The Effect of High Intensity Interval Training (HIIT) Upon Resting and Ambulatory Blood Pressure in Physically Inactive Males and Females.

by

Christian Cottam

Canterbury Christ Church University

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Contents

Abstract.

Purpose: Physical inactivity is associated with and increased risk of hypertension and cardiovascular disease. High intensity interval training (HIIT) has been shown to reduce resting blood pressure. However, the response of HIIT upon ambulatory blood pressure has been limited, despite evidence highlighting that the use of ambulatory blood pressure monitoring can be of clinical significance. Therefore, the aim of the present study was to investigate the effects of HIIT upon resting and ambulatory blood pressure.

Methods: In a randomised controlled trial 41 physically inactive males and females (aged 23 ± 2.7 years) completed 4 weeks of HIIT. The HIIT protocol consisted of 3 x 30s maximal cycle ergometer sprints with a resistance of 7.5% body weight, with 2 minutes active recovery in between intervals. In total, 12 sessions were performed. Ambulatory blood pressure was measured using a Welch Allyn 6100 ambulatory blood pressure monitor.

Results: Following the 4-week HIIT intervention, it was reported that there were statistically significant reductions in resting systolic blood pressure (-6.86 ± 8.76 mmHg, $P < 0.041$) when compared against the control group. It was also reported that there was a statistically significant reduction in 24-hour systolic blood pressure (-4.06 ± 8.08 mmHg, $P < 0.008$), 24-hour diastolic blood pressure (-3.43 ± 8.18 mmHg, $P < 0.012$) and 24-hour mean blood pressure (-2.17 ± 4.04 mmHg, $P < 0.002$) when compared against the control group.

Conclusion: A 4-week HIIT programme was associated with a significant decrease in resting systolic blood pressure in addition to significant reductions in 24 hour systolic, diastolic and mean ambulatory blood pressure.

1.0: Introduction and Literature Review.

1.1: Brief Introduction to The Cardiovascular System.

The cardiovascular system (CVS) is a complex network system interlinking all organ systems and consists of the heart, the blood and the blood vessels (Cheitlin, 2003). The main function of the CVS is to circulate nutrients such as oxygen and amino acids to the tissues via the blood and network of blood vessels, in addition to providing rapid removal of harmful metabolic by products such as carbon dioxide (Levick, 2010).

In order for the CVS to function at optimal levels it relies on numerous factors (Levick, 2010). It is acknowledged that at rest, the adult human heart on average pumps between 4-7 litres of blood from the ventricles per minute, this is known as the cardiac output (Levick, 2010). Cardiac output is not a fixed value and continually changes throughout the day to meet the demands of the body at any specific time e.g. during exercise cardiac output increases four- to six-fold (Shepard & Mancia, 1986). This is inferred to be as a result of changes in heart rate (HR) and stroke volume (Dampney *et al.* 2002). Stroke volume is influenced by two opposing forces; the energy of the contraction of the left ventricle and the aortic pressure it has to overcome before any blood can be ejected (Smith & Kampine, 1990). It can also be documented that stroke volume can be affected by mean arterial pressure (MAP). Mean arterial pressure is a result of total peripheral resistance (TPR) x cardiac output (Q), therefore, changes in Q and/or TPR can have an influence upon stroke volume and blood pressure (BP) (Pescatello *et al.* 2004). The energy of contraction can be increased via preloading of the myocardium during diastole by raising end-diastolic pressure which results in increased contractile energy,

otherwise known as the Frank-Starling mechanism (Dampney, 1994). However, it has been documented within empirical literature that these functions of the CVS can be significantly impaired if an individual has untreated hypertension (Woo *et al.* 2004; Kobirumaki-Shimozawa *et al.* 2014).

1.2: Hypertension.

Hypertension or high blood pressure is reported to be the number one pre-cursor of cardiovascular disease (CVD) worldwide and can be attributed to 7.6 million deaths worldwide (Chow *et al.* 2013; Mozaffarian *et al.* 2015). Blood pressure is classified under the following headings (See table 1). The burden of hypertension is evident as an increase in BP has been reported to contribute to both cardiovascular and cerebrovascular endpoints including heart failure, myocardial infarction and stroke (Banack, Harper and Kaufman, 2012; Santulli, 2013). It can also be documented that retinopathy (Durrani & Patel, 2017), peripheral vascular disease (Rosendorff *et al.* 2015), aortic aneurysm (Ye *et al.* 2016), chronic kidney failure (Ortiz *et al.* 2014) and hypertensive encephalopathy (Price & Kasner, 2014) can all be attributed to hypertension. It has been documented that one in four adults within the UK has high BP and that one in five of all myocardial infarctions can be attributed to high BP (Thompson, 2015).

Table 1: Blood pressure classification for adults aged 18 and over**.**

Blood pressure Classification	Systolic (mmHg)	Diastolic (mmHg
Normal	<120	<80
Prehypertensive	120-139	80-89
Stage 1 hypertension	140-159	90-99
Stage 2 hypertension	>160	>100

Table adapted from Pickering *et al.* 2005.

Hypertension, if untreated, is documented to be closely linked to the development of atherosclerosis, which is a chronic inflammation which leads to endothelial cell dysfunction (Alves, 2014). It is also reported that in patients with hypertension vascular tone may be elevated as a result of increased α-adrenoceptor stimulation, or an increase of angiotensin or endothelins being released (Foëx & Sear, 2004). The release of angiotensin and endothelins are acknowledged to cause an increase in smooth muscle mass within the vasculature, termed vascular remodelling (Intengan & Schiffin, 2001). Both an increase in systemic vascular resistance (SVR) and an increase in vascular stiffness are documented to augment the load imposed on the left ventricle, inducing left ventricular hypertrophy and left ventricular diastolic dysfunction (Tsang *et al.* 2002).

Remodelling and hypertrophy of the left ventricle as a result of hypertension has been strongly associated with the development of congestive heart failure and an increase of other cardiovascular events such as sudden death (Haider *et al.* 1998). As a result of pressure overload remodelling is primarily concentric due to the addition of myocyte sarcomeres in parallel (Lorell & Carabello, 2000). Therefore, left ventricular wall thickness increase to a greater extent than the volume of the left ventricle cavity, resulting in an increase in the left

ventricle to end diastolic volume (Rosen *et al.* 2005). Conversely, it has been reported that disorders that cause a volume overload are more commonly associated with eccentric remodelling and entail a proportional increase in left ventricle mass and volume (Ganau *et al.* 1992). As a result, the risk of myocardial dysfunction and coronary heart failure are increased (Rosen *et al.* 2005).

Hypertension is identified as a modifiable risk factor of CVD (Kannel, 1996) that can be treated in order to reduce the risk of mortality. It is reported that lifestyle changes such as cessation of tobacco and alcohol use, changes in diet and adhering to regular physical activity can have a positive influence in treatment of hypertension (Chobanian *et al.* 2003).

1.3: Physical Activity.

Physical activity as defined by Dishman, Washburn & Schoeller (2001) is any movement by the skeletal muscle that results in energy expenditure, for example; household chores, leisure activities or exercise. It is recommended that individuals should aim to achieve at least 150 minutes per week of moderate intensity exercise (3.5-7 kcals per minute) over 5 days or 60 minutes of high intensity exercise (>7 kcals per minute) over 3 days (Haskell *et al.* 2007). Despite these recommendations it is reported that over 30% of the world's population in not meeting the guidelines of physical activity (Hallal *et al.* 2012). It has also been reported that physical inactivity is estimated to cause around 9% of premature mortality, resulting in around 5.3 million deaths worldwide in 2008 (Lee *et al.* 2012).

It has been documented that physical inactivity is one of the leading preventable causes of mortality (Mokdad *et al.* 2004) and that there in an inverse relationship between the volume of physical activity and all-cause mortality in both men and women (Lee & Skerrett, 2001).

Further evidence supporting this relationship highlights that regular physical activity has numerous health benefits including reduced risk of chronic diseases such as CVD (Thompson *et al.* 2003), type 2 diabetes (Boulé *et al.* 2000) and some cancers (Rajarajeswaren & Vishnupriya, 2009; Kenfield *et al.* 2011). Physical activity has also been linked to help delay the onset of cognitive decline (Blair, 2009).

Evidence suggests that regular physical activity can trigger anti-atherosclerotic adaptations and vascular remodelling within the vascular system as a result of arterial sheer stress, resulting in improved vascular function (Green, 2009). The findings from Green (2009) further elaborate findings by Haskell *et al.* (1993) who highlighted that individuals who participated in regular physical activity had an increased coronary artery size in addition to an increased dilation capacity. It is also documented that regular physical activity influences greater nitric oxide expression and activity within the arterial endothelium, increasing the number of endothelial progenitor cells within the circulation which results in greater endothelial regeneration, subsequently improving endothelial function (Hambrecht *et al.* 1998). It has also been acknowledged that left ventricular hypertrophy can occur with the adoption of regular physical activity (Rawlins, Bhan & Sharma, 2009). In contrast to left ventricular hypertrophy as a result of hypertension, left ventricular hypertrophy as a result of physical activity increases the hearts ability to pump blood, due to an increase in stroke volume, this occurs due to an increase in left ventricular mass and end-diastolic volume (Aubert, Seps, & Beckers, 2003).

1.4: Short Term Blood Pressure Regulation.

Short term regulation of BP is maintained by reflexes within the autonomic nervous system (Grassi *et al.* 1998). Specialised pressure sensors, called baroreceptors, are located in the aortic arch and carotid sinus and are sensitive to changes in arterial pressure (Levick, 2010). When changes in arterial pressure within these arteries occur, afferent signals are sent to the cardiovascular centres in the brain, resulting in autonomic reflexes to be initiated, which subsequently sends efferent signals to the heart in order to respond to changes in BP(Guyton, 2001).

Baroreceptors are sensitive to stretch and rate of stretch by generating action potentials (Levick, 2010). When BP is elevated, baroreceptors are stimulated by an increase in stretch (Heusser *et al.* 2010). In response to the increased BP there is a reflex response to increase vagal tone, which decreases HR and reduces sympathetic neural activity to both the heart and arterioles to normalise BP (Shepard & Balady, 1999). The baroreceptor response to a decreased BP occurs when less stretch is sensed, resulting in an increase in HR due to withdrawal of vagal modulation and an increase in sympathetic nerve activation, resulting in correction of the low pressure (Dampney *et al.* 2002).

