The effects and differences of sprint interval training, endurance training and the training types combined on physiological parameters and exercise performance

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'Your determination today will lead to success tomorrow.'

Operational Definitions and Glossary of Terms

Maximal Oxygen Consumption ($\dot{V}O_{2Max}$)

Maximal oxygen uptake ($\dot{V}O_{2max}$) is the maximum amount of oxygen an individual can take in and utilise and considered to be the gold standard, most objective and primary determinant of endurance ability and exercise performance (Astrand et al., 1977; Davis et al., 1979; Yoshida et al., 1984; Noakes et al., 1998 & Levine et al., 2008). However in order to gain a true representation of an individual's $\dot{V}O_{2max}$, maximal exercise must be achieved, presenting a plateau in oxygen consumption, requiring the subject to exercise to exhaustion.

Peak Oxygen Consumption ($\dot{V}O_{2Peak}$)

Highest achievable oxygen consumption during maximal exercise, which does not produce a plateau instead a peak.

Anaerobic Threshold (AT)

The anaerobic threshold (AT) is the $\dot{V}O_2$ in $ml.kg^{-1}.min^{-1}$ when aerobic metabolism is insufficient to meet the energy demands and so is supplemented by anaerobic metabolism, (Vincent, 2009) and is the level of work or oxygen consumption just below the point at which metabolic acidosis and other associated changes in gas exchange take place (Wasserman et al., 1973; Wasserman et al., 1975; Davis et al., 1979).

Respiratory Exchange Ratio (RER)

The Respiratory Exchange Ratio is the amount of carbon dioxide produced divided by the oxygen uptake. It is used to indirectly measure the relative contribution of carbohydrates and lipids to overall energy expenditure, an indirect measure of the muscle's oxidative capacity to get energy. (Ramos-Jiménez et al., 2008).

Sprint Interval Training (SIT)

Short periods of high intensity exercise followed by intervals of rest. Sprint interval training involves repeated bouts of exercise ranging from 3s (Harridge et al., 1998), 30s (Jacobs et al., 1987) and often to 45s. Usually with periods of rest or recovery between bouts of sprint exercise, enabling intensities of the workload to be increased (Smith, 2008).

Endurance Training (ET)

Endurance training consists of continuous exercise, anything from around 20 minutes to a few hours, (Coburn, 2011) with a constant intensity at around a percentage of 50-70% of maximum where lactate levels are less than 4mmol**.** (Coyle, 1979)

Cardiac Output (Q)

Amount of blood pumped out of the heart in 1 minute. The product of stroke volume and heart rate.

Stroke Volume (SV)

Amount of blood pumped out the ventricle per beat (McArdle et al., 2006)

Abbreviations

SIT	Sprint Interval Training
ET	Endurance Training
COMB	Combined Training
IT	Interval Training
HIIT	High Intensity Interval Training
CT	Continuous Training
AIT	Aerobic Interval Training
$\dot{V}O_{2\,max}$	Maximal Oxygen Consumption (ml.kg-1.min-1) /(L/min)
AT	Anaerobic Threshold (ml/kg/min) / (L/min)
BP	Blood Pressure (mmHg)
SYS	Systolic
DIA	Diastolic
HR	Heart Rate (BP)
MHR	Maximum Heart Rate (BPM)
Q	Cardiac Output (L/min)
SV	Stroke Volume (L/min)
CV	Cardiovascular
$CaO_2 – CvO_2$	Arterial-Mixed Venous Oxygen Content Difference (mL/dL)
aVO_2 difference	Arterio-venous oxygen difference
O_2	Oxygen
CO_2	Carbon Dioxide
RER	Resting Exchange Ratio
VT	Ventilatory Threshold
ECG	Electrocardiogram
BMI	Body Mass Index
RPM	Revolutions Per Minute

RPE	Rating of Perceived Exertion
HDL	High Density Lipoprotein
LDL	Low Density Lipoprotein
CK	Creatine Kinase
La	Lactate
LDH	Lactate Dehydrogenase
PCr	Phosphocreatine
PGC-1a	Peroxisome Proliferator-activated receptor-γ Coactivator
ATP	Adenosine Tri-Phosphate
EPOC	Excess Post Oxygen Consumption
cAmk	Calcium–calmodulin Kinases
ANOVA	Analysis Of Variance
bpm	Beats per minute
MLSS	Maximum Lactate Steady State
CHO	Carbohydrates
ACSM	American College of Sports Medicine
SD	Standard Deviation
SE	Standard Error

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Abstract

Sprint Interval Training (SIT) is a time efficient way in order to elicit similar changes as Endurance Training (ET) on aerobic capacity, with the purpose of the exercise training to alter physiological systems and exceed resting homeostasis to improve and enhance physical work capacity (Hawley et al., 1997), ultimately achieving the most out of each training session, beneficial for health and performance. Research in the area has demonstrated, the positive effects of SIT and ET on some physiological, performance and health parameters, with further needed to establish these adaptations. Yet no research is currently available combining these two training types, in a single training session to obtained potentially greater benefits over the same period of time. The aim of this study was to compare and contrast the effects of SIT, ET and COMB training modalities on physiological parameters and exercise performance after an 8 week training programme.

Twenty nine participants volunteered to take part in the 10 week matched paired study, which included an 8 week training programme (age; 35.1±13.1 years, female; 16). All participants undertook a preliminary $\dot{V}O_{2max}$ test and baseline measurements were taken. Participants were then matched paired into groups, based on sex, $\dot{V}O_{2peak}$ (ml/kg/min) and resting heart rate (HR), then randomly assigned into a sprint interval (SIT), endurance (ET), a combined (COMB) sprint interval and endurance group or control group (CON). Participants in the SIT group undertook; 5-8 repetitions of 5-second sprints over the 8 weeks, on a cycle ergometer with intervals of 30 seconds, twice, interspaced with 4 minutes rest (<50rpm) three times per week. Those assigned to the ET group carried out cycling for 40 increasing to 60 minutes over the 8 weeks, at 60% of $\dot{V}O_{2peak}$ equivalent to 78.5% of maximum HR, three times per week. The COMB group undertook combination of the above two protocols based on the pilot study undertaken. The CON group were not required to undertake any training regime. After 4 week and 8 weeks of the training, all participants were required to undertake a $\dot{V}$O2max test and baseline measures were re-recorded. Prior to each $\dot{V}$O2max test, capillary blood samples were taken for the colorimetric assessment of cholesterol.

Two way factorial analysis of variance (ANOVA) were used for statistical analysis with lowest standard deviation (LSD) correction to reduce the type 1 error. Repeated measures ANOVA were used to assess changes within each individual training modality. Results indicate that SIT, ET, COMB and CON groups were not significantly different at baseline in $\dot{V}O_{2max}$ (p=0.993) and Resting HR (p=0.790) after being match paired into groups by these variables. Significant differences were evident in resting HR between the CON and SIT (p=0.005), CON and ET (p=0.016) as well as CON and COMB (0.026) after the 8 weeks of training. Additionally within the training groups in resting HR; SIT (p=0.006), COMB (p=0.016), ET (p=0.036). Significant differences were seen in relative AT between SIT and CON (p=0.097) after 8 weeks, as well as within the COMB group (p=0.028). Furthermore in diastolic blood pressure after 4 weeks between SIT and COMB (p=0.024), COMB and CON (p=0.029) and after 8 weeks between COMB and ET (p=0.032), COMB and SIT (p=0.033) and COMB and CON (p=0.029). In addition, significance was shown in triglycerides after 8 weeks of training, between ET and CON (p=0.032), SIT and COMB (p=0.025) and COMB and CON (p=0.008) CON. Finally significance was evident in blood glucose between COMB and SIT, halfway (p=0.002) and post training (p=0.019). In terms of age, there was a significant difference in $\dot{V}O_{2max}$ between those aged <35 years and those >35 years in VO_{2max} after 4 (p=0.022) and 8 weeks (p=0.020) of the training programme.
Overall the results indicated that when ET is substituted partly with SIT greater beneficial effects are obtained in numerous variables, demonstrated in this study, which has previously established, SIT is a time efficient training method. Furthermore, a lower duration of sprint i.e. 5 seconds, a more feasible sprint duration, as undertaken in this study provided comparable benefits to previous studies who have adopted longer sprint duration. Finally, these findings on various physiological measures and in a range of ages, indicate that a short time frame or by adopting a combined approach to training, can assist with reducing important health and performance parameters such as blood cholesterol, resting HR, blood pressure and ultimately maximal oxygen consumption and exercise performance, key indicators of cardiorespiratory fitness and health.

Keywords: Sprint interval training, combined training, endurance training, exercise performance, physiological, cardiovascular, heart rate, cholesterol.

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1.0 Introduction

Exercise training is known to have profound benefits on the physiology of the body, including the cardiorespiratory system, as well as increasing exercise capacity and $\dot{V}O_{2max}$. Furthermore, assisting with weight loss and muscular hypertrophy, beneficial for health & wellbeing, (Noakes et al., 1976; Wasserman et al., 1989; Kent, 2011; Gibala et al., 2006) as well as improving the energy status of working muscle, subsequently resulting in the ability to maintain higher muscle force outputs for longer periods of time, predominantly due to the increased mitochondrial density, number and size (Laursen & Jenkins, 2002). Data from the World Health Organization (2011) state that there is strong evidence that men and women who are more active have a lower rate of all-cause mortality, lower blood pressure and increased cardiorespiratory fitness. Current public health recommendations recognise the need for regular exercise and physical activity for the prevention and management of various physiological conditions including diabetes, hypertension, and coronary heart disease, and suggest that at least 150 minutes per week of moderate intensity activity, or 75 minutes of vigorous intensity activity spread across the week or combinations of both, is effective and sufficient enough to prevent an increase in weight gain and to maintain health (Donnelly et al., 2009; Pollock et al., 1998). However, worldwide, approximately one in three adults fail to meet this recommendation (Hallal et al., 2012) and in the UK only 40% of men and 28% of women achieve the recommended exercise guidelines, with the main barrier for this being 'lack of time' (NHS, 2011).

On-going research indicates the beneficial use of sprint interval training (SIT) or high intensity interval training (HIIT), as an alternative to continuous endurance training. Gosselin et al. (2011) showed that 5 bouts of high intensity training (HIT) are no more physiologically taxing than 20 min steady state exercise performed at 70 % $\dot{V}O_{2max}$, so that HIT might be safe and suitable for recreationally active people as well a trained population. Depending on intensity, the load can vary from 5 seconds to 4 minutes, followed by a few, usually 3 or 4 minutes of rest or low intensity (Boutcher, 2011; Gibala, 2009). Some studies have already publicised that HIT leads to improvements of both aerobic and anaerobic fitness (Whyte et al., 2010). Talanian et al. (2007) demonstrated that 2 weeks of HIT led to an increase of $\dot{V}O_{2max}$ of 7 to 12%. Depending on the age and fitness level of the subjects as well as the duration and intensity of the intervention improvements of $\dot{V}O_{2max}$ from 4 to 46% have been reported (Burgomaster et al., 2008; Helgerud et al., 2007; Tremblay et al., 1994; Warburton et al., 2006). All studies mainly included healthy, young trained participants. Consequently, there is still a lack of studies confirming the efficacy and the health relevance of HIT in people that are recreationally active or at an older age.

The purpose of exercise training is to alter physiological systems and exceed resting homeostasis to improve and enhance physical work capacity in turn enabling increased work on subsequent sessions (Hawley et al., 1997). Ultimately to achieve the most out of each training session improving health, exercise capacity and performance, beneficial for both the clinical and athletic populations. Manipulation of the intensity and duration of work and rest intervals changes the relative demands on particular metabolic pathways within muscle cells, as well as oxygen delivery to muscle (Holloszy & Coyle, 1984). In response, changes occur in both central and peripheral systems, including improvements in the cardiovascular system (Buchheit et al., 2009) muscle bioenergetics (Hawley, 2002), as well as enhanced morphological (Zierath & Hawley, 2004) and metabolic adaptations. (Hawley, 2002) The rate at which these adaptations occur is variable (Vollaard et al., 2009) and appears to depend on the volume, intensity, frequency and mode of the training.

Although many people are aware of these health benefits and endeavour to incorporate exercise into their daily lives (Hottenrott et al., 2012), it is suggested by Booth et al., (1997), that 'working people' in particular fail to perform training regularly mainly due to a lack of time (Booth et al., 1997). Therefore, the opportunity of training programmes is necessary to promote aerobic fitness and health as well as performance. The question arises, as to whether working people in particular, would rather benefit from longer; less frequent i.e. the traditional endurance continuous exercise or shorter, more frequent training sessions i.e. high intensity interval training/sprint interval training.

Hypertension is a leading risk factor for cardiovascular disease, other co-morbidities and ultimately death, which can be prevented or reduced by undertaking exercise. It has been demonstrated that endurance exercise can reduce high blood pressure and decrease the risk of other health risks by 25-40% (Kent et al., 2012 & Swaim & Edwards, 2003). Moreover, exercise training has been shown to improve several factors involved in the pathophysiology of hypertension, including sympathetic activity, endothelial function and insulin sensitivity (Ciolac et al., 2012). Multiple studies have shown an association between cardiovascular fitness and cardiovascular mortality, as well as all-cause mortality in men and women of all ages**.** Therefore indicating a strong rationale for undertaking exercise and incorporating it into daily life (Kessler et al., 2012). Epidemiological studies have shown that regular exercise and increased cardiorespiratory fitness can reduce blood pressure *(*Wisloff et al., 2007) in hypertensive and normotensive individuals, consequently reducing hypertension and aiding in the prevention of cardiovascular (CV) disease (Cornelissen & Fagrad, 2005 & Ciolac et al., 2010) .

Additionally, hypercholesterolemia is a major risk factor across the world. Exercise training has been shown to reduce total cholesterol, increase concentrations of high density lipoproteins (HDL) and is associated with a reduced risk of heart disease mortality (Kokkinos, & Fernhall, 1999). It has been demonstrated, that as little as one bout of exercise can have an effect on cholesterol, inducing changes in blood lipid and lipoprotein concentrations (Ferguson et al., 1998). However the amount or type of exercise that needs to be undertaken to elicit significant changes is an under researched area and it has often been suggested that there may be a certain threshold of exercise that needs to be met prior to theses change taking place, in particular in a sedentary population.

1.1 Sprint Interval Training, Endurance Training and Training Types Combined –

The comprehensive benefits of exercise training are well established, whether this be from endurance, sprint interval or resistance type training and it is recommended for the population worldwide. Endurance exercise is the most commonly undertaken form of exercise amongst the population (O'Connor, 2012), due to the widespread research in the area, knowledge and ease of it. However recently, extensive research suggests that SIT or HIIT, an innovative form of training requiring repeated supramaximal bouts of exercise, can stimulate beneficial cardiovascular and muscular adaptations, increased resting glycogen stores with a reduced utilisation and reduced lactate production and increased fat oxidation and oxygen uptake, (Astrand et al., 1964 & Gibala et al., 2012), similar to that gained from undertaking endurance training (ET) at a more time efficient rate (Rognomo et al., 2004 & Vogiatzis et al., 2005). Despite the similar physiological gains from SIT compared with ET, limited research has been carried out which combine the two training types. Research from both training types demonstrates that greater benefits may be observed if combined. Combining the two training types may be a more effective way in order to observe greater enhancements in the measured parameters, beneficial for both the trained and sedentary populations, additionally recent guidelines suggest that a combination of endurance and resistance work should be undertaken, however little is known regarding high intensity exercise combined with ET (Colberg et al., 2010).

The most commonly implemented protocol for sprint interval training is the Wingate protocol (Gibala et al., 2010) However it has been widely established and assessed that this may be impractical for the majority of the population due to the extremely high demand and motivation required, to undertake even just one 30 second sprint, indicating it may not be safe or tolerable for many individuals. Moreover the Wingate-based training model requires an extremely high level of subject motivation as well as the necessary equipment to efficiently and effectively undertake the activity. It is also unlikely that the general population as well as a clinical population could practically undertake the protocol both safely and effectively. Hence the recent investigations and research have implemented a modified version of the Wingate protocol, which can have similar benefits for the traditional Wingate test. One example is that from Gibala et al., (2012) who introduced 10x60s high intensity bouts, as opposed to the 30-second sprint and 30-second recovery, for use in a clinical population or that from Tabata and colleagues (1996) who adopted a protocol of 20-seconds exercise and 10-seconds rest at an intensity of 170% $\dot{V}O_{2max}$.

While it has been recognised that both high-volume training and high-intensity training are important, it is still unclear how to best manipulate these components in order to achieve optimal exercise performance, in well-trained athletes and in the general population. Important factors to consider when undertaking training include; intensity, frequency and duration. Additionally, it has been shown in well trained athletes, that a short term period of high intensity training can improve performance, however little information is available about the impact of changes in the volume of training (Laursen & Jenkins, 2002 & Fiskerstrand & Seiler, 2004).

Team-sports such as football, rugby and hockey require players to perform repeated sprints at a high intensity interspaced with period of rest or a reduced intensity throughout the game situation. Often the recovery between these sprint are longer than a minute and enough to allow for sufficient recovery so subsequent sprints or bursts are not affected, however recent game analysis has demonstrated that, in fact, a large percentage of the sprint activity in a game are separated by much shorter periods of recovery i.e. around 30 seconds (Spencer et al., 2004). Therefore, it has been suggested that one of the fitness requirements of team-sport athletes is the ability to perform short-duration sprints (< 10 s) with a short recovery time (< 30 s), indicating the applicability of SIT training to a sports setting (Balsom et al., 1992).

The time course in which adaptions occur in relation to these training protocols may also differ. Burgomaster and colleagues (2005) showed that, as little as 2 weeks of SIT can stimulate benefits similar to that achieved by undertaking ET, however the nature of the exercise and the duration of training may impact the physiological adaptations that occur. Sprint interval training, due to the high intensity, may stimulate adaptations at a faster rate, in comparison to endurance training. Contrary to this, 2 weeks may not be long enough to assess these differences and maintain the benefits. However, if these training types are combined over the period of times are further enhancements may be obtained.

Therefore, reasons for undertaking the current research include the fact that previously, much of the literature has carried out studies on training protocols lasting commonly around 6 weeks and even as little as 2 weeks. Therefore it remains to be determined, whether similar adaptations are apparent after months of low volume high intensity intervals training as well as higher volume interval training in the future.

1.11 Endurance Training

Endurance training consists of continuous exercise, ranging often from around 20 minutes to a few hours, (Coburn & Mailek, 2011) at a constant intensity of 50-70% of $\dot{V}O_{2max}$, where lactate levels are less than 4mmol (Coyle, 2005). Continuous exercise predominantly requires the aerobic energy system; however other metabolic processes will play a role, particularly at the start of the exercise. Profound benefits from undertaking ET are observed in sedentary or unwell individuals as well as sporting athletes (Neumann, Pfützner and Berbalk, 1999). A recent meta-analysis which assessed the benefit from undertaking exercise at light and moderate exercise intensities, demonstrated that 30 minutes of moderate exercise five times per week, reduced all-cause mortality by 19% versus no activity. ET is associated with enhancement of muscle oxidative capacities and results in improvements in $\dot{V}O_{2Max}$ and submaximal endurance performance. Capillary density also plays a part and a central role in oxygen supply to mitochondria and it has been established that skeletal muscle is able to adapt to ET by enhancing the capillary supply (Daussin et al., 2008).

Various biochemical, physiological and cellular adaptations including increased; oxygen delivery and extraction, fat oxidation and capillarization, that occur with ET due to the increase in energy demands. Manipulation of the intensity and duration of work and rest intervals changes the relative metabolic demands within muscle cells as well as oxygen delivery to muscle cells. The subsequent adaptations that occur, both at the cellular and systemic level, are specific to the particular characteristics of the training programme employed (Laursen et al., 2010). However when endurance exercise becomes habitual, in particular for endurance athletes, further improvements in exercise performance with an increase in training volume do not normally occur. (Laursen et al., 2002) Indeed the muscle of the trained athlete has 3-4 times more oxidative enzymes activity and up to 3 times more capillaries per muscle as well as a greater percentage of slow twitch muscle than untrained (Henriksson et al., 1992). Therefore additional improvement in this population in particular requires are greater stimuli than just volume i.e. intensity.

In terms of a healthy population, ET seems to be the more 'preferred' method, most used and most researched. Despite public health guidelines stating that 30 minutes of moderate intensity exercise should be undertaken 5 times per week in at least 10 minute bouts, similar achievements can be obtained over a shorter period of time, by increasing the intensity of the exercise or undertaking HIIT (Gibala et al., 2008). Not only would this be more beneficial and appealing but could result in more suitable guidelines for the general population in particular.

1.12 Sprint Interval Training

High intensity training (HIT) is an umbrella term for all types and modalities of exercise undertaken at a high intensity, regardless of the method or equipment used. These types of high intensity training include; sprint interval training where by repeated sprinted or short bursts are performed at a high intensity with different energy system requirements , aerobic interval training where by exercise is undertaken at an intensity below the peak power output of sprint interval training in interval type sessions and finally high intensity interval training, similar to sprint interval training but incorporates a range of modalities so this could be cardiovascular resistance or sprints undertaking at a high intensity in interval sessions (Laursen et al., 2002 & Talianan et al., 2007).

Sprint interval training involves repeated bouts of exercise ranging from 3s (Harridge et al., 1998), 30s (Jacobs, Esbjörnsson, Sylven, Holm and Jansson 1987) and often to 1 minute (Gibala et al.,2012). Usually with periods of rest or recovery between bouts of sprint exercise, enabling intensities of the workload to be increased (Smith, 2008) Cellular adaptations that occur from SIT facilitate the faster rate of ATP production from anaerobic glycolysis (Bompa & Haff, 2009). Aerobic metabolism is the main route of ATP resynthesise in exercise lasting longer than 2 minutes. The cause of the fatigue during as well as after exercise, is due to the build-up of hydrogen ions (Tomlin & Wenger, 2001) in the blood, lowering the pH, which inhibits muscle contraction and affects energy production (Myers, & Ashley, 1997). Factors responsible for the training induced improvements obtained from HIIT on exercise capacity are complex, vast and determined by numerous physiological parameters e.g. cardiovascular, respiratory, neural as well as psychological factors incorporating mood, motivation and perception of effort.

