mmol/L; P=0.230). There was a significant effect of protocol on change in RPE (P=0.03). Change in RPE was lower during 30:120x6 compared to 30:30x12 (P=0.03), and 30:30x6 (P=0.003), and 60:60x6 compared to 30:30x6 (P=0.02). There were no further differences between protocols (P>0.05; **Figure 4**).

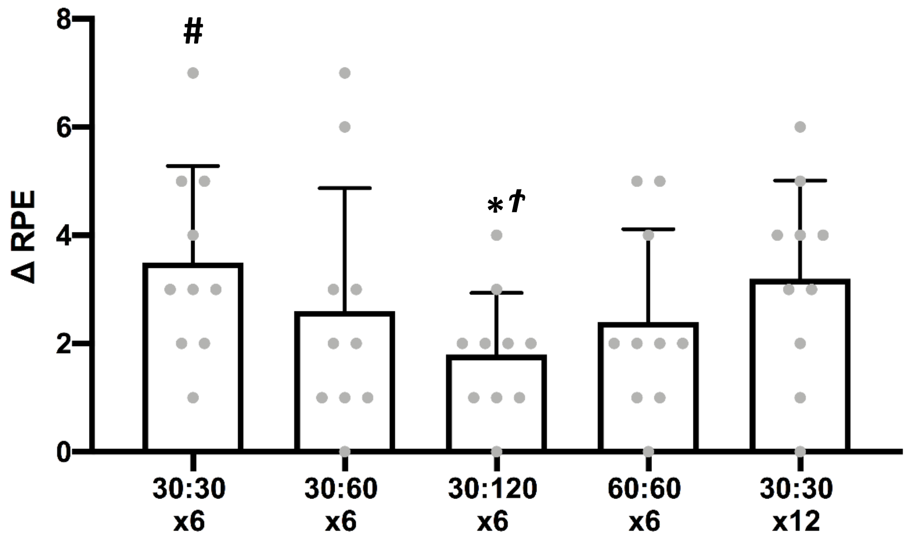

Figure 4. *Rate of perceived exertion scores across all acute protocols. Values are means ± SD. * Significant difference from 30:30x12, # Significant difference from 60:60x6 (P<0.05). † Significant difference from 30:30x6.*

5.1.3.2 Feeling Scale

There was a significant difference in the minimum reported Feeling Scale score between protocols (*P*=0.006), with 30:120x6 having a significantly higher minimum reported feeling scale score compared to all other protocols (*P*<0.05; **Figure 5**). There were no further differences between protocols (*P*>0.05).

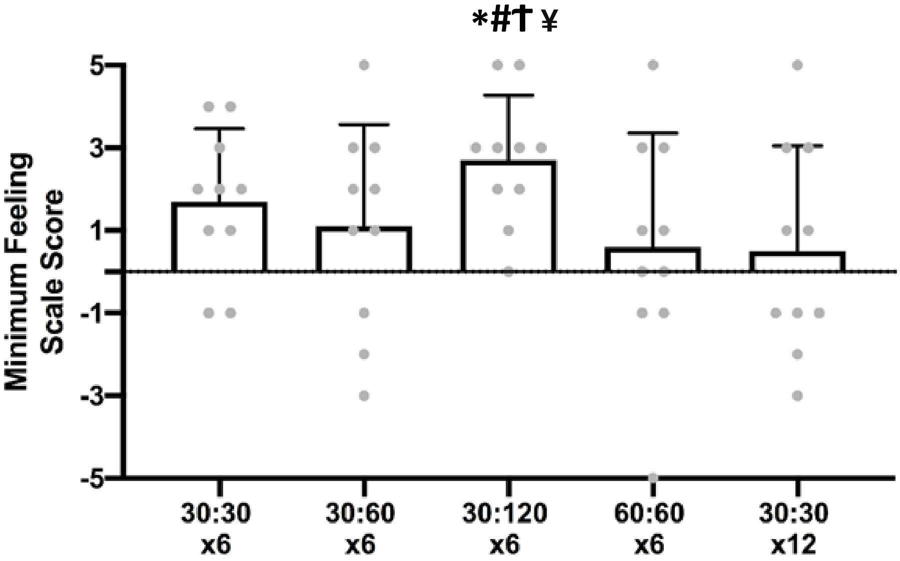

Figure 5. *Minimum recorded Feeling Scale score across all acute protocols. Values are means ± SD. * Significant difference from 30:30x12, # Significant difference from 60:60x6 (P<0.05). † Significant difference from 30:30x6. ¥ Significant difference from 30:60x6, (P<0.05).*

5.1.3.3 Intrinsic Motivation Inventory

There were no significant differences on the interest/enjoyment or perceived competence subscale of the IMI between protocols (*P*>0.05; **Figure 6**).