A decrease in baroreflex sensitivity (BRS) has been associated with increased mortality (La Rovere *et al.* 2001) in addition to showing strong links with hypertension (Bristow *et al.* 1969; Sun, 2015). It is reported that in patients with hypertension baroreceptors are reset in response to increased BP as well as a decrease in BRS (Grassi *et al.* 1998; Foëx & Sear, 2004). It has also been documented that participants with hypertension, the baroreceptor-heart rate reflex

has diminished sensitivity primarily due to reduced maximum capacity of the cardiac vagal component rather than a change in sympathetic neural activity (Head, 1994). It is also documented that reduced BRS is associated with increase in vascular calcification and arterial stiffness (Chesterton *et al.* 2005) which as previously highlighted, can result in an increased load on the left ventricle (Tsang *et al.* 2002).

It has been reported that the adoption of exercise can increase BRS as well as baroreflex control of muscle sympathetic nerve activity, which is depressed in patients with hypertension (Laterza *et al.* 2007). It can also be documented that exercise can cause baroreceptor resetting (Raven, Fadel, & Ogoh, 2006). This resetting of the baroreceptors can move the operating point of the reflex away from the centring point and closer to the threshold, thereby increasing the ability of the baroreflex to buffer hypertensive stimuli (Raven, Fadel, & Ogoh, 2006). This supports findings by Somers *et al.* (1991) who found that physical activity can bring participants with borderline hypertension back to within normal limits as a result in increased BRS. It has been acknowledged that an increase in BRS has been linked to a decrease in mortality rates (La Rovere *et al.* 1998).

1.5: Long Term Blood Pressure Regulation.

Long term regulation of BP is linked closely to volume homeostasis through the renal body fluid feedback systems (Mitchell & Navar, 1995). A key factor of the renal body fluid feedback control system is pressure natriuresis, the ability of the kidneys to respond to the change in arterial pressure by altering renal excretion of sodium and water (Lohmeier, 2001). It is

reported that the sensitivity of the pressure natriuresis mechanism can be modified via a number of extrarenal neurohormonal regulatory systems such as the renin-angiotensin-aldosterone system (RAAS), which plays an important role in arterial pressure homeostasis (Mitchell & Navar, 1995). Resetting of pressure natriuresis is evident in patients with hypertension and is characterised either by a parallel shift to higher blood pressures and salt-insensitive hypertension, or by a decreased slope of pressure natriuresis and salt-sensitive hypertension (Foëx & Sear, 2004).

The RAAS is one of the major hormonal systems that can influence BP (Beevers, Lip & O'Brien, 2007). The RAAS modifies BP through a variety of effects in different tissues included changes in vascular tone, augmentation of sympathetic neural activity, changes in the function and structure of the cardiovascular beds, as well as renal salt and water homeostasis, in response to low BP (Laragh & Brenner, 1990; Weir & Dzau, 1999). The RAAS causes kidneys to release the enzyme renin, which stimulates the formation of angiotensin I in the lungs which is quickly converted into angiotensin II by the angiotensin converting enzyme (ACE) (Turner & Hooper, 2002). Angiotensin II is a powerful vasoconstrictor of the blood vessels and stimulates the adrenal cortex the release aldosterone, resulting in an increase in sodium and salt retention in the kidneys, increasing fluid retention to increase BP (Atlas, 2007). It is documented that dysregulation of the RAAS can be detrimental to health and play a key role in the development of CVD as it inhibits insulin metabolic signalling within the vascular endothelial cells (Aroor, Mandiavia & Sowers, 2012). This results in reduced antioxidant and anti-inflammatory effects, resulting in impaired insulin induced vasodilation and capillary recruitment subsequently augmenting increases in arterial stiffness (Aroor *et al.* 2013).

Another hormone that can play a role in long term BP regulation is antidiuretic hormone (ADH) (Johnson *et al.* 2014). The main function of ADH at normal plasma concentrations is the regulation of water excretion via the kidneys (Levick, 2010). However, under stress, such as low BP, high concentrations of ADH are secreted and increase the permeability of the collecting tubules of the kidneys to stimulate water retention as well as an increase in vasoconstriction, subsequently increasing BP (Levick, 2010).

Atrial naturetic peptide (ANP) is a hormone that can support long term regulation of BP and is secreted from the atria of the heart in response to an increase in blood volume (Beevers, Lip & O'Brien, 2007). Levick (2010) highlights that high concentrations of ANP cause an increase of salt excretion via the kidneys by reducing fluid reabsorption in the collecting ducts, furthermore, it relaxes the renal arterioles and inhibits sodium reabsorption in the distal tubule. It is documented that dysregulation of naturetic peptides have been associated with hypertension as well as obesity, glucose intolerance and type 2 diabetes (Zois *et al.* 2014). It is also reported that reduced naturetic peptide effects, together with an increase in RAAS activity can play a key role in the development of hypertension and CVD (Sarzani *et al.* 2008).

Furthermore, it has been documented that adoption and adherence to regular physical activity can help maintain and improve the efficacy of these long-term BP regulating mechanisms, in addition to other cardiovascular protective benefits (Cornellison & Fagard, 2005; Fletcher *et al.* 2013).

1.6: Traditional Aerobic Training.

It has been widely acknowledged within contemporary literature that adoption of a physically active lifestyle, such as traditional aerobic training (40-60% maximum HR), can induce numerous cardiovascular health benefits (DiLorenzo *et al.* 1999). It has been documented that traditional aerobic training can improve exercise capacity (Hawley, 2002), in addition to improvements in numerous other physiological markers in health such as, central haemodynamic function, autonomic nervous system function and peripheral vascular and muscular function (Fletcher *et al.* 2013). It is inferred that regular aerobic exercise also has shown significant improvements in BP (Hambrect *et al.* 1998).

Improvements in cardiovascular health and BP can be acknowledged via a meta-analysis by Cornelisson & Fagard (2005). They found that following 72 trials consisting of normotensive, pre-hypertensive and hypertensive participants, significant reductions in systolic blood pressure (SBP) were found amongst individuals who were classed as normotensive (-2.4 mmHg, $P < 0.01$), pre-hypertensive (-1.7 mmHg, $P < 0.05$) and hypertensive (-6.9 mmHg, $P < 0.001$). It was also reported that the reductions in SBP were significant among each group ($P < 0.001$). this is of clinical importance as it is reported that just 2 mmHg reduction in SBP can reduce the number of deaths from ischemic heart disease by approximately 7%, while also reducing the number of deaths attributed to strokes by approximately 10% (Lewington *et al.* 2002). The meta-analysis also showed that diastolic blood pressure (DBP) was significantly reduced in normotensives (-1.6 mmHg, $P < 0.001$), pre-hypertensives (-1.7 mmHg, $P < 0.001$) and in hypertensives (-4.9 mmHg, $P < 0.001$). It was also reported that the reductions in DBP were significant among each group ($P < 0.001$). It is also reported that VO_{2max} significantly

improved (4 mL/min^{-1}·kg^{-1}, $P < 0.001$), which is an indicator of improved cardiovascular health (Keteyian *et al.* 2008). It is inferred that an increase in VO_{2max} is associated with a decreased risk of mortality (Barlow *et al.* 2012). They also reported that resting HR reduced significantly (4.8 bpm^{-1}, $P < 0.001$) as well as reductions in weight (1.2 kg, $P < 0.001$) and body fat (1.4%, $P < 0.001$). This further highlights the effectiveness of aerobic training as a non-pharmacological intervention to improve health and reduce cardiovascular risks.

Cornelisson & Smart (2013) support findings from Cornelisson & Fagard (2005) as their systemic review and meta-analysis also found that following traditional aerobic exercise, participants classed as normotensive, pre-hypertensive or hypertensive had significantly reduced SBP and DBP (both P <0.0001), however, they found that the reductions in BP were more pronounced in participants with hypertension. It has been highlighted that the majority of studies focussed on traditional aerobic training primarily looked at resting BP, however, more recently studies have begun to investigate the effects upon ambulatory blood pressure (ABP) (Cornelisson and Fagard, 2005).

It is accepted that BP is variable and that the use of 24-hour ambulatory measurements of BP can lead to better predications of clinical outcomes, such as white-coat hypertension, as well as detecting problems in patients whose BP fails to decrease the normal amount of around 10-20% of daytime BP during night time (Pickering, Shimbo & Haas, 2006). A meta-analysis by Pescatello *et al.* (2004) included 11 studies that followed a randomised controlled trial looking into the effects of ABP in response to traditional aerobic exercise. It was reported that following aerobic training the average reduction of 24-hour ambulatory and daytime SBP and DBP was 3.0 and 3.2 mmHg, respectively and was reported as statistically significant ($P < 0.05$).

Pescatello *et al.* (2004) did not include night time ambulatory readings in their analysis as it was reported as not affected or less influenced by the effects of exercise.

An investigation by Fairbrother *et al.* (2014) highlighted that nondipping of BP during nocturnal hours is a significant risk factor for left ventricular hypertrophy and CVD. These findings contradict results of Pescatello *et al.* (2004) as they found that bouts of acute aerobic exercise (30 mins on a motorised treadmill at 65% HR_{max}) improved nocturnal dipping response of SBP and DBP significantly ($P = 0.034$ and $P = 0.031$, respectively).

1.7: Isometric Training.

Another method of exercise training that has gained support in the reduction of BP is isometric exercise training (IET) (Wiley *et al.* 1992; Wiles, Coleman & Swaine, 2010). A recent study by Wiles, Goldring & Coleman (2017) looked at the effects of IET on normotensive participants. They found that following 4 weeks of IET significant reductions in resting SBP (-4 ± 5 mmHg), DBP (-3 ± 3 mmHg) and mean blood pressure (MBP) (-3 ± 3 mmHg) compared against the control condition (all $P < 0.001$). They also reported clinically relevant reductions (≥ 2 mmHg) in SBP and DBP in 68 and 71% of the participants, respectively. The findings of Wiles, Goldring & Coleman (2017) are similar in magnitude to that of Devereux, Wiles, & Swaine (2010) and found within an equal time frame. Devereux found that following 4-weeks IET, statistically significant reductions in SBP and DBP were reported (both $P <0.01$).

