THE EFFECT OF A HIGH INTENSITY INTERVAL TRAINING PROGRAM ON HEALTH-RELATED OUTCOMES IN OLDER ADULTS

By

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DECLARATION

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ABSTRACT

Low levels of regular physical activity in older adults may lead to accelerated declines in overall health and functional capacity. Moderate continuous aerobic training (MCAT) has generally been recommended to combat the prevalence of lifestyle diseases in older adults, however adherence rates to this type of training are low, which necessitates the need for a viable alternative. High intensity interval training (HIIT) has been successfully implemented in young and clinical populations, yet there is limited evidence that advocates the use of HIIT in older adults to attain health benefits. Thus, the primary aim of this study was to determine the effect of HIIT on health-related outcomes in older adults.

Twenty four sedentary older adults (age 62.8 ± 6.5 years; 37.3 ± 7.6 % body fat) volunteered for the 16 week HIIT and MCAT intervention. Participants were randomly assigned into 2 experimental groups: HIIT or MCAT. HIIT consisted of 4 stages of 4 minutes treadmill running at 90-95% of age predicted maximum heart rate (APMHR) with 3 minutes of active recovery between intervals. MCAT consisted of treadmill walking for 47 minutes at 70-75% of APMHR. The participants were tested for body composition, insulin resistance, blood lipids, functional capacity, cardiorespiratory fitness and quality of life, pre and post intervention. The pre-post intra-group changes were compared using paired t-tests and the magnitude of differences between groups was calculated using Cohen's effect sizes. In addition the time x group interaction effects between HIIT and MCAT were calculated using 2x2 ANOVA.

Both HIIT and MCAT elicited significant improvements in body fat percentage (HIIT: 1.9% vs MCAT: 2.2%), sagittal abdominal diameter (HIIT: 1.7cm vs MCAT: 1.6cm),

waist circumference (HIIT: 4.1cm vs MCAT: 4.4cm) and hip circumference (HIIT: 5cm vs MCAT: 5.1cm) ($p < 0.05$). In addition, HIIT significantly improved fasting plasma glucose (HIIT: 0.3mmol/l vs MCAT: 0.1mmol/l) and cardiorespiratory fitness (HIIT: 7.6ml/kg/min vs MCAT: 1.8ml/kg/min) relative to MCAT ($p < 0.05$). Although not statistically significant, HIIT also exerted a greater practically significant improvement on the lipid profile and functional capacity relative to MCAT (ES = 0.41, 0.30 respectively). In contrast, MCAT succeeded in improving quality of life to a greater extent relative to HIIT, especially with regards to bodily pain (ES = 0.64).

These results demonstrate that HIIT is a viable, tolerable and beneficial form of exercise in older adults. Although both HIIT and MCAT are able to significantly improve body composition, HIIT had a greater practically significant effect on insulin resistance, functional capacity and cardiorespiratory fitness relative to MCAT in older adults. These benefits translate into a reduced cardiovascular disease risk as well as an improvement in activities of daily living. Despite HIIT inducing a greater amount of bodily pain in participants, HIIT still elicited favourable changes in health outcomes.

OPSOMMING

Lae vlakke van gereelde fisieke aktiwiteit by ouer volwassenes kan tot versnelde agteruitgang in algehele gesondheid en in funksionele kapasiteit lei. Matige aaneenlopende aërobiese oefening (in Engels moderate continuous aerobic training of MCAT) word tans oor die algemeen aanbeveel om die voorkoms van lewenstylsiektes by ouer volwassenes te beveg, maar handhawingskoerse vir hierdie soort oefening is laag, wat ’n soeke na ’n lewensvatbare alternatief noodsaak. Hoë-intensiteit-interval-oefening (in Engels high intensity interval training of HIIT) is wel reeds suksesvol in jong en kliniese populasies geïmplementeer, maar daar is slegs beperkte bewyse om die gebruik van HIIT vir die verkryging van gesondheidsvoordele by ouer volwassenes voor te staan. Daarom was die primêre doel van hierdie studie om die uitwerking van hoë-intensiteit-interval-oefening op gesondheidsverwante uitkomste by ouer volwassenes te bepaal.

Vier-en-twintig onaktiewe ouer volwassenes (ouderdom 62.8 ± 6.5 jaar; liggaamsvet 37.3 ± 7.6%) het hulself vrywillig verklaar om aan ’n 16-weeklange HIIT en MCAT intervensie deel te neem. Deelnemers is ewekansig in twee eksperimentele groepe verdeel: HIIT of MCAT. HIIT het bestaan uit vier fases van vier minute hardloop op ’n trapmeul teen 90-95% van ouderdom-voorspelde maksimum hartspoedtempo (in Engels age predicted maximum heart rate of APMHR) met drie minute se aktiewe herstel tussen intervalle. MCAT het bestaan daaruit om vir 47 minute op ’n trapmeul te loop teen 70-75% van APMHR. Die deelnemers is getoets vir liggaamsamestelling, insulien weerstandigheid, bloedlipiede, funksionele kapasiteit, kardiorespiratoriese fiksheid en lewensgehalte, voor en na die intervensie. Die pre- en post-intragroep-veranderinge is vergelyk met die gebruik van gepaarde t-toetse

en die grootte van verskille tussen groepe is bereken deur Cohen se effekgroottes te gebruik. Die tyd x groep interaksie effek tussen HIIT en MCAT is addisioneel bereken met 2x2 ANOVA.