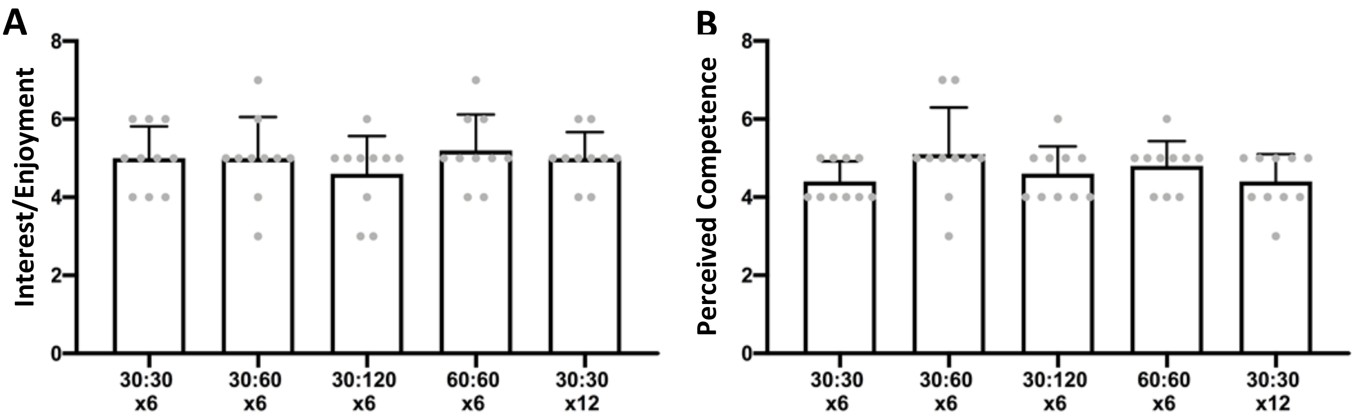

Figure 6. *Intrinsic motivation inventory responses to the acute HIIT protocols. (A) refers to the Interest/Enjoyment (B) refers to the perceived competence. Values are means ± SD.*

5.2 Study 2: Chronic Phase

5.2.1 Participant characteristics

48 participants were recruited for the study. However, only 28 participants completed at least 1 full phase of the HIIT intervention and therefore were included in the analysis. This is because only 16 participants completed both interventions, with a further 7 and 5 participants completing only 30:120HIIT or 60:60HIIT, respectively. As such, 23 and 21 participants completed 30:120HIIT and 60:60HIIT, respectively. See **Figure 7** for a consort flow diagram. Baseline characteristics (values recorded during the first pre-training testing session) for all participants and pre-training characteristics for 30:120HIIT and 60:60HIIT are reported in **Table 3**.

Table 8 shows the linear mixed model results examining mean change from pre- to post-training and magnitude of change with 30:120HIIT and 60:60HIIT (with associated 95% confidence interval and p-values). See **Appendix 1** for group level descriptive statistics across the study (mean ± SD).

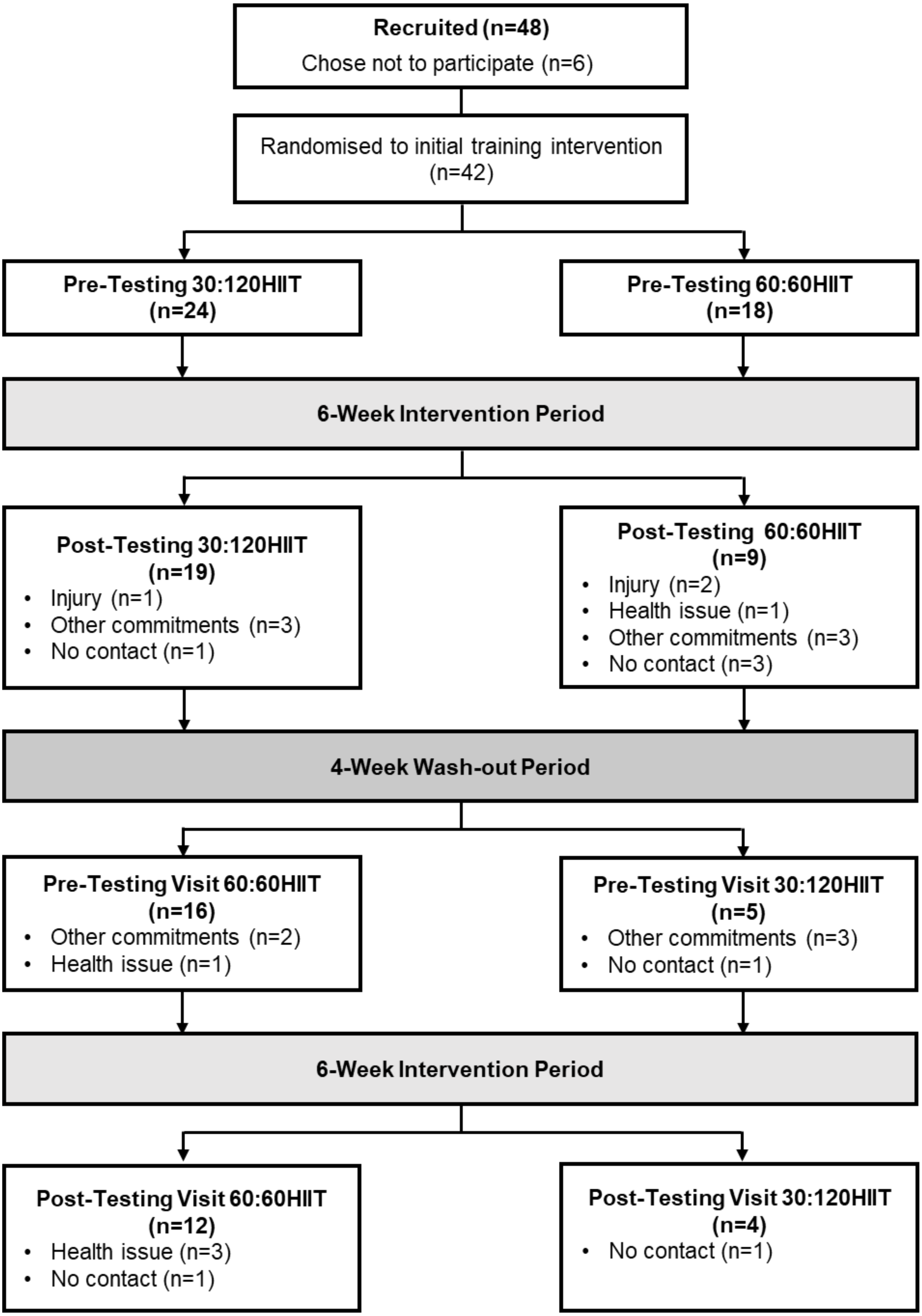

Figure 7. Consort participant flow diagram.

Table 8. Estimated change relative to baseline.