SIT was first introduced 70 years ago by Woldemar Gerschler to primarily improve ‘athletic explosiveness’ (cited by Johnson, 2009). Studies undertaken during this time suggested that SIT caused little or no changes in mitochondrial enzyme activity (Henriksson et al., 1976 & Hickson et al., 1976). Additionally, it was believed that HIIT of a low volume does not put enough stress on the body’s aerobic systems to elicit changes in aerobic metabolism. However, in recent years research has presented a conflicting view, suggesting that HIIT can stimulate beneficial cardiovascular, muscular and metabolic adaptations. Adaptations include, increased activity of mitochondrial enzymes meaning an increase in density and number so that more energy becomes available to working muscles, producing greater force for a longer duration, allowing an athlete to run longer at a higher intensity, for example (Burgomaster, Hughes, Heigenhauser, Bradwell and Gibala, 2005 & Gibala et al., 2006). Resting glycogen stores are also increased, with a reduced utilisation and production of lactate production, along with an increase in fat oxidation and oxygen uptake (Gibala et al., 2012), similar to that obtained from ET.

A further metabolic benefit of HIIT is excess post exercise oxygen consumption (EPOC). After an exercise session, oxygen consumption and therefore caloric expenditure remains elevated as the working muscle cells restore to their pre-exercise levels including replenishment of fuel stores and cellular repair. These processes result in a higher and longer calorie burning period after the exercise has finished in comparison to standard endurance exercise. It has been suggested by MacPhearson et al., (2011) that HIIT it could promote a larger lipid and overall energy deficit. The intense exercise increases the concentration and activity of the proteins and enzymes that are involved in beta oxidation as well as the transport of fat into the mitochondria, potentially altering chronic fat stores, and helping with body fat loss. It has been suggested that the extent of this EPOC is proportional to the metabolic stress from the exercise dependant on the duration, intensity and type of exercise undertaken (Borsheim and Bahr, 2003). However these mechanisms and the effect of HIIT on EPOC require further research.

Cardiovascular adaptations to HIIT are similar, and in some cases superior, to those that occur with continuous ET and despite the higher intensity. Adaptations observed and obtained with HIIT, are similar to those gained with ET with less time invested in the training sessions (Rognmo, Hetland, Helgerud, Hoff and Slordahl, 2004 & Vogiatzis et al., 2005). In terms of other health benefits, researchers in the field of obesity have acknowledged the beneficial use of SIT to help with weight management (Hunter et al., 1998). There is growing appreciation of the potential of SIT, to stimulate beneficial cardiovascular and muscular adaptations in various populations including diseased states (Rognomo et al., 2004 & Vogiatzis et al., 2005). However due to the high intensity of the exercise, increasing the strain on the body, it is not commonly prescribed outside of the athletic population yet, it has been deemed suitable for those with cardiovascular disease (Helgerud et al. 2007) . In agreement with this, a recent study from Rognomo et al., (2012) 4846 patients with coronary artery disease (CAD), from three different cardiac rehabilitations centres were recruited to take part in a study, which aimed to assess the cardiovascular risk of high intensity exercise versus moderate intensity exercise. Unfortunately a time frame was not stated instead the study was undertake over a 'rehabilitation period' whereby approximately 37 exercise sessions were undertaken.

The risk of cardiovascular events was examined throughout the organised training sessions and it was shown that there was 1 fatal cardiac arrest during moderate intensity exercise and 2 non-fatal events during the high intensity interval training. The results overall from the study concluded, the risk of a cardiovascular event after either high intensity or moderate exercise in a cardiac rehabilitation setting is low, and therefore considering the greater significant benefits, adaptations and cardioprotective effects from undertaking high intensity exercise, it should be considered, encouraged and undertaken in the future, in particular in those with CAD. Furthermore in agreement with the benefit of high intensity exercise Rognomo and colleagues (2012) state that in fact, the relative intensities that these participants with CAD work at, are often in fact very low and replicate activities undertaken during daily life such as rushing for a bus or marching up stairs. In response to this research, it has been suggested however that further wide scale and larger studies are necessary to confirm the findings and the outcome events of high intensity exercise and therefore should be undertaken in a controlled setting.

Other researchers including Wilsoff et al., (2007), who conducted a smaller study in a cardiac rehabilitation setting, have demonstrated that high-intensity interval training enables superior clinical effects and benefits to be obtained, compared to undertaking moderate intensity exercise. In this study from Wilsoff, patients with heart failure were recruited to take part in a randomised study to assess the effects of aerobic interval training versus moderate continuous training. A much smaller scale study than that undertaken by Rognomo et al., (2012), recruiting just 27 patients, post infarction, were randomised into a training modality undertaking either aerobic interval training versus moderate continuous training and a control group three times per week for 12 weeks. The results indicate that $\dot{V}O_{2peak}$ increased more with aerobic interval training than moderate continuous training ($p<0.001$) and associated with reverse left ventricular remodelling i.e. structural changes, yet endothelial function was greater with aerobic training. To conclude the ManNew global score used in this study indicates that the quality of life for these patients with CV disease increase with both training modalities, indicating that both are beneficial to the participants with the interval training again demonstrating a greater benefit in oxygen consumption.

Furthermore a recent review from Meyer et al., (2013) agrees that high intensity exercise has a greater improvements and impact on maximal oxygen consumption in those with a reduced left ventricular ejection fraction and heart failure, which therefore indicates a better quality of life and functional capacity. Additionally they suggested that with high intensity exercise a greater energy is expended in a much shorter period of time in comparison to moderate intensity exercise which could play an important factor in a cardiac rehabilitation setting. In conclusion, studies performed in those with HF and in particular in the NYHA class II of HF did not demonstrate safety issues, therefore promoting the modality yet further research is still warranted.

Burgomaster et al., (2008), found that 6 weeks of SIT elicited adaptations in metabolic markers in skeletal muscle and suggested that SIT may provoke changes in cardiovascular and respiratory systems when compared to ET. HIT is often dismissed outright as unsafe, impractical, or intolerable for many individuals. However, there is growing appreciation of the potential for intense, interval-based training to stimulate improvements in health and fitness in a range of populations, including persons with coronary artery disease. (Rognomo et al., 2013 & Wilsoff et al., 2007) In addition, some data suggest that a low-frequency, high intensity approach to training is associated with greater long-term adherence as compared with a high-frequency, low-intensity approach. (Gibala et al., 2007)

Beneficial for health as well as performance, regular endurance training improves performance during tasks that rely mainly on aerobic metabolism, in large part by increasing the body's ability to transport and utilise O_2 and by altering substrate metabolism in working skeletal muscles (Saltin & Gollnick, 1983). In contrast SIT is generally thought to have a less effect on endurance (Gibala et al., 2007). However, many studies have shown that HIT performed for sufficient time and volume increases $\dot{V}O_{2peak}$ and the maximal activities of mitochondrial enzymes in the skeletal muscles (Kubekeli et al., 2002, Laursen and Jenkins, 2002, Ross and Leveritt, 2001). Recent research has suggested and shown that SIT can in fact improve exercise capacity to a greater extent than traditional endurance training, yet little is known if these training types are combined, are greater benefits obtained or do the adaptations conflict each other.

1.13 Training Types Combined

Several studies have been undertaken, comparing the effects of SIT versus ET on various physiological parameters including; metabolic alterations in skeletal muscle peripheral arterial stiffness mitochondrial function, ventilatory threshold (VT), lactate threshold (LT) (Poole et al., 1985) and commonly exercise performance (Gibala et al., 2006; Burgomaster et al., 2008; Rakobowchuk et al., 2008; Daussin et al., 2008; Tabata et al., 1996 & Poole & Gaesser, 1985). A key message in many of these studies is that SIT is a time efficient way in order to elicit comparable results to ET, (Gibala et al., 2006; Burgomaster et al., 2008; Coyle et al., 1984) as well as to enhance aerobic fitness (Kent, 2011).

Despite the similar physiological gains from undertaking SIT compared with ET, limited research has been carried out which combines the two training types. Combining the two training types may lead to greater enhancements in the measured parameters, beneficial for both the trained and sedentary populations. As previously stated, the main barrier for not undertaking exercise, is time, suggesting the current exercising guidelines, may not be as suitable for the general population, so if alternative methods can be implemented a be as beneficial, if not more so, this may be more appealing to the population, additionally helping prevent boredom (Smith, 2008). Additionally for athletes, if a set time for training is allocated, then the aim is to achieve the greatest benefits and use of this time as possible, therefore justifying why it may be useful to combine the two training types. Finally, the inter-changeability of the two is also feasible, with very few, if any studies seeking to examine this, thereby demonstrating a gap in the research.

One study from Metcalfe at al., (2012), that did seek to investigate a combination of the training types, required participants to undertake an endurance bout of exercise at a low intensity followed by all out sprints increasing from one bout of 10 seconds in week 1 increasing to two bouts of 20 seconds in week 6, however, this failed to state the intensity or duration of the endurance bout that was undertaken. The research stated that the whole protocol undertaken lasted 10 minutes, the duration of the endurance component was not clearly stated. Additionally, it is not clear if this was their intention to find the effect of the training types combined, or if the endurance cycling bout was used as a warm up period. Garber et al., (2011) suggested to optimise the metabolic, cardiovascular and psychological benefits that exercise can offer, people should be encouraged to perform a large volume of both moderate and vigorous intensity cardiorespiratory exercise on most days of the week, which indicates the necessity for further research and confirmation in the area. Furthermore, the order in which the training types i.e. sprint interval training and endurance training is to be undertaken in the combined training group of the main study and in particular as a standardised protocol for future research, is unknown. In a study from Rodas et al., (2000), it is suggested that usually endurance is undertaken first followed by a period of high intensity exercise however there is no evidence to support this. It is widely accepted that if resistance and endurance training were to be carried out in a training session, the resistance training would precede the endurance, to enable a greatest force output from the muscle and to ensure the muscle is not already fatigued, followed by the lower intensity endurance training (Bompa & Haff, 2009). However, research related to high intensity exercise with endurance exercise is lacking (Colberg et al., 2010).

A recent pilot study carried out by Hurst (2013) at the University of Hertfordshire in preparation for this investigation, demonstrated that SIT should be undertaken after a bout of endurance training, the research showed that in terms of power output, even though the SIT prior to the ET produced greater power output at the start of the session, this declined at a more rapid rate than when undertaking the SIT after the ET. However when the SIT bout was undertaken after a period of ET, the power output reduction of the sprint declined at a much slower rate, with a similar power output maintained throughout. Additionally, two out of the seven subjects experienced feelings of sickness and fatigue after the maximal sprints and therefore had to stop exercising. However all subjects who undertook the ET first completed the sprint. Furthermore, feedback from the participants suggested the preferred method was endurance before sprint and this too replicated a cycling event.

In a study from Iaia (2008) runners who trained 45km/week lowered their training volume to 15km/week for 4 weeks and supplemented it with 8-12 x 30 second sprints, 3-5 times per week. Results indicted maintenance of 10km run $\dot{V}O_{2max}$ and skeletal muscle oxidative enzyme activity and capillarisation compared with the control group who continued with the 45 km/week. However those who supplemented the training with HIIT improved 30 second Wingate performance as well as increased intense exercise performance. Therefore indicating that when endurance training is supplemented with HIT at a much reduced time requirement, the same and potentially grater benefits can be obtained, however it is not known if this is undertaken in the same session and matched for time if the same or greater benefit are obtained.

1.14 Previous research and training programmes

The majority of research assessing the effect of SIT has used the Wingate protocol (Gibala et al., 2006, Burgomaster et al., 2008 & Rakobowchuck et al., 2008). This comprises 30 seconds of “all-out” maximum force against a high resistance, usually on a cycle ergometer, repeated 4-7 times 4 minutes recovery between bouts. This protocol technique is highly demanding, requires a very strong level of motivation to complete the sprint efficiently and effectively, which is demonstrated in previous research from Gibala and colleagues (2006). Power output typically falls by 25% to 50% over the course of the test as the subject fatigues, implying that those sprints undertaken towards the end of the session are not as effective as those undertaken at the start but do contribute highly to the adaptations that occur. Therefore, not only may the traditional 30-second Wingate method be unrealistic and unsuitable for the majority of the population due to its high intensity nature and strong required motivation, factors such as power output, can be affected during the training bout.

It had been demonstrated that adaptions can potentially be obtained in a shorter period of time. In the study from Gibala et al., (2006) during each training session, subjects repeated the test four to seven times, separated by 4 minutes of recovery, for a total of 2 to 4 minutes of intense exercise. Six training sessions were performed over 2 weeks, resulting in a total exercise time of approximately 15 minutes and a total training time commitment of1.5 hours (Gibala et al., 2007) demonstrating a potentially valuable approach to increasing population activity levels and population health, yet realistic more suitable for a trained population. However in this study, no control group was present in order to make valid comparisons and instead comparisons were made to previous research (Burgomaster et al.,

2005) concluding there would be no change in the control group, in terms of cycle endurance capacity or exercise performance.

Additionally, studies undertaken by Gibala et al., (2006) in 16 active men, Burgomaster et al., (2008) and Rakobowchuk et al., (2008) in 20 young healthy men and women, required SIT subjects to undertake the Wingate protocol, requiring repeated 30-second maximal sprints with a 4 minute recovery between each, with 4 repetitions in week 1 increasing to 6 repetitions in week 5 and 6. With the ET group undertaking 90-120 minutes of ET throughout, at an intensity of 65% $\dot{V}O_{2peak}$. Results showed that there was a significant increase in the exercise performance and similar muscle adaptations between both groups, implicating that SIT results in similar improvements to ET. Tabata et al., 1996, used a different SIT programme– 20-seconds exercise and 10-seconds rest at an intensity of 170% $\dot{V}O_{2max}$, requiring a less intense period of SIT, but induced increases in aerobic capacity and $\dot{V}O_2$max. Conversely, this study failed to sustain the benefits of the training i.e. increase in $\dot{V}O_{2max}$ for more than 3 weeks, unlike the other studies, which showed advantageous improvements in these parameters. This potential limitation in the study by Tabata et al., (1996), also speculated by MacPherson et al., (2011), was that a training programme, too short can cause solely peripheral changes leading to, reversibility and detraining without further exercise. Burgomaster et al., (2008), acknowledge that the short duration of the training study i.e. 2 weeks undertaken by Gibala et al, (2006) - may elicit remodelling of the skeletal muscle fibres from undertaking SIT, which would show benefits post training for an undetermined period and that ET would take a longer period of time for sustained results. Burgomaster and colleagues (2008) also found that after 6 weeks of training, no further differences were observed in muscle oxidative capacity, suggesting mitochondrial changes occur early with SIT. Likewise, Cunningham et al., (1979), showed significant increases in $\dot{V}O_{2max}$ after 12 weeks, of SIT. These benefits were achieved in the first 4 weeks of training and after this time improvements were not seen, similar to research from Tabata (1996). Conversely, Daussin et al., (2008), carried out training for 8 weeks followed by a 12 week de-training period, with improvements in $\dot{V}O_{2max}$ observed with continuous training (CT) rather than SIT resulting mainly from peripheral adaptations.

Gibala and colleagues have recently examined a reduced volume method, adopting 10 second bouts instead of 30 seconds, claiming, this too is more suitable for the population and in turn can still produce replicable and comparable results (GIbala et al., 2010).

Additionally earlier research from Linosser et al., (1993) and Gaitianos et al., (1993) adopted a similar yet reduced duration repeated sprint method, comprising of repeated 5/6 second sprints, demonstrating improvements in $\dot{V}O_{2max}$ values as well as anaerobic ability, however no endurance groups were incorporated into the research for comparison. Using this protocol, however, may be more suitable and feasible for the general population instead of the 30 seconds Wingate protocol. It is generally recognised that during a single short duration <10 second sprint, the contribution of aerobic metabolism to ATP resynthesis during the sprint is negligible. However when this type of exercise is repeated with short recovery intervals, the relative contribution from aerobic sources increases and may be important to maintain power output (Chistenen et al., 1960). Additionally, Bompa and colleagues (1999) suggest that creatine phosphate stores can be trained or enhanced by undertaking SIT lasting less than 6 seconds.

In addition to this, recent pilot work undertaken as part of an undergraduate dissertation (Hurst et al., 2012), it was demonstrated that, a lower intensity and volume of sprint interval training, elicited enhanced and beneficial results, similar to that achieved via endurance training. For this research 5 second sprint durations were adopted, in line with research from Linosser et al., (1993) and Gaitianos et al., (1993) who showed that creatine phosphate stores can be trained or enhanced with SIT and that power output reduction will not be as evident with 6 seconds instead of 30 second sprints.

Finally, in review of previous literature, the length of the training protocol is an un-researched area, to which needs to be explored to understand the minimum and optimal length, as well as the required intensities needed in order to elicit maximal or beneficial improvements. Cioalic et al., (2012) suggests that the optimum quantity of HIT still needs to be established, requiring larger trials to be undertaken to investigate different combination of duration, intensities, intervals and recovery periods and frequency in varying populations. Previous research has primarily investigated anywhere from 1 week to 6 weeks, with a few venturing to 8 weeks or more, when potentially the greatest benefits could be observed, or even plateaus in data detected in terms of maximal oxygen consumption and exercise performance. This is important to note as MacPhearson et al., (2011) speculated that, a training programme, too short can cause solely peripheral changes leading to, reversibility and detraining without further exercise.

In terms of endurance exercise the majority, if not all studies use the standard public health guidelines of 40-60mintue session as a comparison with SIT. The reasons for this would be to standardise the time and intensity of the exercise and to demonstrate current applicability with guidelines.

1.141 Recovery

Rest periods from exercise and in between bouts of exercise and necessary for recovery. Insufficient recovery during periods of exercise, can lead to declines in an individual's exercise performance (Garrett et al., 2000) particularly important during sprint interval training to enable sufficient resynthesises of ATP. Additionally, cellular adaptations that occur from SIT, facilitate the faster rate of ATP production from anaerobic glycolysis assisted during recovery.

Tremblay, Simoneau & Bouchard (1994) used a passive recovery between sprint bouts, resting until heart rate returned to 120 to 130 beats per minute. Yet, active recovery has been suggested for lactate clearance (Corder, et al., 2000) and provides superior performance to passive rest in repeated short-term, high intensity cycling sprint bouts.

Adaptations that occur as a result of training, lead to a reduced accumulation of lactate in the muscle during post training significantly, compared to pre training (Rodas et al., 2000). It is suggested by Granier et al., (2005), that this reduction in anaerobic energy production should correlate with the increase in activity of the oxidative pathway, important in sprint exercise at a high intensity. Additionally, it is suggested that the reduced lactate accumulation post training is also possible due to decreased glycolysis activation, and increased efflux of lactate into blood (Fox et al., 1989) or increased lactate utilisation in the muscle fibre. Furthermore, a study from Burgomaster et al., (2008) found that 2 weeks of HIT reduced the rate of lactate production and glycogen utilisation, normally seen with endurance training. A study from Barnett and colleagues (2004) also demonstrated a reduction in lactate production after the SIT training bout, although this did not include an endurance group.

However the optimal method to maximise the benefits of these training types, is still unclear with little research assessing their compatibility in a single training session. The combination of these distinctly different forms of exercise training, may work together to optimise the development of both the aerobic and anaerobic energy systems. There are however a few studies who have sought to find some benefit of incorporating both of these training types by substituting a whole endurance training session with a high intensity training session to see if great effects in particular on the aerobic system of the body.

Many SIT and HIT training protocols have adopted a 4 minute recovery between intervals (Gibala et al., 2006 & Burgomaster et al., 2008) and it is postulated and supported by McCartney (1986) that - PCr recovery can take 4 minutes between maximal sprints and full PCr repletion may take longer after repeated sprints than after single sprint.

1.142 Subjects

Various factors including age, sex and training status play an important part in terms of physiological adaption and in particular when implementing an exercise training programme, which can influence and effect outcome of results.

The majority of studies comparing SIT and ET, including that from Gibala et al., (2006); Goulder et al., (2010); Tabata et al., (1996); Poole et al., (1985) & Overend, (1992), recruited young healthy male subjects, few have used both men and women (Burgomaster et al., 2008; Rakobowchuk et al., 2008, & Daussin et al., 2008) and very little just women. (King et al., 2001). The lack of research in females suggests the data often cannot be generalized to the general public. Additionally using gender biased sample for research may have implications on the data outcome, as various factors need to be taken into consideration in particular if and when measuring parameters such as force output.

Gorostiaga et al., (1991) 12 subjects were recruited; the interval training group consisted of 1 male and 5 females, with the ET group with 2 males and 4 females. This allocation is vastly unbalanced and the reasoning for this is not explained, nor how the participants were assigned into the groups to justify this variability. Variance in the literature, when comparing SIT and ET may be attributed to the different training programmes approached. Currently there is no standardised method or training suitable for sedentary or trained athletes, in particular for SIT, to elicit benefits in various parameters, as these would differ amongst sedentary and trained individuals. However, Burgomaster et al., (2008) & Gibala et al., (2006), implemented ET that reflected the general recommendations from the public health guidelines. It has been suggested by Ogawa et al., (1992), that changes from a period of exercise in terms of cardiovascular measures are potentially due to body fat percentage differences in men and women, however this is opposed by an additional study from Bowen et al., (2012) observed the effects of HIT and high volume training in college age students (11 males and 6 females). One of the primary measures for this study was power output, yet it is known that due to differentiating muscular physiology and adaptions, males will genetically have a greater force output than females; there is an already bias into the effects of the results. Moreover in the analysis there is no indication of between gender differences as to how many males and females were assigned to each training type group.

It is known that a more sedentary population will have more room for improvement than a highly trained group of athletes, in particular when undertaking an endurance protocol. It has been shown that, to induce greater adaptions in highly trained athletes, high intensity interval work is needed rather than just an increase volume at a lower intensity, (Laursen et al., 2002) therefore matching patients and selection criteria is important to ensure no anomalies or biased data in the results.

A final factor is age. It has been suggested by Pollock et al., (1987) that $\dot{V}O_{2max}$ and body composition, deteriorate with age. This too is supported by ACSM (2000) stating that with training and purely as a result of aging, there are consistent finding demonstrating 5-15% decrease in $\dot{V}O_{2max}$ per decade, after 25-30 years old, which can be attributed to the reduction associated with age in maximal cardiac out and a-vO_2 difference furthermore an diminution in maximum heart rate is evident by six to ten beats per minute per decade. However, endurance training can enable older adults to achieve the same 10-30% increase in $\dot{V}O_{2max}$ the same as their younger counterparts, achievable via variable intensity, duration and volume, yet very little reach has sought to observe the adaptations or changes obtained with high intensity exercise. Additionally the early work which assessed the effect of training on age and $\dot{V}O_{2max}$ suggests that findings may not have been evident in particular in elderly or older subjects due to the intensity of the exercise undertaken, with more vigorous exercise demonstrating more favourable adaptations, rather than the age effect (Badenhop et al., 1983 & Barry et al., 1966).