Beide HIIT en MCAT het tot betekenisvolle verbeterings in liggaamsvetpersentasie (HIIT: 1.9% vs MCAT: 2.2%), sagitale abdominale deursnit (HIIT: 1.7cm vs MCAT: 1.6cm), middelomtrek (HIIT: 4.1cm vs MCAT: 4.4cm) en heupomtrek (HIIT: 5cm vs MCAT: 5.1cm) ($p < 0.05$) gelei. Verder het HIIT, relatief tot MCAT, vastende-plasmaglukose (HIIT: 0.3mmol/l vs MCAT: 0.1mmol/l) en kardiorespiratoriese fiksheid (HIIT: 7.6ml/kg/min vs MCAT: 1.8ml/kg/min) ($p < 0.05$) betekenisvol verbeter. Hoewel nie statisties betekenisvol nie, het HIIT ook ’n sterker praktiese betekenisvolle verbetering van die lipiedprofiel en funksionele kapasiteit relatief tot MCAT (ES = 0.41, 0.30 onderskeidelik) gehad. Hierteenoor het MCAT wel daarin geslaag om lewensgehalte tot ’n groter mate relatief tot HIIT te verbeter, veral ten opsigte van liggaamspyn (ES = 0.64).

Hierdie resultate demonstreer dat HIIT ’n lewensvatbare, hanteerbare en voordelige vorm van oefening vir ouer volwassenes is. Hoewel beide HIIT en MCAT in staat is om liggaamsamestelling betekenisvol te verbeter, het HIIT, relatief tot MCAT, ’n groter prakties betekenisvolle uitwerking op insulien weerstandigheid, funksionele kapasiteit en kardiorespiratoriese fiksheid in ouer volwassenes. Hierdie voordele word omgeskakel in ’n verminderde risiko vir kardiovaskulêre siekte, sowel as in ’n verbetering in aktiwiteite van die daaglikse lewe. Ten spyte daarvan dat HIIT meer liggaamspyn in deelnemers veroorsaak, lei HIIT steeds tot gunstige veranderinge in gesondheidsuitkomstes.

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DEDICATION

I dedicate this thesis to my parents Clive and Cindy Nieuwoudt

For encouraging me to pursue an academic path

LIST OF ABBREVIATIONS AND ACRONYMS

α	:	Alpha
β	:	Beta
%	:	Percentage
%BF	:	Percentage body fat
±	:	Plus-minus
≥	:	Greater than or equal to
≤	:	Smaller than or equal to
>	:	Greater than
<	:	Smaller than
1 MET	:	One metabolic equivalent of task
ACSM	:	American College of Sports Medicine
AHA	:	American Heart Association
AIT	:	Aerobic interval training
ANOVA	:	Analysis of variance
APMHR	:	Age predicted maximum heart rate
BIA	:	Bio-electrical impedance analysis
BM	:	Body mass
BMI	:	Body mass index
BP	:	Blood pressure
Bp	:	Bodily pain
CAD	:	Coronary artery disease
cm	:	Centimetre
CPR	:	Cardiopulmonary resuscitation
CVD	:	Cardiovascular disease

ECG	:	Electrocardiogram
ES	:	Effect size
F	:	Foot
FC	:	Functional capacity
GH	:	General health
HbA_{1c}	:	Glycosylated haemoglobin
HC	:	Hip circumference
HDL-C	:	High-density lipoprotein cholesterol
HF	:	Heart failure
HIIT	:	High intensity interval training
HOMA-IR	:	Homeostasis model assessment of insulin resistance
HR	:	Heart rate
HR_{max}	:	Maximum heart rate
ISAK	:	International Society for the Advancement of Kinanthropometry
kg	:	Kilogram
$kg.m^{-2}$	:	Kilogram per metre squared
LA	:	Left arm
LDL-C	:	Low-density lipoprotein cholesterol
MCAT	:	Moderate continuous aerobic training
MCS	:	Mental component summary
MH	:	Mental health
Min	:	Minute

ml/kg/min	:	Millilitres per kilogram body weight per minute
ml/min	:	Millilitres per minute
(mIU/L)	:	milli-international units per litre
mmHG	:	Millimetres mercury
mmol/l	:	Millimol per litre
n	:	Number
N	:	Neutral
PAR-Q	:	Physical activity readiness questionnaire
PCS	:	Physical component summary
PF	:	Physical function
Pre	:	Pre-intervention
Post	:	Post-intervention
RP	:	Role-physical
RPE	:	Rating of perceived exertion
RA	:	Right arm
RE	:	Role-emotional
s	:	Seconds
SAD	:	Sagittal abdominal diameter
SD	:	Standard deviation
SF	:	Social functioning
SF-36v2	:	Short form health survey 36 version 2
SIT	:	Sprint interval training
SV	:	Stroke volume
T2DM	:	Type 2 diabetes mellitus

TC	:	Total cholesterol
TG	:	Triglycerides
TUG	:	Timed-Up-and-Go
VO_{2max}	:	Maximal oxygen uptake
VO_{2peak}	:	Peak oxygen uptake
VT	:	Vitality
WC	:	Waist circumference
WHO	:	World Health Organisation
X^a	:	Trivial practical significance
X^b	:	Small practical significance
X^c	:	Moderate practical significance
X^d	:	Large practical significance

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 Background

Physical inactivity is rapidly increasing globally, with 31.1% of the world population physically inactive (Hallal *et al.,* 2012). Evidence demonstrates that regular physical activity enhances protection against cardiovascular disease, metabolic disease, some cancers, musculoskeletal disorders and can improve self-esteem, life satisfaction as well as reduce levels of anxiety and clinical depression (Heath *et al.,* 2012; Nelson *et al.,* 2007; Rejeski *et al.,* 2001). Regular physical activity has the ability to reduce cardiovascular disease and all-cause mortality by 20-35% in men and women (Warburton *et al.,* 2006). However regular exercise is not consistent across age groups and physical inactivity increases with age reaching its peak in adults older than 65 years (Schutzer & Graves, 2004). The American College of Sports Medicine (ACSM) and the American Heart Association (AHA) recommend that older adults should participate in a multi-dimensional physical activity program consisting of moderate intensity aerobic training, combinations of moderate and vigorous intensity activity, muscle strengthening activities, flexibility and balance training (Nelson *et al.,* 2007). However, adherence rates are low with only 30% of older men and 15% of older women regularly engaging in exercise (Schutzer & Graves, 2004).