	30:120HIIT	P-value	60:60HIIT	P-value	30:120HIIT Vs 60:60HIIT	P-value
Exercise Capacity						
VO_{2peak} absolute (l.min)	0.13 (0.20, 0.06)	<0.001*	0.11 (0.18, 0.05)	0.002*	0.01 (-0.06, 0.08)	0.732
VO_{2peak} relative ($ml.kg^{-1}.min^{-1}$)	1.79 (-2.75, 0.84)	<0.001*	1.78 (0.79, 2.77)	0.001*	-0.004 (-0.97 0.98)	0.994
Body Composition						
Body Mass (kg)	0.15 (-0.59, 0.90)	0.684	-0.26 (-1.04, 0.52)	0.504	0.41 (-0.34, 1.17)	0.277
BMI ($kg.m^2$)	0.06 (-0.22, 0.33)	0.680	-0.10 (-0.38, 0.19)	0.509	0.15 (-0.13, 0.42)	0.289
Muscle Mass (kg)	0.08 (-0.34, 0.49)	0.717	-0.003 (-0.42, 0.42)	0.989	-0.08 (-0.33, 0.50)	0.693
Fat Mass (kg)	-0.35 (-1.16, 0.47)	0.401	-0.53 (-1.36, 0.31)	0.213	0.16 (-0.68, 0.99)	0.713
Fat Mass (%)	-0.33 (-0.47, 1.13)	0.409	-0.22 (-1.04, 0.60)	0.594	-0.14 (-0.95, 0.68)	0.742
Cardiovascular Responses						
Systolic Blood Pressure (mmHg)	-3.48 (-6.69, -0.27)	0.034*	-1.38 (-4.74, 1.98)	0.414	-2.20 (-5.43, 1.04)	0.180
Diastolic Blood Pressure (mmHg)	-2.83 (-7.55, 1.90)	0.231	-0.86 (-5.80, 4.09)	0.726	-2.05 (-6.79, 2.69)	0.388
Pulse Wave Velocity (m.s)	-0.43 (-0.69, -0.17)	0.002*	-0.49 (-0.77, -0.21)	0.001*	0.07 (-0.21, 0.34)	0.639

*Mean change post 6-week intervention compared to pre-testing. 95% CI and P-values are presented. * indicates a significant value.*

5.3 Training Intensity

Mean HR traces for both protocols are shown in **Figure 8.** A description of the heart rate responses during the interventions are displayed in **Table 9**. Interval HR_{mean} and Interval HR_{peak} significantly decreased over the 6-wk training period in both interventions (P<0.05). Mean values for all HR variables considered across the 6-wk interventions were significantly higher in 60:60HIIT compared to 30:120HIIT (P<0.05; **Table 10**).

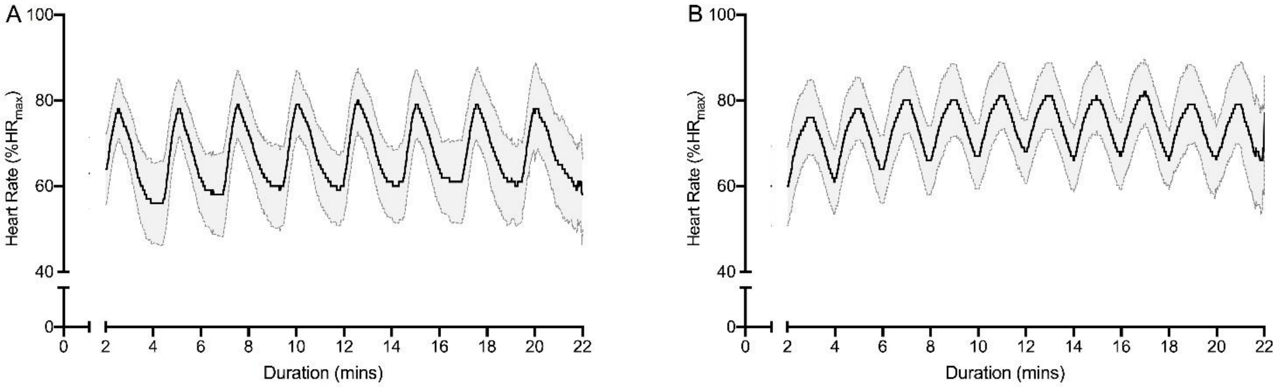

Figure 8. Heart rate responses to the chronic HIIT protocols. *Mean ± SD heart rate traces during (A) 30:120HIIT (30s exercise with 120s rest in-between), (B) 60:60x6 (60s exercise with 60s rest in-between).*

Table 9. Descriptive heart rate responses during each week of training, for both 30:120HIIT and 60:60HIIT.

	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Change from Week 1 to Week 6 (P-value)
Interval HR_{mean} (%PHR_{max})							
30:120HIIT	74 ± 5	73 ± 6	71 ± 8	71 ± 7	70 ± 6	70 ± 5	P=0.001
60:60HIIT	77 ± 8	75 ± 9	75 ± 7	75 ± 7	74 ± 7	75 ± 6	P=0.004
Interval HR_{peak} (%PHR_{max})							
30:120HIIT	87 ± 5	86 ± 5	84 ± 7	84 ± 5	83 ± 6	84 ± 5	P=0.001
60:60HIIT	89 ± 8	87 ± 8	88 ± 7	87 ± 7	84 ± 10	87 ± 6	P=0.013

Variables calculated as the mean of all exercise intervals over the 3 HIIT sessions during each week. ***Interval*** $\boldsymbol{HR_{mean}}$***,*** *interval mean heart rate as a percentage of predicted* HR_{max}*;* ***Interval*** $\boldsymbol{HR_{peak}}$***,*** *interval peak heart rate as a percentage of predicted* HR_{max}*. Values are presented as Mean±SD.*