A meta-analysis conducted by Millar *et al.* (2014) reported that isometric training in both normotensive and hypertensive (medicated and non-medicated) patients, also showed reductions in resting SBP and DBP following IET. They reported average reductions in SBP

and DBP (10-13 mmHg and 6-8 mmHg, respectively). However, it must be noted, that of the 16 trials reported in Millar *et al.* (2014) meta-analysis, only around 50% of the trials engaged in a randomized controlled trial or crossover design (Devereux, Wiles, & Swaine, 2010), subsequently increasing the risk of type I error.

Despite a lack of evidence looking into IET and 24-hour ABP, one study by Pagonas *et al.* (2017) compared the effect of traditional exercise training and IET on resting and ABP in hypertensive patients. Following a 12-week investigation it was reported that traditional aerobic training had significant reductions in 24-hour ambulatory SBP (-4.88 mmHg, $P < 0.025$) compared against two IET conditions (handgrip 1.58 mmHg, Sham handgrip, -1.09 mmHg), respectively. This indicates that although IET is beneficial in reducing resting BP, aerobic exercise provides greater reductions in systolic ABP, however further investigations will be needed in order to generalize these findings.

Despite the breadth of evidence indicating that IET is an effective method in the reduction of BP, especially in participants with hypertension (Chrysant, 2010), it currently not in the American and European hypertension guidelines (Pagonas *et al.* 2017). It is also documented that a within the research of isometric exercise training several desired measures such as continuous BP monitoring is lacking, making it difficult to understand the mechanistic interpretation isometric exercise has as a non-pharmacological intervention in the treatment of hypertension (Inder *et al.* 2016). Therefore, the need for other methods of exercise training in line with the American and European hypertension guidelines need to be investigated.

1.8: High Intensity Interval Training (HIIT).

Despite the breadth of empirical literature supporting the efficacy of traditional aerobic exercise and the numerous cardiovascular benefits this method of training can induce, many individuals state that a lack of time and enjoyment of this method of exercise as reasons why they do not adhere to exercise (Strutts, 2002; Trost *et al.* 2002). It has therefore been inferred that adoption of high intensity interval training (HIIT) can induce similar cardiovascular protective adaptations in a smaller time frame compared against a traditional aerobic training programme (Whyte, Gill & Cathcart, 2010). High intensity interval training (HIIT) can be defined as short bursts of maximal effort interspersed by a few minutes of rest or active recovery (Gillen & Gibala, 2013). It has also been documented that participants who underwent a HIIT intervention had a greater sense of enjoyment compared against traditional aerobic training due to the varied nature of the exercise (Tjonna *et al.* 2008). Helgerud *et al.* (2007) further support the efficacy of HIIT as they reported that sessions of HIIT (4 x 4-minute intervals at 95% HR_{max}) compared against a traditional aerobic exercise intervention (45-minute continuous exercise at 70% HR_{max}) showed greater improvements in stroke volume and cardiac output, which as a result can reduce the amount of strain placed upon the cardiac muscle, subsequently reducing the risk of metabolic disorders. It has been documented within recent contemporary literature that HIIT is a safe and effective method of training that can be utilised by a number of clinical populations including those with coronary heart disease (CHD), heart failure, hypertension and those considered as having a high cardiovascular risk (Guiraud *et al.* 2012; Arena *et al.* 2013).

The benefits of a HIIT intervention compared against a traditional aerobic exercise intervention are evident in a systemic review and meta-analysis by Weston, Wisloff & Coombes (2013). The aim for their investigation was to quantify the efficacy and safety of HIIT compared to

traditional aerobic training in individuals with chronic cardiometabolic lifestyle diseases as a result of poor lifestyle. They found as a result of 10 randomised control studies consisting of 273 patients, that individuals who underwent a HIIT intervention, VO_{2peak} significantly increased (19.4%) compared against the traditional aerobic exercise intervention (10.9%) ($P < 0.001$). in addition, it was also documented that greater reductions in resting BP were found following the HIIT intervention in comparison to the traditional aerobic exercise intervention. Weston, Wisloff & Coombes (2013) concluded that although there is limited data, HIIT is considered as well tolerated and safe amongst individuals with high risk of cardiometabolic disease.

The effects of HIIT and the subsequent effect on reduction of BP has been well documented within empirical literature. An early study by Paffenbarger & Lee (1997) found that amongst alumni those that participated in higher intensity sports lead to a decreased risk of hypertension. Despite this showing an early insight into exercise at higher intensities, this study only investigated sports play at moderately vigorous intensities compared against walking, stair climbing and light sports play. However, it can be acknowledged that this was one of the first studies to investigate different exercise intensities and incidence of hypertension, and current research aims to build upon these findings.

Cornelissen *et al.* (2010) investigated the effects of two different exercise intensities upon resting BP. The investigation consisted of healthy, physically inactive males and females who were over 55 years old. The investigation used a randomised crossover design comprising of three 10-week periods in which participants underwent either low intensity (33% HR reserve) or high intensity (66% HR reserve) in the first and third period, respectively, in random order,

with a sedentary period in-between. Following the investigation, significant reductions in SBP were found in both intensity groups (P <0.05). However, despite no significant reduction in SBP being found between the groups it could be argued that despite a higher intensity of 66% of HR reserve, it is not high enough to be considered as HIIT. It should also be noted that each session lasted 1 hour which is too long of a session to be classed as HIIT.

Furthermore, an investigation by (Cocks *et al.* 2013) looked at the effects of HIIT upon young sedentary males (defined as performing less than 1 hour of organised exercise per week). The participants were randomly assigned into either a moderate intensity group or HIIT group and underwent a 6-week intervention. Following the 6-week intervention it was reported that both conditions significantly reduced MAP (endurance -2 mmHg, HIIT -4 mmHg) respectively, and DBP (endurance -4 mmHg, HIIT -3 mmHg) respectively, (both $P < 0.05$). However, it can be observed that HIIT elicited a greater reduction upon MBP than that of moderate intensity exercise. It is also documented that both intensity groups did not have a statistically significant reduction in SBP following the intervention. Despite the findings of the study highlighting positive results it must be noted that 16 participants were involved in the investigation which makes generalising problematic. It must be noted that the participants were all male and future research would benefit from investigating the effects upon females to fully understand the magnitude of the BP reducing effect in a female population.

A recent study by Eicher *et al.* (2010) investigated the effects of differing exercise intensities upon 24-hour ABP. They randomly assigned 45 men into a non-exercise control, low intensity exercise group (40% HR_{max}), moderate intensity exercise group (60% HR_{max}) and a high intensity exercise group (100% HR_{max}). They reported that following the intervention systolic

ABP decreased in the low (2.8 ± 1.6 mmHg), moderate (5.4 ± 1.4 mmHg) and HIIT groups (11.7 ± 1.5 mmHg) (all P <0.001). It can be observed that the greatest reduction in SBP following the intervention was in the HIIT group. It can also be observed that diastolic ABP decreased significantly following low (1.5 ± 1.2 mmHg), moderate (2 ± 1 mmHg) and HIIT (4.9 ± 1.3 mmHg) (all P <0.010) but it can be acknowledged that the reduction was more pronounced in the HIIT group. The results of this study highlight the effect of differing intensities upon BP reduction however, it must be noted that the investigation looked at males only and the results were taken directly after training. This indicates that the results are looking at a more acute response to a single bout of training such as post exercise hypotension as opposed to any chronic changes. Therefore, future research would have to take into account the mechanism of post exercise hypotension and accommodate training and post testing to investigate more chronic changes in the mechanisms relating to BP reduction.

An investigation by Molmen-Hansen *et al.* (2012) looked into the effects of HIIT and traditional aerobic training had upon 24-hour ABP in hypertensive patients. The study followed a randomised control protocol and randomised participants into either a HIIT (10-minute warm up, 4 x 4-minute intervals at 90-95% maximum HR, 3 minutes active recovery between intervals, 3 minutes cool down), traditional aerobic training (walking/running at around 70% maximum HR for 47 minutes to ensure similar isocaloric training sessions as HIIT group) or control group. They found that following the HIIT and traditional aerobic training protocol significant reductions were found in ambulatory systolic BP (12 mmHg and 4.5 mmHg, respectively) and it was documented that the HIIT group showed a significantly greater reduction that the traditional aerobic training group. It was also reported that daytime SBP was significantly reduced in both HIIT and traditional aerobic exercise groups (10 mmHg and 5 mmHg). However, no significant difference was found between groups in systolic ABP at daytime. It was also reported that there was a more pronounced reduction of night time systolic

ABP in the HIIT group (-10.5 mmHg, P <0.05) compared against the traditional aerobic training group. It can be argued that despite positive results, the duration of the HIIT session (38 mins) is still long and participants may not adhere to a session of this duration in the long-term due to lack of time.

1.9: Rationale.

It is highlighted within empirical literature that HIIT offers numerous cardiovascular protective benefits such as reductions in resting BP similar to or greater than traditional aerobic training with less of a time commitment. Despite HIIT not being included in the European and American hypertension guidelines, the American College of Sports Medicine (ACSM) includes the option of performing HIIT 3 times per week for 20 minutes as opposed to the standard 150 minutes of traditional exercise training over 5 days (Oliveros *et al.* 2017). Therefore, this investigation will utilize HIIT to further elucidate the effects that this method of training has as a non-pharmacological treatment in reducing the risk of hypertension.

The benefits of resting BP reduction as a result of HIIT in different clinical populations is evident in empirical literature, however, literature surrounding ABP monitoring in response to HIIT has been limited. It can also be acknowledged that few studies have investigated HIIT in in mixed gender populations. It can also be reported that females are underrepresented in HIIT research (Taylor *et al.* 2004; Higgins *et al.* 2016). This finding is further reinforced through the findings of the literature review used within this thesis (Paffenbarger & Lee, 1997; Cornelissen *et al.* 2010; Eicher *et al.* 2010; Molmen-Hansen *et al.* 2012; Cocks *et al.* 2013; Weston, Wisloff & Coombes, 2013) as it further demonstrates that females are less represented amongst the HIIT research (males n= 6517, females n = 58, % of females = 0.882%).