1.2 Problem statement

Several barriers to exercise exist in the ageing population that hinder the adoption and maintenance of an exercise program. These barriers includes perceived “lack of time", health concerns, environmental challenges, lack of exercise knowledge and fear of injury (Schutzer & Graves, 2004). Moderate continuous aerobic training (MCAT) and resistance training are typically prescribed to ageing adults. MCAT has been shown to improve aerobic capacity whereas, resistance training leads to improvements in muscle mass, strength, power and ability to perform activities of daily living (Hunter *et al.,* 2004; Taylor *et al.,* 2004). Although beneficial, these modes of exercise are not effectively adhered to with adherence rates being worse in moderate intensity aerobic exercise training compared to resistance training (Picorelli *et al.,* 2014; Hong *et al.,* 2008). This may be attributed to among other, higher incidence of joint disease such as osteoarthritis in older populations (Picorelli *et al.,* 2014). However, there is no central factor explaining these low levels of regular physical activity. Therefore, it may be worthwhile to investigate a viable, sustainable alternative mode of exercise.

This alternative exercise mode is in the form of high intensity interval training (HIIT). HIIT can be defined as vigorous aerobic exercise performed at high intensities (85-95% maximum heart rate) for a brief period of time (30 seconds to 4 minutes), interposed with recovery intervals of low to moderate intensity (50-70% maximum heart rate) (Kessler *et al.,* 2012). HIIT has commonly been used in elite athletes but is rapidly increasing in popularity in sedentary and clinical populations, with most research focusing on the effects of HIIT on individuals with coronary artery disease, congestive HF, metabolic syndrome and T2DM (Terada *et al.,* 2013; TjØnna *et al.,* 2008; WislØff *et al.,* 2007; Rognmo *et al.,* 2004). In comparison to MCAT, HIIT has elicited positive results with significant increases in VO_{2max} and insulin sensitivity. Despite the benefits of HIIT being extensively studied, the research has primarily focused on young and clinical populations (Terada *et al.,* 2013; TjØnna *et al.,* 2009;

TjØnna *et al.,* 2008; WislØff *et al.,* 2007; Rognmo *et al.,* 2004). The effects of HIIT and its associated benefits in healthy older adults has not been previously examined, specifically the effects of HIIT on body composition, metabolic blood measures (blood lipids and insulin resistance), cardiorespiratory fitness, functional capacity and quality of life. Further research is necessary to determine if HIIT is a viable and tolerable form of exercise in the ageing adult, relative to other types of exercise. Therefore, the primary aim of this study was to determine the effect of a HIIT program on health-related outcomes in healthy, older adults. The secondary aim was to compare the effects of HIIT relative to the effects of MCAT.

1.3 Objectives of the study

The primary objectives of the study were to compare the effects of HIIT and MCAT on:

- Body composition,
- Measures of insulin resistance,
- Blood lipids,
- Functional capacity,
- Cardiorespiratory fitness, and
- Quality of life.

1.4 Hypotheses

- HIIT will result in a significant improvement in body composition relative to MCAT.
- HIIT will result in a significant improvement in measures of insulin resistance relative to MCAT.
- HIIT will result in a significant improvement in blood lipids relative to MCAT.

- HIIT will result in a significant improvement in functional capacity relative to MCAT.
- HIIT will result in a significant improvement in cardiorespiratory fitness relative to MCAT.
- HIIT will result in a significant improvement in quality of life relative to MCAT.

1.5 Chapter overview

This study will present the comprehensive effect of high intensity interval training on health outcomes in older adults, and compare the validity of this type of training to MCAT. Results are presented in a traditional thesis format consisting of five chapters.

Chapter one focuses on the prevalence and relevance of physical inactivity in older adults. The reasoning for the study is established and the specific aims are addressed.

Chapter two introduces the need for the study and provides an in depth analysis of the relevant research associated with HIIT and the older population.

Chapter three includes the research design, protocols and equipment used for testing and the exercise intervention.

Chapter four illustrates the findings of the study and reveals the statistical and practical significance of the results.

Chapter five provides a detailed description of the findings and the significance of these in older adults. This chapter also discusses the practical aspect of HIIT and how it can translate into a "real-world" setting.

CHAPTER 2

LITERATURE REVIEW

A. Introduction

Lack of regular physical activity in older adults can lead to severe health and functional problems during ageing (Hamer *et al.,* 2014). It has been reported that less than 50% of American adults adhere to the World Health Organisation guidelines of physical activity, which recommends that older adults should participate in 150 minutes of moderate intensity aerobic physical activity per week or 75 minutes of vigorous intensity aerobic physical activity per week or an equivalent combination of both (Kilpatrick *et al.,* 2014). Lack of regular physical activity combined with the rapid increase of obesity in older adults has increased the risk of cardio-metabolic disorders in this population group (Peltzer *et al.,* 2011). Physical activity has well known positive effects on strength, flexibility, aerobic capacity, walking capacity, balance, mental well-being and cognition (Hamer *et al.,* 2014). Despite these numerous benefits 44% of South African adults older than 50 years report low physical activity levels (Peltzer *et al.,* 2011). Even more concerning is that this percentage increases with age, with 53.5% of adults older than 60 years and 56.7% of adults older than 70 years reporting low levels of regular physical activity (Peltzer *et al.,* 2011).