Table 10. Heart Rate (HR) responses to the Chronic HIIT protocols

	30:120HIIT	60:60HIIT	P Value
Session HR_{mean} (%)	68 ± 1	75 ± 1*	*P*<0.001
Session HR_{peak} (%)	86 ± 1	88 ± 1*	*P*=0.012
Interval HR_{mean} (%)	71 ± 1	75 ± 1*	*P*<0.001
Interval HR_{peak} (%)	85 ± 1	87 ± 1*	*P*=0.017
HR ≥80% max (min)	2.4 ± 1.7	5.2 ± 3.6*	*P*<0.001
Proportion of Intervals meeting a HR ≥80% max (%)	57 ± 6	70 ± 6*	*P*=0.037

**Represents significant difference to 30:120HIIT (P<0.05). Variables calculated as the mean of all recorded HIIT sessions over the 6-week intervention. Session HR_{mean}: mean heart rate achieved during the whole exercise session. Session HR_{peak}: maximum heart rate achieved during the whole exercise session. Interval HR_{mean}: average mean heart rate achieved during each of the intervals only. Interval HR_{peak}: average maximum 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)) during the entire session. Proportion of intervals meeting a HR ≥ 80% max, proportion of the intervals meeting the high-intensity criterion (≥80% of maximum heart rate). Values are mean ± SD.*

5.4 Chronic Physiological Responses

5.4.1 Cardiorespiratory Fitness

Figure 9 shows changes in CRF from pre- to post-training. CRF increased following both 30:120HIIT and 60:60HIIT (absolute and relative VO_{2peak}) (P<0.05). However, the magnitude of change in CRF with 30:120HIIT and 60:60HIIT was not different (P>*0.05*) (**Table 8**).

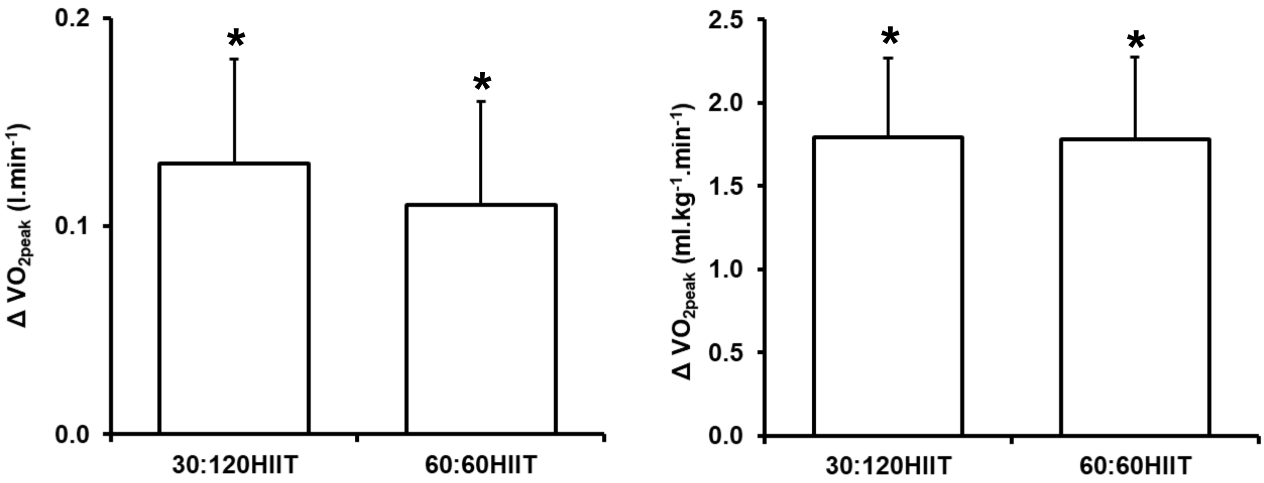

Figure 9. Mean change in cardiorespiratory fitness from pre- to post intervention in 30:120HIIT and 60:60HIIT. *A) Absolute change in VO_{2peak}, B) relative change in VO_{2peak}. Data presented as mean + SD. * Significant from pre-training.*

5.4.2 Body Composition

There were no significant changes in body mass, BMI, fat mass, body fat percentage, nor muscle mass, for either 30:120HIIT or 60:60HIIT (P>0.05). The magnitude of change in body composition variables with 30:120HIIT and 60:60HIIT was also not different (P>0.05 (**Table 8**).

5.4.3 Cardiovascular Responses

Compared to pre-training, 30:120HIIT significantly reduced systolic blood pressure (*P*=0.03), but there was no significant change in diastolic blood pressure (*P*=0.23). There were no significant improvements in systolic (*P*=0.41) or diastolic (*P*=0.73) blood pressure following 60:60HIIT. Despite differences in training response the magnitude of change in systolic (*P*=0.31) or diastolic (*P*=0.52) blood pressure with 30:120HIIT and 60:60HIIT was not different. There was a significant reduction in aPWV compared to pre-training in both 30:120HIIT (*P*=0.002) and 60:60HIIT (*P*=0.001), but the magnitude of change with 30:120HIIT and 60:60HIIT was not different (*P*=0.73) (**Table 8**).

5.4.4 Carry-over effect of 4-week wash out period

There were no carry-over effects evident as significant differences in CRF (absolute and relative) (*P*=0.13, *P*=0.20), body mass (*P*=0.89), BMI (*P*=0.96), fat mass (*P*=0.76), body fat percentage (*P*=0.56), muscle mass (*P*=0.24), systolic and diastolic blood pressure (*P*=0.95, *P*=0.86), nor aPWV (*P*=0.68) at baseline prior to and following the 4 week washout period. (**Appendix 1**).

5.4.5 Order effects

There were no order effects for the impacts of 30:120HIIT and 60:60HIIT for magnitude of change in CRF (absolute and relative) (*P*=0.09, *P*=0.28), body mass (*P*=0.72), BMI (*P*=0.51), fat mass (*P*=0.30), body fat percentage (*P*=0.77), muscle mass (*P*=0.41), systolic and diastolic blood pressure (*P*=0.08, *P*=0.25), nor aPWV (*P*=0.54).