1.15 Mechanisms of Action

Mitochondrial biogenesis is a well-established response to aerobic exercise training (Howard et al., 1985) and is defined as an increase in muscle mitochondrial number, volume and density via the stimulation of peroxisome proliferator-activated receptor-γ coactivator (PGC-1a) a regulator of energy metabolism (Liang, 2006). Changes occur in all three fibres types with greater effects seen in type 11a than in type 1 and type 11x fibres. Training induced increases in metabolic enzymes activities and mitochondrial density result in enhanced respiratory control sensitivity and consequently a lower ADP required to achieve the same level of oxygen consumption (Coyle 1984). Similar to endurance exercise it has been suggested (Wright et al. 2007 & Little et al. 2010) that high intensity interval training, may activate PGC-1a (Little et al. 2011), due to the short bursts of intensity exercise. It has been suggested by Gibala et al., (2009) that signalling pathways that activate PGC-1α and mitochondrial biogenesis from high intensity exercise have not been clarified however possibly due to the robust changes in the intramuscular ATP changes following the exercise and activation of AMP-activated protein kinase (AMPK).

Research is still on going in this area, in particular as to how these adaptations are achieved, however it has been suggested or speculated that although the same gains or benefits are achieved. They may potentially be obtained via different signalling pathways, Gibala et al., (2009) and Little et al., (2010). From Laursen et al., (2010) a diagrammatic process is shown, suggesting that despite similar physiological adaptations from continuous endurance exercise and high intensity interval training including increased mitochondrial density and increased fat oxidation, this is done via different signalling pathways due to the different intensity of the exercise. Therefore it is proposed that HIIT stimulates these adaptions via AMPK pathways due to the altered energy status in muscle associated with small reductions in ATP concentrations, such as that present during high intensity exercise, elicits a relatively large concomitant rise in adenosine monophosphate (AMP), which activates the AMPK. Whereas, endurance exercise stimulates the CAmK due to the prolonged rise in intramuscular calcium that occurs during endurance exercise, activating a mitochondrial biogenesis messenger called the calcium–calmodulin kinases, both then stimulating the activation of PGC-1a. Yet it is unknown that if in one training session, these training types are combined, what pathways are stimulated.

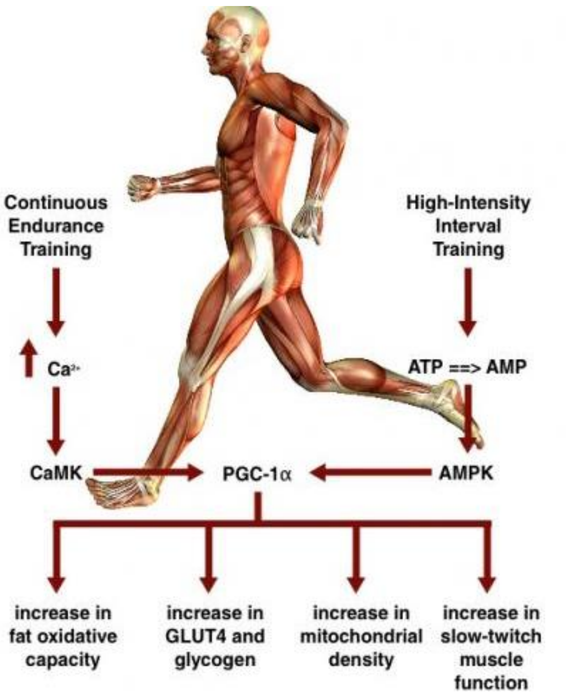

Fig1. Metabolic pathways of continuous endurance training and high intensity interval training (Laursen, 2010).

Supporting this finding from Laursen, (2010), evidence suggests that exercise intensity is the key factor influencing PGC-1α activation in human skeletal muscle (Egan et al., 2010). Additionally, Gibala et al. (2009) showed significant increases in AMPK after 4 repeated 30-s Wingate sprints as well as a 2 fold increase 3 hours after the exercise n PGC-1alpha, however, this was shown to occur without an increase in the CAmK, which are known to be stimulated during prolonged exercise.

1.2 Cardiovascular Parameters

Hypertension is a leading risk factor for cardiovascular (CV) disease and subsequently death. It has been demonstrated that ET can reduce high blood pressure and decrease the risk of other health risks by 25-40% (Kent et al., 2012 & Swaim & Edwards, 2003). Moreover, ET has been shown to improve several factors involved in the pathophysiology of hypertension, including sympathetic activity, endothelial function, pulse wave velocity and insulin sensitivity (Ciolac et al., 2012). Multiple studies have shown an association between cardiovascular fitness and cardiovascular mortality, as well as all-cause mortality in men and women of all ages (Do Lee at al., 1999). These findings provide a strong rationale for undertaking exercise and incorporate it into lifestyle improvement programmes that are designed to prevent or treat the metabolic syndrome and its components (Kessler et al., 2012). As well as assisting to significantly alter various cardiovascular parameters, in particular if they are elevated, could provide great health implications and recommendations for much of the population including those with CV diseases (Wisloff et al., 2007). Minimal research has investigated the changes elicited by SIT on blood pressure with the use of reliable equipment such as the Portapres used in this study (Finometer MIDI, Finapres Medical Systems, The Netherlands) therefore this investigation will aim to assess this and whether greater improvements in blood pressure are seen with both training types combined.

Little research has been carried out which incorporates SIT with cardiovascular patients, potentially due to its high intensity nature. The safety implications of undertaking SIT in particular in those with CV diseases, has often been questioned (Wisloff et al., 2007). Warburton, Nicol and Bredin, (2006), has shown that HIIT in fact improved the CV fitness and health of patients with cardiovascular disease and in comparison to traditional endurance training, high intensity interval training improved the participants anaerobic capacity to a greater extent, without any further risk to the patient, demonstrating a more effective and beneficial method. Furthermore, Vella et al., (2001) suggested, the beneficial reasoning for undertaking this type of exercise is that, for the healthy as well as the clinical population, the high intensity nature of the exercise, promotes greater adaptations via increased cellular stress, with the short interval and recovery bouts allowing for sufficient recovery and enabling the individuals to train harder than they originally would at steady state. Moreover, if the training types were combined it is not known if further benefits are obtained, assisting with the enhancement of CV and other physiological parameters. Finally, a recent systematic review demonstrated no cardiac or other potentially lethal events across seven HIIT studies in patients with coronary artery disease (Cornish et al., 2001). As previously stated a large scale study from Rognomo et al., (2013) indicates that in fact the high intensity interval training not only has greater cardiovascular benefits than moderate intensity exercise but the incidents of the controlled rehabilitation session demonstrated 1 fatal event in moderate exercise and 2 non-fatal in HIT, suggesting the safety of undertaking HI exercise is equal to moderate and should be pursued.

1.21 Cardiac Output (Q) and Stroke Volume (SV)

It has been postulated that stroke volume (SV) and cardiac output (Q) increase with exercise training, in particular ET (Spina et al., 1992). Epidemiological studies have also shown that regular exercise can reduce blood pressure (Wisloff et al., 2007) not only in hypertensive but also in normotensive individuals, which consequently, aid hypertension and the prevention of cardiovascular diseases (Corneliseen et al., 2005).

Research suggests that at maximal exercise, oxygen supply is limited and Q seems to be a major factor in determining oxygen delivery (Helgrund et al., 2007; Hoff et al., 2004) Spine et al., (1993), showed Q, in the male subjects during maximal exercise was significantly increased by 12% and HR max was also decreased. However in contrast to this in the female subjects; Q during maximal exercise did not change significantly as a result of training and HR max was unchanged after the training programme. Astrand and colleagues (1964) suggest this could potentially be explained by the lower concentrations of haemoglobin (Hb) in the blood in women than men, and that cardiac output in males is more effective in the transportation of oxygen explained by this difference in Hb content (Astrand, 2003).

Limited research exists on the effects and differences between SIT and ET or the training types combined, on SV and Q. However, a study from Daussin et al., 2008 demonstrated that maximal SV and Q, increased after a period of interval training, but not with endurance training. Similar to that found by Cunnginham et al., (1979) who after 12 weeks of training, found that in the endurance group no significant changes were seen in Q, but significant adaptations were evident in the interval training group, therefore instead of a time factor which may have affected the results in the study from Daussin et al., (2008), in this study changes may have been due to the lower intensity of work and duration of each session undertaken by all. In the study from Cunningham and colleagues, SV significantly increased after 4 weeks but with a return to resting values after 12 weeks, suggesting that the results may have been peripheral rather than central. Conversely, research from Spina et al., (1992), found that SV and Q increased with exercise training, more so with ET. However, Astorino, Allen, Roberson and Jurancich, (2012) suggests that further research in this area is needed to confirm these findings and importantly the optimal protocol length to induce the most beneficial adaptations.

One factor which may affect the extent of the changes on the CV system is training duration. Previous research undertaken in a pilot study by Hurst & Kass, (2012) demonstrated a significant decrease in heart rate with 4 weeks of SIT but not ET, despite a 143% greater work undertaken. Similar results were also demonstrated by Valik et al., (2011) who reported after 4 weeks of low intensity sprint interval training, heart rate was reduced and SV increased in unfit sedentary individuals. On the other hand, after 2 weeks of sprint interval training, Astorino et al., (2012), did not demonstrate any changes in heart rate or blood pressure, indicating this time period may have been too short to elicit any significant changes. Research suggests there often is a greater change in CV parameters due to the increased and greater demand and workload on the CV system. However, very few studies have measured these CV measures parameters over a longer period of weeks i.e. 6 weeks to see if there are any greater beneficial effects. Potential mechanisms which may have caused the increase in SV include an enlargement of the left ventricular chamber as a result of regular training, (Moore 2006; Saltin et al., 1968), a slight increase in blood volume (Warburton et al., 2006), and cardiac muscle hypertrophy with enhanced contractility during systole (Moore, 2006). Potential mechanisms for the reduction in heart rate may be due to the increased parasympathetic and reduced sympathetic stimulation of the sinoatrial node (Moore, 2006).

It is known that $\dot{V}O_{2max}$ increases with exercise training (McArdle et al., 2007). Research has attributed this increase to increments in Q and maximal av-O_2 difference (Cunningham, 1979). Hartley (1969) postulated that the increase they observed in $\dot{V}O_{2max}$ was solely the result of an increase in SV, with no changes in the av-O_2difference, possibly due to the low training intensity that was adopted in the research. This study carried out by Cunningham, unfortunately did not use a control group, suitable to be compared to those undertaking ET and SIT as there were significant differences in body mass at the start of the study, and no significant difference after the training programme. Ogawa et al., (2000), estimated that the increase in maximal Q as a result of exercise training, accounts for 88-99% of the difference in maximal oxygen uptake between trained and untrained men. These results are in accordance with Stratton et al., (1993), who found a 16% increase at peak exercise in their male subjects aged 60-82 years. Significant increases were also seen in SV from IT after 4 weeks of training with a fall towards pre training values after 12 weeks, this suggests that when limited muscle mass is involved in an exercise task e.g. cycling, results are beneficial in a short time period, but limited if training is not continued within a few months.

Changes take place in terms of Q, SV and HR at rest, submaximal exercise and maximal exercise. As previously stated, Q is calculated by multiplying the HR by SV and it is these two factors which regulate Q during varying intensities of work to maintain and sustain a cardiac output. At rest, regardless of training status, the Q remains unchanged after a period of endurance training. Instead the changes that take place include a reduction in HR yet an increase in SV due to the greater efficiency of the ventricular pumping mechanism of the heart and greater ventricular volume, enabling these factors to alter but Q to remain unchanged. (Smith & Fernhall et al., 2011) During submaximal exercise the Q too remains relatively unchanged, as the SV and HR rise proportionally to meet the demands of the exercise and plateaus. However during maximal exercise Q increases significantly. This is a due to an increase in the maximal SV as the maximal HR is attained and unchanged with training. At maximal intensity of exercise cardiac output can be increased to up to 30% or more than at rest or with submaximal exercise (Saltin and Rowell 1980). Despite HR having a greater impact on the Q, the main or dominant factor which causes these changes is SV from endurance training. This is due to an increase in plasma volume which in turn increases the blood volume, an increase in the end diastolic volume due to the increased volume of blood and a greater contractility and hypertrophy of the ventricles (Seals et al.1994 & George et al., 1991).

1.22 Heart Rate and Blood Pressure

A major risk factor for cardiovascular disease is physical inactivity and it has been shown that people who are less active have a 30-50% greater risk of suffering from high blood pressure (Whelton et al.,2002). Continuous exercise has been shown to be beneficial in reducing blood pressure in varying population and is often the recommended treatment to do so. However a few studies have recently demonstrated that HIT can have superior benefits in reducing blood pressure and improving cardiorespiratory fitness (Ciolac et al., 2011 & Tjønna et al., 2008). The schematic diagram in Figure 2, demonstrates the adaptions obtained from HIT vs. Continuous Moderate Training (CMT) – the same as ET, as well as the abnormalities faced in those with the risk of hypertension.

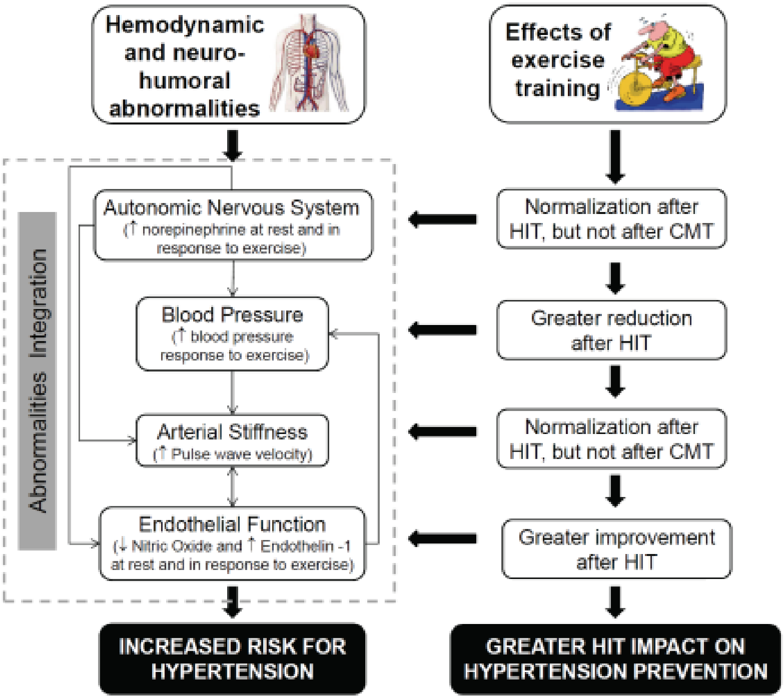

Fig 2.Schematic diagram representing the abnormities of normotensive individuals at risk of hypertension, the effect of exercise i.e. SIT vs. ET and the implications for hypertension prevention (Ciolac et al, 2012).

In a study from Ciolic et al, 2010 & Ciolic et al, 2011, normotensive young women at an increased risk of hypertension, who embarked on a 16 week programme achieved, greater increases in $\dot{V}O_{2max}$ in the high intensity interval group, (16%) compared to the continuous moderate intensity group (8%). Additionally, in those with metabolic syndrome, resting blood pressure was reduced after 16 weeks of high intensity exercise and continuous endurance exercise, with no difference between the modalities. These results demonstrate the effectiveness of the training and the time efficiency of high intensity interval training to achieve similar beneficial results in comparison to ET (Tjonna et al., 2008).

A meta-analysis by Kessler et al., (2012) examined the effects of training on blood pressure in 12 different studies. It was discovered that those lasting 2-10 weeks did not demonstrate any change in blood pressure when undertaking 'aerobic interval training' (AIT). AIT was classified by Kessler and colleagues as another type of HIT but performed at a slightly lower intensity than SIT but for a longer duration. For example a typical AIT protocol includes 4 minutes of high-intensity work at 80–95% $\dot{V}O_{2max}$ followed by 3–4 minutes of recovery time at 65-70% $\dot{V}O_{2max}$, for 4–6 cycles performed on a treadmill or bicycle ergometer, rather than 'sprints'. However in this review, the single study involving SIT did, in fact, demonstrate a decrement in diastolic blood pressure in young men who carried out 2 weeks of SIT on a cycle ergometer.

In patients with hypertension, who were not being treated with medication, undertaking AIT lasting 12-16 weeks in duration, in fact, showed a reduction in blood pressure in comparison to the continuous exercise group however no control group or pharmacological intervention group which make it difficult to determine the potential effect of the medication against the exercise. However it is evident that exercise in fact has a beneficial effect without the need to take medication. The 12-week study in the review, observed young males with borderline elevated systolic blood pressure and demonstrated a reduction in blood pressure with both HIT and ET however only a reduction in diastolic with ET . However the baseline diastolic blood pressure of those in the study, were normal in the HIT group. However, the absence of effect on blood pressure may not display a true representation of the changes that occurred as, participants instead could have been matched on these various parameters prior to the training, being that this was the main parameter they were observing and to ensure that the baseline values in each group were equal prior to starting the training programme. Overall from the review, it was concluded that exercise training clearly had beneficial effect on blood pressure. No change was observed for those patients who were already being treated effectively for hypertension, but the true impact of HIT on their blood pressure may have been masked by medication.

Finally, in relation to exercise performance, in a study on participants who had metabolic syndrome, which included hypertensive patients, $\dot{V}O_{2max}$ was shown to increase by 35% in those undertaking the HIT training and by 15% in those undertaking the continuous protocol (Tjønna et al., 2008).

1.3 Exercise Performance

1.31 Maximal Oxygen Consumption

In order to gain a true representation of a person's $\dot{V}O_{2max}$, maximal exercise must be achieved, represented by a plateau in oxygen consumption, requiring the subject to exercise to exhaustion. This plateau in $\dot{V}O2$ is something that a low percentage of the population are able to achieve and in particular a deconditioned population who do not undertake regular exercise. The achievement of maximal exercise requires the simultaneous and integrative ability of the heart, lungs and metabolic processes to produce an increased cardiac output, increased oxygenated blood flow to the working muscles as well as efficient extraction, in order to achieve optimal performance, usually through high muscle mass exercise e.g. cycling (Saltin et al., 1992).

Low $\dot{V}O_{2max}$ and physical inactivity are risk factors for developing cardiovascular disease, hypertension and diabetes, these individuals are at an increased risk of morbidity and mortality (Katzmarzyk et al. 2004). Therefore, improving $\dot{V}O_{2max}$ is essential for reducing risk of cardiovascular and other chronic diseases amongst the population.

It is suggested that the most efficient and effective way to increase $\dot{V}O_{2max}$ and exercise performance is to train as near to possible to the $\dot{V}O_{2max}$. (Kent, 2011 & Midgley, & McNaughton, 2006) This statement is evident when looking at research that has been undertaken demonstrating similar results to be obtained from high intensity training over a much shorter time frame than endurance training. Implying that SIT is a more time efficient and effective way to elicit similar results in aerobic performance and CV health compared to endurance training. (Coyle et al., 1984; Hawley et al., 1997; Gibala et al., 2006 & Burgomaster et al., 2008)

1.311 Previous research

Various studies have considered exercise performance changes between SIT and ET, and assessed the variations that have been induced as a result of a training programme, with the majority of studies demonstrating an increase in exercise performance in both exercise types and with few demonstrating significant differences between them**.** Quantifying 'exercise performance' differs amongst the research, so too does the study length. Gibala et al., (2006), classified performance increases by a decreased time to complete 50KJ and 750KJ time trials. Whereas many of the other studies used a $\dot{V}O_{2max}$ assessment including; Daussin showing a 9% increase in ET and a 15% in IT, Burogmaster et al., (2008)and Eddy, D. O., Kenneth & Adelizi (1977), showing almost identical improvements in the ET and IT groups.. Moreover, Tabata et al., 1996, examined the effect of six weeks of moderate-intensity endurance training compared to HIIT. Both training methods significantly increased $\dot{V}O_{2max}$, whilst the ET had no impact on the anaerobic capacity, HIIT increased it by 28%. It was, therefore, concluded that the HIIT imposed a more intensive stimuli on both energy systems. Fox et al., (1975) however indicated that SIT is as effective in elevating $\dot{V}O_{2\ max}$ as is ET. Throughout previous research, the variability in the training time for each study varied from 2 weeks (Burgomaster et al., 2005) up to 10 weeks (Overend, Paterson & Cunningham, 1992), yet similar results overall, particularly in exercise performance and $\dot{V}O_{2max}$ were displayed. Despite this research on the effects of SIT and ET, few studies have examined them combined to determine the effects on exercise performance parameters, whether this be in terms of $\dot{V}O_{2max}$, time trial performance or power output.

The length of the training protocol is an un-researched area which needs to be explored to understand how long or the intensity the training programmes i.e. SIT need to be in order to elicit maximal or beneficial improvements. A study undertaken by Tabata et al., (1996), carried out two simultaneous studies, comparing ET and IT over 6 weeks. Results showed, overall anaerobic capacity improvements were found only in the IT (28%) and no changes were established in the ET ($p>0.10$). However from the results, (Fig. 3) it's shown that the IT group started with a lower overall $\dot{V}O_{2max}$, so therefore could have had greater room from improvements in the specific values. This is a disadvantage to the study, but also, those in the IT group, did actually carry out one steady state session per week, which would influence the results and give a potentially false perception for the SIT phenomenon.

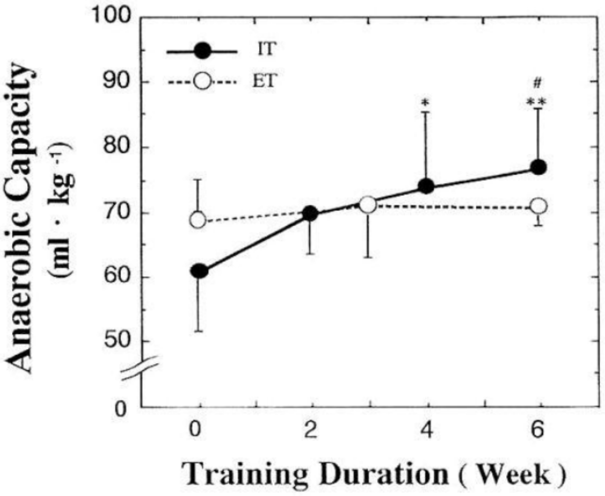

Fig. 3 – Anaerobic changes in SIT and ET after a 6 weeks training programme (Tabata et al., 1996).

Burgomaster et al., (2003) reported 6 SIT sessions over 2 weeks, radically increased overall time to exhaustion as well as improving endurance capacity in active males and females. Hughes et al., (2004) demonstrated that 6 sessions of SIT Training over a 2 week period, decreased the time required to complete a fixed amount of work by 10.4% and increased resting muscle glycogen by 53%. The protocol consisted of 4-7, 30-second Wingate tests, separated by 4 minutes recovery. Both of these studies show a low time commitment and study length, yet beneficial results were achieved, however this is high intensity for a fairly long period of time – 30 seconds, exercise which may be difficult for the sedentary population to undertake. Furthermore, a recent review by Kent, (2011) looked at the effects of SIT on aerobic fitness and noted an association. Improvement gains across the studies for SIT were 4%, ~8-10% and ~15% after 1, 2 and 6 weeks of training. Not only does this show that SIT is a time efficient way (90% less) in order to elicit changes to aerobic performance, but also often more appealing to untrained individuals, which may in turn have an effect on physical activity guidelines for adults to maintain health.