Resistance training is well-known to benefit the ageing population especially with respect to increases in muscle mass, strength, power, improved body composition, leading to an increase in physical activity levels and overall activities of daily living (Hunter *et al.,* 2004). In addition, resistance training is known to improve the symptoms of numerous chronic diseases including arthritis, depression, T2DM, osteoporosis, sleep disorders and cardiovascular disease, as well as reducing the incidence of falls (Seguin & Nelson, 2003). In comparison, aerobic training improves endurance capacity and cardiorespiratory fitness in older adults as reflected through improvements in insulin sensitivity, resting blood pressure, resting and recovery heart rate and body composition (Taylor *et al.,* 2004). Although the benefits of resistance and aerobic training are well documented, exercise adherence in the older population is still low indicating the need for a sustainable alternative.

Generally HIIT has been associated with high metabolic stress in older adults and was considered too high risk for adverse events in deconditioned older adults as well as at-risk older adults (Whitehurst, 2012). For this reason, a conservative approach has been applied to the ageing population limiting exercise to moderate intensity (50-70% of maximum heart rate) aerobic exercise (McArdle *et al.,* 2010). Despite the safety concerns, HIIT interventions with longer work intervals (1-4 minutes) ranging 12-16 weeks has been successfully implemented across different population groups including sedentary adults, overweight and obese adults, heart disease patients and type 2 diabetics (Terada *et al.,* 2013; Schjerve *et al.,* 2008; TjØnna *et al.,* 2008; WislØff *et al.,* 2007). These studies have focused on improving the risk factors associated with chronic diseases as well as improving quality of life, however, limited evidence is available to justify the use of HIIT in older populations and whether this form of high intensity exercise will not only be tolerable but also beneficial and result in both physical and psychological gains. There are large gaps existing in the literature regarding the optimal HIIT protocol to elicit consistent improvements in health-related outcomes in healthy, older adults, as exercise needs to be adjusted according to the desired health benefits required during ageing.

This literature review focuses on the extent of research concerning HIIT. This includes the definition of HIIT, the effects of HIIT in different population groups and the influence of HIIT on general health. Firstly, the general benefits of HIIT are discussed relative to moderate continuous aerobic training. Secondly the mode, methods and types of HIIT used are discussed, followed by the effects of HIIT in clinical populations (coronary artery disease, HF, metabolic syndrome and T2DM). Lastly the effects of HIIT on numerous health outcomes (body composition, blood lipids, insulin sensitivity, cardiorespiratory fitness, functional capacity and quality of life) as well as gender-specific responses to HIIT are deliberated.

B. Moderate continuous aerobic training (MCAT) vs High intensity interval training (HIIT)

Moderate continuous aerobic training (MCAT) involves exercising at a slow and steady pace (50-70% of maximum heart rate) and it is usually recommended to novice exercisers or older individuals diagnosed with cardiovascular or metabolic diseases who want to accumulate a large caloric expenditure for weight loss (McArdle *et al.,* 2010). According to Whitehurst (2012), the peripheral and central adaptations, including improved body composition, increased insulin sensitivity, improved lipid profile, decreased blood pressure, increased oxygen uptake, decreased resting heart rate and increased lung capacity that are experienced with high volume, low intensity exercise, are well documented, and are consistent across gender, age groups and level of physical conditioning. These are attributed to MCAT being a sustained activity and this induces an increase in the capacity of muscle cells to generate energy via oxidative phosphorylation (Whitehurst, 2012). The oxidative capacity is directly facilitated by an increase in mitochondria with key signalling cascades set in motion during and following MCAT, which supports mitochondrial biogenesis (Whitehurst, 2012).

In comparison, HIIT involves repeated bursts of vigorous intensity exercise combined with low intensity recovery (Keating *et al.,* 2014). As previously suggested (Whitehurst, 2012), HIIT promotes many of the same peripheral adaptations as MCAT. However, there is growing evidence that HIIT can lead to an array of cardiovascular (increased cardiorespiratory fitness) and metabolic benefits (increased insulin sensitivity) that are the same as or even greater than those achieved with moderate continuous aerobic exercise (Keating *et al.,* 2014). It has been demonstrated that as little as 6 near maximal exercise sessions over a period of 2 weeks can increase skeletal muscle oxidative capacity and endurance performance (McArdle *et al.,* 2010). Considering that stroke volume (pumping capacity of the heart) is a limiting factor of VO_{2max}, intervals create resting or active recovery periods that enable the participants to complete short bouts of work at higher intensities. This process challenges the pumping ability of the heart more than that experienced at lower intensities (TjØnna *et al*., 2008). For this reason interval training may be a better training option, relative to continuous training.

However, there is no set HIIT protocol that specifies mode, duration and intensity of HIIT to induce these adaptations, which makes comparison between studies challenging. Studies in patients with cardiovascular and metabolic diseases have generally followed a HIIT intervention using longer work intervals of 4 to 6 minutes at 80-95% of maximum heart rate for 12 to 16 weeks (TjØnna *et al.,* 2008; WislØff *et al.,* 2007). More recently studies have utilized HIIT protocols with shorter work intervals (30 seconds -1 minute at 100% of maximum heart rate) (Sloth *et al.,* 2013; Terada *et al.,* 2013; Whitehurst, 2012; Whyte *et al.,* 2010). Exercise intensity in HIIT and MCAT studies is usually expressed as a percentage of maximal heart rate (HR_{max}), percentage of maximal workload, percentage of peak VO_2, percentage of heart rate reserve or VO_2 reserve, or as an intensity corresponding to the ventilatory anaerobic threshold and the respiratory compensation point (Pattyn *et al.,* 2014).