It has been documented that the use of and evaluation of ABP monitoring can be beneficial in investigating the mechanisms underlying white-coat hypertension, nocturnal hypertension and morning hypertension, and provide more efficient means of detection, treatment and follow up of these conditions (Shimada, 2014).

Therefore, the aim of this investigation is to ascertain the effects of a 4-week HIIT programme upon resting and 24-hour ABP in male and female participants who are physically inactive.

1.10: Hypothesis.

In relation to empirical literature and the rationale for the investigation, the following hypothesis will be theorised;

Null 1 (H_0) - There will not be a statistically significant difference in resting systolic blood pressure following HIIT compared to a control condition.

Null 2 (H_0) - There will not be a statistically significant difference in resting mean blood pressure following HIIT compared to a control condition.

Null 3 (H_0) – There will not be a statistically significant difference in resting diastolic blood pressure following HIIT compared to a control condition.

Null 4 (H_0) - There will not be a statistically significant difference in ambulatory systolic blood pressure following HIIT compared to a control condition.

Null 5 (H_0) - There will not be a statistically significant difference in ambulatory mean blood pressure following HIIT compared to a control condition.

Null 6 (H_0) – There will not be a statistically significant difference in ambulatory diastolic blood pressure following HIIT compared to a control condition.

2.0: Method.

2.1: Participants Information.

Forty-five participants including a mix of male and females who were physically inactive from Canterbury Christ Church University volunteered to participate in the study. The participant's demographics (see table 2), including age (Control = 22 ± 3.5 years, HIIT = 21 ± 1.7 years and height (Control = 172.4 ± 8.8 cm, HIIT = 173.7 ± 9.5 cm) were recorded prior to each phase of the study. Height was measured using a stadiometer (Seca model 220, Seca Gmbh & co.kg, Hamburg, Germany) and weight was measured using balance scales (Seca Model 710, Seca Gmbh & co.kg, Hamburg, Germany).

Table 2: Participant demographic information pre-intervention.

	Control (n = 20) Mean ± SD	HIIT (n = 21) Mean ± SD
	Pre	Post
Weight (kg)	74.3 ± 15.9	73.9 ± 14.4
BMI ($kg \cdot m^2$)	24.9 ± 4.5	23.4 ± 3.2
BSA (m^2)	1.87 ± 0.22	1.84 ± 0.22
Resting sBP (mmHg)	120.9 ± 9.6	121.2 ± 10.3
Resting mBP (mmHg)	88.6 ± 7.6	87.8 ± 8.4
Resting dBP (mmHg)	69.9 ± 7.4	69.5 ± 10.8
Resting PP (mmHg)	51.2 ± 8.6	51.7 ± 12.3

All procedures for the investigation were approved by the Canterbury Christ Church University ethics panel. Inclusion criteria for the study were as follows; healthy, but physically inactive

male and female participants, with no known CVD and/or classified as hypertensive and who are non-smokers. All participants completed a physical activity readiness questionnaire (PAR-Q) and signed informed written consent prior to the investigation.

It must be documented that although forty-five participants were recruited for the study, due to undisclosed reasons, only forty-one participants completed the investigation.

2.2: Instrumentation.

Resting BP was measured using a Dinamap blood pressure monitor (Dinamap, PRO 200, GE Medical Systems Information Technologies GmbH, Munzinger Strasse 3, 79111, Freiburg, Germany). The Dinamap is a valid tool for measurement of resting BP as it meets the standards of the AAMI/ANSI (Lai *et al.* 2013).

Resting haemodynamics were measured using the Task Force® Monitor (TFM®) (CNSystems, Graz, Austria). The TFM® is documented as a valid non-invasive monitoring system that can be used to measure real time haemodynamic parameters (Fortin *et al.* 2001). The TFM® was used to measure beat-to-beat BP and is automatically corrected to oscillometric BP values obtained from the brachial artery of the contralateral arm (Sharma *et al.* 2015). Baroreceptor reflex sensitivity (BRS) was calculated using a sequence method (Bertinieri *et al.* 1985), which is based on a computer identification of successive increases and decreases of SBP (three beats) and assessment of the effects upon pulse interval (Sharma *et al.* 2015). Baroreflex sensitivity

control of the heart is calculated by a regression slope between SBP and pulse interval in each sequence (Valipour *et al.* 2005).

Ambulatory blood pressure recordings were performed using a Welch Allyn 6100 ambulatory BP monitor (Welch Allyn Inc. Skaneateles Falls, NY, USA). The use of the Welch Allyn ambulatory blood pressure monitor has been documented as a reliable and valid tool for measurement of AMPM (Shimada, 2014).

The HIIT intervention that the participants performed was based on a Wingate test protocol on a Wattbike cycle ergometer (Wattbike Ltd, Nottingham, UK). The Wattbike was used as Hopker et al. (2010) demonstrated that the Wattbike provided close agreement to power outputs compared to the SRM power meter. It is highlighted that results from the Wattbike are accepted as valid and reproducible (Driller, Argus, & Shing, 2013). The Wattbike was programmed using the Wattbike expert software (V2.50.42, Wattbike Ltd, Nottingham, UK) which allowed the participants to programme in specific commands relevant to the study protocol.

2.3: Procedure.

Figure 1 outlines the experimental protocol. The participants were informed of the experimental procedure of the study and were informed that participation was voluntary and that they could withdraw at any point. Prior to all laboratory testing the participants were advised to avoid eating and drinking 4 hours before their time slots, especially caffeine, as this could interfere with the quality of the results, however, water was allowed. It was also requested that participants refrained from alcohol consumption at least 24 hours prior to their allotted

time slots. It was also advised that the participants adhered to the same dietary habits prior to each phase of testing. Adherence was confirmed verbally at the start of each session.

Prior to each phase of testing the participants had their heights and weights recorded. The participants were randomised, using stratified randomisation for gender (Good, 2006), into either HIIT intervention or control group. This was used to ensure that there was an equal number of male and female participants in each condition, in addition to reducing any bias with pre-test variables. The participants were then required to have 15 minutes seated rest while they had their seated resting BP and HR recorded. A reading was taken every 5 minutes in order to calculate an average. Each participant was also asked to lie in a supine position in complete silence, with the lights turned off, while connected to the TFM® for 15 minutes to ensure that they were in a completely rested state. Haemodynamic data was recorded continuously for 5 minutes pre-and post HIIT and pre-and post-control phase of the investigation. After TFM® assessment, each participant was asked to wear a 24-hour ABP monitor which followed a 20/40/60 protocol meaning a reading was taken every 20 minutes during daytime readings (9am-9pm) and every hour during night time (1am-6am) in line with recommendations O'Brien *et al.* (2000). This protocol ensured that enough readings were taken in order for the data to be valid. This was performed pre-and post HIIT and Control phases. Upon completion of the 4-week intervention participants were asked to come into the lab 48 hours after the last HIIT session to monitor any potential changes. The rationale behind participants coming in 48 hours prior to the last HIIT session is to ensure that sufficient time had been left for any post exercise hypotension to subside (Forjaz *et al.* 2000; Macdonald, 2002).

The participants in the HIIT intervention group underwent a four-week HIIT intervention, consisting of three repeated intervals of 30-second maximal sprints with a 2-minute active recovery in between intervals on a Watt bike cycle ergometer. This follows a similar protocol to that of Astorino *et al.* (2012). The protocol that was applied was 3 x 30 second sprints, 3 x per week over 4 weeks for a total of 12 sessions and a resistance of 7.5% bodyweight. Upon completion of the 4-week intervention the participants underwent the same procedure as pre-testing, 48 hours after the final HIIT session, in order to assess the influence HIIT had upon BP variables.

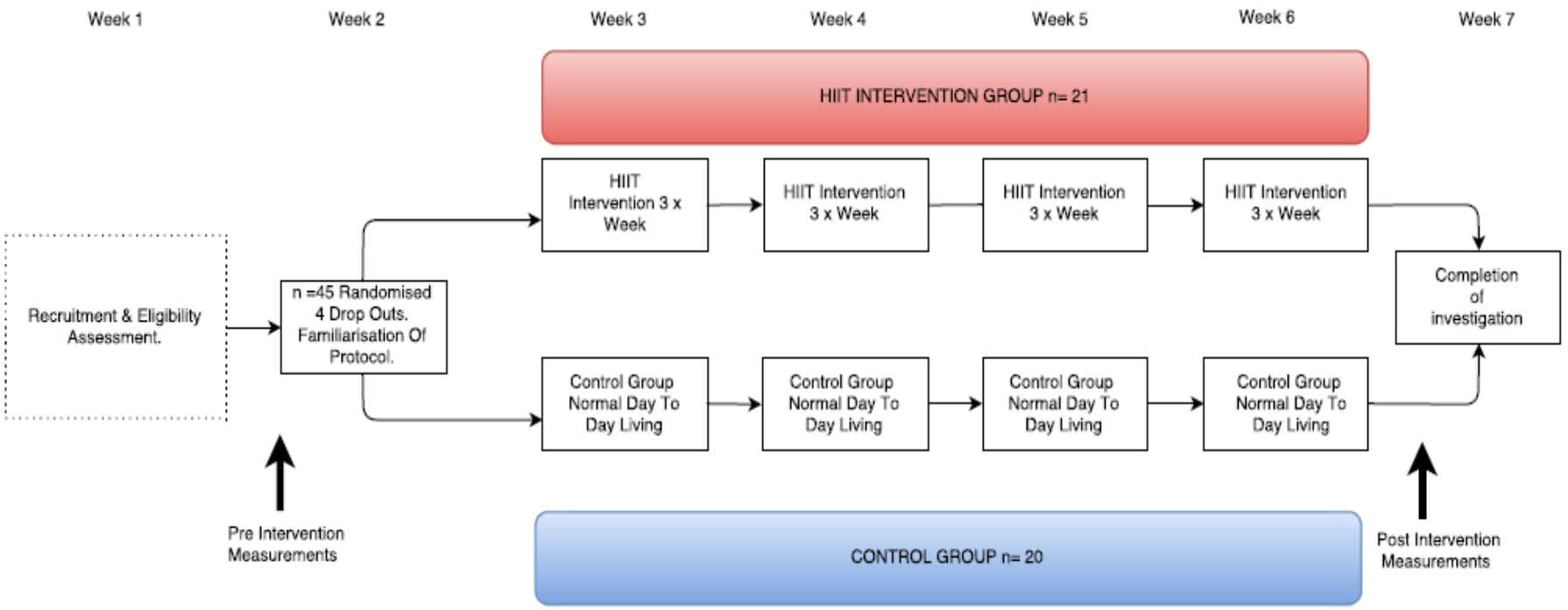

Figure 1: Study flow diagram of the experimental procedure

2.4: Test for Statistical Power.