A second review from Kessler (2012) which incorporated 17 studies, examined the effects of different types of interval training including; SIT and AIT as well a continuous exercise on $\dot{V}O_{2max}$, included three SIT studies of 2-6 week duration and 14 AIT studies lasting 4 weeks to 6 months with the aim of all to increase $\dot{V}O_{2max}$. All but one group demonstrated an increase in their $\dot{V}O_{2max}$ after either of the AIT and SIT training programme. All four studies of 4- to 8-weeks'duration that included a continuous moderate exercise arm to the study, induced a similar improvement in $\dot{V}O_{2max}$ in comparison to both the SIT/AIT.

Such results may have been seen in the diseased or highly untrained population similarly due a training effect as they previously would not have undertaken any exercise so these increments would have occurred due to this addition in physical activity.
Individuals with a higher $\dot{V}O_{2max}$ are also likely to attain a higher $\dot{V}O_2$ during sprinting and at the start of recovery. This will result in more aerobically-derived energy during recovery, despite endurance-trained athletes also having a more rapid recovery of excess post-exercise O2 consumption (Short and Sedlock, 1997). In addition, $\dot{V}O_{2max}$ has been reported to be significantly correlated with the rate of PCr recovery in the quadriceps muscle following exhaustive exercise (Takahashi et al. 1995). Therefore, a higher $\dot{V}O_{2max}$ appears to be associated with a greater ability to resynthesise PCr. Restoration of PCr levels during recovery has been suggested to be critical for maintenance of performance during repeated 6-s sprints (Gaitanos et al. 1993).

In previous research from Hamilton et al. (1991) & Tomlin & Wenger (2002), correlations (r =0.78–0.83) have been demonstrated between $\dot{V}O_{2max}$ and the aerobic contribution to repeated sprint exercise. These correlations suggest that the aerobic contribution to repeated sprint exercise is related to $\dot{V}O_{2max}$, indicating that a high $\dot{V}O_{2max}$ or aerobic fitness is important and indicative of repeated sprint ability exercise. Additionally Bishop et al., 2006, whose subjects were matched for initial sprint performance found that those with a moderate $\dot{V}O_{2max}$ score recorded a smaller work decrement across the five sprints that were undertaken and performed significantly more work on the final sprint in comparison to those with a lower $\dot{V}O_{2max}$ score. This not only suggests the correlation between the two measured variables but also indicted the necessity to match pair participants on the important measure variable prior to the training intervention, to enable a fair increment of variable in particular the $\dot{V}O_{2max}$ (Bishop et al., 2006).

1.32 Anaerobic Threshold

$\dot{V}O_{2max}$ is typically used as the prime measure of exercise performance. (Levine, 2008) It is the maximum amount of oxygen an individual can take in and utilise (Keller et al., 1991) originating from the work of Hill et al., (1923). A drawback of $\dot{V}O_2$max is that the body's capacity to maximally utilise the oxygen, is often limited by the heart and lungs and ability to deliver sufficient oxygen to the working muscles (Saltin et a, 1992; Bassett et al.,1997). Despite the beneficial use of $\dot{V}O_{2max}$ and it being considered the gold standard, most objective and primary determinant of endurance ability, Noakes, (1997), believes $\dot{V}O_2$ is not a valid measurement, as the homeostasis of the body is disrupted, from working at maximal rates, as well as stating that the $\dot{V}O_{2\ max}$ does not reflect an individual's true maximal capability of oxygen transportation. In disparity to this, the anaerobic threshold (AT) does not require motivation in order to elicit suitable values, which in turn may be more suitable for the general population and even athletes, not requiring them to work to a maximal state before a sufficient value can be obtained.

The AT is the $\dot{V}O_2$ in $ml.kg^{-1}.min^{-1}$ when aerobic metabolism is insufficient to meet the energy demands and so is supplemented by anaerobic metabolism, (Vincent, J. L., 2009) and is the level of work or oxygen consumption just below the point at which metabolic acidosis and other associated changes in gas exchange take place (Wasserman, Whipp, Koyal, & Beaver, 1973; Wasserman & Whipp, 1975 & Davis et al., 1979). Other research suggests that AT - a valid and valued indirect measurement of endurance capacity (Davis et al., 1979), is the $\dot{V}O_2$ or work rate at which metabolic acidosis occurs. (Yoshida, 1984). Or when aerobic metabolism in insufficient to meet the energy demands of the exercise and so is supplemented anaerobic metabolism (Vincent, 2009). The AT typically occurs around 60-70% of an individual's $\dot{V}O_{2max}$ (Swaim, 2003). The AT, a variable used both in a clinical and performance setting, can enable physiological values to be gained without the requirements of maximal effort.

Divergence between the meaning of AT is controversial due to the confusing nature of the lactate threshold (LT), ventialtory threshold (VT) and AT – which occur a different yet similar points. In particular, as the muscles are not entirely 'anaerobic' this term may be confusing to some (Myers et al., 1997), yet it does occur (Wasserman et al., 1979).

The AT is often determined using the following criteria from Wasserman and Colleagues (2005); a disruption in the parallel relationship of VCO_2 and VO_2 due to an increase in CO_2, a resting exchange ratio (RER) of >1.0 and a rise in $PetO_2$ with a constant $PetCO_2$ value until a period of isocapnic buffering is reached when after the $PetCO_2$ is increased. Once exercise has exceeded the AT, the increase in glycolysis causes an increase in lactate acidosis from the production of hydrogen ions, which are in turn buffered by bicarbonate and result in increased CO_2 production (Wasserman et al., 1994).

1.321 Previous research

Few studies have looked at the AT with exercise training and very little if any, have compared the effects of different exercise training types on the AT. It is known that the AT is significantly enhanced by endurance training and intermittent training alone, but to what extent these differ or if they are combined is not well known.

Wilmore, (1977) and Astrand et al., (1977) proposed, endurance athletes may continue to enhance their performance even if their $\dot{V}O_2$ has reached a plateau, therefore in order to quantify these performance and physiological improvements; other measures need to be obtained (Davis et al., 1979). One of these measures is AT, which occurs at 60-70% of an unfit individual's $\dot{V}O_{2peak}$ (Swaim, 2003) or at 65-95% of a person's maximum heart rate (MHR) (Benson, 2011). A study undertaken by Davis et al., (1979), displayed an increase in the AT after a 9 week endurance training programme, however differences were not significant compared to the control group. The exercise intensity was 50% for the first four weeks and then 70% of $\dot{V}O_{2max}$ for the final 5 weeks. The non-significance of the results may have been due to exercising below the percentage of the AT for half the study. So, conversely, Ready et al., 1982, indicated that 9 weeks of ET, is sufficient provide significant changes in the AT, with participants cycling at 80% of $\dot{V}O_{2peak}$ for 30-minutes, 4 times/week. Finally a more recent study from pilot work from Hurst et al., (2012), which did compare the two training types, found that 4 weeks of exercise training increased the relative AT by 9.8% in the ET and 4.5% in the SIT, but this was not significant and possibly due to the short time period and time requirement of the training programme, therefore further investigation is needed in this area to confirm and develop these results

1.4 Blood Measures

1.41 Cholesterol

Hypercholesterolemia is a major risk factor across the world. A reduction of just 1mmol/l of total cholesterol in the blood can reduce the risk of coronary heart disease between 15-56%, in turn reducing the risk of coronary heart disease (British Heart Foundation, 2012). Exercise training has been shown to reduce cholesterol, increase concentrations of high density lipoproteins (HDL) and is associated with a reduced risk of cardiac heart disease mortality (Kokkinos, & Fernhall, 1999). Additionally low density lipoprotein (LDL), a major predicator of coronary artery disease, has not been shown in many studies to reduce with aerobic exercise (Durstine et al., 2002).The amount or type of exercise that needs to be undertaken to elicit significant changes in cholesterol measures, is an under researched area and it has often been suggested that there may be a certain threshold of exercise that needs to be met prior to these change taking place, in particular, in a sedentary population. It has been demonstrated however, that as little as one bout of exercise can have an effect on cholesterol, inducing changes in blood lipid and lipoprotein concentrations (Ferguson et al., 1998). Opposing this, Davis et al. (1992) found no change in lipid and lipoprotein concentrations in trained men with normal blood cholesterol after two treadmill exercise sessions at intensities of 50 and 75% of maximal oxygen consumption, possibly due to the lower intensity or method of exercise undertaken.

It is suggested that the required volume of exercise required to induce fat weight reduction, which in turn will have the most favourable impact on blood lipids in those with high total and LDL cholesterol is 150 minutes or more per week in line with the current physical activity guidelines, (American College of Sports Medicine Position Stand, 1998), at least at 45% capacity (Durstine, Grandjean, Cox & Thompson 2002). However it is not known if SIT, a much reduced volume but higher intensity, has similar or more beneficial effects, even on those with a normal blood cholesterol level, or if the training types combined have a greater effect.

Whilst these cardiometabolic risk factors which often cause metabolic disorder such as diabetes, can be treated with medication, lifestyle modification strongly recommend. Multiple studies have shown an association between cardiovascular fitness and CV mortality as well as all-cause mortality in men and women of all ages (Kessler et al., 2012).

Physical activity, whether one session or several, has been shown to have a beneficial effect on cholesterol metabolism (Durstine & Haskell, 1994). The specific mechanics of how this occurs are unclear, however evidence and research suggests that other factors including diet, body fat, weight loss, and hormone and enzyme activity interact with exercise to alter the rates of synthesis, transport and clearance of cholesterol from the blood (Durstine & Haskell 1994). Firstly, exercise stimulates the enzymes that help move LDL from the blood and blood-vessel walls to the liver. From there, the cholesterol is converted into bile for digestion or excreted. So the more you exercise, the more LDL your body expels. Secondly, exercise increases the size of the protein particles that carry cholesterol through the blood. The combination of protein particles and cholesterol known as lipoproteins meaning that due to the increase in size of these lipoproteins both good and bad lipoproteins can be carried.

To date, despite the standard public health exercise guidelines of 30 minutes a day 5 times per week, there are no standardised guidelines to indicate the amount of exercise required or that which is of most benefit to reduce cholesterol and in turn its risk of co morbidities. However, research at the Duke University Medical Centre in 2002, found that, more intense exercise is actually better than moderate exercise to reduce cholesterol levels. In a study of overweight, sedentary people who did not change their diet, the researchers found that those who undertook moderate exercise (12 miles of walking or jogging per week) did lower their LDL level. Those who did more vigorous exercise for example, the equivalent of 20 miles of jogging a week lowered LDL to a greater extent. Additionally, those who exercised vigorously also raised their levels of high-density lipoprotein, further assisting with the clearance of cholesterol in the blood. On the other hand, this does not suggest whether it is the intensity or the volume of exercise undertaken which had greatest benefits on reducing cholesterol levels, which therefore warrants further research.

In the review from Kessler and colleagues (2012), it is suggested that a minimum 8 weeks was needed to see improvements in HDL, however only 3 of the ten studies lasted 8 weeks or more, therefore more research would be needed to validate this finding. The studies however that didn't display this finding involved young participants who presented with very low baseline HDL values. Finally the sparse findings in terms of beneficial effect of sprint interval/high intensity interval training, on LDL and triglycerides, may be due to the short duration of the majority of studies that were not long enough to observe improvements. This therefore indicates a potential dose response relationship between the exercise volume intensity and changes in blood lipids.

1.42 Lactate

At any exercise intensity lactate is produced as a bi product of exercise, however as the exercise intensity increases so too will the production of lactate and inevitably a contributing factor to fatigue, muscle soreness and potentially a decline in performance due to the increase production of hydrogen ions. In terms of intensity, it is thought that higher bouts of high intensity exercise can provoke an increased lactate production in comparison to a lower intensity bout of continuous lower intensity exercise, due to the anaerobic breakdown of glycogen for energy and an increase in hydrogen ions provoking potential muscle soreness and fatigue. However, it is also thought that endurance exercise can, in turn, induced fatigue due to the depletion of glycogen stores, over a longer period of time.

According to Astrand et al., (1977) endurance training reduces the accumulation of lactic acid in skeletal muscle and blood during exercise of any intensity, with the reduced accumulation in trained individuals due to the greater oxidative capacity and reduce lactate production. However, this is may not be entirely true as suggested by Donovan et al., (1983) trained and untrained individuals have a similar oxygen consumption at any given submaximal work load and therefore lactate undergoes both production and removal during exercise. On the other hand, it is thought that lactate production may actually be reduced in trained individuals due to the shift of carbohydrate towards lipid utilisation, and reduction in lactate dehydrogenase (LDH). However recent research suggests it is not so much the amount of lactate that is produced, instead it is more focused on how our body is able to use this by product from the exercise and convert it efficiently in the liver for use as an energy source for further exercise (Stallknecht, et al., 2007).

Recent research indicates that the goal of endurance training shouldn't be to reduce the production of lactic acid but to improve the ability to clear lactate from the blood (Menzies et al., 2010). Therefore assessing how our body can effectively use the lactate produced during exercise as an energy source is more important than how we are able to increase our tolerance of the lactate.

It is well known that endurance training attenuates lactate removal, with the mechanism of this continually being established yet little is known in comparison on the effects of sprint/high intensity interval training and if this too assists with lactate removal and clearance. One explanation or reasoning for the reduction in lactate after a period of training, is that training decreases lactate production from CHO utilisation by increasing skeletal muscle mitochondrial density, provoking fatty acid oxidation and decreasing reliance on muscle glycogen stores as a source of fuel during exercise (McRae et al., 1992 & Costill et al., 1973) Therefore reduced lactate concentrations seen after a period of training are partially due to substrate use. The increase in mitochondria in the muscle and the activity of these mitochondrial enzymes as a result of exercise training in turn enable an increase in ATP production, decreasing glycolic flux, inevitably reducing lactate production rate.

Better performance is associated with increased lactate clearance requiring training at the threshold or above this to be undertaken. Due to the onset of exercise, lactic acid is accumulated in the muscle during or very soon after a bout of sprint exercise. The hydrogen ions formed from the dissociation of lactic acid then have the potential to cause fatigue. However the muscle then has the ability to offset the pH through the use of various buffering mechanisms including bicarbonate and phosphate buffers. It has been demonstrated also that the ability of these muscle buffers are significantly improved with training thereby assisting the removal of lactate in the muscle and blood, however very few studies have sought to discover this in terms of short sprint interval training.

Recovery from exercise and in between bouts is necessary. Insufficient recovery during periods of exercise, can lead to declines in an individual's exercise performance and this is (Garrett et al., 2000) particularly important during sprint interval training to enable sufficient resynthesise of ATP. Tremblay and colleagues (1994) used a passive recovery between sprint bouts, resting until heart rate returned to 120 to 130 beats per minute. Yet, active recovery accelerates lactate clearance (Corder et al., 2000) and provides superior performance to passive rest in repeated short-term, high intensity cycling sprint bouts.

In the combined trial, depending on whether endurance exercise precede or comes after the SIT could mean it works as a cool down and potential clearing mechanism of lactate in the blood after the SIT bout of exercise.

In comparison to endurance training, fewer research papers have explored the effects of high intensity interval training on lactate production and clearance. We do know that as the intensity increases so too does the production due to the lack of oxygen. However, it has been postulated that specific training can help the body become more efficient at lactate removal and facilitating lactate removal in the body.

1.43 Creatine Kinase

Creatine kinase (CK) is an enzyme that catalyses the phosphorylation of creatine to creatine phosphate. There are three main tissues found in the body containing CK, these include; cardiac muscle, skeletal muscle and the brain (Wyss and Kaddurah-Daouk, 2000). Creatine kinase measured in the blood is deemed as an indirect marker of muscle damage primary in a clinical setting for the diagnosis of myocardial infarction and dystrophy, but also as a measure after a period of exercise. (Baird, Graham, Baker and Bickerstaff, 2012) Controversy does exist however, whether this is a valuable and valid measure of muscle damage depending on the intensity of exercise and due to the different sources in the body. Another reason why there is variance in the research and data is because some people often have different CK levels compared to others when the same exercise protocol of any intensity is undertaken, even if gender, age and training status are account for (Baird et al., 2012). This could possibly be attributed to genetic and ethnic differences, additionally; some studies have reported that serum levels of CK are affect by the individual's hydration status, in particular after eccentric exercise (Fielding et al., 2000 & Baird et al., 2012).

It has been postulated that, an increase in CK may represent cellular necrosis and tissue damage following acute and chronic muscle injuries. (Garry et al., 2000) Increased levels of serum CK in healthy subjects, is suggested to be correlated to physical training status, with greatest increases in CK occurring in less trained subjects. Additionally a large increase in serum CK combined with a reduced exercise tolerance has been suggested to be a marker of overtraining (Hartmann et al., 2000). Research however, has shown that CK is elevated with high intensity exercise in healthy subjects, although markedly high levels are also found after long endurance exercise (Brancaccio, Maffulli, & Limongelli, 2007). This leads to the question of which type of training provides the athlete with the greater muscle damage over a period of time, which in turn may influence performance. It is difficult however, to determine, where the CK is obtain from i.e. the brain heart and muscle when taking it from a blood sample.

1.5 Summary and Conclusion

In conclusion, despite various comparisons made between SIT and ET, the combined effects are very under researched, in particular in the parameters to be observed in this study. The optimum dosage of SIT in terms of time, intensity and duration is yet to be established. Since a large percentage of the population fail to meet the minimum physical activity criteria, a combination of standard endurance exercise with sprint interval training may be more appealing as well as beneficial. Additionally, for athletes, this combined approach may in turn provide greater beneficial enhancements in physiological parameters thereby enhancing performance. Future research could consider looking at the effects of different sprint durations ie., 5 seconds, 10 seconds and 30 seconds, and the effects of these on various physiological parameters over varying periods of time.

1.6 Overview, Aims and Rationale

Previous undergraduate research presented at the Physiology 2012 Conference in Edinburgh by Hurst (2012), and that undertaken by others in the area, has stimulated this investigation. The purpose of the current research is to further examine the effects of three training conditions; sprint interval training (SIT), endurance training (ET) and the training types combined, on cardiovascular and physiological parameters and exercise performance.

The rationale for undertaking this research is firstly to confirm the findings from previous undergraduate research, that using a much shorter volume i.e. 5 second sprint intervals, can elicit beneficial impacts on various physiological parameters, but also to assess these adaptations in comparison to endurance training. Currently there is no standardised method used when undertaking sprint interval training, so it is often difficult to justify the reasoning for the use of different protocols , however the majority of studies have used the Wingate 30 seconds sprint approach, requiring a high intensity and high volume training bout**,** with recent research from Gibala et al., (2012), reducing this to 10x60 seconds, due to the high intensity nature of the normal Wingate protocol and its suitably to the general population. Therefore, unlike the high intensity approach which many of the previous research articles adopted, this study incorporates a more low volume approach which in turn may be more suitable for a greater percentage of the population and can potentially demonstrate comparable results. Additionally very few studies have sought to combine these training types in a training session to see if greater adaptions and enhancements can be obtained, or if there is a preferred training modality. Furthermore, undertaking the training programme over a longer period of time i.e. 8 weeks, longer than some of the research previously undertaken, may permit changes to be established and assessed. Finally, these training types are beneficial to both a trained and healthy populations and assessing the health implications these can elicit could potentially indicate improved exercise prescription and guidelines.

The aims of the study are shown below;

• To analyse the changes between the training conditions on maximal oxygen consumption ($\dot{V}O_{2max}$), anaerobic threshold (AT) and exercise performance.
• To assess the changes to cardiovascular parameters, including heart rate, blood pressure, stroke volume and cardiac output, from 8 weeks of each of the three training conditions.
• To determine the effects and changes that occur on glucose and lactate, after 8 weeks of either one of the training conditions.
• To compare the effects of a period of 8 weeks of each of the training conditions on cholesterol.
• To compare the effects of sprint interval training, endurance training and combined sprint interval training on muscle damage assessed by creatine kinase over a training period of 8 weeks.
• Pilot work will be undertaken to establish the order in which the training types, sprint interval training and endurance training should be undertaken in the combined training of the main study
• Pilot work will be undertaken to test the reliability of the electronically braked cycle ergometer against the weighted basket cycle ergometer in terms of heart rate responses to training.

1.7 Hypotheses

Research Hypothesis

H_1 There will be a significant difference between the sprint interval, endurance or combined group in the maximal oxygen consumption measured between pre and post training.

H_2 There will be a significant difference between the training groups in terms of the anaerobic threshold after 8 weeks of training

H_3 There will be a significant difference in blood cholesterol between the three training groups after the 8 week training programme

H_4 There will be significant differences in the resting heart rate in the sprint interval training group after 4 weeks and 8 weeks of the training programme

H_5There will be significant differences in the resting blood pressure between the training modalities and the control group from pre to post training

H_6 There will be significant differences in the resting stroke volume between the training modalities and the control group

H_7 There will be significant differences in the resting cardiac output between the training modalities and the control group

H_8 Significant differences will be evident in creatine kinase between the training groups

H_9 Significant differences will be shown amongst the groups when lactate is measured after the $\dot{V}O_{2max}$ test undertaken after 8 weeks of training.

H_{10} There will be a significant difference between the groups in body fat percentage after the 8 week training regimes

2.0 Reliability Study

A reliability study was carried out prior to the main study to ensure valid reasoning of the protocols and reliability of specific equipment to be used during the training and testing. Increased reliability ensures better precision of results and therefore enables changes in data to be noticed. Differences in outcome data can often be a result of equipment as well as human error (Pietro et al., 2000 & Cuschieri et al., 2008). Therefore it is often necessary to undertake reliability studies to reduce this error and increase the validity of the results. This study examined the use of two different cycle ergometers; an electronically braked cycle ergometer and a weighted basket cycle ergometer.

The protocol of the main study is to use the electronically braked cycle ergometer, the preferred method as it is a more accurate way in order to increase the loading on the bike over time in the $\dot{V}O_{2max}$ testing. I then planned to use the weighted basket cycle ergometer throughout the 8 weeks of training. The majority of research carried out in the area, which has adopted a test-retest protocol, including a period of training, has used the same cycle ergometers, however there are a few research studies which have used two or even three different cycle ergometers (Stepto et al., 1998 & McKay et al., 2009,) throughout the testing and worked at a percentage of data from one cycle ergometer when working on another, yet authors have failed to suggest any reliability testing to ensure replicable results can be obtained, therefore this study proposes to clarify and validate this. The aim of the reliability study is therefore to see if there are any differences between the two cycle ergometers, in particular in terms of heart rate when working at the same intensity and duration. The results from this will then determine the use of the cycle ergometers in the main study.