C. Types of aerobic interval training

Aerobic exercise may include bicycling, walking, running, rowing, swimming, rope skipping, stair climbing and many more. However, the most common modes of HIIT are cycling, treadmill walking or running. There are two distinct types of aerobic interval training programs, sprint interval training (SIT) and high intensity interval training (HIIT) (Kessler *et al.,* 2012). SIT is usually described as 4 to 6, 30 second maximal sprints (100% maximum heart rate) with four minutes of recovery (Kessler *et al.,* 2012). This is generally referred to as low volume HIIT as the exercise sessions are extremely short (Kilpatrick *et al.,* 2014). Most studies performed SIT on a cycle ergometer (Richards *et al.,* 2010; Whyte *et al.,* 2010; Babraj *et al.,* 2009; Burgomaster *et al.,* 2008), although a few recent studies have also implemented SIT on a treadmill (Hazell *et al.,* 2014; Macpherson *et al.,* 2011). Even though this mode of training is effective, it is highly exhausting, and some researchers question its safety for at-risk populations (Kessler *et al.,* 2012). For this reason, this protocol is often limited to young and healthy participants. Despite these concerns, several studies with clinical populations (obese and type 2 diabetics), have implemented SIT and have found significant improvements in cardiorespiratory fitness and insulin sensitivity with minimal adverse effects (Little *et al.,* 2011; Whyte *et al.,* 2010).

The second type of aerobic interval training is HIIT, which consists of longer intervals (1-4 minutes) performed at slightly lower intensities (80-95% maximum heart rate) (Kessler *et al.,* 2012). HIIT protocols can be performed on either a cycle ergometer or a treadmill and has been used in both young, healthy participants and clinical populations, including those with coronary artery disease, HF and metabolic syndrome patients (TjØnna *et al.,* 2008; WislØff *et al.,* 2007; Warburton e*t al.,* 2005; Rognmo *et al.,* 2004). These population groups have all experienced significant improvements in aerobic capacity following HIIT and have reported no adverse events. This method is generally referred to as high volume HIIT as the exercise sessions are typically longer than 30 minutes (Kilpatrick *et al.,* 2014). Considering the large number of work and recovery intervals, designing an appropriate HIIT protocol should take in consideration the exercising population group (Guiraud *et al*., 2012).

1. Cycling vs Treadmill protocols

The most common cycling SIT protocol is the Wingate test. This consists of a 30 second maximum cycling effort against a supra-maximal workload. A typical SIT session would consist of 4 to 6 of these workout bouts separated by approximately 4 minutes of recovery (Gibala *et al.,* 2012). A session would normally last 20 minutes (Gibala *et al*., 2012). Several studies that implemented this protocol have consistently found an increase in skeletal muscle oxidative capacity (Gibala *et al.,* 2007; Gibala *et al*., 2006; Burgomaster *et al.,* 2005). Other endurance like adaptations documented following this protocol, include an increased resting glycogen content, a reduced rate of glycogen utilization and lactate production during matched-work exercise, an increased capacity for whole-body and skeletal muscle lipid oxidation, enhanced peripheral vascular structure and function, improved exercise performance as measured by time-to-exhaustion tests or time trials and increased maximal oxygen uptake (Rakobowchuk *et al.*, 2008; Gibala *et al.*, 2006; Burgomaster *et al.*, 2005). This protocol consisting of Wingate based HIIT is demanding and may not be tolerable or appealing for some individuals as it is difficult and requires a high level of motivation (Gibala *et al.*, 2007). These methods of HIIT, although effective and time efficient, require a specialized ergometer and result in extreme fatigue (Hood *et al.*, 2011) and are therefore not ideal for older, overweight or obese individuals.

The use of the treadmill for walking or running as a high intensity interval intervention has been successfully demonstrated in several studies and relative to different population groups, including obese adults (Schjerve *et al.,* 2008), adults diagnosed with metabolic syndrome (TjØnna *et al.,* 2008), patients with coronary artery disease (Rognmo *et al.,* 2004), patients with HF (WislØff *et al.,* 2007) and healthy younger adults (Helgerud *et al.,* 2007).

A treadmill walking or running protocol is generally characterised by 1 to 4 minutes of high intensity intervals at 85-100% of HR max followed by 1 to 4 minutes of active recovery at 50-70% HR max (TjØnna *et al.,* 2008). Walking or running interventions are usually implemented for a period of 8 -16 weeks and are generally completed three times per week (TjØnna *et al.,* 2008; WislØff *et al.,* 2007; Rognmo *et al.,* 2004). These training programs are well-tolerated by the general population, as walking is the most common form of movement.

Using a treadmill HIIT protocol is superior in improving cardiovascular fitness compared to moderate continuous aerobic activity and resistance training (Schjerve *et al*., 2008; TjØnna *et al.,* 2008; WislØff *et al.,* 2007). These protocols are easily implemented and do not require specific, expensive equipment. Although exercising on a treadmill causes significantly more impact on the ankle, knee, hip and pelvic joints than a cycling protocol, the improvements in VO_{2max} are superior (Schjerve *et* *al*., 2008; TjØnna *et al*., 2008; WislØff *et al*., 2007). Using HIIT, compared to MCAT, reduces the overall exercise time per session and per week and therefore does not necessarily cause more impact on the joints than longer duration moderate intensity exercise.

D. HIIT in clinical populations

In general, exercise training has been shown to decrease cardiovascular risk factors including obesity, dyslipidaemia, hyperglycaemia and hypertension (O' Donovan *et al*., 2005). One of the largest studies on men conducted by Blair *et al*. (1995) over a five year period and involving 9,777 participants, demonstrated that an increase in physical fitness causes a substantial reduction in cardiovascular disease relative to those who are inactive and considered unfit. Conventionally HIIT has not been a common exercise prescription in a clinical setting, due to fear that participants may be injured or not being able to tolerate the exercise intensity (Hwang *et al.,* 2011). Moderate continuous aerobic training is usually the clinical standard for cardiac patients; even though this exercise is less intense, it requires a longer duration which may not be always be well tolerated by these patients (Hwang *et al.,* 2011). Furthermore, WislØff *et al*. (2007) reported that it is exercise intensity and not exercise duration that is the determining factor in achieving exercise related cardiac benefits.