6. Discussion

The main novel finding of the present study is that a bodyweight HIIT protocol (30:120HIIT) that uses a shorter interval duration (30s) and a longer work-to-rest ratio (1:4) can produce similar increases in CRF to 60:60HIIT, despite producing significantly lower blood lactate and heart rate responses. Importantly, during exercise 30:120HIIT was perceived as less averse than all other protocols tested, including 60:60HIIT. These data demonstrate that bodyweight 30:120HIIT is an efficacious model for improving CRF. However, future studies are needed to evaluate if the less aversive perceptions of 30:120HIIT result in greater long-term adherence to the protocol, and therefore, improved ‘real world’ effectiveness.

6.1 Perceptual Responses to an Acute bout of HIIT

The 30:120x6 protocol was perceived as less aversive than all the other HIIT protocols investigated. Given there were no differences in interval number, interval duration or physiological responses (change in lactate and heart rate variables) between 30:120x6 and 30:30x6 and 30:60x6 this suggests that the work-to-rest ratio and/or the rest duration plays a critical role in determining in-task affective response to bodyweight HIIT. This is likely to be an important observation for the design of future HIIT interventions as evidence suggests that positive in-task affective responses to moderate-intensity continuous exercise are reliably linked with future exercise participation and adherence (Rhodes & Kates 2015). As such, if the positive relationship between in-task affect and adherence demonstrated with moderate intensity continuous exercise holds true for HIIT, the less aversive nature of 30:120HIIT may influence future behaviour, leading to improvements in long term adherence when evaluated in a ‘real world’ environment. A future randomised controlled trial is needed to evaluate if 30:120HIIT can lead to improvements in adherence. In addition, future work should continue to focus on how manipulating work-to-rest ratio and/or rest duration can influence affective responses during exercise, focusing on more at-risk groups than considered in the current study.

Despite producing significantly higher physiological responses the 60:60x6 and 30:30x12 protocols produced similar in-task affect to 30:30x6 and 30:60x6. This data contrasts with previous studies which have shown that greater physiological strain during HIIT exercise is associated with more aversive responses (Boyd *et al.,* 2013; Kilpatrick, Greeley and Collins, 2015). These studies have been used to support the application of Dual-Mode theory for HIIT, suggesting that affective responses experienced during exercise are influenced by the metabolic demands relating to the exercise (Ekkekakis, 2011). In contrast to the current study only exercise intensity was different between protocols in these earlier studies, and the same interval duration and work-to-rest ratios were employed. In addition, exercise was conducted on a cycle ergometer. As such this study may suggest that exercise mode (cycle ergometer vs. bodyweight exercises) and manipulation of work-to-rest ratio, interval number and interval duration could interfere with the utility of Dual-Mode theory for HIIT. This is supported by Wood *et al.* (2016) who observed similar affective responses during HIIT and SIT, despite significant increases in lactate accumulation during SIT. Importantly, the SIT protocol employed by Wood *et al*. (2016) used a shorter interval duration (30s vs. 60s) and longer work-to-rest ratio (1:3 vs. 1:1) than the HIIT protocol.

6.2 Bodyweight HIIT Increases Cardiorespiratory Fitness in 6-weeks

In the current study, similar improvements in cardiorespiratory fitness were seen following 6 weeks of 30:120HIIT (1.79 ± 0.35 $ml.kg^{-1}.min^{-1}$) and 60:60HIIT (1.78 ± 0.36 $ml.kg^{-1}.min^{-1}$). A recent meta-analysis reported a 2-15% increase in CRF following HIIT in healthy non-athletic or sedentary individuals (Weston *et al.,* 2014) which is similar to the 6% and 5% increase in CRF following 30:120HIIT and 60:60HIIT, respectively. The increase is also similar to previous studies using the same bodyweight 60:60HIIT protocol in obese individuals with elevated cardiovascular disease risk (6%)(Scott *et al.,* 2019) and Type 1 diabetes (7%) (Scott *et al.,* 2018), over 4 and 6 weeks, respectively. The increase in CRF observed following 30:120HIIT and 60:60HIIT is important as having higher levels of CRF reduces the risk of all-cause and cardiovascular mortality in men and women regardless of age, ethnicity, adiposity, smoking status, alcohol intake, and health conditions (Lee *et al.,* 2010). Kavanagh *et al.* (2002) also demonstrated that a 1 $ml.kg^{-1}.min^{-1}$ increase in CRF was associated with a 10% reduction in cardiovascular mortality risk.

6.3 Training Intensity and Cardiorespiratory Fitness

Comparable increases in CRF were observed following 30:120HIIT and 60:60HIIT, despite 60:60HIIT resulting in greater acute increases in blood lactate (study 1) and acute (study 1) and training (study 2) increases in heart rate responses than 30:120HIIT. It is not clear from the current study why differences in training load did not induce differences in CRF between the protocols, as recent studies have suggested that the magnitude of physiological adaptations following HIIT may be linked to the accumulation of lactate and heart rate responses during exercise. Hoshino *et al.* (2015) found pharmacological blunting of lactate accumulation in mice, through chronic administration of dichloroacetate, attenuated increases in mitochondrial enzyme activity (CS and b-HAD) and protein content (COXIV) following 4 weeks of HIIT (10x60s high intensity treadmill running with a 1 min rest), compared to control animals treated with saline. This suggests that repeated lactate accumulation during HIIT is important for training–induced mitochondrial adaptations and that acute physiological responses may dictate long-term training outcomes to HIIT. Furthermore, Fiorenza *et al.* (2018) demonstrated that speed endurance exercise (18x5s “all out” efforts), which was associated with higher muscle lactate accumulation and lower muscle pH, increased PGC-1α mRNA response compared to work matched repeated-sprint exercise (6x20 s “all-out” efforts). In addition, the current data contrasts previous work using longer duration aerobic interval training (4x4min intervals interspersed with 3min of rest) which has suggested higher interval HRmean leads to greater increases in CRF. In this study, Moholdt *et al.* (2014) demonstrated that patients with coronary heart disease who exercised at ≥92% HR_{max} achieved significantly greater improvements in CRF (approx. 2ml.kg^{-1}.min^{-1}) than patients who exercised at <92%HR_{max}, over 12 weeks. We hypothesize that although statistically significant the differences in blood lactate accumulation (2mmol/L) and heart rate responses (chronic (study 2) interval HRmean 4%) between 30:120HIIT and 60:60HIIT were not enough to cause long terms differences in CRF, and/or that higher workloads (chronic interval HRmean 71% PHR_{max} 30:120HIIT and 75% PHR_{max} 60:60HIIT) may be needed to induce differences between protocols, as demonstrated by Moholdt *et al.* (2014) where HRmean was >92%.