2.01 Subjects

Nine participants volunteered to take part in the reliability study (Age: 23.3±3.2 years, Weight: 73.2±3.4kg, Height 174.1±2.5cm, Resting HR: 71±2bpm). All participants were sport and exercise science students from University of Hertfordshire and recruited via word of mouth and email. The experimental protocol was approved by the University of Hertfordshire Research Boards Ethics Committee. Written informed consent was obtained by all participants at the start of the study along with a health screen questionnaire.

2.02 Methods

The cross over design experimental protocol required participants to attend the human physiology laboratory on two separate occasions, over a period of a week. At each testing session baseline preliminary data were obtained including height, weight, resting heart rate and blood pressure. Once the seat height and handle bars were adjusted at the comfort of the participant, a 3 minute warm up was commenced. After a 3 minute warm up at 60rpm, the participant cycled at 100watts lasting three minutes on either an electronically braked (Lode Excalibur 268E, Monark, Germany), or weighted basket (Monark Lode, Leipzig, Germany), randomised between session 1 and session 2. Heart rate and power output measured and recorded throughout; in particular, at a period of steady state. The same process was undertaken on the second session, to determine if there were significant differences in heart rate when working at the same power output on two different cycle ergometers. All participants completed a consent form at the start of the study and a health screen questionnaire at each session. The same ergometer for each type was used at each of the sessions, by all participants, to avoid intra-equipment variability.

2.03 Statistical Analysis

Prior to statistical analysis, a Sharpiro-Wilk test of normality was carried out on each data set. Pearson’s correlation was then used for statistical analysis, with an alpha value set at 0.05.

2.04 Results

The results indicated that the heart rate recorded from each participant on each cycle ergometer, showed a statically significant correlation(r=0.972, p=<0.01). Figure 4. demonstrates this positive correlation graphically.

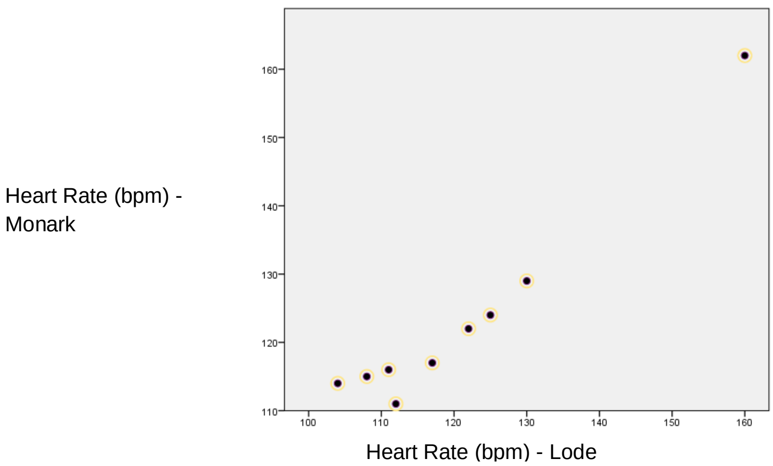

Figure 4. Correlation of heart rate measure on the Lode electronically braked and Monark manually loaded bike.

2.05 Conclusion

The results indicate that in terms of heart rate; the variable to be used during the training sessions to ensure the participants are cycling at the correct intensity was statistically significant and highly correlated between both the weighted basket cycle ergometer and the electronically loaded cycle ergometer. This therefore indicates that the weighted basket cycle ergometer can be used in the training sessions whilst the electronically loaded cycled ergometer, can be used to undertake the $\dot{V}O_{2max}$ testing.

2.1 Pilot Study

Limited research has been carried out which combine the two training types; endurance training and sprint interval training, however research from both training types demonstrate it is evident that greater benefits could be observed if combined, providing a more effective way in order to observe greater enhancements in the measured parameters, beneficial for both the trained and sedentary populations, (Colberg et al., 2010). However the order, in which these training modalities are to be undertaken in a training session for the best results, is unknown. A pilot study was carried out, to determine which training type (sprint interval or endurance), should precede in the combined training group of the main study.

2.11 Subjects

Six participants volunteered to take part in the pilot study. All were recruited from the University of Hertfordshire Sport and Exercise Science and Sports Therapy degree courses, via word of mouth and email. The experimental protocol was approved by the University of Hertfordshire Research Boards Ethical Committee. Written informed consent was obtained by all participants at the start of the study along with a health screen questionnaire.

2.12 Methods/Experimental Design

The cross over design experimental protocol, required all participants to attend two sessions over a period of 2 weeks, where a different exercise protocol was carried out at each in a randomised fashion. The two sessions to be carried out were either a) 30 minutes cycling at 65% of $\dot{V}O_{2max}$ followed by 7x 5 seconds sprints, twice with 30 second recovery between each sprint, with a 4 minute recovery between each set or b) 7x 5 seconds sprint, twice with 30 second recovery between each sprint, with a 4 minute recovery between each set followed by 30 minutes cycling at 65% of $\dot{V}O_{2max}$.

Prior to each training session, resting heart rate and blood pressure were obtained whilst the participant was seated after a period of 5 minutes rest. Measures of height and weight were also recorded. A 5 minute warm up preceded each training protocol. Power output along with heart rate were measured and monitored throughout each exercise session. At 4 time points during each protocol i.e. at rest, halfway through the endurance bout, before the sprint and after the sprint protocol and cool down initiated and concluded each session. One the protocol had been completed a cool down was undertaken.

2.13 Results

There were no significant differences in blood lactate between the two training orders (p=0.055). On average, there was a trend for the SIT undertaken before ET had a slightly higher lactic acid production, however when SIT was undertaken after ET, the lactate production after the SIT was greater than undertaking it before. There were no significant differences in terms of blood glucose throughout the two training methods (p>0.05). In terms of power output, even though the SIT prior to the ET produced greater power output at the start, this declined at a more rapid rate than when undertaking the SIT bout after the ET.

2.14 Conclusion

The sprint undertaken after the endurance, power output reduced at a slower rate with a more similar and consistent power output being produced at from each sprint. Additionally the participants themselves found the ET followed by the sprint much more enjoyable and easier to undertake. Additionally two out of the seven subjects experienced feelings of sickness and fatigue after the maximal sprints and therefore had to stop exercising. However all subjects who undertook the ET first completed the sprint with no problems and reported no discomfort.

Main Study

3.0 Introduction

Exercise training is known to have profound benefits on the physiology of the body, including the cardiorespiratory system, as well as increasing exercise capacity and $\dot{V}O_{2max}$. Additionally exercise training assists with weight loss and muscular hypertrophy, is beneficial for health & wellbeing, (Noakes et al., 1976; Wasserman et al., 1989; Kent, 2011; Gibala et al., 2006) and improves the energy status of working muscle, subsequently resulting in the ability to maintain higher muscle force outputs for longer periods of time, predominantly due to the increased mitochondrial density, number and size (Laursen & Jenkins, 2002). Despite the public health guidelines, the main barrier to exercise is time (Hallal et al., 2012). The purpose of exercise training is to alter physiological systems and exceed resting homeostasis to improve and enhance physical work capacity in turn enabling increased work on subsequent sessions (Hawley et al., 1997). Achieving the most out of each training session benefits health, increases exercise capacity and performance, and is beneficial for both the clinical and athletic populations.

Endurance training is known to have pronounced beneficial effects on the cardiorespiratory system, exercise performance and the body as a whole, yet a continuous growing body of research has further established the time efficient method of sprint interval training, also known as high intensity interval training, as a means of improving the cardiorespiratory and metabolic systems and function. It has been suggested that HIT increases stress and demands placed onto the body with protocols that elicit maximal oxygen uptake or at least near enough to maximally stress the oxygen transport and utilization systems and enable the greatest effects and changes to take place. HIT may be the most effective way in order to improve the $\dot{V}O_{2max}$ (Laursen et al., 2002 & Midlgey et al., 2006), increase muscle fibre recruitment and stress the cardiovascular system (Buchheit et al., 2013).

Despite these innovative findings, very little research, if any, has yet to combine these two methods of training in a single session to see if further enhancements can be obtained over the same time period, essentially maximising the outcome of a training session.

3.1 Methods

3.11 Participants

Forty participants volunteered to take part in the 10 week matched paired study, which included an 8 week training programme. 11 participants dropped out prior to the commencement of the main training programme. Twenty nine recreationally active participants (age; 35.1±13.1 years, female; 16) then undertook the preliminary testing and training regime. All participants were recruited via word of mouth, email and flyer advertisement from the University of Hertfordshire's students and staff and from Hertfordshire Sports Village. The experimental protocol was approved by the University of Hertfordshire Research Boards Ethics Committee. All participants were briefed about the study and what it entailed both at the start and throughout and were informed of any potential risks. Written informed consent was obtained by all participants at the start of the study and a health screen questionnaire was undertaken at each session.

Inclusion and exclusion criteria were implemented prior to the commencement of the study via a subject briefing. The reasoning of selecting such criteria was to incorporate a range of individuals eligible to participate in the study without any bias in the selection, additionally to ensure that all participants were in a physically healthy state i.e. with no current musculoskeletal injuries or illness that may be worsen by the training to be undertaken. The criteria employed were as follows;

Inclusion Criteria:

- Male/Female
- Age: >18 years, <65 years
- No previous injuries that may affect performance and exercise tolerance or not currently suffering from any musculo-skeletal injury
- Physically Active i.e. undertaking regular exercise training (>3-5 hours/week)
- No experience of regular cycling in the past 12 months
- No history of or currently have high/low blood pressure
- No heart problems/defects
- Not under the influence of alcohol or any other psycho-active substance
- Hasn't had a cold or flu in the past 2 weeks
- Currently not on any medication (excluding asthma inhalers or oral contraception)
- No blood born disorders

Exclusion Criteria:

- Age: <18 years or >65 years
- Had previous injuries or current injuries that may affect performance/ exercise tolerance and capacity
- Had previous experience of regular cycling
- Currently suffering from any musculo-skeletal injury
- History of or currently has high or low blood pressure
- Heart problems/defects

- Currently under the influence of alcohol or psycho-active substance
- Has had a cold or flu in the past 2 weeks.
- Currently on medication (excluding asthma inhalers or oral contraception)
- Has a blood born disorder.
- Has been advised not to exercise.

In the study all participants were required to carry out a $\dot{V}O_{2max}$ test prior to the training programme, after 4 weeks and after the training programme. Before each $\dot{V}O_{2max}$ test the equipment was calibrated for pressure, gas and volume. The pressure was entered into the computer software from an external barometer. Oxygen (O_2) and carbon dioxide (CO_2) gases were calibrated by sampling room air using 17.02% O_2 and 4.98% CO_2 and to analyse volume, a 3-litre syringe was used to pump air through the turbine, attached to the mouthpiece to collect the respiratory data. Ambient temperature and humidity were also recorded prior to each $\dot{V}O_{2max}$ test via an external barometer. A record of calibration data was recorded from each test to ensure correct values were obtained and maintained within the normal limits. To reduce the effect of the uncontrolled variables, all subjects were required to maintain current dietary, activity and lifestyles habits. This was ensured by carrying out a 1 week food diary prior to the training, which was kept by the participants and to be followed, as closely as possible, for the duration of the study.

3.12 Pre experimental procedure

The match paired, randomly assigned protocol required all participants, prior to the training programme, to undertake a preliminary $\dot{V}O_{2max}$ test, after a familiarisation session. This was carried out on an electronically loaded cycle ergometer (Lode Excalibur, Monark, Germany) to volitional exhaustion and prior to this, baseline measurements were recorded including; height to the nearest 0.1cm using a stadiometer (Seca:Model 220, Hamburg, Germany), weight to the nearest 0.01kg using column scales (Seca, Hamburg, Germany), body fat percentage with the use of a bioimpedance body composition analyser (Tanita, Tokyo, Japan), resting HR via short range telemetry (Polar Ltd, Kempele, Finland) and resting BP (Omron Healthcare, MX3 Plus, Hoofddorp, The Netherlands). Resting heart rate and blood pressure were obtained whilst the participant was seated on a chair. Additionally other resting cardiovascular measured were obtained from each participant including; stroke volume, cardiac output, heart rate and blood pressure via a beat to beat blood pressure monitor (Finimter Midi, Finapress, FMS, The Netherlands). Capillary blood samples were taken for the colorimetric assessment of total cholesterol, triglycerides, high density lipoproteins (HDL), lactate and glucose. Finally, 24 hours after the testing session, some participants (n=5) attended the laboratory for a further capillary blood sample to assess creatine kinase (Rx Monza, Randox, London, United Kingdom) . All participants were required to attend the laboratory prior to the testing session and $\dot{V}O_{2max}$ in a fasted state.

The $\dot{V}O_{2max}$ test, a ramped protocol on a cycle ergometer, firstly required the participant to undertake a 3 minute warm up at 60-80 revolutions per minute (rpm), at a resistance of 50 watts. The participant was then required to cycle against a continually increasing resistance at 60-80 rpm until volitional exhaustion or unless any chest pains, discomfort was felt or they required to stop, with the resistance increasing automatically by 25-35 watts per minute, dependant on their current exercise activity with the test lasing between 8-12 minutes. The value used for $\dot{V}O_2$peak, was the highest value achieved over the test with data averaged in 30 second breaths. Specific $\dot{V}O_{2max}$ determination criterion to ensure a maximal value is attained was used, in accordance with the American College of Sports Medicine (2010) and British Association of Sport and Exercise Science (2008);

- A respiratory exchange ratio (RER) value of $\geq$ 1.15
- A VE/VO_2 value of > 30
- A post exercise blood lactate concentration of $\geq$ 8 $mmol.l^{-1}$
- A rating of perceived exertion (RPE) of 19-20
- A plateau in oxygen consumption (If not plateau, defined as VO_{2peak})
- A heart rate within ± 10 $beats.min^{-1}$ of age predicated maximum

During the test, every 2 minutes HR, power output, rpm and a rating of perceived exertion (RPE) from the Borg Scale (6-20) were measured. The test was terminated once the participant could no longer cycle or maintain >40rpm or required to stop for any reason i.e. leg fatigue. A cool down was then undertaken (<60rpm). During the test participants were attached to a 12 lead electrocardiogram (ECG) (12-channel ECG Custo Cardio 2000 USB, CustoMed, Germany) to monitor the electrical activity of the heart. For this, the skin was cleaned with a sterile wipe (Isopropyl Alcohol 70%v/v), before the 10 electrodes were attached, which was connected to the computer (Custo Diagnostics, CustoMed, Germany) to enable analysis and observations to be undertaken. Additionally a heart rate strap was worn along with a respiratory mask in which breath by breath analysis was collected and measured (Cortex Metalyzer 3BR2, Biophysik, Version Metasoft 3.9.7 & Cardiocontrol 3000, Leipzig, Germany), via a soft rubber face mask (Hans Rudolph, Germany), into which a bidirectional turbine (Hans Rudolph, Germany) was placed to measure the flow of air and concentrations of gases from the participant throughout rest, the exercise test and cool down periods. Immediately after the termination of the $\dot{V}O_{2max}$ test, a further capillary blood sample was taken to measure lactate and glucose. After this preliminary testing session and all results were obtained, participants were matched paired into groups of four based on; sex, relative $\dot{V}O_{2peak}$ (ml/kg/min) and resting heart rate. Once matched in groups of four, they were then randomly assigned into one of four training groups either; the combined sprint interval training and endurance training group (COMB), a sprint interval (SIT), endurance (ET) or control group (CON). Table 1. displays the subject characteristics of the participants in each of the training groups.

Table 1. Participant Characteristics & *matched parameters* (+/- SD) for CON, ET, SIT and COMB

	CON (*SD)	ET (SD)	SIT (SD)	COMB (SD)
Sex (M/F)	3/4	4/4	3/4	¾
Mean Age (years)	35.4 (9.9)	33.1 (14.9)	35.4 (13.7)	39.1 (14.6)
BMI (kg/m)	25.3 (3.9)	24.1 (2.6)	25.7 (3.5)	23.7 (3.1)
Body Fat (%)	27.3 (8.9)	24.5 (6.5)	27.8 (8.8)	24.5 (8.5)
$\dot{V}O_{2peak}$ (ml/kg/min)	33.0 (8.0)	33.8 (10.0)	34.0 (10.1)	32.7 (8.8)
Resting Heart Rate (bpm)	66.0(6.7)	64.0 (5.1)	64.4 (10.7)	66.0 (7.9)

*SD=Standard Deviation

3.13 Experimental Design and Training Protocols

Participants attended the laboratory three times per week for 8 weeks to undertake the training. Participants in the SIT group undertook maximal all out sprints on a cycle ergometer (Monark Ergomedic 874 E, Monark, Sweden) consisting of; 5x5 second sprints with recovery intervals of 30 seconds during which the participant cycled at a cadence of <50rpm, twice, interspaced with a 4 minute rest period (<50 rpm), carried out three times per week, on a cycle ergometer. This progressed from 6x5 second sprints in week 1 -3 to 7x5 seconds in week 4-6 and to 8x5 seconds in week 7-8 (Based on protocols used by Gaitanos et al., 1993 & Linossier et al., 2003). The resistance on the bike was calculated by 0.075kg/kg body weight (Goulder et al., 2010). Immediately prior to each sprint the participant was instructed to cycle at maximum capacity with no resistance on the bike for 5 seconds, before the resistance of 7.5%of body mass (kg) was applied to the fly wheel of the cycle ergometer, with the subject then continuing to peddle as fast as possible for the 5 seconds. The rest periods undertaken for 30 seconds during each sprint and 4 minutes between bouts, were carried out at <50rpm to prevent venous pooling and to avoid light-headedness.

Those assigned to the ET group carried out cycling for 40 minutes in week 1-3, 50 minutes in week 4-6 and 60 minutes in week 7-8. The ET was carried out at 60% of pre training $\dot{V}O_{2peak}$, which is the equivalent to 78.5% of maximum HR, twice per week, at a cadence of

60rpm (Based on ACSM health guidelines, 1998) and adjust after the subsequent 4 week $\dot{V}O_{2max}$ test.

Finally those in the COMB group undertook a combination of the above two protocols based on the pilot study that was undertaken. Firstly, 36 minutes increasing to 52 minutes over the 8 weeks of endurance exercise at 60% of $\dot{V}O_{2peak}$ or 78.5% of maximum HR followed by, 6x5 seconds increasing to 8x5 in week 8, with intervals of 30 seconds between each sprint, during which the participant cycled at a cadence of <50rpm, twice, interspaced with a 4 minute rest period (<50 rpm) between each set, carried out three times per week, on a cycle ergometer. During each training session, HR was measured and monitored at rest, during the exercise and during recovery. Health questionnaires were completed prior to every testing session. All participants were verbally encouraged throughout the training. A warm up and cool down were carried out at each session. Figure 5. demonstrates the week 1-3 training protocols undertaken for each of the training modalities.

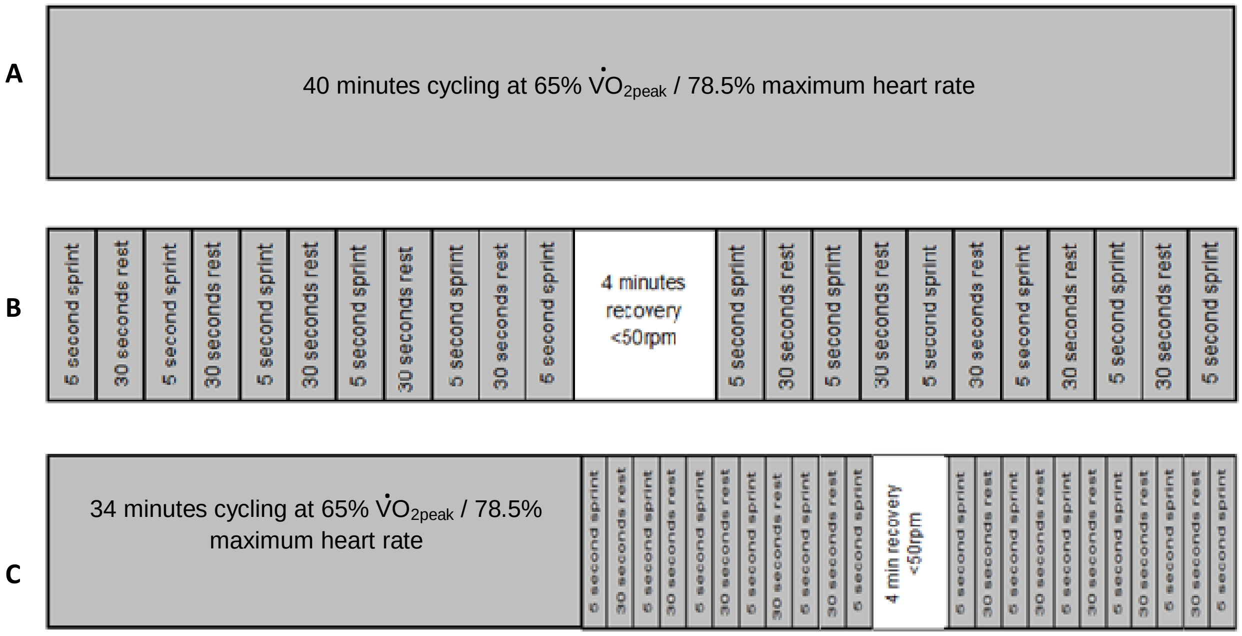

Figure 5. Training protocol undertaken in Week 1-3 for A - Endurance training, B - Sprint Interval Training and C – Training types combined

Participants undertaking the 8 week <u>endurance training protocol</u> completed the following protocol of training;

Week 1-3 - 40 minutes cycling at 65% of $\dot{V}O_{2max}$ - 3 times per week

Week 4-6 - 50 minutes cycling at 65% of $\dot{V}O_{2max}$ - 3 times per week

Week 7-8 - 60 minutes cycling at 65% of $\dot{V}O_{2max}$ - 3 times per week

Participants undertaking the 8 week sprint interval training completed the following protocol of training;

Week 1-3 - 6x 5 seconds, twice with 30 second recovery between each sprint and a 4 minute recovery between each set – 3 times per week

Week 4-6 - 7x 5 seconds, twice with 30 second recovery between each sprint and a 4 minute recovery between each set – 3 times per week

Week 7-8 - 8x 5 seconds, twice with 30 second recovery between each sprint and a 4 minute recovery between each set – 3 times per week

Participants undertaking the 8 week sprint interval and endurance training protocol completed the following protocol of training;

Week1-3 - 34 minutes cycling at 65% of $\dot{V}O_{2max}$ & 6x 5 seconds, twice with 30 second recovery between each sprint and a 4 minute recovery between each set – 3 times per week

Week 4-6 - 43 minutes cycling at 65% of $\dot{V}O_{2max}$ & 7x 5 seconds, twice with 30 second recovery between each sprint and a 4 minute recovery between each set – 3 times per week

Week 7-8 - 52 minutes cycling at 65% of $\dot{V}O_{2max}$ & 8x 5 seconds, twice with 30 second recovery between each sprint and a 4 minute recovery between each set– 3 times per week

During the 30 second recovery period between each sprint, the participants were be required to cycle at a cadence <50rpm. The resistance on the bike for the sprints will be calculated by 0.075kg/kg body weight (Goulder et al., 2010). The sprint protocols are based on previous research and protocols used by Gaitanos et al., 1993 & Linossier et al., 2003.