A reduction of 5 mmHg in SBP from resting and ambulatory measures is considered clinically significant (Beevers, Lip, & O'Brien, 2007). Based on instrument coefficient of variation (4.6%) (Dinamap BP monitor) (Wiles, Coleman, & Swaine, 2010), a sample size of 20-participants in each group has 80% power to detect this difference with a 2-sided $p<0.05$. We estimated a dropout rate of between 5-10% leading to an overall sample size of 44 participants.

2.5: Data Analysis.

All data was analysed using a statistical package for social sciences (SPSS V22.0, release version for windows; SPSs Ins., Chicago, IL, USA). Continuous variables are presented as mean ± standard deviation unless stated otherwise. Data was analysed using analysis of covariance (ANCOVA) which was used with resting BP values as covariates to assess whether changes in resting and ambulatory BP (SBP, MBP and DBP) following both intervention and control group was influenced by the initial resting BP values. Data was reported as statistically significant when $P < 0.05$.

3.0: Results.

As previously stated 41 participants out of the 45 who volunteered completed the investigation. There was no significant change in the participants pre and post demographic data between groups following the intervention (see table 3).

Table 3: Participants demographic data pre and post intervention.

	Control (n=20) Mean ± SD		HIIT (n=21) Mean ± SD	
	Pre	Post	Pre	Post
Weight (kg)	74.3 ± 15.9	74.2 ± 15.7	73.9 ± 14.4	74.3 ± 15.0
BMI ($kg \cdot m^2$)	24.9 ± 4.5	24.8 ± 4.4	23.4 ± 3.2	23.5 ± 3.4
BSA (m^2)	1.87 ± 0.22	1.87 ± 0.23	1.84 ± 0.22	1.84 ± 0.23
Resting sBP (mmHg)	120.9 ± 9.6	119.7 ± 10.9	121.2 ± 10.3	114.6 ± 8.8
Resting mBP (mmHg)	88.6 ± 7.6	88.8 ± 9.3	87.8 ± 8.4	85 ± 6.3
Resting dBP (mmHg)	69.9 ± 7.4	69.9 ± 8.8	69.5 ± 10.8	66.1 ± 5.9
Resting PP (mmHg)	51.2 ± 8.6	49.7 ± 7.9	51.7 ± 12.3	48.5 ± 8.34

3.1: Resting Blood Pressure.

Following 4 weeks of HIIT there was a significant reduction in resting SBP (-6.86 ± 8.76 mmHg) compared against the control group (-1.15 ± 9.4 mmHg, $P = 0.041$). There were no significant differences found in resting DBP or MBP in either the HIIT group or control group (see table 4).

3.2: Ambulatory Blood Pressure.

Four weeks of HIIT resulted in significant reductions in 24hr SBP (-5.2 ± 8.08 mmHg, $P = 0.08$), 24hr DBP (-2.3 ± 8.18 mmHg, $P = 0.012$) and 24hr MBP (-3.1 ± 4.04 mmHg, $P = 0.002$) (see figure 2). There were no significant changes found in the control group. There was also a

significant difference found in 24hr SD DBP (-1.9 ± 2.58 mmHg, *P* = 0.037) (see table 3.3). There was no significant change in these parameters in the control group. There were no significant differences reported in 24hr SD SBP (-.95 ± 3.43 mmHg vs. .19 ± 2.43 mmHg) or 24hr SD MBP (-.87 ± 2.91 mmHg vs. -.38 ± 2.48 mmHg) in either the HIIT group or control group respectively (see table 5).

The results also highlight that there were significant reductions in ambulatory daytime SBP (-3.5 ± 7.89 mmHg, *P* = 0.032) and ambulatory daytime DBP (-1.8 ± 4.11 mmHg, *P* = 0.046) (see figure 3). There were no significant changes found in the control group. There were also significant reductions found in ambulatory daytime SD SBP (-2.8 ± 3.63, *P* = 0.023) and ambulatory daytime SD DBP (-2.4 ± 3.53, *P* = 0.009) (see table 5). Blood pressure variability is expressed as SD as this is easily calculated by most physicians who use ABP monitoring in their clinical practice, therefore it is more widely used (Prattichizzo & Galetta, 2002). There were no significant changes found in the control group. There were no significant reductions found in ambulatory daytime MBP in either the HIIT or control group; however, there was a significant reduction in ambulatory daytime SD MBP (-1.8 ± 3.19 mmHg, *P* = 0.027) (see table 5). There were no significant changes found in the control group.

The results also show that there were significant reductions in 24hr night SBP (-5.6 ± 10.1 mmHg, *P* = 0.008) and 24hr night MBP (-2.6 ± 4.47mmHg, *P* = 0.016) (see figure 3). There were no significant changes found in the control group. In addition, there was also significant reductions found in 24hr night SD SBP (-5.6 ± 4.2 mmHg, *P* = 0.008) and 24hr night SD MBP (-3.4 ± 2.58 mmHg, *P* = 0.016) (See table 5). These parameters did not significantly change in the control group. There were no significant reductions found in either 24 hr night DBP (see

figure 3) (-.81 ± 2.58 mmHg vs. -.31 ± 4.72mmHg) or 24hr night SD DBP (-.27 ± 2.62 mmHg vs. .24 ± 2.89mHg) in both HIIT or control group respectively (see table 5).

Following the 4-week intervention it must be documented that of the control group, 13 participants were classified as dippers pre-intervention and 14 participants post intervention (Bankir *et al.* 2008). Of the HIIT group, 9 participants were classified as dippers pre-intervention and 11 participants post intervention (Bankir *et al.* 2008). There was no significant difference in the proportion of dippers pre (P = 0.155) and post (P = 0.248) intervention between groups.

3.3: Heart rate, Pulse pressure, Rate Pressure Product and Baroreflex Sensitivity.

Following the 4 weeks HIIT intervention there were no significant differences reported in 24hr HR, 24hr daytime HR or 24hr night HR in either the HIIT or control group.

There were no significant differences reported in 24hr pulse pressure (PP), 24hr daytime PP or 24hr night PP in either the HIIT or control group. It is also highlighted that there were no significant differences reported in 24hr rate pressure product (RPP), 24hr daytime RPP in either the HIIT or control group. However, there was a significant difference in 24hr night RPP (-59.01 ± 1913.9, $P < 0.035$) in the HIIT group (see table 4). This parameter did not significantly change in the control group. There was also no significant difference reported in BRS compared to the control group.

Table 4: Mean values for resting and ambulatory haemodynamic variables in control and HIIT intervention groups.

Parameter	Control		HIIT	
	Pre	**Post**	**Pre**	**Post**
Dino sBP (mmHg)	120.9 ± 9.4	119.7 ± 10.9	121.7 ± 10.3	114.3 ± 8.1*
Dino dBP (mmHg)	69.6 ± 7.4	69.9 ± 8.8	69.9 ± 10.7	66.5 ± 6.3
Dino mBP (mmHg)	88.6 ± 7.6	88.8 ± 9.3	88.3 ± 8.5	85.3 ± 6.2
24hr HR (b.min^{-1})	67.9 ± 9.3	67.6 ± 9.2	62.9 ± 10.1	63.3 ± 9.3
24hr HR day (b.min^{-1})	69.8 ± 9.2	69.4 ± 9.4	65.1 ± 10.5	65.8 ± 9.7
24hr HR night (b.min^{-1})	61.3 ± 12.2	61.9 ± 10.9	55.2 ± 9.5	56.9 ± 9.2
24hr PP	64.3 ± 10.3	63.4 ± 10.7	61.1 ± 11.5	58.9 ± 8.6
24hr PP day	64.2 ± 10.4	63.5 ± 10.8	61.1 ± 11.56	59.8 ± 8.7
24hr PP night	63.5 ± 11.2	62.2 ± 11.1	61.4 ± 12.5	56.8 ± 9.3
24hr RPP	9010.8 ± 2001.03	8827.4 ± 1350.01	7699 ± 1403.4	7564.9 ± 1290.4
24hr RPP day	9416.4 ± 2045.8	9282.2 ± 1345.1	8138.9 ± 1425.5	8119.7 ± 1431.9
24hr RPP night	7582.7 ± 2536.8	7159.8 ± 2303.7	6158.2 ± 1382.1	6290.9 ± 1075.2*
BRS	27.9 ± 11.3	28.9 ± 11.5	35.6 ± 15.4	39.03 ± 15.2

Values are presented as mean ± SD. sBP, systolic blood pressure; dBP, diastolic blood pressure; mBP, mean blood pressure; PP, pulse pressure; RPP, rate pressure product. * indicates significant ($P < 0.05$) difference in the pre- to post-change value between control and HIIT intervention group.

Table 5: Blood pressure variability variables in the control and HIIT intervention groups.