6.4 Other Health Related Markers

In the present study there were no significant differences in any of the body composition variables measured following 6 weeks of either 30:120HIIT or 60:60HIIT. This is in line with findings reported in a recent meta-analysis from Sultana *et al.* (2019), where low-volume HIIT, involving either walking, running, or cycling, had no significant impact on body composition. However, this meta-analysis included studies using HIIT protocols of varying exercise intensity, interval duration, interval number, work-to-rest ratio, and total intervention duration. In contrast, Gillen et al. (2013) showed that 6 weeks of a similar 60:60HIIT protocol (18 sessions of 10x60s with 60s recovery), performed on a cycle ergometer at 90% HRmax, resulted in significant reductions in whole body percent fat in overweight women. Interestingly, a meta-analysis by Maillard *et al.* (2018) showed that exercise intensities during HIIT above 90% HRmax are more effective for reducing whole-body adiposity than lower exercise intensities. Therefore, the lack of change in body composition observed in the current study could be explained by the lower heart rate responses observed in both 30:120HIIT (interval HRmean 71% PHR_{max}) and 60:60HIIT (75% PHR_{max}).

There was also a significant reduction in aPWV following both 30:120HIIT (-0.43m.s or -8.1%) and 60:60HIIT (-0.49m.s or -9.1%). These results support those of Scott *et al.,* (2019) who found a 17% reduction in aPWV following 12 weeks of a similar 60:60HIIT bodyweight HIIT protocol in obese individuals with elevated cardiovascular disease risk. This reduction in aPWV is of clinical relevance as increased central artery stiffness is associated with negative cardiovascular outcomes even in young individuals (Zebekakis *et al.,* 2005). Systolic BP was significantly reduced following 30:120HIIT with no differences following 60:60HIIT. In addition, no differences in diastolic BP were observed following either training mode. The difference in systolic blood pressure between 30:120HIIT and 60:60HIIT was unexpected and the reason for this discrepancy is unknown. It was hypothesized that BP would be unchanged in both groups as BP measures presented at baseline were healthy (Dasgupta *et al.,* 2014), therefore, the possibility to further decrease these values with just 6 weeks of training was minimised.

6.5 Bodyweight HIIT a Practical Training Model

The current study adds to a growing body of work that suggests Home-based HIIT protocols are an efficacious alternative mode of HIIT (Scott *et al.,* 2018, Scott *et al.,* 2019, Gibala *et al.,* 2020, Blackwell *et al.,* 2017). Unlike cycling or running based HIIT protocols using body weight exercises eliminate major perceived barriers that prevent numerous people from exercising. This protocol was performed within participants homes or a place of their choosing without any equipment or supervision. Therefore, major barriers such as 'intimidating' gym environments, inadequate financial resources, complications with access to facilities, travel time (Trost *et al.,* 2002, Morgan *et al.,* 2016), difficulty with transportation (Korkiakangas *et al.,* 2009) and poor weather (Das and Petruzzello, 2016) were removed. In addition, the study further confirms that sedentary individuals are able to complete home-based HIIT at sufficiently high exercise intensities to elicit health benefits when performed at home without supervision (Scott *et al.,* 2018). However, participants were provided with heart rate monitors to guide exercise intensity. Cost of heart rate monitors may form an additional barrier to exercise, as such, future studies should evaluate the effectiveness of home-based HIIT when simple indicators of exercise intensity such as RPE alone are used. A recent study using brief intense stair climbing intervals suggested that using RPE to guide intensity can lead to increases in CRF in sedentary women (Gibala *et al.,* 2020).

6.6 Future Directions

In the current study, both home-based HIIT protocols were carried out under almost ideal conditions, i.e. 3 days a week over a 6-week period, totalling 18 sessions, and although participants were not directly supervised they were provided with HR monitors to self-assess that they were working at the desired intensity of ≥80% PHR_{max}.

Under these conditions, 30:120HIIT produced similar improvements in CRF to that of 60:60HIIT despite producing significantly lower physiological responses during exercise, and even with 30:120HIIT producing less aversive in-task perceptions than all the other protocols, including 60:60HIIT in the acute study. Thus demonstrating that both protocols are efficacious.

If findings from MICT regarding the influence of in-task affect on subsequent adherence work for HIIT, we would hypothesize that 30:120HIIT would result in greater adherence than 60:60HIIT. In the present study, adherence of above 80% was enforced, so the influence of in-task perceptions on adherence could not be investigated, but it was observed that more people dropped out during 60:60HIIT than in 30:120HIIT. To truly evaluate the potential of 30:120HIIT to influence adherence a future randomised controlled trial is needed. This would demonstrate if 30:120HIIT is truly more effective and if it works under real-world conditions.