In recent year more evidence has emerged showing that HIIT has a significant positive effect on cardiovascular risk factors in a range of clinical populations namely those with coronary artery disease (CAD), congestive HF, metabolic syndrome and type 2 diabetic patients.

1. Implementing HIIT in patients with coronary artery disease (CAD)

Exercise intensity is considered to be an important factor in the effectiveness of a cardiac rehabilitation program (Pattyn *et al.,* 2014). MCAT is known to be safe and physiologically beneficial in CAD patients and can reduce all-cause mortality in cardiac patients by up to 27% (Cornish *et al.,* 2011). Patients diagnosed with CAD have generally been prescribed regular aerobic exercise at intensities ranging from 40-90% of VO_{2peak} (Rognmo *et al.,* 2004). Despite these guidelines, CAD patients often perform training programs set at low to moderate intensities (40-70% VO_{2peak}) (Rognmo *et al.,* 2004), as it has appeared that moderate intensity continuous aerobic training is sufficient to reduce cardiovascular risk and cardiovascular mortality (Pattyn *et al.,* 2014). However, this has led to low levels of exercise adherence and less impact on the disease (Pattyn *et al.,* 2014). Greater focus has now been placed on HIIT to offer cardio-protective effects in CAD and HF patients (Pattyn *et al.,* 2014). HIIT has shown to be effective in improving VO_{2peak} in stable CAD patients (Rognmo *et al.,* 2004) and is able to improve cardiorespiratory fitness, endothelial function, left ventricle morphology and function and exercise adherence to a greater extent relative to MCAT with no adverse or life-threatening effects (Pattyn *et al.,* 2014; Cornish *et al.,* 2011; Warburton *et al.,* 2005).

Although both HIIT and MCAT are able to elicit significant improvements in VO_{2peak} in stable CAD patients; HIIT produces superior improvements (Amundsen *et al.,* 2008; Rognmo *et al*. 2004). Furthermore, improvements in left ventricular filling speed and diastolic relaxation have been seen with HIIT only (Amundsen *et al.,* 2008). This indicates that exercise intensity may be the key factor in improving aerobic capacity if the two training protocols are isocaloric (Amundsen *et al.,* 2008; Rognmo *et al*., 2004). HIIT also produces a greater tolerance for strenuous exercise in CAD patients. This improved tolerance is beneficial in improving activities of daily living which would lead to an increased independence and health status (Warburton *et al.,* 2005).

Analysis of randomised control trials has shown that although HIIT is more effective in improving aerobic capacity, MCAT has a greater effect on reducing body mass in CAD patients (Pattyn *et al.,* 2014; Currie *et al.,* 2013; Rocco *et al.,* 2012). This suggests that an increase in exercise volume is required to increase fat loss. Due to the intense workloads, patients performing HIIT may lose body fat but may also increase their muscle mass, thereby maintaining their body mass (Pattyn *et al.,* 2014). However, fat loss is not the primary focus for CAD patients but rather improvements in cardiac functioning is of main concern.

The significant improvement in VO_{2peak} in response to HIIT has a strong clinical implication, as VO_{2peak} is a strong predictor of mortality in patients with coronary artery disease (Giuraud *et al.,* 2012). This has clinical relevance as each 1 ml/kg/min increase in VO_{2peak} can result in a 17% decrease in all-cause mortality, as well as a 16% decrease in cardiovascular mortality in men diagnosed with CAD and a 14% decrease in both all-cause and cardiovascular mortality in women with CAD (Pattyn *et al.,* 2014). HIIT may also serve to provide additional health benefits for this population group in allowing them to be physically active for longer periods with decreased effort (Warburton *et al.,* 2005). In conclusion, HIIT is able to effectively improve cardiorespiratory fitness to a greater extent relative to MCAT in CAD patients thereby improving quality of life and reducing the risk of cardiovascular disease death. These findings are significant as cardiovascular disease is one of the leading causes of death globally (Pattyn *et al.,* 2014) and older adults are at a seemingly higher risk for developing these diseases.

2. Heart failure (HF) and HIIT

Prior to 1980 exercise was deemed a contraindication for patients with congestive HF (Freyssin *et al.,* 2012). This belief has been abandoned and aerobic exercise has strongly been advocated for patients with HF and reduced left ventricular ejection fraction, as it has been shown to be a strong prognostic marker of cardiovascular mortality (Meyer *et al.,* 2013; Freyssin *et al.,* 2012). Aerobic exercise is able to improve the symptoms of the disease and enhance the quality of life in these patients (Meyer *et al.,* 2013). Moderate intensity aerobic exercise is still considered the clinical standard in HF patients (Arena *et al.,* 2013) as it is sufficient to reduce the development of cardiovascular disease or recurrence (Guiraud *et al.,* 2012). However, considering the evidence advocating the use of HIIT to produce significant improvements in aerobic capacity in heart disease patients (Rognmo *et al.,* 2004), a few studies have investigated the effect of HIIT on the exercise capacity and physiological adaptations in HF patients as well.