Parameter	Control		HIIT	
	Pre	**Post**	**Pre**	**Post**
24hr SD Sbp (mmHg)	15.6 ± 4.5	15.57 ± 3.8	12.7 ± 3.3	11.9 ± 3.5
24hr SD sBP day (mmHg)	14.2 ± 4.7	13.6 ± 4.2	11.5 ± 2.7	9.9 ± 3.2*
24hr SD sBP night (mmHg)	11.5 ± 6.3	13.76 ± 6.3	12.2 ± 5.7	8.9 ± 3.4*
24hr SD dBP (mmHg)	13.1 ± 2.8	12.4 ± 2.5	10.8 ± 2.6	9.9 ± 2.8*
24hr SD dBP day (mmHg)	12.2 ± 3.1	11.4 ± 2.7	10.4 ± 3.5	8.7 ± 2.6*
24hr SD dBP night (mmHg)	8.6 ± 3.3	8.9 ± 2.8	7.5 ± 3.5	7.1 ± 3.1
24hr SD mBP (mmHg)	13.6 ± 2.6	13.1 ± 2.5	11.3 ± 2.8	10.4 ± 2.9
24hr SD mBP day (mmHg)	12.7 ± 3.1	11.7 ± 2.9	10.4 ± 2.8	8.8 ± 2.7*
24hr SD mbp night (mmHg)	9.5 ± 3.8	10.4 ± 2.8	8.4 ± 3.6	7.4 ± 3.1*

Values are presented as mean ± SD. systolic blood pressure; dBP, diastolic blood pressure; mBP, mean blood pressure. * indicates significant ($P < 0.05$) difference in the pre- to post-change value between control and HIIT intervention group.

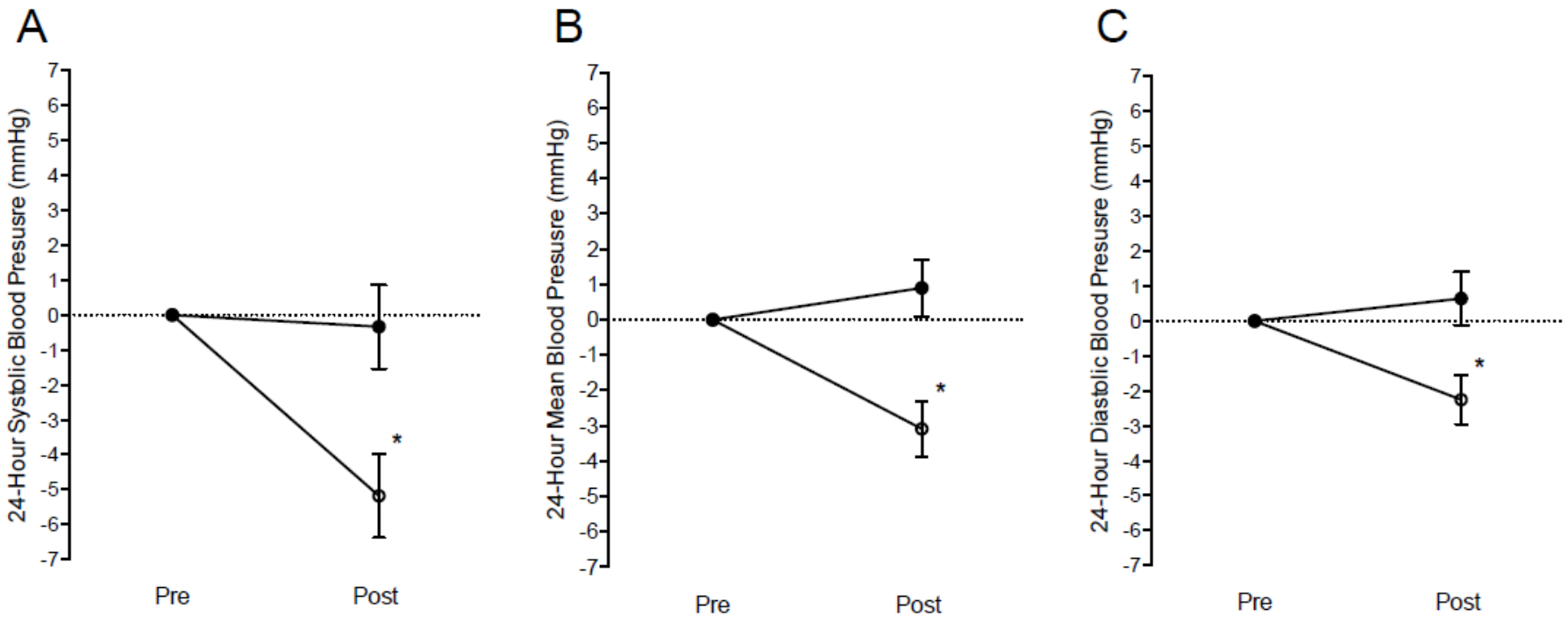

Figure 2: Mean 24-hour systolic (A), diastolic (B), and mean arterial (C) pressure change values for the control (filled circles) and HIIT (open circles) intervention groups. Error bars indicate standard error of the mean. * Significant ($P < 0.05$) difference in the control and HIIT intervention change value.

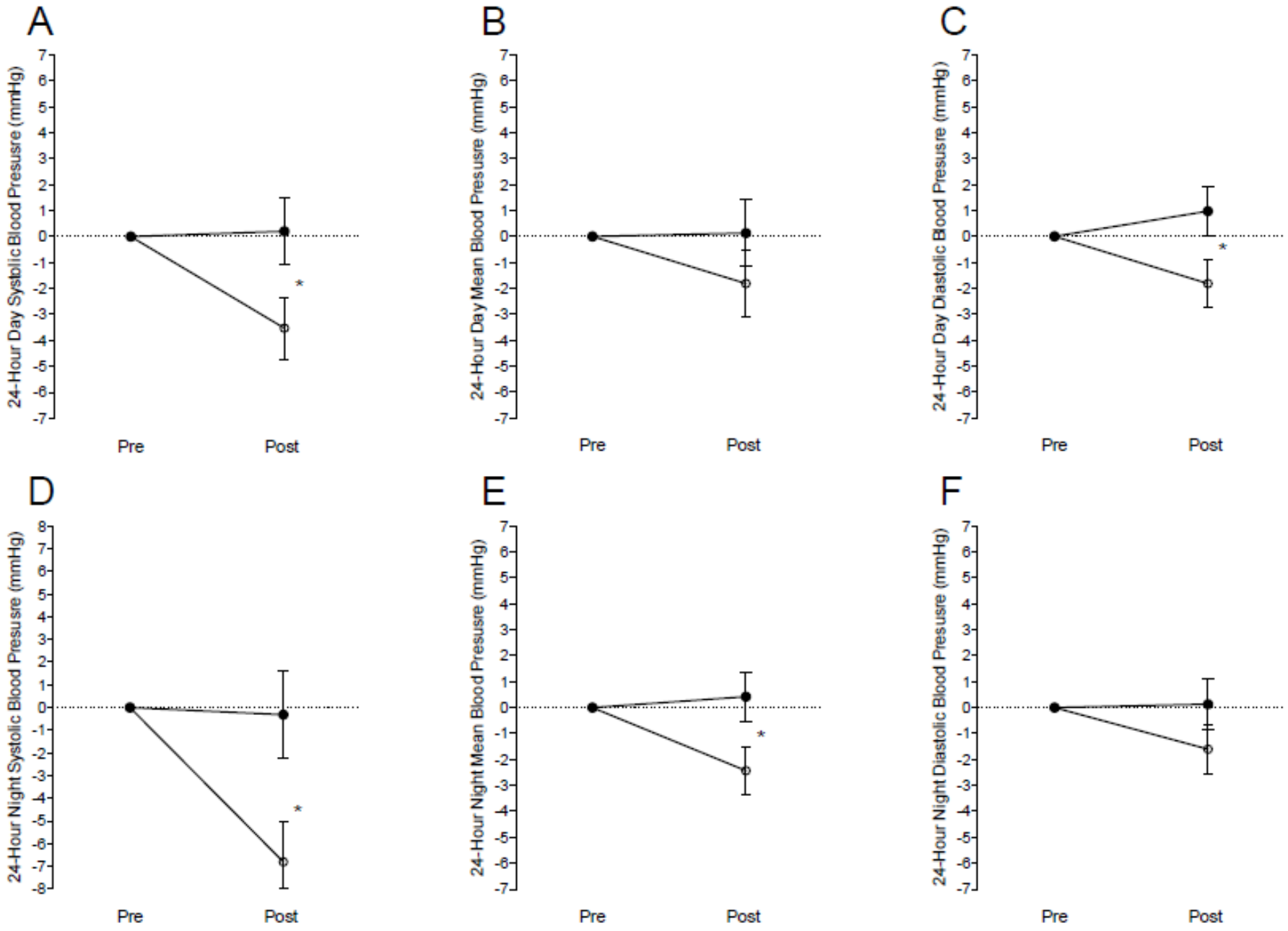

Figure 3: Mean 24-hour day systolic (A), mean arterial (B) diastolic (C), and 24-hour night systolic (D), mean arterial (E), and diastolic (F) pressure change values for control (*filled circles*) and HIIT (*open circles*) intervention groups. *Error bars* indicate standard error of the mean. * Significant ($P < 0.05$) difference in the control and HIIT intervention change value.

4.0: Discussion.

The aim of the present study was to investigate the effects of a 4-week HIIT intervention upon 24-hour ambulatory blood pressure in physically inactive males and females. The results demonstrate that HIIT over a 4-week period can statistically improve haemodynamic variables including resting SBP, 24-hour ambulatory SBP, 24-hour DBP and 24-hour MBP.

4.1: Summary of Findings.

The present study is one of few studies that has investigated the effects of a 4-week HIIT intervention upon physically inactive males and females. This randomised control trial demonstrated that following the HIIT intervention resting SBP was significantly reduced by -7.3 ± 7.9 mmHg ($P = 0.041$) compared against the control condition. Therefore, null hypothesis 1 can be rejected. However, null hypothesis 2 and 3 can be accepted as there was no significant difference reported in resting MBP or resting DBP. The reduction in resting SBP is clinically relevant since reductions ≥ 2 mmHg has been documented to reduce the risk of deaths from strokes by approximately 10% and deaths from ischemic heart disease by approximately 7% (Lewington *et al.* 2002). There has been much support within empirical literature highlighting that adoption of a physically active lifestyle can reduce the risks CVD such as hypertension, subsequently reducing the risks of mortality (Fagard, 2005). The results of the present study are similar to the findings of Cornelissen *et al.* (2010) who found significant reductions in SBP (-6 ± 2.6 mmHg, $P < 0.001$) when compared against the traditional aerobic intensity group. However, the results from the present study produced significant reductions in BP in less time since Cornelissen *et al.* (2010) study was a 10-week intervention. Despite both investigations

showing significant reductions in SBP, protocol differences may explain the quicker reduction from the present study compared against the findings by Cornelissen *et al.* (2010).