This contrasts with previous research which suggests that exercise intensity during HIIT influences long term outcomes. In the present study, it was suggested that participants should aim to reach ≥80% PHR_{max}, however the session and interval HRmeans were lower than the target in both HIIT protocols. Perhaps if individuals were given a higher target of ≥90% PHRmax it would result in higher HRmeans possibly reaching the original ≥80% PHR_{max}. We hypothesize that the difference between the protocols or the workloads induced were not high enough to produce differences between the intervention. Therefore, future research should evaluate protocols with greater physiological intensities to see if these can influence CRF and other health variables. This could clarify what intensities are needed to produce significant improvements in health outcomes and once the optimal exercise intensity has been titrated a future RCT should investigate if this protocol will be adhered to by participants and if it can be effective in the real world.

In the present study, only healthy but sedentary participants were recruited, and it is important to note that individuals' perceptual responses during exercise differ between various populations. Differences between active and inactive individuals' perceptions towards exercise have been observed with feeling scale ratings appearing more negative in low active groups than in high active groups (Parfitt and Eston, 1995). More recently Martinez *et al.,* (2015) found that in overweight-to-obese, insufficiently active adults, pleasure and enjoyment were higher during HIIT sessions with shorter interval trials (30s) than during longer intervals (120s), supporting our findings with 30:120HIIT. However, a Home-HIIT protocol mirroring 60:60HIIT has proved efficacious in improving health markers in obese individuals with elevated cardiovascular disease risk (Scott *et al.,* 2019a) and people with type 1 diabetes (Scott *et al.,* 2019b). Importantly, no studies have evaluated the efficacy of 30:120HIIT in other populations. Future work should look at how the manipulation of work to rest ratios can influence in-task affect in different at-risk populations to see if the relationship shown in sedentary individuals is similar to the findings in the current study. If this is the case HIIT studies should look to influence affect and therefore long-term adherence by changing the work-to-rest ratio.

Although the use of HR monitors is a cheap, reliable, and an objective way to monitor intensity of bodyweight exercises, it could also be an additional barrier preventing the public from participating in HIIT. Therefore, alternative methods to prescribe exercise intensity need to be evaluated. The use of RPE could be an alternative as it is a free and useful measure of exercise intensity. Recently Allison *et al.* (2017) demonstrated that brief intense stair climbing using RPE to prescribe exercise intensity was effective at increasing CRF in sedentary women. Future work should evaluate the effectiveness of using RPE to prescribe exercise intensity during HIIT in a variety of populations, using blinded heart rate monitors to provide an objective assessment of participants exercise intensity when guided by RPE.

6.7 Conclusions

In summary, this study demonstrates that 6-weeks of either 30:120HIIT or 60:60HIIT result in similar improvements to CRF and aPWV. This suggests that either protocol can be used as an efficacious training mode in sedentary individuals. Interestingly, these differences were observed despite 30:120HIIT producing significantly lower lactate and heart rate responses than 60:60HIIT. In addition, 30:120HIIT resulted in less aversive perception during exercise. A future RCT is needed to evaluate if these differences in in-task affect result in greater long-term adherence to 30:120HIIT, and therefore, improved real-world effectiveness of the protocol.

6.8 COVID-19 contingency

Due to the covid-19 pandemic, my training intervention study (Study 2) was affected. Before lockdown was officially announced in March 2020, I had a few participants that were either unable to finish the training sessions or had finished but were unable to come in for post-testing. Their reasonings given at the time were because of health issues (**Table 7**). In hindsight, this could have been due to them contracting Covid-19, although this is speculation. Once lockdown was officially announced it meant the closure of all university buildings. This closure meant that I was unable to analyse my blood samples for glucose, nor was I able to analyse the FMD data for arterial function. This is because specialist equipment and computer software are needed which I did not have access to. Although the pandemic has caused a lot of disruption for many individuals, I feel very fortunate that I was coming towards the end of my data collection and ultimately, I had plenty of data to analyse and write up which I was able to do from home.

7. References

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8. Appendices

Appendix 1. Physiological responses to 30:120HIIT and 60:60HIIT.

Variable	30:120HIIT		60:60HIIT	
	Pre	Post	Pre	Post
Exercise Capacity				
VO_{2peak} absolute (l.min)	2.3 ± 0.9	2.5 ± 0.9*	2.4 ± 0.9	2.5 ± 0.9*
VO_{2peak} relative ($ml.kg^{-1}.min^{-1}$)	30.1 ± 10.6	33.8 ± 9.5*	32.6 ± 8.6	34.4 ± 8.9*
Body Composition				
Body Mass (kg)	72.6 ± 16.2	72.8 ± 15.9	72.6 ± 15	72.3 ± 15.5
BMI ($kg.m^2$)	25.2 ± 3.4	25.3 ± 3.2	25.1 ± 3.7	25.0 ± 3.7
Muscle Mass (kg)	24.7 ± 7.1	24.6 ± 7.3	25.0 ± 6.6	25.0 ± 6.7
Fat Mass (kg)	21.2 ± 8.3	21.2 ± 8.2	21.1 ± 8.1	20.5 ± 7.2
Fat Mass (%)	29.0 ± 8.5	29.1 ± 8.5	28.6 ± 8.8	28.4 ± 7.5
Cardiovascular Responses				
Systolic Blood Pressure (mmHg)	113.2 ± 9.4	109.7 ± 8.0*	111.4 ± 10.8	111.4 ± 10.8
Diastolic Blood Pressure (mmHg)	68.0 ± 11.6	65.2 ± 6.1	66.0 ± 7.3	66.0 ± 7.3
Pulse Wave Velocity (m.s)	6.2 ± 0.7	5.7 ± 0.7*	5.5 ± 0.9	5.0 ± 0.9*

Means ± SD reported for pre and post 6-week Home-HIIT interventions. ** indicates a significant value from pre.*

Appendix 2. Oral glucose tolerance test (OGTT) and Flow mediated dilation (FMD) methodology.