HIIT has led to greater improvements in VO_{2peak}, ejection fraction and endothelial function as well as reduced end diastolic and end systolic volumes relative to MCAT in HF patients (Meyer *et al.,* 2013; Freyssin *et al.,* 2012; Giuraud *et al.,* 2012; Fu *et al.,* 2011; Tomczak *et al.,* 2011; WislØff *et al.,* 2007). Improvements in VO_{2peak} produced by HIIT ranged from 22-46% (Freyssin *et al.,* 2012; Fu *et al.,* 2011; WislØff *et al.,* 2007); these large improvements are significant as increases in cardiovascular protection is of primary concern in these patients. Smart *et al.* (2013) suggested that HIIT is the optimal exercise prescription for HF patients and that the largest improvements in VO_{2peak} are noted in HIIT programs with longer work intervals (4 minutes) and high interval intensities (95%) compared to SIT programs.

As in CAD patients, the relative intensity of the exercise sessions rather than the duration may be more significant in decreasing all-cause and coronary heart disease mortality (Giuraud, 2012). In contrast, certain evidence has demonstrated a comparable improvement in VO_{2peak} between HIIT and MCAT (Iellamo *et al.,* 2012; Dimopoulous *et al.,* 2006). These contradictions may be attributed to the HIIT protocol used and patient baseline characteristics, inferring the need for the individualisation of HIIT programs in patients with HF.

More recently, low volume HIIT has been investigated in HF patients, as previous studies have focused on implementing protocols with longer intervals (Koufaki *et al*., 2014). In comparison to MCAT, low volume HIIT is able to elicit a 21.6% increase in VO_{2peak} relative to 8.9% in MCAT, despite the MCAT protocol having a higher caloric expenditure (Koufaki *et al*., 2014). These findings suggest that low volume HIIT is a feasible and time-efficient strategy to improve aerobic capacity in HF patients.

HIIT interventions in this population has shown to increase quality of life, motivation, functional capacity, safety and efficiency and has not resulted in any significant arrhythmias, signs of myocardial injury or acute deterioration of left or right ventricular function (Koufaki *et al*., 2014; Meyer *et al.,* 2013; Guiraud *et al.,* 2012; Kemi & WislØff, 2010). In addition, HIIT was performed with lower ratings of perceived exertion in this population group; this allowed the patients to complete the HIIT exercise session which was not always possible with longer duration MCAT (Meyer *et al.,* 2013).

In conclusion, although HIIT has shown superior improvements in VO_{2peak} in HF patients compared to continuous aerobic training, the studies completed have included just over one hundred HF patients (Arena *et al.,* 2013). This indicates that although there is evidence advocating the use of HIIT in HF patients, further trials are warranted in larger population groups before HIIT is to replace MCAT as the clinical standard (Arena *et al.,* 2013). In addition, further research is needed to determine if HIIT is able to effectively protect older adults from developing heart disease (Smart *et al.,* 2013).

3. HIIT and metabolic syndrome

The metabolic syndrome is classified as a cluster of cardiovascular risk factors, which includes high blood pressure, dyslipidaemia, impaired glycaemic control and abdominal obesity (TjØnna *et al*., 2008). With 20% of the world population being overweight, the incidence of the metabolic syndrome is expected to rise even more (Haram *et al.,* 2009). Individuals diagnosed with this syndrome have an increased risk of developing coronary heart disease, which increases their cardiovascular morbidity and mortality rate (TjØnna *et al*., 2008). This widespread and growing epidemic needs to be combatted and viable treatment strategies need to be investigated and implemented.

Current treatment for individuals diagnosed with the metabolic syndrome includes lifestyle modification which consists of a restrictive diet and physical activity (Dutheil *et al.,* 2013). This treatment strategy has priority over a pharmaceutical intervention as it is suggested to be the most effective method in reducing visceral obesity (Dutheil *et al.,* 2013). However, given the evidence advocating HIIT as an exercise mode to improve abdominal adiposity, evidence is warranted to determine if HIIT would be able to elicit cardio-metabolic benefits in metabolic syndrome patients and reverse the diagnosis.

It has been demonstrated that HIIT can increase aerobic capacity in patients diagnosed with the metabolic syndrome (Stensvold *et al.,* 2010; TjØnna *et al.,* 2008). This improvement in VO_{2max} may be attributed to improvements in central oxygen delivery and peripheral oxygen use, plus increases in skeletal muscle oxidative capacity (TjØnna *et al*., 2008). Improvements in maximal stroke volume, calcium cycling and increased mitochondrial capacity in skeletal muscle with HIIT may also contribute to the improvement in aerobic capacity (TjØnna *et al.,* 2008).

In addition, HIIT has been demonstrated to cause similar improvements in body composition in metabolic syndrome patients compared to continuous aerobic training (Kemmler *et al.,* 2014; TjØnna *et al.,* 2008). Specifically, it has been shown that HIIT has a significant effect on the waist circumference of individuals with metabolic syndrome patients (Mora-rodriguez *et al.,* 2014; Stensvold *et al.,* 2010). This is important as an increased waist circumference is associated with a higher risk of mortality (Katzmarzyk *et al.,* 2006). Since HIIT results in a significant improvement in aerobic capacity combined with a decrease in waist circumference, leading an active lifestyle rather than only prioritizing weight loss, may be more important to reversing the metabolic syndrome; although improvement of both would be ideal (TjØnna *et al*,. 2008). In addition, HIIT can also reverse risk factors of the metabolic syndrome to a greater extent than continuous training, with more patients no longer being diagnosed with the metabolic syndrome following HIIT (Salas-Romero *et al.,* 2014; Gremeaux *et al.,* 2012; TjØnna *et al.,* 2008).