3.14 Mid and Post-experimental procedure

Halfway through the training programme and at the end of the 8 week training programmes, all participants were required to undertake a further $\dot{V}O_{2max}$ test and baseline measures were taken including capillary blood samples. The same protocol as stated in the pre experimental procedure was carried out, in order to allow for comparison and analyses from pre to mid and post training. Again a warm up and cool down were carried out and subjects were verbally encouraged throughout each $\dot{V}O_{2max}$ test. Each $\dot{V}O_{2max}$ test for each participant was undertaken at the same time of day (± 2 hours) to help prevent any bias in time of day. Finally, the methodological layout of the study is demonstrated in Figure 6.

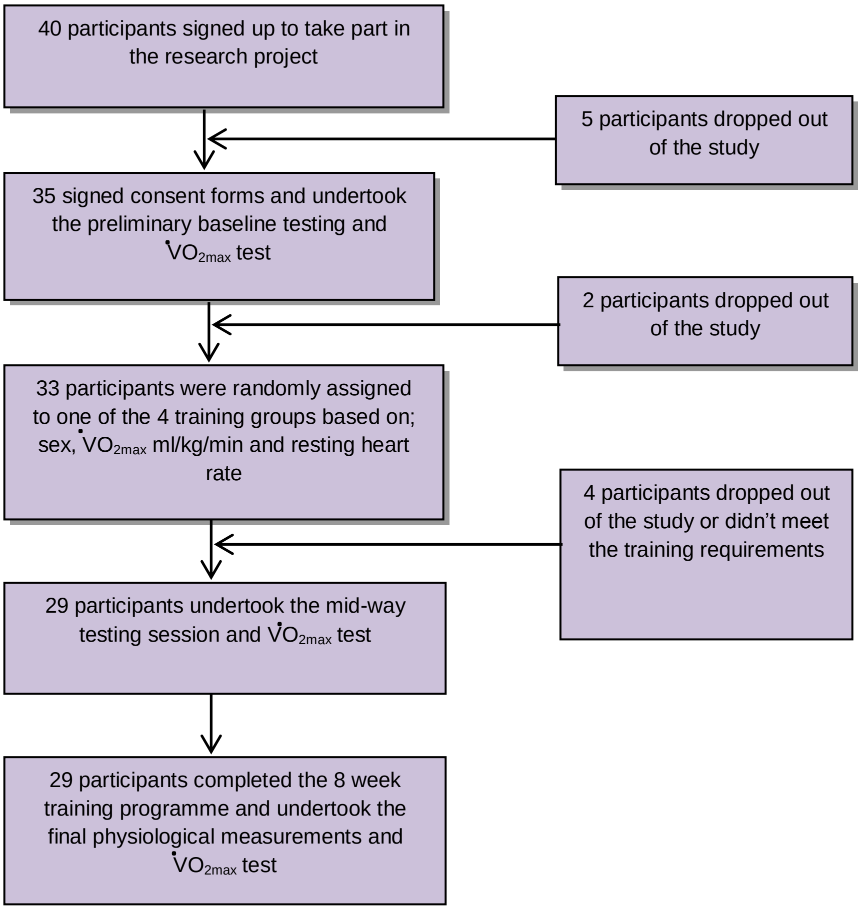

Figure 6. Flow diagram demonstrating the subject recruitment and attrition of the study.

<u>3.14 Blood Analysis</u>

The analysis of total cholesterol, triglycerides and HDL cholesterol were undertaken on the clinical chemistry analyser (Rx Monza, Randox, Northern Ireland, UK) whilst glucose and lactate were analysed using the blood lactate and glucose analyser (Biosen C Line, EKF Diagnostics, Madgeburg, Germany) Calibration and reliability tests were untaken to test the reproducibility, reliability and validity of the measures. For the analysis of blood firstly a fingertip was wiped with a sterile wipe (Isopropyl Alcohol 70%v/v) and let to air dry before lancing to obtain required capillary blood. Batch analysis method was used to analyse the blood measures, with all tests of a specific parameters undertaken on the same day, at the same time of day. All bloods were stored in the freezer for the same period of time at -75°c and defrosted the same amount of times to ensure no variance between samples.

Furthermore, equipment was calibrated prior to use to known standard references and finally the blood was taken and analysed by the sole and same investigator throughout the study, and intra individual and repeated blood measure analysis were undertaken to assess the reproducibility of results in terms of both the equipment and blood measure taken. Quality control measures were taken into consideration ensuring, the correct functioning of the instrument settings and light source, cleanliness of equipment and expiry dates of kit and materials used. Throughout the COSHH and Health and Safety Act (1974) were abided by.

3.141 Cholesterol

For the analysis of the four cholesterol parameters to be measures namely; TC, HDL, LDL and triglycerides, 800 micrograms of blood was collected in EDTA collection tubes for the analysis of cholesterol. This was then spun in a centrifuge at 8,000 revs for 5 minutes enabling the separation of whole blood and plasma. The plasma was then pipetted off and placed into an eppendorf tube and stored in the freezer at -75 degrees centigrade (°c). For the analysis of cholesterol, samples were defrosted until room temperature. Sample calibration was undertaken prior to each test batch that was run, with the concentration of the cholesterol set at 5.25mmol/l as stated in the material safety data sheets (MSDS). All values were measured in mg/dL.

When analysing, total cholesterol, 50ul of cholesterol reagent was placed into a cuvette with 5ul of the blood plasma, mixed and left for 10 minutes at room temperature; the sample was then placed into an incubator for 5 minutes at 37.5°c. After this time, the cuvette containing the sample was placed into the machine for analysis of total cholesterol. The same process was undertaken for the analysis of triglycerides, instead the triglyceride reagent was mixed with the blood plasma.

For the analysis of HDL, firstly the calibration was carried out requiring a blank standard (S0) and a sample supernatant (S1). In S0 50ul of distilled water was pipetted with 500ul of the cholesterol reagent, this was mixed, incubated for 5 minutes at 27°c, and then inserted into the flowcell holder of the Rx Monza for analysis, required within 60 minutes of incubation. A precipitation process was then required prior to the analysis of the blood plasma samples collected. 200ul of the plasma was mixed with 500ul of cholesterol reagent. This was then placed into the centrifuge an spun at 12,000 revolutions for 2 minutes, The plasma was then decanted off into an eppendorf tube then 5ul of this pipetted into a cuvette mixed, with 50ul of the HDL reagent, This was mixed then left for 10 minutes at room temperature. After this time the sample was then placed into an incubator for 5 minutes at 37.5°c, and then placed into the machine for analysis of HDL. To analyse triglycerides, the same calibration and analysing processed were used in order to calibration and obtained the required values, as for the cholesterol assay, instead the triglycerides enzymes reagent/ supernatant was used. Finally the HDL and total cholesterol values were used to assess the LDL values. This was calculated by subtracting the HDL value from the LDL value.

3.142 Lactate and Glucose

Lactate and glucose sample were collected in glass capillary tubes (20 microlitres) placed into an eppendorf tube containing a stabilising reagent, and mixed well for 15 seconds then placed into the EKF for immediate analysis of lactate and glucose.

3.1.4.3 Creatine Kinase

To analyse creatine kinase, blood sample were again collected in an EDTA collection tube, 24 hours after the $\dot{V}O_{2max}$ test had taken place, spun in a centrifuge, with the plasma pipetted off and placed into an eppendorf tube, then stored in the freezer. When required for use, the sample was defrosted. Prior to the analysis of CK, it was necessary to calibrate the analyser. For this, 1.0ml of the combined enzymes and substrate were pipetted and mixed with 0.02ml with a sample, in this case for calibration saline was used as recommended in a semi micro cuvette. The solution was mixed and incubated at 37°c for 1 minute. After this time the semi micro cuvette containing the solution was placed into the analyser for calibration. The process then in which to analyse a blood plasma sample, was as above with blood plasma used instead of saline as the sample.

3.2 Data analysis / Statistical Analysis

Statistical analysis was carried out on SPSS statistical software package (Version 20, IBM SPSS Inc. Chicago, USA). The level of statistical significance was set at $p \leq 0.05$.) Prior to statistical analysis, a Sharpiro-Wilk test of normality was carried out on each data set. Delta data was used for statistical analysis. Two way factorial analysis of variance (ANOVA) was used for statistical analysis with lowest standard deviation (LSD) correction. Two way ANOVAs were used to assess changes and differences between sex and age.
Repeated measure ANOVA were used to assess changes within each individual training modality.

3.3 Results

Preliminary measures and testing indicated ET, SIT, COMB and CON were not significantly different at the start of the training programme, as required, in terms of the parameters they were matched on; $\dot{V}O_{2max}$ and Resting HR prior to the commencement of the training programme.

Time commitments for each group were vastly different with ET and combined groups time matched and undertaking 1170 minutes (19 hours 30 minutes) and SIT 337 minutes (5 hours 37 minutes) throughout the whole 8 week training programme. Equating to 110.5% more work undertaken by those in the endurance and combined group over the period of time than the SIT group with a time difference of 14 hours 7 minutes.

3.31 Subject Characteristics

There were no differences in body mass (kg) between or within the training groups, amongst participants in all training groups after 4 and 8 weeks of the training programme ($p>0.05$).

There were no differences in body fat percentage within the groups over time or between groups at any time point ($p>0.05$).

Fat Free Mass (FFM), often a marker of muscle hypertrophy or increased glycogen stores, showed no differences between the training groups over the 8 weeks training programme ($p>0.05$).

Changes in BMI were not significant amongst or between all training groups after 4 weeks and 8 weeks of the training regime ($p>0.05$). A trend towards significance was seen between ET and SIT ($p=0.089$) and SIT and COMB ($p=0.076$).

3.32 Exercise Performance

3.321 Maximal Oxygen Consumption (Relative)

$\dot{V}O_{2max}$, a matching factor prior to the start of the training programme demonstrated no significant difference between the groups before the instigation of the training programme. Changes over the 8 week training programme in relative oxygen consumption, demonstrated no significance between the four training modalities ($p>0.05$). A trend towards significance was seen between SIT and COMB ($p=0.083$). Repeated measures ANOVA to analyse statistical significance in changes within the training groups established a significant change in the SIT group ($p=0.06$) with Post-Hoc analysis identifying this change from PRE to POST training ($p=0.006$). Additionally significance was demonstrated within the ET group ($p=0.029$) Post-Hoc analysis demonstrated this change from PRE to POST training ($p=0.044$) Furthermore significance was also found within the COMB training group ($p=0.004$) with Post-Hoc analysis again demonstrating a significant change from PRE to POST training ($p=0.049$), furthermore in the COMB group from PRE to MID training ($p=0.003$). No changes were observed within the control group ($p>0.05$). Changes over the 8 weeks are demonstrated graphically in Figure 7.

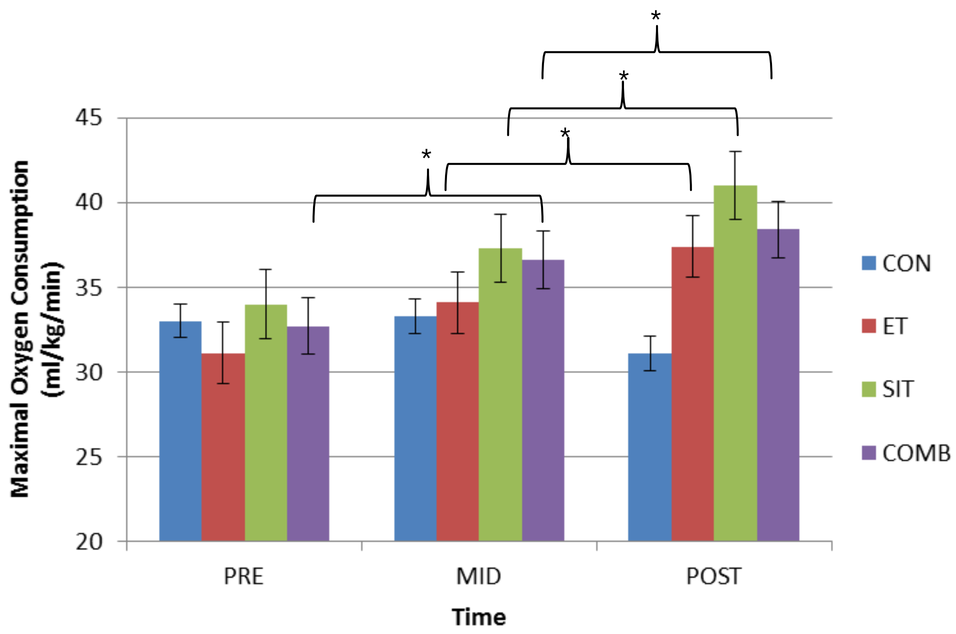

Figure 7. Changes in relative maximal oxygen consumption over the 8 week training period with standard error. * Indicates significance.

3.322 Maximal Oxygen Consumption - Absolute

There were no changes between the training groups in terms of absolute $\dot{V}O_{2max}$ value after 4 or 8 weeks of training (p>0.05). When observing within group changes, significant differences were found within the ET group (p=0.017) with Post-Hoc analysis indicating the significance between PRE and MID training (p=0.01) as well as from PRE to POST training (p=0.050).

3.323 Anaerobic Threshold - Relative

Two way factorial ANOVA showed a significant difference between SIT and CON from PRE to POST training (p=0.039). Statistical analysis undertaken to assess changes within each training group, identified significant changes only within the COMB group from PRE to POST training (p=0.028).

3.324 Anaerobic Threshold - Absolute

Improvements in the absolute AT values, were not significant amongst the four groups from PRE, MID to POST training programme (p>0.05). In terms of within training groups changes, significant difference were measured in the ET group throughout the whole 8 week training prior (p=0.027). Significant change were evident in the COMB training group (p=0.037) with Post-Hoc analysis stating the significance from MID to POST training (p=0.020), as well as in the SIT group (p=0.041), with no changes within the control group (p=0.608).

3.33 Cardiovascular Parameters

There were no in resting heart rate amongst the groups at the start of the 8 weeks, as expected, as participants were match paired prior to the commencement of the training (Table 2.) Significant differences were evident between ET and CON (p=0.016), SIT and CON (p=0.005) and COMB and CON (p=0.026). Post hoc analysis indicated significance was seen form PRE to POST between SIT and CON (p=0.04) and COMB and CON (p=0.025). Changes over the 8 weeks are demonstrated in Figure 8.

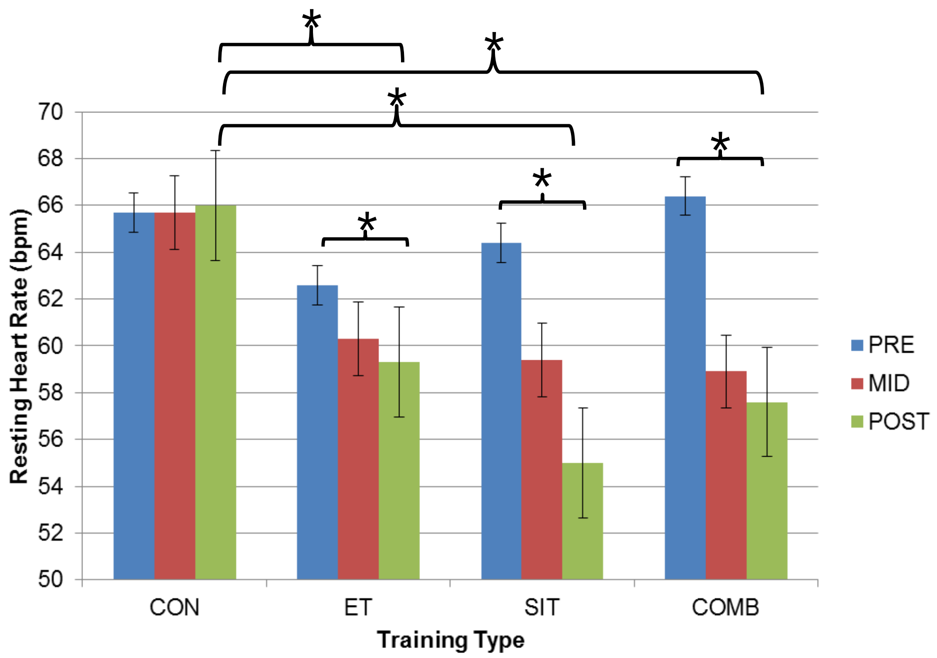

Figure 8. Changes in resting heart rate over the 8 weeks of trianing. * Indicates signifance

Significant changes were evident within, the sprint interval training group (SIT: p=0.006), endurance training (p=0.036) and the combined training group (p=0.016), Post-Hoc analysis indicated significance after 8 weeks in the SIT and ET training groups, (p=0.050) & (p=0.035) respectively. With near significance in the COMB groups after 8 weeks (p=0.053), and after 4 week in the SIT group. (p=0.057). No changes were evident within the control group (p>0.05).

A trend towards significance was seen between the training groups in systolic blood pressure (p>0.05) (Table 2.). Significance was established in systolic blood pressure only within the SIT group (p=0.008) with Post-Hoc analysis indicating this significance between the start and end of the training programme (p=0.013).

In terms of diastolic blood pressure, significance was seen prior to the training programme between SIT and COMB (p=0.029), after 4 weeks between SIT and COMB (p=0.024) and between COMB and CON ($p=0.029$). Finally after 8 weeks of training between COMB and ET ($p=0.032$), COMB and SIT ($p=0.033$) and COMB and CON ($p=0.029$). There were no changes within each training modality at any time point measured ($p>0.05$) (Table 2.).

Table 2. Cardiorespiratory Parameters; Average (SE), n=29, HR, heart rate; SV, Stroke Volume; Q, Cardiac output, * significant difference between groups. (p<0.05) † significant different within training type

	CON			ET			SIT			COMB		
	PRE	MID	POST	PRE	MID	POST	PRE	MID	POST	PRE	MID	POST
Resting HR (bpm)	66.0(3)	66.0(3)	66.0(2)*	60.0(2)	59.0(2)	60.0(2)*†	64.0(4)	59.0(4)	55.0(2)*†	66.0(8)†	59.0(1)†	58.0(2)*†
Resting SYS (mmHg)	125(5)	125(4)	126(4)	126(4)	122(2)	123(3)	134(4)†	128(3)†	124(2)†	126(5)	125(3)	124(3)
Resting DIA (mmHg)	77(3)	81(2)*	81(2)	81(1)	80(1)	80(2)*	84(2)	81(1)*	80(1)*	77(2)	74(3)*	74(4)*
Resting SV (ml/min)	81(9)	83(8)	80(6)	82(9)	84(9)	86(9)	80(5)	90(6)	84(6)	86(10)	88(9)	98(9)†
Resting Q (ml/min)	5.3(0.4)	5.7(0.4)	5.4(0.4)	5.4(0.6)	5.5(0.7)	5.8(0.6)	5(0.4)	5.2(0.2)	5.2(0.2)	5.5(0.4)	5.3(0.4)	6.2(0.4)†

3.331 Stroke Volume

Throughout the training programme, there were no changes in resting stroke volume between the training modalities (p>0.05). In terms of within group changes, in resting stoke volume were observed, however, significance was displayed solely within the combined group (p=0.047, Post-Hoc; p=0.053) from week 4 to week 8 of the training.

3.332 Cardiac Output

Cardiac output changes were not significant over the training period between the training modalities (p>0.05). This was too evident within the SIT, ET and CON groups (p>0.05) however significance was shown within the COMB group, (p=0.046) with Post-Hoc analysis indicating this change from MID to POST training (p=0.017).

3.34 Blood Measures

3.341 Total Cholesterol

Fasted total blood cholesterol measures were not altered significantly between the training groups after the 8 week training programme. (p>0.05). Significance within training groups was not present after 4 or 8 weeks of the training programme (p>0.05).

3.342 Triglycerides

Additionally triglycerides measures were not significantly altered between the training groups after 4 weeks (p>0.05). However significant changes were evident after 8 weeks of the training programme between ET and CON (p=0.032), SIT and COMB (p=0.025) and COMB and CON (p=0.008). With near significance seen between ET and SIT (p=0.085).Repeated measures ANOVA undertaken to assess differences within the training groups presented a significant change within the COMB group (p=0.035) and within the SIT training group (p=0.017). Changes over the 8 weeks are indicated in Figure 9.

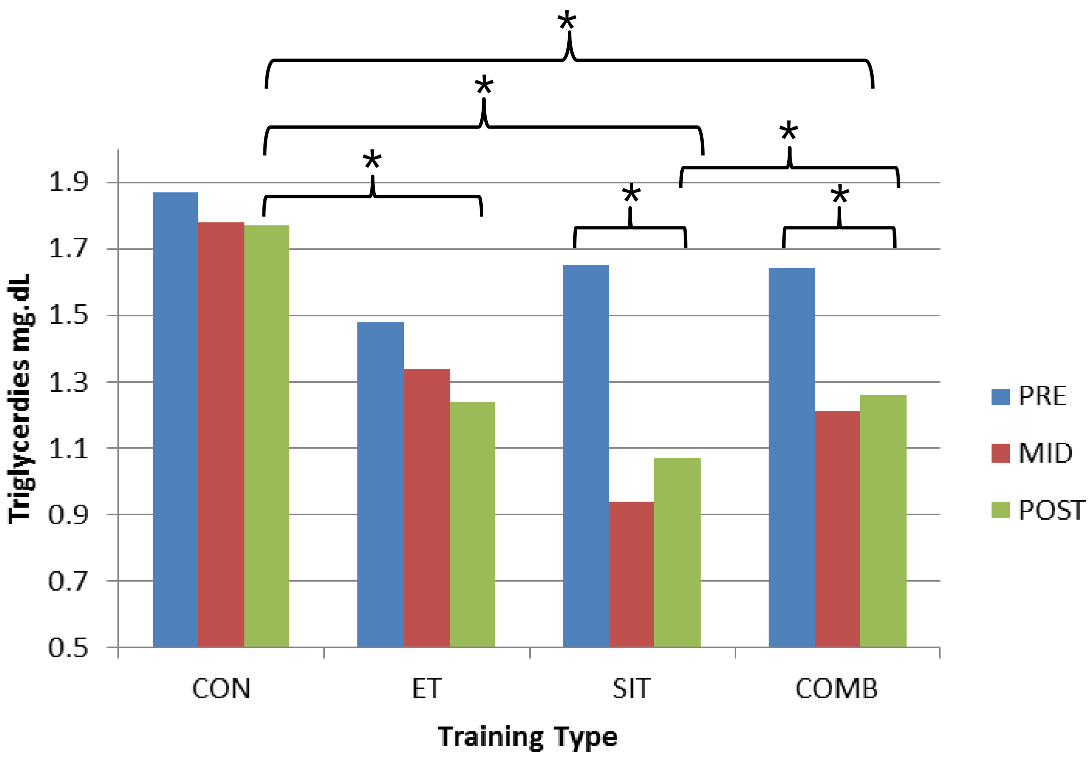

Figure 9. Changes in triglycerides measures in each of the training types over the 8 week training programme. * Indicates significance

3.343 HDL and LDL

A significant difference was seen prior to the training programme between ET and COMB (p=0.029) in HDL. No other significant difference were obtained in HDL amongst or within the training groups (p>0.05). Significant differences were also seen prior to the training programme between ET and COMB (p=0.033). No other significant difference were seen in LDL between or within the training groups (p>0.05).