The current study also demonstrated that 24-hour ambulatory SBP, MBP and DBP was significantly reduced by -4.1 ± 8.1 mmHg ($P = 0.008$), -1.5 ± 3.4 mmHg ($P = 0.012$) and -2.2 ± 4 mmHg ($P = 0.002$), respectively. These reductions are also clinically relevant and as such, null hypothesis 4, 5 and 6 can be rejected.

The results of this study support the findings of Molmen-Hansen *et al.* (2012) who found that following HIIT, significant reductions in ambulatory SBP and DBP were found (12 mmHg and 8 mmHg, respectively, $P < 0.001$ for both). The present study showed significant reductions following HIIT in daytime SBP (-3.5 ± 7.9 mmHg) and daytime DBP (-1.9 ± 4.6 mmHg) compared to control. The findings by Molmen-Hansen *et al.* (2012) also report significant reductions in ambulatory daytime SBP and DBP (13 mmHg, $P < 0.001$, 8.5 mmHg, $P < 0.001$) respectively. Results from the present study also show significant reductions in night time SBP (-6.8 ± 9.9 mmHg, $P <0.008$) and these coincide with reductions found by Molmen-Hansen *et al.* (2012) who reported that night time ambulatory SBP reduced by (-10.5 mmHg, $P < 0.001$). It can be observed that findings by Molmen-Hansen et al. (2012) show greater reductions in variables of ABP than results in the present study; however, it should be noted that the present study was 4 weeks in duration compared against the 12 weeks by Molmen-Hansen *et al.* (2012). Therefore, it could be postulated that if the present study was continued for 12 weeks, similar if not greater reductions in BP could be observed, since the current study incorporated a higher intensity training intervention compared to Molmen-Hansen *et al.* (2012). It is documented within the investigation by Molmen-Hansen *et al.* (2012) that the protocol followed 4 x 4-minute intervals as opposed to 3 x 30 second intervals in the present study. It can also be reported that the intensity levels of the participants in Molmen-Hansen *et al.* (2012) study were 85-90% of $\dot{V}O_2max$ as opposed to maximal effort in the present study. Therefore, the findings

of the present study infer that shorter intervals at maximal effort could potentially elicit similar if not greater results than those of Molmen-Hansen *et al.* (2012); however, further research would be needed to clarify this. It should also be documented that the study by Molmen-Hansen *et al.* (2012) used both males and females with hypertension and empirical literature has highlighted that hypertensive populations can elicit greater reductions in BP compared to pre-hypertensive or normotensive individuals (Cornelissen & Smart, 2013).

As previously mentioned the findings of the present study show significant differences in resting and ABP following HIIT. It should also be noted that there were significant reductions in the standard deviation of 24-hour DBP (-1.9 ± 2.58 mmHg, P = 0.037), 24-hour SD SBP day and night (-2.45 ± 3.63 mmHg, P = 0.023, -5.6 ± 4.2 mmHg, P = 0.008, respectively), 24-hour SD DBP day (-2.37 ± 3.53 mmHg, P = 0.009) and 24-hour MBP day and night (-1.8 ± 3.19 mmHg, P = 0.025, -2.4 ± 4.47 mmHg, P = 0.046, respectively). Despite not being an aim of the present study, the standard deviation of ABP is an indicator of blood pressure variability. The results highlight a reduction in the variability of BP which is of clinical relevance as it is reported that reduced BP variability is associated with a decreased risk of mortality (Schillaci, Pucci, & Parati, 2011).

A BP drop at night (≥10%) is another important prognostic marker for cardiovascular health. Indeed, Birkenhäger & Van Den Meiracker (2007) highlight that the clinical relevance of a non-dipping blood pressure lies in its proven association with target organ damage and improved prediction of an increased CVD risk in hypertensive and normotensive populations. However, there was no significant difference in the proportion of dippers pre (p=0.155) and post (p=0.248) intervention between HIIT and control groups.

It can be observed from the present study that BP was significantly reduced following 4 weeks of HIIT; however, HR did not significantly change following the intervention, which coincide with findings by Astorinio *et al.* (2012) who also reported no significant change in resting HR following a similar Wingate based HIIT protocol. However, this contradicts findings of Kiviniemi *et al.* (2014) as they reported significant reductions in resting HR of 2 $b.min^{-1}$ following a 2-week intervention utilising a similar intervention protocol. It can also be documented that there was a trend in the decrease in PP following the HIIT intervention. This finding is of some interest given that an increased PP is an independent risk factor of CHD (Franklin *et al.*1999) and that adopting a HIIT programme can help decrease PP. However, further research is needed to assess the effectiveness of HIIT upon PP. It can also be observed that non-significant changes in 24-hour RPP and 24-hour day time RPP were reported; however, a significant difference in 24-hour night time RPP were observed. Despite, there being a significant increase in RPP during the night time, it is still acknowledged that the value is classified as normal (McArdle, Katch, & Katch, 2010).

It can also be observed that following the intervention BRS increased slightly following the HIIT intervention; however, it did not change significantly despite a significant reduction in BP. It can be acknowledged that despite the reliability and validity of non-invasive methods such as TFM® and the sequence technique for measurement of BRS, it may not be sensitive enough to monitor changes in BRS in the current study. Therefore, it could be argued that the use of intravenous bolus injection of vasoactive drugs (sodium nitroprusside and phenylephrine) may show a change in BRS coinciding with the reduction in BP (Taylor *et al.* 2017). However, despite this, empirical literature supports the use of the sequence technique for measuring BRS in clinical and healthy populations (Parati *et al.* 1988).

The findings of the present study offer consistent findings with empirical literature in the role of HIIT and the reduction of resting BP, in addition to offering new insights of the role of HIIT upon ABP in both physically inactive male and female populations. These findings also elicit further understanding of the role of HIIT and offer an option for inclusion in future physical activity guidelines and primary health care.

4.2: Adaptations in Resting and Ambulatory Blood Pressure.

The effects of HIIT upon resting BP have been well documented within the literature; however, its effects upon ABP are poorly documented and this required further research. The present study demonstrates that following a short 4-week HIIT intervention, significant reductions in both resting and ABP occur. As previously highlighted MAP is a result of TPR x Q, therefore, BP reductions documented within the present study must be related to alterations in one or both of these variables (Pescatello *et al.* 2004; Wiles, Goldring, & Coleman, 2017).

It has been reported that endothelial function is improved by adopting and adhering to physical activity (Hambrecht *et al.* 1998). It is documented as a result of HIIT that endothelial function is significantly improved due to a greater increase in nitric oxide bioavailability (Tjonna *et al.* 2008). This increase in endothelial function and increased production of nitic oxide from vascular endothelial cells has been reported to have a considerable effect in the reduction of BP through a decrease in SVR (Maeda *et al.* 2001). The decrease in SVR allows the blood vessels to vasodilate, reducing strain placed upon the heart (Chobanian *et al.* 2003). This decrease of BP and SVR can be evidenced by reduced levels of plasma noradrenaline and plasma renin activity compared against untrained individuals (Fagard, 2006). It is reported that

reduced levels of plasma noradrenaline are indicative of an increase in cardiac parasympathetic activity (Sztajzel, 2004). It is also reported that an increase in cardiac parasympathetic activity can result in stimulation of baroreceptors, resulting in an increase in efferent cardiac parasympathetic activity and decreases in sympathetic activity due to its inability to stimulate the SA node (Triposkiadis et al., 2009). An increase in baroreceptor impulse frequency inhibits a vasoconstrictor action and results in blood vessel vasodilation, subsequently reducing SVR (Gibala, Little et al., 2012). Evidence suggests vascular function not only depends upon cells within the vessel wall but are also significantly modulated by circulating cells derived from the bone marrow (Asahara *et al.* 1997). It has been documented that a subset of these stem cells (known as endothelial progenitor cells) promotes angiogenesis, promotes vascular repair, improve endothelial function, inhibit atherosclerosis, and increase ventricular function (Hill *et al.* 2003). These cells are known as endothelial progenitor cells (Laufs *et al.* 2004). It is documented that with an increase in nitic oxide bioavailability is associated with a subsequent increase in the number of endothelial progenitor cells within circulation, which promotes greater endothelial regeneration (Tjonna *et al.* 2008). This highlights an improvement in endothelial function and nitric oxide bioavailability may be a potential mechanism explaining the reduction in BP following a HIIT intervention.

Research has documented that following an aerobic or HIIT program can induce physiological changes in the vasculature and trigger anti-atherosclerotic adaptations (Green, 2009). A study by Hambrecht *et al.* (2003) investigated the effect on the internal mammary artery following a 4-week cycle ergometer exercise intervention, and they reported that improved acetylcholine and adenosine-mediated blood flows were improved. This indicates that both conduit and resistance artery endothelium-dependant vasodilator function were enhanced. It was also reported that as a result of the training intervention, endothelial nitic oxide synthase and shear stress-related endothelial nitric oxide synthase phosphorylation were increased, inferring that

a shear stress-dependant mechanism could explain increased nitric oxide bioactivity as a result of training (Green, 2009). These findings are further reinforced by Fletcher *et al.* (2013) who highlight that repeated bouts of exercise subsequently increases arterial wall stress, which over time can increase lumen size and dilation capacity, which may improve myocardial efficiency via a reduced after-load due a decrease in TPR. These adaptations can lead to a reduction in BP, which has been associated with a decreased risk of CVD (Cornelissen & Fagard, 2005; Cornelissen & Smart, 2010). The findings that vascular adaptations can take place within a 4-week period prove consistent within the literature as it is documented that physiological remodelling can take place in as little as 14 days (Green *et al.* 2004; Gibala & Jones, 2013; Granata *et al.* 2016).