Brachial artery endothelial function was assessed using the flow mediated dilation technique (FMD). The right arm was extended and positioned 80° from the torso. A rapid inflation/deflation pneumatic cuff (D.E. Hokanson, Bellevue, WA) was placed around the forearm (immediately distal to the olecranon) to produce the stimulus of forearm ischemia. A 15-MHz multifrequency linear array probe, attached to a high-resolution ultrasound machine (T3300; Terason, Burlington, MA), was then used to image the brachial artery in the distal third of the upper arm. When an optimal image was obtained, the probe was held stable and the ultrasound parameters were set to optimize the longitudinal, B-mode image of the lumen–arterial wall interface. The ultrasound was also used to attain simultaneous continuous Doppler velocity using the lowest possible insonation angle (60°). A recording of resting diameter and velocity was taken for 1 minute, then the forearm cuff was inflated (>200 mm Hg) for 5 minutes. Both diameter and velocity recordings resumed 30 seconds before cuff deflation and continued for 3 minutes post deflation.

An Oral Glucose Tolerance test (OGTT) was conducted to assess glucose tolerance. A cannula was inserted into the antecubital vein of one arm. After a 5ml baseline sample was obtained, subjects consumed a beverage containing 75g glucose dissolved in 250ml of water. Further 5ml blood samples were obtained after 30, 60, 90 and 120 minutes, and were collected into EDTA-containing vacutainers. Plasma samples for each time point were obtained through centrifugation (10 min at 2500g at 4°C) and stored at -80°C for subsequent analysis.

Appendix 3. Pilot Testing

Methods

The aim of this pilot testing was to compare an acute bout of two bodyweight HIIT protocols to identify if a heart rate of ≥80% HRmax was achievable during exercise intervals, without verbal encouragement or specialised equipment.

Pre-exercise screening

Participant's suitability to undertake the study was assessed using the American College of Sports Medicines (ACSM) Physical Activity Readiness Questionnaire (PAR-Q+). A total of 26 healthy participants were deemed eligible to take part in the study (Table 11).

Pilot Testing

First participant's peak oxygen consumption (VO_{2peak}) was assessed. After this, a randomised crossover design was implemented to compare acute responses to two different Home-based HIIT protocols; 30:120HIIT (6 x 30s of "all-out" efforts interspersed with 2 minutes of recovery) and 60:60HIIT (6 x 60s of efforts interspersed with 60s of recovery). Each involved a 2-minute warm-up, six body weight exercises were carried out in total, a different exercise for each interval, (spotty dogs, jump overs, burpees, jogging with high knees, mountain climbers and squat thrusts) followed by a 2-minute cool down. All three visits were separated by ≥24 h. HR was monitored continuously throughout each session and participants were advised to reach 80% Predicted HRmax (PHRmax = 220-age) during the exercise intervals.

Table 11. Participants characteristics.

Variable	n = 26
Age (yr)	23 ± 3
Height (cm)	174 ± 9
Body Mass (kg)	72 ± 11
BMI ($kg.m^{-2}$)	24 ± 3
VO_{2peak} ($ml.min^{-1}.kg^{-1}$)	43 ± 9

Results

Heart Rate

Mean HR traces for both protocols are shown in **Figure 10**. Mean values for all HR variables considered were significantly higher in 60:60HIIT compared to 30:120HIIT ($P<0.05$) (**Table 12**).

Time spent (in minutes) above the criterion HR (HR ≥80% of max) was significantly higher during 60:60HIIT compared to 30:120HIIT ($P<0.05$).

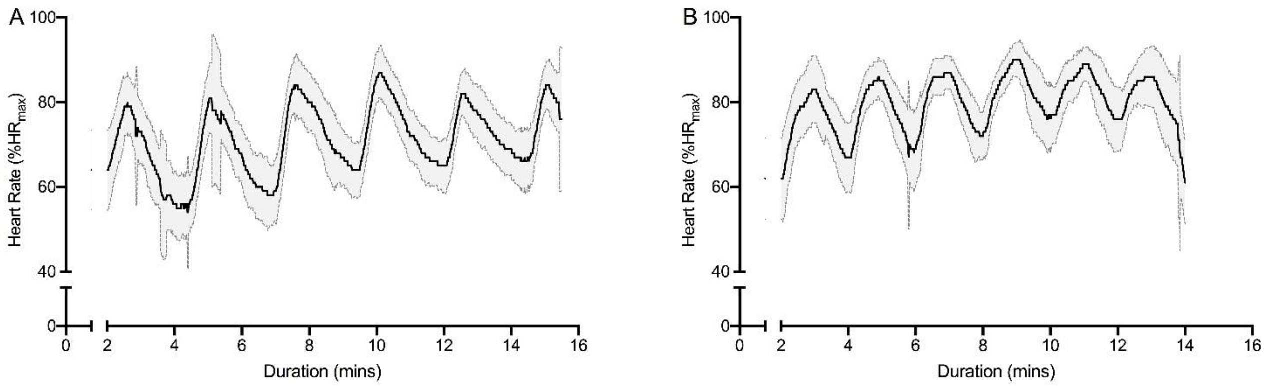

Figure 10. Heart rate responses to the HIIT protocols. *Mean ± SD heart rate traces during (A) 30:120HIIT (30s exercise with 120s rest in-between), (B) 60:60HIIT (60s exercise with 60s rest in-between).*

Table 12. Heart Rate (HR) responses to 30:120HIIT and 60:60HIIT.

	30:120x6	60:60x6	P Value
Session HR_{mean} (%)	70 ± 5	80 ± 5	P<0.001
Session HR_{peak} (%)	89 ± 5	92 ± 4	P=0.008
Interval HR_{mean} (%)	72 ± 5	81 ± 4	P<0.001
Interval HR_{peak} (%)	82 ± 5	88 ± 4	P<0.001

Discussion Although all HR variables for 60:60HIIT were significantly higher than in 30:120HIIT. It was still possible to reach a HR of ≥80% HRmax during 30:120HIIT.