3.344 Creatine Kinase

There were no changes in creatine kinase between or within the training modalities after 4 or 8 weeks of the training programme (p>0.05). Additionally subject numbers were too low in order to gain a true representation of the cohort

3.345 Lactate and Glucose

Two way factorial analysis indicated no significance between or within the group in the blood lactate measures taken at rest (p>0.05) or post (p>0.05) the VO_{2max} test. Significant differences were indicated in the glucose concentrations halfway and after the 8 week training programme, between the SIT and COMB training types both MID and POST training (p=0.002 and p=0.019, respectively).

3.35 Age differences

Firstly in terms of $\dot{V}O_{2max}$, in this study, despite the participants being match paired into groups based on sex, $\dot{V}O_{2max}$ and resting heart rate, when split into ages, the older group i.e. those older than 35 years had a significantly lower starting $\dot{V}O_{2max}$ (28.9ml/kg/min) value than those less than 35 years (38.2ml/kg/min) ($F=9.305$, $p=0.006$). Significance between the two age groups was also demonstrated after 4 weeks ($F=6.165$, $p=0.022$) and 8 weeks of training ($F=6.314$, $p=0.020$). Changes in resting heart rate between the age ranges were not significantly different after 4 or 8 weeks of the training programme (PRE: $F=0.003$; $p=0.956$, MID: $F=0.136$, $p=0.715$; POST: $F=0.000$, $p=0.988$).

In terms of percentage change overall, those aged >35 years increased thier $\dot{V}O_{2max}$ value by 13.1% whereas those under 35 years increased this by 11.3%. When assesing the effects of each training modalties on the age differences, it is demosntarted that for the COMB group those under 35 years had a percnetage increase of 14.4% whereas for those over 35 years had an overall percentage increase of 31%, this trend was only seen in the SIT group with the under 35 years indicating a percentage increase of 14.7% yet those over 35 increasing by 23.1%. Addtionally in terms of ET not a great difference between the ages where observed however, those under 35 increased by 15.2% with those over by 17.3% In both age brackets the CON group demosntrated a percenatge decrease. These results are displayed graphically in Figure 10.

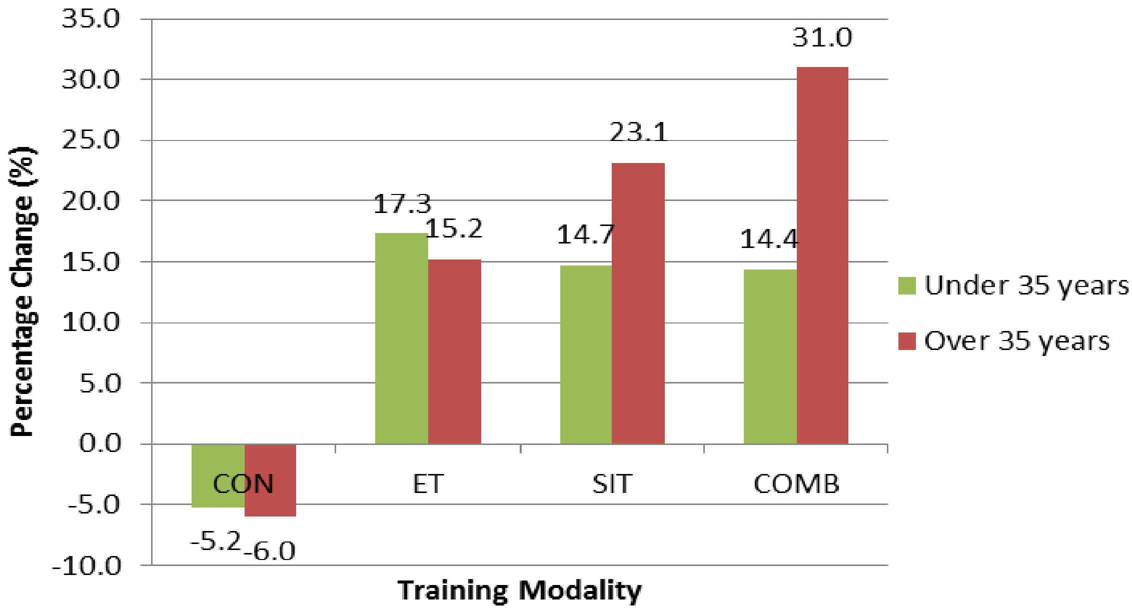

Figure 10. Percentage changes in each training type for those under 35 years and over 35 years after the 8 week traiing programme

3.36 Sex differences

Preliminary difference in $\dot{V}O_{2max}$, prior to the start of the training programme, indicated males had a greater $\dot{V}O_{2max}$ than females on average (Male: 39.9 ml/kg/min & Females: 29.1 ml/kg/min) The increase after the training programme again too indicate a greater dominance in $\dot{V}O_{2max}$ in the males, with males demonstrating an increase of 13.8% and females 10.1% ($F=7.52$, $p=0.001$). Post-Hoc analysis displayed a significant difference between males and females from the start to halfway of the training ($p=0.025$) as well as from the start to end ($p=0.008$). In terms of resting heart rate between the males and females, there were no significant differences throughout ($F=0.145$, $p=0.792$).

3.4 Discussion

The purpose of this study was to investigate the effects of an 8 week training programme of sprint interval training, endurance training, the training type combined and a control group, on physiological parameters and exercise performance, namely; $\dot{V}O_{2max}$, cardiovascular parameters, body composition and blood measures in recreationally active participants. The main findings from this study indicated that after an 8 week training programme SIT and COMB training types had the greatest impact and change on the measured parameters, with SIT being the most time efficient overall. Significant changes were evident between the training groups in resting heart rate as well as blood triglycerides, relative AT and diastolic blood pressure. With near significance shown several of the measured parameters.

An important factor prior to the commencement of the training programme, which many training studies do not consider (Tabata et al., 1997; Helgerud et al., 2007 & Daussin et al., 2008), leading to biased or skewed end results is matching the participants at the start of the intervention, before randomisation into groups. This is to ensure similar values obtained between each group act as an equal initial platform for the changes from training to build upon and that measures that are going to be observed throughout are not influenced to begin with. This was an essential factor to enable the analysis of change to be observed and measured accurately. The matching parameters adopted included sex, $\dot{V}O_{2max}$ then resting HR. Preliminary measures and testing indicated COMB, SIT, ET and CON were not significantly different at the start of the training programme in terms of the parameters they were matched on; $\dot{V}O_{2max}$ ($p=0.993$) and resting HR ($p=0.790$), parameters prior to the commencement of the training programme, therefore implying there was a high correlation or closeness between the participant data at the start of the training programme in the specified.

It is well documented that initial $\dot{V}O_{2max}$ values are vital for further improvements and percentage of aerobic capacity change, whether this be low due to the untrained nature of the participants which may enabled a greater improvements or higher starting $\dot{V}O_{2max}$ individually or between groups, which may be only maintained to increase at a slower rate. Match paring the participants, ensured this potential limitation is eliminated. Additionally as the training period is over 8 weeks, research has shown that after 4 weeks depending on the training type often a higher intensity is need to see further improvements. By having an equal and non-significant starting value amongst each training group changes up to and also after 4 weeks were observed and analysed accurately.

Despite the 110% lower training time requirement, the SIT after 8 weeks still demonstrated a greater performance increase and favourable alteration in various physiological parameters. These results indicate SIT is a much more time efficient method than the other modalities, as has previously been demonstrated and established by other researchers. (Coyle et al., 2005; Gibala et al., 2006; Burgomaster et al., 2008; Hawley et al., 2009; Cock et al., 2013) Additionally the ET group and COMB group were time matched, yet the COMB group demonstrate greater improvements indicating of the same time a greater work achievement can be obtained by including a bout of SIT with ET to maximising the time. Minimal research however, is available or considered; assessing this concept of combined SIT and ET in one training session, in particular over a period of 8 weeks.

3.41 Exercise Performance

As expected, the results from this study demonstrate that exercise training did have a beneficial effect on $\dot{V}O_{2peak}$, over the 8 week period however there was no significant difference between the training groups. Instead significant changes were evident within all three training groups, when oxygen consumption was relative to body mass, yet solely in ET when the absolute measurements were taken.

Percentage change overall within the training groups indicated a 18.7% increase (7ml/kg/min) in the SIT group , 18.3% increase (6.3ml/kg/min) in the ET group and a 16.1% increase (5.7ml/kg/min) in the COMB group, with a reduction in the control group of 5.8% (-2 ml/kg/min) These results are concurrent with previous research (Overend et al., 1992; Rakobowchuk et al., 2008 & Burgomaster et al., 2008) demonstrating similar changes in ET and SIT over the training period. Furthermore, a study from Daussin et al. (2008) that measured the change in $\dot{V}O_{2max}$ in men and women, found that after an 8 week SIT and ET programme, demonstrated greater increases in the high intensity trial (15%) were seen, than in the continuous group (9%). Likewise, in a study from Eddy et al., (1977) $\dot{V}O_{2max}$ changes within the groups were similar to this study, for SIT 15.2% and ET 14.3%. Additionally in the study from Burgomaster comparable results were obtained, with again, the SIT group improving to a greater extent over the time period than the ET group. Moreover, in the study by MacPhearson et al., (2011) both the SIT and ET training groups established similar improvements in VO_{2max} over the 6 week study. Additionally, Tabata et al., (1996) found no change in the ET group yet a 28% increase in the SIT group – however no control group was present to enable comparisons to be made to baseline. These results therefore confirm the previously established finding that SIT is a time efficient way than ET, in order to elicit similar and if not greater achievements in terms of $\dot{V}O_{2max}$ than ET. Finally, research from Burgomaster and colleagues (2008), indicated the young adults recruited in their study had similar increase in $\dot{V}O_{2max}$, with the SIT group training volume just 10% of the endurance and a time difference of 3 hours per week of training time. In terms of the results in relative oxygen consumption, the COMB group demonstrated significance after the 8 week training programme ($p=0.049$) and greater significance after 4 weeks ($p=0.003$), suggesting changes took places earlier on in the training programme than the other training modalities i.e. SIT ($p=0.006$) & ET ($p=0.044$), which both demonstrated a significant change solely after the 8 weeks of training.

Despite the changes in the absolute maximal oxygen consumption, no significant changes were measured in this parameter between the training groups over the 8 weeks and solely in the ET after 4 weeks, in terms of within each training type. Therefore, although the relative oxygen consumption values within the SIT and COMB training groups displayed significance, this was not the case in terms of absolute oxygen consumption. This there proposes that weight had a greater impact on the relative oxygen consumption values obtained, when SIT was undertaken, as significance is seen when relative to individual's body mass yet it is not when measured alone.

The current findings suggest the potent use of sprint interval training within a training programme to obtain maximal benefits in maximal oxygen consumption in comparison to ET alone, however on average the percentage increase in the COMB group was actually lower than in the ET and SIT groups after the 8 weeks of training overall.

As this study also aimed to compare the ET with the COMB, as the two groups were time matched in addition to the comparison of SIT, as previously stated, the COMB group demonstrated a greater change than ET alone, implying that combining both ET and SIT in one training session, does have a greater beneficial effect on the measured parameters namely, $\dot{V}O_{2peak}$ than just ET alone, over the same period of time. On the contrary, it may have been expected that in the COMB group, by undertaking a whole SIT protocol along with an additional bout of endurance exercise in one session over the 8 weeks, greater results would have been obtained overall, exceeding SIT alone however this was not the case in terms of maximal oxygen consumption after 4 or 8 weeks of training, with SIT indicating to some extent greater improvements alone in particular in the exercise performance parameters. Further benefits of combining the training types are that an extensive warm up is necessary prior to undertaking high intensity sprint training, primary to prevent injury. Which therefore implies the endurance training bout acts as an extensive warm up prior to the sprint training,

Despite the very limited literature in the area of COMB training or as it is also known in some literature as a method of ‘concurrent;’ training, previous research has considered this method with strength and endurance training. Data from these studies however have suggested an inference effect to explain why improved or favourable results are often not measured when resistance training is combined with endurance training in a single session. Two postulated mechanisms for this interface effect are chronic and acute hypothesis. (Leveritt et al., 1999 & Paulo et al., 2007). Firstly the chronic hypothesis suggest that, the adaptations that occur as a result of strength training including; muscular hypertrophy and metabolic changes are significantly different and sometimes the opposite of the adaptations that occur from endurance training. Therefore the muscles encounter conflict in terms of the adaptations when the exercise types are performed and has been suggested the required changes to and from each modality are unable to be completed as effectively at the same time. The acute hypothesis states that the enduring fatigue as a resultant from too much endurance exercise in turn affects the strength training, (Craig, Lucas, Pohlman and Stelling, 1991) which too could be presented in the study and suggest potentially why the combined group, despite including the bout of SIT as well as endurance work, did not exceed the SIT adaptions and changes. As a time saving factor SIT may therefore the preferred choice**.** On the other hand, the synergy between SIT and ET is shown as effective as greater gains are obtained than just ET alone, however when considering the concurrent effects of the training on power output the changes may not have been as effective from the SIT point of view, as the muscle fibres may have been partially fatigued and therefore the power output reduced enabling less adaptations than solely SIT. Additionally although there may have been some interference, in order to achieve greater gains, the changes in the training types may have too been beneficial, but as this study is the first of potentially many, it is then to determine how much endurance exercise in terms of intensity, duration and method of exercise, is too much or also too little or potentially obtained greater gains over the longer period of time in comparison to SIT alone. Furthermore, a number of studies (Craig et al., 1991; Kraemer et al., 1995 & Bell et al., 2000; Hickson, 1980) have investigated the effects concurrent endurance and strength training on strength and endurance development and adaptation, suggesting it may be affected or reduced in particular if the session or period is too long or at a high intensity. (Hickson et al., 1980; Leveritt et al. 1999, Mikkola et al. 2007) indicating an overload principle, which may potentially have contributed to the results in this study.

However, although SIT is not the same as and not classified as strength training, it is a high intensity repeated load or measure, yet does not induce marked hypertrophy like strength training (Gibala et al., 2008) Likewise, Ross and colleagues (2001) suggested that that both sprint and strength training induce a comparable transition through training programmes, yet adaptations are not the same as the requirements in the muscular contractions and energy system are different.

Potential reasons as to why physiological parameters improved to a greater extent with SIT over the 8 weeks, despite the much reduced time expenditure overall may be due to the increase load on the cardiovascular, metabolic and respiratory systems. It has been advocated and demonstrated that HIT protocols that elicit maximal oxygen uptake or at least a very high percentage of the individuals maximal oxygen uptake, maximally stress the oxygen transport and utilization systems and may in turn provide the most effective and efficient stimulus to enhance $\dot{V}O_{2max}$ (Laursen at al., 2002 & Kent et al., 2011) as well as enabling and sustaining exercise eliciting the maximal cardiac output (Gollnick et al., 1974). Furthermore, it has been well established by numerous researchers that the ability of SIT to induce changes in the skeletal muscles oxidative capacity is due to the high and increased stress on the type II muscle fibres as well as increased level of muscle fibre recruitment, yet the mechanisms for this are unclear (Barnett et al., 2004 & Burgomaster et al., 2008).

Furthermore, another potential reason for the increase in $\dot{V}O_{2max}$ overall may have been due to the learning effect obtained by the participants in the first instance of undertaking the $\dot{V}O_{2max}$, however familiarisation session were undertaken by all, which would not suggest this a major influential factor, in addition a control group was included to address this. Finally, it is well documented that initial $\dot{V}O_{2max}$ values are related to further improvements and percentage of aerobic capacity change. Low initial VO_{2max} due to the untrained nature of the participants, may enabled a greater improvements or higher starting VO_{2max} individually or between groups, may be only maintained to increase at a slower rate. By match pairing the participants, ensured this potential limitation of varied preliminary values between groups and participants prior to the start of any training regime or intervention. This was evident in other previous research where often participants were not matched at the start of the intervention and therefore may have contributed to the difference in outcomes (Tabata et al., 1997, Helgerud et al., 2007 & Daussin et al., 2008). In addition to these theories, it has been postulated by Gibala et al., (2006) it is possible that the metabolic adaptations occurred as a result of HIT are in fact facilitated partly through the same signalling pathways that are associated with ET, which on the other hand agrees with the acute hypothesis from Craig et al., (1991), as this pathway may have be primarily partially fatigued form undertaking ET prior to the SIT. (Figure 1)

3.42 Anaerobic Threshold

After the 8 week training programme, the relative anaerobic threshold (AT) showed a significant change between the SIT and CON groups (p=0.039), with no significant changes between the other training groups (p>0.05). Significant changes were evident within the COMB training group who, demonstrated an overall 22.2% increase in the AT value from PRE to POST training. No significant changes were measured within the ET group (p>0.05) despite a 22% increase in AT values overall from PRE to POST, nor within SIT (p>0.05) with a 19.3% increase training types and as expected no significant changes were indicated in the CON group.

Furthermore, with regards to the absolute AT**,** no significant differences between the groups were measured (p>0.05), but significance within group differences were measured in the ET group both after 4 weeks (p=0.01) and after the 8 weeks of training (P=0.050), in the SIT group after 8 weeks (p=0.037) and COMB also after 8 weeks (p=0.041).

Very few studies, if any have compared the changes in AT between SIT and ET training programmes, with no study to yet compare these changes in COMB training, therefore data in the area in particular is limited. However, the increase in AT as a result of ET is representative of previous research (Davis et al., 1979).

Endurance training improves performance during tasks that rely on aerobic energy metabolism, by increasing the body’s ability to transport and use oxygen and altering substrate metabolism by working skeletal muscle, (Gibala et al., 2008) and therefore the amount of work which could be carried out by the participants in the ET group, in particular without a rapid break down in muscle glycogen and blood lactate accumulation was increased post training (Davis et al., 1979). Additionally, a consistent finding from previous research (Ekblom et al., 1969; Saltin et al., 1971 & Tabata et al., 1999) suggests that exercise training at sub maximal level i.e. that undertaken by the ET training group, delays the onset of lactate acidosis and which may indicate the greater increases in ET than SIT. Consequently the specificity of the exercise may therefore elucidate these mechanisms. Finally muscle fibre recruitment during the ET training would have predominantly been type I oxidative fibres, which In turn would have increased oxidative capacity, alternatively SIT would have relied mainly on type IIx fibres as well as requiring and increasing mitochondrial activity and oxidative capacity of both fibre types, (Poole et al., 1988) yet not as suited to the aerobic nature of the $\dot{V}O_{2max}$ test, so a greater volume of training may have been required to stimulate more comparable results to ET. Tabata et al., (1996) analysed anaerobic capacity using maximum lactate steady state (MLSS), however the results displayed no greater changes in continuous training compared to SIT. Their protocol was at a much high volume with participants in both groups training for 5 days a week and the SIT group undertaking greater period of high intensity exercise which may demonstrate the increase (23%) in anaerobic capacity. A study from Parra et al. (2000) also showed no significant change in anaerobic work capacity which was concluded to be a result of fatigue. Despite the increased stress on type II muscle fibres during the sprint training, it has been shown in some studies that in fact there is a decrease in the type II muscle fibres with an increase in the type I instead, however this may be due to the different training protocols adopted, insufficient recovery or length of the programme is too short (Ross et al., 2001).

Potential reasons for the significant changes within the training types undertaken, in particular in this study, may be due to the intensity at which the participants exercised, with this exceeding the intensity at which the AT occurs. The AT is suggested to fall at around 60-75% of the participant's $\dot{V}O_{2max}$, with the ET training groups working at this intensity throughout the training programme. In terms of COMB training, despite no other comparative research, significance was demonstrated in both absolute and relative anaerobic threshold measures, the significance may have been due to the intensity of the COMB training being undertaken at and above the AT, eliciting these beneficial changes within the training type, yet not between the training modalities which then suggested the previous hypothesis of fatigue muscles fibres types and 'competing' for adaptions between the two pathways.

3.421 Age and sex differences

In this study, for $\dot{V}O_{2max}$, despite the participants being match paired into groups based on sex, $\dot{V}O_{2max}$ and resting heart rate, when split into ages, the older group i.e. those older than 35 years had a significantly lower starting $\dot{V}O_{2max}$ (28.9ml/kg/min) value than those less than 35 years (38.2ml/kg/min) ($F=9.305$, $p=0.006$). Significance between the two age groups was also demonstrated after 4 weeks ($F=6.165$, $p=0.022$) and 8 weeks of training ($F=6.314$, $p=0.020$). Percentage changes overall for the < 35 years and the > 35 years were 11.3% and 13.10% respectively after the 8 weeks of training. Throughout the training programme, i.e. at the start, after 4 weeks and then at 8 weeks the difference between the two groups ranged from 25%-28% indicating that despite the training the younger participants overall had the greatest improvement but too has the greater stating $\dot{V}O_{2max}$.