Despite not being directly measured within the present study it is important to address another potential mechanism that can play a key role in the long-term regulation of BP following a HIIT intervention is the RAAS. The RAAS is complex and research investigating the effects of this system is limited. However, it is documented that following exercise training that the efficiency of the RAAS system is increased, and as a result insulin metabolic signalling within the vascular endothelial cells is increased (Arror, Mandiavia & Sowers, 2012). It is also documented that following HIIT, circulating renin, angiotensin converting enzyme, angiotensin II and aldosterone is significantly attenuated (Wan *et al.* 2007). This subsequently leads to increased antioxidant and anti-inflammatory effects, which improve insulin induced vasodilation and capillary recruitment, which has been documented to reduce arterial stiffness (Aroor *et al.* 2013). This is beneficial to health as it is documented that arterial stiffness is an independent predictor of CVD and all-cause mortality (Laurent *et al.* 2001). Therefore, improvements in RAAS and the subsequent reduction of arterial stiffness can lead to improved

endothelial function, which in turn has been shown to decrease the risk of mortality (DeSouza *et al.* 2000).

A further potential adaptation that may explain the reduction in BP is adaptations in cardiac output. It has been documented that hypertrophy of the heart, more specifically of the left ventricle, can potentially account for an increased Q (Mezzani, Corrà, & Giannuzzi, 2008). It is inferred that as a consequence of increased left ventricular hypertrophy, the hearts ability to pump blood will increase, primarily due to an increase in stroke volume, which occurs as a result of greater end-diastolic volume and an increase in left ventricular mass (Aubert, Seps & Beckers, 2003). Exercise training has been shown to reverse these cardiac maladaptations, which may result in a reduction in Q.

4.3: Limitations.

There are several limitations to the present study that warrant discussion. Previous research surrounding HIIT and ABP is limited, especially in a young physically inactive male and female population, which makes it somewhat difficult to make generalisations. It must also be noted that the study was a single centre trial, which reduces generalisation of results. In addition, caution must be applied when considering these findings to clinical populations. It must also be noted that the population studied was healthy, yet physically inactive. However, the results of the present study highlight that HIIT produced a significant reduction in resting and ABP.

It has also been previously mentioned that the use of the TFM® for measurement of BRS may not be sensitive to detect changes in BRS in the current population, meaning an alternative

method may be needed in future to detect changes. It must also be noted that the RAAS is complex and although not directly measured in this investigation, it may be a potential mechanism that could explain the reduction in BP following 4 weeks of HIIT. However, a lack of trained staff at taking blood to measure renin and other inflammation markers at time of testing means that the potency of the investigation was not maximised.

It must also be noted that the present study only used an intervention group compared against a control group. The results of the study could be further improved if compared against another method of training such as isometric exercise training. It must also be noted that participants performed the HIIT in group cycle sessions, which could have had an impact on exercise participation, engagement, adherence and enjoyment during the investigation. Therefore, the exercise effect of HIIT upon resting and ABP response when performed in isolation are requires further research.

4.4: Future Directions.

Future research could be directed to using the same protocol in a multicentre and multi-ethnic trial, in populations with different resting BP characteristics. This would increase the efficacy of the HIIT protocol used within the present investigation and ascertain if there are different responses depending upon baseline BP, which may make the results more generalisable. Future research could also be directed to including the taking of blood to measure inflammation markers and renin content in the blood. This would allow for further understanding into the RAAS and the role it plays in the reduction of BP following HIIT.

It could also be implied that the present study would be further improved by including another exercise intervention group such as traditional aerobic training or isometric training in order to find out the most effective method of training which should be utilised as a non-pharmacological treatment in the reduction of BP.

Evidence surrounding HIIT and its efficacy as a time efficient method of exercise in reducing BP is well supported within the literature when compared against traditional aerobic training intervention; however, other cardiovascular benefits associated with HIIT in the long term when compared with traditional aerobic training has yet to be investigated. It would be beneficial for future research to investigate long term effects of both HIIT and traditional aerobic training to investigate whether benefits of HIIT continue to be greater than those of traditional aerobic training, or if the effects of HIIT plateau.

4.5: Conclusions.

The findings of the present study demonstrate that a 4-week HIIT programme can significantly reduce both resting and ABP when compared against a control group. This again highlights that HIIT can be a time effective non-pharmacological intervention for the treatment of BP and other cardiovascular benefits compared against traditional aerobic training. Therefore, null hypothesis 1, 4, 5 and 6 can be rejected. However, it should be noted that further research is needed, in particular understanding the potential mechanisms behind BP reduction such as the RAAS. Future research into this area and response to HIIT could offer further clarification and clinical implications and create an option for this method of training to be included in future guidelines for the treatment of BP, in addition to further assessing the effectiveness of HIIT as an intervention.

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6.0: Appendices.

6.1: Appendix A- physical activity readiness questionnaire.

Section of Sport and Exercise Sciences

Informed Consent & Health and Fitness Questionnaire

Name: ……. Postcode: ……..

Date of Birth: …… Age: …… Sex: ……

Please answer the following questions by *circling* the appropriate response and if necessary providing extra information in the spaces provided.

ANY INFORMATION CONTAINED HEREIN WILL BE TREATED AS CONFIDENTIAL

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

   Untrained / Moderately trained / Trained / Highly trained

2. Average number of hours spent exercising **…….……per week**

3. How would you describe your present bodyweight?

   Underweight / Ideal / Slightly overweight / Very overweight

4. How would you describe your smoking habits?

   Non smoker / Previous smoker / Currently smoking

5. How would you describe your alcohol intake?

   Never Drink / An occasional drink / A drink every day / More than one drink a day

   (Note 1 drink = 1 unit)

6. Have you had to consult your doctor within the last six months? **Yes / No**

   If you have answered **yes**, please give details: **…….**

7. Are you presently taking any form of medication? **Yes / No**

   If you have answered **yes**, please give details: **……**

8. Do you suffer or have you ever suffered from any of the following?

a. Diabetes	**Yes / No**	b. Asthma	**Yes / No**
c. Epilepsy	**Yes / No**	d. Bronchitis	**Yes / No**
e. Any form of heart complaint	**Yes / No**	f. Serious Back or Neck Injury	**Yes / No**
g. High blood pressure	**Yes / No**	h. Aneurysm [1] or Embolism[2]	**Yes / No**

1: Arterial wall weakness causing dilation. 2: Obstruction in the Artery.

9. Is there a history of heart complaint in your family? **Yes / No**

If you have answered **yes**, please give details: **……**

10. Do you have any allergies? **Yes / No**

If you have answered **yes**, please give details: **……**

11. Do you currently have any form of muscle or joint injury? **Yes / No**

If you have answered **yes**, please give details: **……**

12. Have you had to suspend your normal training/physical activity in the last two weeks? **Yes / No**

If you have answered **yes**, please give details: **……**

6.2: Informed consent form.

INFORMED CONSENT

Name:

Age:

D.O.B:

Term Time Address:

Student Email:

Mobile Number:

The full details of the tests and protocol have been explained to me. I am clear about what will be involved and I am aware of the purpose of the tests.

I know that I am not obliged to complete the tests. I am free to withdraw myself from the research at any point and am not required to give a reason.

The test results are confidential and all data will be made anonymous for analysis.

I have been given the opportunity to ask any questions I may have about the research and these have been answered adequately.

As far as I am aware, there is nothing that might prevent me from successfully completing the tests that have been outlined to me.

Signature of Participant: ……..

Signature of Sport Scientist: ……..

Date: ……..

6.3: Participant information sheet (HIIT).

Participant information sheet

High intensity interval training, known as HIIT, is a form of exercise training involving very short intervals of very high/maximal intensity exercise. HIIT is considered an effective time-efficient strategy to induce numerous metabolic adaptations usually associated with traditional endurance training. HIIT has recently become a popular method of exercise training and is also of interest as a potential method of improving cardiovascular health. The physiological responses to this training method require further exploration, therefore the aim of this study is to compare cardiovascular measures at the beginning and end of a 4-week period in participants in both training and non-training participants. Some participants will complete a HIIT intervention for 4 weeks, while a control group will maintain their normal lifestyle and physical activity during the same 4 weeks.

Laboratory schedule- HIIT

Week 1: High Intensity Interval Training Baseline (HIIT) characteristics.

- Participant demographics will be taken (Height, Weight, Resting Heart Rate)
- Initial resting heart rate variability and resting blood pressure in a supine position (task force monitor).
- 24-hour Ambulatory blood pressure measurements recorded

Week 2-5: HIIT group sessions.

- Participants will have hearts scanned pre and post HIIT Intervention- HIIT (3 x 30s bouts of exercise at 7.5% body weight with 2 minute's active recovery in between bouts) over 3 days

Week 6: HIIT group post intervention measurements.

- Participants will undergo same baseline procedure as week 1

Week 1: HIIT test for short-term responses. Participants will need to be able to participate for 2 hours in order to complete this phase of testing.

- Participant demographics will be taken (Height, Weight, Resting Heart Rate)
- Initial resting heart rate variability and resting blood pressure in a supine position (task force monitor).
- Participants will have hearts scanned pre and post HIIT (3 x 30s bouts of exercise at 7.5% body weight with 2 minute's active recovery in between bouts) to measure acute responses).
- Post HIIT task force monitor to measure acute heart rate variability and blood pressure responses.

6.4: Participant information sheet (control).

Participant information sheet

High intensity interval training, known as HIIT, is a form of exercise training involving very short intervals of very high/maximal intensity exercise. HIIT is considered an effective time-efficient strategy to induce numerous metabolic adaptations usually associated with traditional endurance training. HIIT has recently become a popular method of exercise training and is also of interest as a potential method of improving cardiovascular health. The physiological responses to this training method require further exploration, therefore the aim of this study is to compare cardiovascular measures at the beginning and end of a 4-week period in participants in both training and non-training participants. Some participants will complete a HIIT intervention for 4 weeks, while a control group will maintain their normal lifestyle and physical activity during the same 4 weeks.

Laboratory Schedule - CONTROL

Week 1: Control intervention baseline characteristics

- Participant demographics will be taken (Height, Weight, Resting Heart Rate)
- Initial resting heart rate variability and resting blood pressure in a supine position (task force monitor).
- 24-hour Ambulatory blood pressure measurements recorded

Week 2-5: Control intervention sessions.

- Participants will refrain from any HIIT for the duration of the 4-week control period.
- Participants will attempt to maintain their normal lifestyle without making any major changes with regards to diet, physical activity, smoking status.

Week 6: Control group post intervention measurements.

- Participants will undergo same baseline procedure as week 1