It has been postulated that there is approximately a 10% decline per year in $\dot{V}O_{2max}$ in healthy sedentary males and females after the age of 25–30 years. (Heath et al. 1981; Buskirk & Hodgson, 1987; FitzGerald et al.,1997; Tanaka et al.1997; Eskurza et al., 2002; Pimentel et al., 2003). With previous investigations also suggesting that the rate of decline in maximal oxygen consumption is often 50% less in exercise trained than sedentary athletes (Heath et al., 1981; Kasch et al., 1990)

Tanker & Seals (2003) also suggest that in general, running performance is maintained until the approximate age of 35 years, after which it decreases to the age of 50-60, with further progression after this time. Furthermore the magnitude of change is often greater in women than in men (Tanaka & Seals 1997, Donato et al., 2003). Additionally, it has been suggested that the overall reduction in peak exercise performance with age tends to be greater in endurance than in sprint events (Tanka & Seals 1997, 2003). It is unknown as to why this decline in peak performance for different training modalities is the case however, one possibility is that endurance and sprint events rely on different energy-producing pathways to sustain muscle activity. Furthermore, some studies have also indicated that the decline in exercise capacity is in fact greater with aerobic than anaerobic work, (Grimby & Saltin, 1983; Tanaka & Seals, 1997). Research suggests that type II muscle fibres have a greater loss with increasing age, in particular in those who are inactive (Evans at al., 2010). Additionally, in terms of type I and type II muscle fibres, it has been widely establish that with age type II muscle fibres decrease at a greater rate than type I, which is why we see those of the older generation undertaken endurance based activity, despite the research opposing this. It is therefore interesting to note in this study in particular that high intensity work could actually be as beneficial and if not more than endurance or moderate intensity exercise, over the same period of time (Tanaka et al., 2008).Furthermore it has been postulated that the reasons for the slight decrease with age in exercise performance with endurance exercise is due to the reduced intensity, volume and duration exercise is undertaken (Pollock et al. 1997; Tanaka et al. 1997; McGuire et al. 2001; Eskurza et al. 2002). Bortiz et al (1996), who proposed that in their cohort, from the age of 35-65 the average yearly decline in performance was 0.5%, with reasons from Kasch et al.,(1990) for this decline in $\dot{V}O_{2max}$ in the untrained being, two thirds due to disuse and one third due to age.

Preliminary difference in $\dot{V}O_{2max}$, prior to the start of the training programme, indicated males had a greater $\dot{V}O_{2max}$ than females overall, with the males having a greater and significant increase overall from pre to post training. These results are concurrent with previous research, that indicates males have a 10%-25% (Keller et al., 1991) or 12%-15% (Sparling, 1980) higher $\dot{V}O_{2max}$ than women mainly due to differences in muscle mass size but also as a results of differences in haemoglobin levels, fat free mass and average body mass (Keller et al., 1991).

3.43 Cardiovascular parameters

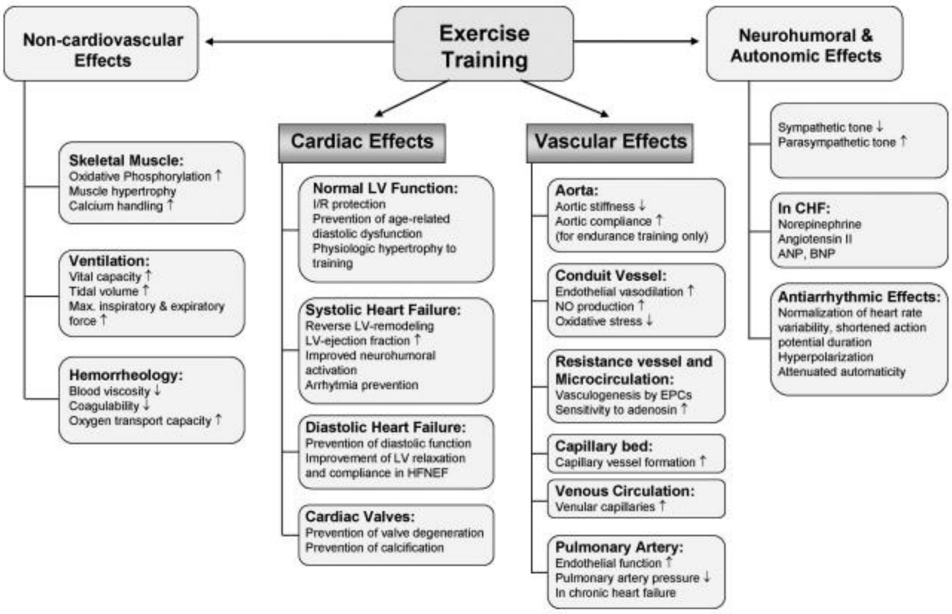

Figure 11. Cardiovascular adaptations to exercise. Various cardiovascular adaptations take place as a results of the exercise training (Gielen et al., 2010)

Prior to the start of the training programme, resting heart rate was one of the matching factors, allocating participants to a training group and as expected, the results verified that there were no significant differences in resting heart rate amongst the groups at the start of the 8 week training regime, however after the 8 weeks significant difference was measured between the SIT and as well as COMB and CON, indicating that SIT whether undertaken alone or combined with ET has profound effects on resting HR.

Additionally, significant changes were evident throughout the training programme within all three training modalities. These results are concurrent with the pilot work and research undertaken prior to this study, indicating a significant change in resting heart rate after 4 weeks of training (Hurst et al., 2012). Similar results were demonstrated by Valik et al., 2011 who reported after 4 weeks of low intensity sprint interval training, heart rate was reduced and stroke volume increased in unfit sedentary individuals, but this was not significant. However in contrast to these change in resting heart rate, after 2 weeks of sprint interval training, Astorino et al., 2012, did not demonstrate any changes in heart rate or blood pressure, indicating this time period may have been too short to elicit any significant changes, and therefore again displaying a time effect element or threshold, with too short of a training programme not stimulating beneficial changes in cardiovascular parameters.

Franks et al., (1969) suggested that excessively vigorous exercise i.e. that working towards maximal as in this study, may result in increased sympatho-adrenergic activity, as well as the greater efficiency and hypertrophy of the heart muscle, which may contribute to the explanation for the significant reduction in HR in the SIT and COMB groups compared to the ET and CON group. Additionally, HR has also been suggested to reduce with exercise due to the reduced filling rate of the ventricles (Wilmore, 1977) as a result of increased exercise. Moreover, SIT/HIT at an intensity of 85-90% of $\dot{V}O_{2max}$ has been suggested to induce and hypertrophic response in the cardiomyocytes which can be observed after a few weeks (Wilsoff et al., 2009). Furthermore, it has been suggested by numerous researchers that the reduction in resting heart rate from undertaking exercise training is possible due to the increase in parasympathetic activity with a small decrease in sympathetic discharge (Katona et al., 1982 & Smith et al., 1989)

Little previous research has sought to compare the two training types, let alone incorporating a combined concurrent trial, however research from Bouri et al., (2010) assessed the effect of HIT and endurance exercise over a period of 8 week in coronary artery disease (CAD) patients. They found that despite public health guidelines questioning the use of HIT, this method of training was superior in reducing resting heart rate and proved to be an independent risk factor of cardiovascular disease in men and women without diagnosed cardiovascular disease. Furthermore in this study from Bouri and colleagues (2010), significant changes were observed in the reduction of systolic and diastolic blood pressure in the HIT group whereas this was not evident in the endurance training group**.** Therefore indicating the benefits for not only healthy individuals but for also a CV population and the results from this study are concurrent with the research in terms of diastolic blood pressure, with significance shown.

A reduction in both systolic and diastolic blood pressure (BP) may be due to the reduced sympathetic nervous activity as well as an increased nitric oxide mediated vasodilation (Whyte et al., 2010) from exercise. It has been postulated that the mechanism involved in lowering blood pressure from undertaking aerobic exercise specifically, maybe be due to the hormones norepinephrine and epinephrine, as regular exercise has been shown to reduce the level of norepinephrine, limiting vasoconstriction of the arteriole enabling a reduce blood pressure (Duncan et al., 1985). Furthermore, this reduction in the sympathetic neural activity that may help to reduce the blood pressure from undertaking aerobic exercise (Kravitz et al., 2001).

Cornelissen et al., (2005) suggested that blood pressure decreases after an acute bout of exercise and returns to pre exercising levels within 12-16 hours, so along with this proposed theory and to allow for sufficient recovery of the muscle fibres and PCr resynthesis it was ensured that the training sessions were carried out with at least 24 hours between. These findings in BP, however are partly concurrent with those from Nybo et al., (2010) who whoever did not find any significant changes, in diastolic blood pressure which was attributed to the study number as well as that reductions are not directly related to changes in $\dot{V}O_{2max}$.

3.431 Cardiac Output & Stroke Volume

Despite a reduction, no significant changes in both resting SV and Q between the training modalities were measures. However, a significant change was observed within the COMB group from MID to POST training in SV, in the second half of the 8 week ($p=0.017$).No significant difference were measured however in the SIT, ET or CON groups ($p>0.05$). Indicating that stoke volume played a great part in the changes of overall cardiac output in the COMB group.

SV changes are similar to those obtained in the study from Cunningham et al., (1979), who required participants in the continuous training group to undertake 20 minutes of continuous exercise at 70% of their measured $\dot{V}O_{2max}$ our time per week. Whilst the interval training group worked at 90% of $\dot{V}O_{2max}$ completing 2 minute intervals interspaced by 1 minute rest for the same amount of time, four times per week. The research found improvements after 4 weeks, which diminished however in the latter few weeks of the training programme, with no significance shown between groups. As products of Q, it is inevitable that if changes in HR and SV, which was shown in this study to in both training groups and in comparison to the control group

Astrand et al., (1977) proposed that increase in stroke volume is the result of an enhanced cardiac output, with maximum heart rate remaining unchanged from undertaking endurance training. There is evidence to suggest that exercise training elicits changes in vascular tone which leaded to enhanced distribution of blood flow where capillaries are recruited without change in capillary density (Heiss et al 1976, Laughin, Overholser & Bhatte 1989). Furthermore, it has long been established that endurance exercise causes a lowering of resting heart rate, which has been suggested to be as a result of alterations in the autonomic nervous system as well as changes in the intrinsic automaticity of the sinus node. (Ekbom et al., 1973; Lewis et al., 1980). The mechanisms underlying the training induced increase in vagal tone are thought to be increased activation of the cardiac baroreceptors in response to the enlargement of blood volume and ventricular filling (Convertino, Mack and Nadel et al., 1991). Research suggests there often is a greater change in CV parameters as a result of higher intensity exercise and exercise training, due to the increased and greater demand and workload on the CV system. Potential mechanisms which may have caused the increase in SV include an enlargement of the left ventricular due to regular training, increased blood volume as well as hypertrophy and increase contraction rate. (Saltin et al. 1968, Warburton et al. 2006 & Moore, 2006).

A potential limitation to these findings from this study however is that Fargard et al., (1993), calculated a decline of 1.2L/min per decade in maximal cardiac output. This may have had an effect on the cardiac output results in this study, as a range of ages were included, however 8 weeks may not have been long enough to actually instigate any age related changes

The optimal nature and intensity of exercise needed to produce the greatest SV adaptations is not known firstly this is due to differences in individual characteristics, including; fitness level, training status and various individual haemodynamic behaviours to different exercise modes. However from the known research and information available in the literature, it is wise to suggest or recommend a variety of training methods which incorporate varying intensity to enable the benefits obtained from each type to be achieved and in particularly high intensity interval exercise enabling maximal work output and cardiovascular functioning allowing the participants or athlete to reach high haemodynamic measures during both work and rest period, pushing the cardiorespiratory system to its limits, which are beneficial for the body as a whole.

This research study has therefore endeavoured to implement this and analyse how incorporating various training modalities overtime in healthy individuals has an effects of the cardiovascular parameters measures, however further research is necessary to established the changes over varying intensities, sprint durations and recovery periods. Previous research has also suggested that further work is needed to establish the timing of the session undertaken, as often this varies, in particular in a sports training situations and what effects varying times have also the effects of time of day on this, which needs to be examined.

3.44 Blood Measures

The results obtained from this research study, in terms of HDL and LDL were in line with previous research (Kessler et al., 2012). Beneficial changes were measured, yet no significant difference between or within the training modalities were seen. When analysing the results in this study, the SIT group overall, started with a lower LDL value in comparison to the other training modalities. This LDL value was already classed as 'optimal' in the ATPII classification from the AHA association guidelines (2006), which therefore may have led to reduced room for improvement over the 8 weeks of training.

Furthermore, in the review from Kessler (2012), despite beneficial changes in the measured blood lipid parameters, none of the studies reported a significant change in the TC between or within the training group (i.e. SIT and ET), a finding that was also present within this study after 4 weeks. However, after 8 weeks of training, a significant change was evident in the TC between the SIT and control group in this study. Furthermore, with minimal research in the area combining the training types, the COMB group and the SIT group, demonstrated significance within the group over the 8 week period in triglycerides, different to that currently demonstrated in the literature, yet no significant changes within the ET group.

Previous research MacPherson et al., (2011) suggested that the potential reason for the absence of significant changes in their findings were due to the duration of the study not being long enough, however in this study the duration of the exercise undertaken over 8 week was equal to or in some cases less than that undertaken by other researchers, yet with beneficial results obtained. Moreover, Kessler (2012) suggested that a minimum duration of 8 weeks was necessary to see improvement in HDL, however only three out of ten studies in the review, that did last for longer than 8 weeks showed any improvements, indicating other factors such as intensity, duration recovery need to be taken into consideration and that the fact this study lasted for 8 weeks may be a possibility for the non-significance measured in HDL. Conversely Douglas and Keyser (1999) reported that moderate intensity training over 12 weeks was sufficient enough to improve HDL with HIT providing no further health benefits.

Differences in the baseline data at the start of the study may also have contributed to the non-significance or different changes in the measured parameters over time, which can demonstrated in the standard deviations measured. Furthermore, the significant changes within the COMB and SIT training groups may have been due to the higher mean starting value in comparison to the endurance training group, which therefore would have a greater room for improvement or change than the endurance group, which may have contributed to the significant change. It was postulated by Babraj et al., (2009) that results of training studies on participants with normal cholesterol levels vary considerably, which may be due to differences in the pre training lipid concentrations, changes in weight and training intensity and volume contribute to the contrasting findings.

Finally, the non-significance in the creatine kinase after 4 or 8 weeks of the training programme is potentially due to the very low sample numbers, as it required the participants to return to the lab 24 hours after undertaking the $\dot{V}O_{2max}$ test, which was not feasible for many.

3.45 Training programme structure

Very little research is currently available assessing the adaptations of repeated sprints lasting less than 15 seconds. In a sports specific situation or undertaking activities, a much shorter duration of exercise seems more applicable and relevant than the standard used 30 second Wingate test (Biscotti et al., 2004; Dellal et al., 2012, Buchheit et al., 2013). Due to the nature of the exercise i.e. sprints less than 10 seconds, with ATP requirements met predominantly by glycolytic phosphorylation, exercise intensity is required to be high in order to obtain benefits and to elicit high oxygen consumption responses, however this has not yet been investigated in comparison to the standard used 30 second Wingate protocol (Buchheit et al.,2013). It is known that prolonging the exercise duration increases the relative aerobic energy requirements of the exercise (Gastin et al., 2001).

The changes in this study are noteworthy in particular in the SIT group despite the much reduced 90% lower time training commitment in comparison to the other two training groups. The majority of previous research has adopted the 30 second Wingate approach (Gibala et al., 2006, Burgomaster et al., 2008 & Kent et al., 2011) and have demonstrated comparable changes and results to this study, which adopted 5 second sprints. Our protocol provided greater improvements not only over 8 weeks, but over 4 weeks also, indicating that 5 second sprints are just as effective, if not more effective and time efficient, than 30 second sprints. Not only does this reduced duration and highly efficient and effective method produce comparable results, yet it is more realistic for the general population to achieve, maintain and sustain a continuously high power output and maximal effort over the shorter period of time.

Recovery plays an important part in the training programmes, as it is recognised that phosphocreatine (PCr) recovery can take 4 minutes between maximal sprints and full PCr repletion may take longer after repeated sprints than after a single sprint (McCartney et al., 1986). Full resynthesis and recovery of the anaerobic threshold will also take 3-5 minutes (McArdle et al., 2006). Therefore the recovery period during the training programme of those in the SIT group as well as the sprint part of the COMB trial, may have facilitated this effect and recovery of PCr stores, enabling greater improvements to be obtained over a shorted time period. This agrees with that suggested by Smith et al., (2008) & Burgomaster and colleagues (2008) who stated that during the recovery period, the body adapts to the stress of the exercise, in particular during sprinting, where enhanced physiological effects can be observed. By decreasing the number of SIT sessions and allowing the body time to recover, physiological benefits are improved. These effects include changes in glycotic and oxidative enzyme content and activity, and with participants in SIT group working at a higher intensity than ET during the training, potentially causing the effects of the exercise to occur at a more rapid rate, due to the enhanced stress on the cardiorespiratory, muscle and metabolic systems.

Exercise heart rate is commonly used as a marker of exercise intensity (Gilman et al., 1996) in particular during training studies, as in this research project, HR has been suggested to be suited for monitoring the intensity of prolonged submaximal exercise, but limited in higher intensity work as it cannot be as accurately measured. Additionally, heart rate is expected to reach maximal levels i.e. to around 90-95% of maximum heart rate, during sprint training, dependant on the power output, speed and duration of the work undertaken. If the duration of the sprint is fairly long i.e. 30 seconds, towards the end of the bout the heart rate may not be sustained at this high percentage, however very short sprints, due to the heart rate lag at the onset of exercise, the maximum heart rate may not be reached. These factors however are much easier to control with cycling than running which often why it is the preferred method. In study, in terms of the high intensity exercise bouts, training was not set to specific heart rate intensity or levels to achieve, participants were required to work as close to maximal as possible. In the endurance bout heart rate was used as a factor to control the intensity at which the work was undertaken, however factors such as cardiac drift needed to be taken into consideration, the heart rare was monitored and maintained throughout with additional weight applied when needed and measured from the cycle ergometer.

Further research is warranted to address the different changes, both physically and changes over time statistically in terms of different sprint duration i.e. 30 seconds compared with a much short duration i.e. 5 seconds as in this study, to establish if similar results are obtained when the same protocol is undertaken over the same period of time and too to see if there is an optimal sprint duration.

Different to previous research (Eddy et al., 1997) this study did not match work the training programme, so the overall training time for the ET group was 110.6% greater than that for the SIT group. This reduced SIT training time, therefore enabled effectiveness and the efficiency of SIT on the improvement of specific cardiorespiratory parameters at a reduced time commitment to be observed.

3.45 Body Composition

Despite the knowledge that endurance exercise assists weight reduction and reduces body fat percentage and that SIT can also be beneficial for weight management (Hunter et al., 1998), the results from this study demonstrated a non-significant reduction in weight and body fat percentage in all three training modalities. The greatest changes in body mass however, were evident in the SIT group demonstrating a reduction in body fat percentage of 6.5% with the ET training group a 1.7% reduction, yet an increase in the COMB group of 0.4%. These results are concurrent with some previous research (Tremblay et al., 1992) who also found that high intensity exercise, reduced body fat percentage to a greater extent after 25-30 minutes of repeated 10-15 seconds or 60-90 seconds bouts of HIIT, at 70% of maximal heart rate reserve, than 30-45 minutes of moderate intensity exercise, with the subcutaneous fat loss suggested to be nine fold greater in the high intensity than the ET.

Furthermore, the explanation for this, in this study, may be due to the short time period or possibly the participant's lifestyles, despite being requested to maintain a similar diet and throughout as well as continue with normal daily activities as prior to the study. It would be expected that due to the increased energy expenditure, in particular in the COMB group undertaking both a bout of ET and then the SIT protocol, there would potentially be an reduced body fat percentage or weight reduction.

Finally, the phenomenon of polymorphism and exercise can potentially indicate why some individuals may not be responders to exercise with the use of gene testing to confirm this. It is not known if any of the participants in this study were 'non responders' however it is a postulated reason to why some participants may have presented greater improvements than others. Specific effects that can differentiate amongst participants as a result of polymorphism i.e. the ACE gene for example, include, left ventricular hypertrophy and the volume of decrease in muscle strength with age (Tobina et al., 2007).

3.5 Summary and Conclusion

Eight weeks of sprint interval training elicited comparable if not more significant changes than endurance training, furthermore by combining the two training types in one session had further beneficial effects over the same period of time than undertaking endurance training alone. The results suggest and agree with previous research that, SIT is a time efficient way in order to obtain comparable and in some cases superior benefits in numerous physiological, cardiorespiratory and health parameters. Furthermore, in terms of SIT alone and combined with endurance in the COMB trial, it is proved that even sprints as short as 5 seconds, a much more compliable, manageable and feasible duration for much of the population can in fact provide as beneficial adaptations than the standard used the 30 second Wingate protocol. Additionally, this study has demonstrated beneficial health factors which indicate the need and requirements of exercise in the clinical and healthy populations, defeating the barrier to exercise being time. In terms of a sporting population, with a set training time the most efficient way as demonstrated in this study is to incorporate both sprint interval and endurance training for improved cardiorespiratory fitness, as well as improved haemodynamic functioning and reduction in blood lipid measures. Furthermore, it has been shown in this study that 8 weeks is necessary to demonstrate significant changes in many of the parameters whether this be between or within the training groups, with 4 weeks often being too short for sustained benefits.

3.51 Further recommendations and limitations

Future research should consider comparing the effect of varying sprint duration of the same period of time i.e. 5 seconds, 10 seconds, 20 seconds and 30 seconds, to see if there is an optimal sprint duration in terms of exercise performance, health and performance parameters. To therefore assess the most effective duration, intensity and volume of training required. Moreover, oxygen consumption during a sprint bout could be measured to analyse changes in energy expenditure throughout endurance and sprint sessions as well as the training types combined to then enable more accurate analysis and to ensure participants are working at correct intensities. Additionally, further research is required to confirm the findings made for this study in particular in terms of the combined training modalities and to further established its effectiveness in comparison to undertaking just endurance training alone. Finally incorporating this method of training into a fitness classes or rehabilitation setting and making the population aware of it benefits, may in turn provide an alternative exercise training method, which could potentially offer beneficial improvements in various health parameters.

A limitation to this study would be the sample size. This is partly due to the number of different groups that were used for comparison and additionally the dropout rate due to the length and time commitments of the study.

3.6 Hypothesis

From the results and data presented, I formally accept the Null hypothesis, which concluded there are no significant differences between ET, SIT, COMB and control training groups in maximal oxygen consumption, creatine kinase, body fat percentage, stroke volume and cardiac output after the 8 week training programme. However I can reject the null hypothesis and formally accept the research hypothesis to state that a significant difference was observed between the training modalities in the anaerobic threshold, blood cholesterol, resting heart rate, lactate and blood pressure - however solely diastolic, after the 8 week training programme. Significance was also demonstrated between the age brackets observed i.e. more than or less than 35 years in $\dot{V}O_{2max}$ as well as in sex between males and females in $\dot{V}O_{2max}$ after the 8 weeks of training.

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