Despite these positive outcomes produced by HIIT, contradictions have been found in the literature concerning blood lipids and glycaemic control in this population group (Bruseghini *et al.,* 2015; Kemmler *et al.,* 2014; TjØnna *et al.,* 2008). The only improvement with regards to these variables was reported by TjØnna *et al.* (2008)

who demonstrated a significant improvement in fasting plasma glucose and insulin sensitivity, as well as a 25% increase in HDL-C with HIIT. This may be due to these patients having elevated blood lipids, glucose and insulin values, suggesting HIIT as an effective exercise protocol to induce favourable changes in those with dyslipidaemia and poor glycaemic control. On the other hand, individuals with healthy metabolic measures exhibited minimal changes with HIIT (Kemmler *et al.,* 2014), but there is evidence to suggest that as little as 6 weeks of MCAT can induce favourable changes in HOMA-IR, glucose levels and free fatty acids in overweight and obese pre-menopausal women (Wiklund *et al.,* 2014).

In conclusion, although HIIT is a viable alternative to reverse several of the risk factors associated with the metabolic syndrome, a multi-treatment strategy, including physical activity and dietary intervention is more advisable for long term treatment and prevention. Further research is required to determine the implications of HIIT in older populations diagnosed with risk factors of the metabolic syndrome.

4. Type 2 diabetes mellitus (T2DM) and HIIT

Exercise is a well-known strategy to improve glycaemic control (Hansen *et al.,* 2010). It has been recommended that individuals diagnosed with T2DM should engage in at least 150 minutes of moderate to vigorous intensity exercise per week (Terada *et al.,* 2013). In addition, exercise training has clearly demonstrated to reduce the progression of prediabetes to T2DM by 28.5-58% (Rynders & Weltman, 2014). Exercise training, specifically combined resistance and endurance training have shown to reduce blood glycosylated haemoglobin HbA_{1c} by 0.8% (Hansen *et al.,* 2010). This is significant as high levels of HbA_{1c} lead to an increased risk of cardiovascular disease and pre-mature death (Hansen *et al.,* 2010). Further health benefits elicited by resistance and endurance training include a decrease in adipose mass, improvement in blood lipid profile, reduced mean arterial blood pressure and enhanced pancreatic β-cell function (Hansen *et al.,* 2010). In addition MCAT has shown to reduce body fat percentage (De Filippis *et al.,* 2006), improve glycaemic control (Sigal *et al.,* 2007; Maiorana *et al.,* 2002) and enhance endothelium-dependent vasodilation (Kadoglou *et al.,* 2007; De Filippis *et al.,* 2006) in T2DM patients. Research needs to determine if HIIT would have similar benefits for type 2 diabetic patients than strength and endurance training.

Evidence shows that as little as 2 weeks of low volume HIIT increases skeletal muscle mitochondrial capacity and improves glucose tolerance and insulin sensitivity in healthy adults (Little *et al.,* 2011). These favourable results were also seen in T2DM patients, where a HIIT intervention (Mitranun *et al.,* 2014) and a SIT intervention (Little *et al.,* 2011) improved glycaemic control, blood lipids and aerobic fitness. These improvements in glycaemic control are associated with an increase in mitochondrial biogenesis which is a direct outcome of HIIT (Little *et al.,* 2011). However, it seems that improvements in HbA_{1c} only occur following structured exercise programs exceeding 150 minutes per week (Umpierre *et al.,* 2011). This was shown by Terada *et al.* (2013) who demonstrated that although HIIT was equally effective than MCAT in lowering body fat which is of primary concern to combat T2DM, HIIT had no effect on HbA_{1c} in patients diagnosed with T2DM. However, recent evidence has contrasted this finding, where a significant decrease in HbA_{1c} was found following HIIT in type 2 diabetic patients (Mitranun *et al.,* 2014). This contrast in findings may be attributed to the different baseline levels of HbA_{1c} in the two studies. The T2DM patients investigated by Terada *et al.* (2013) had baseline levels of 7.9 mmol/l compared to 9.6mmol/l in the study of Mitranun *et al.* (2014). This suggests that significant changes in HbA_{1c} occurs in individuals with the greatest level of insulin resistance, as both Terada *et al.* (2013) and Mitranun *et al.* (2014) performed similar HIIT programs (1 minute intervals at 85-100% of VO_{2peak} for 12 weeks) in older men and women aged between 55 and 75 years.

In addition to poor glycaemic control and obesity, patients diagnosed with T2DM typically present with reduced maximal oxygen consumption even in the absence of accompanying cardiovascular disease (Mitranun *et al.,* 2014). In agreement with the effect of HIIT on aerobic capacity in other cardio-metabolic diseases (Schjerve *et al.,* 2008; TjØnna *et al.,* 2008), HIIT significantly increased VO_{2max} relative to MCAT in type 2 diabetic patients (Mitranun *et al.,* 2014). This is essential as cardiovascular fitness provides a strong protective effect against cardiovascular mortality which is of primary concern in patients diagnosed with T2DM.

Further research is required to determine if HIIT should be used as a preferred exercise treatment strategy to combat T2DM. Although limited, the studies completed have suggested that HIIT might be a viable alternative to continuous training as it has the ability to enhance glycaemic control, improve insulin sensitivity, increase the skeletal muscle oxidative capacity and increase cardiorespiratory fitness in this population group. However, research findings are not consistent and demonstrate the need for further research.

E. Effect of HIIT on health-related outcomes

1. HIIT and body composition

Evidence concerning the effect of HIIT on body composition is inconclusive and contradictory; no single HIIT protocol has consistently resulted in positive changes in body composition measures across different populations. HIIT interventions of less than twelve weeks appear to have a minimal effect on improving body composition in adult men, overweight adults and CAD patients (Wallman *et al*., 2009; Moholdt *et al*., 2009; Tsekouras *et al*., 2008; Rognmo *et al*., 2004), whereas, HIIT interventions exceeding three months have shown to improve body composition in overweight and obese adults as well as those diagnosed with the metabolic syndrome (Moreira *et al*., 2008; Schjerve *et al*., 2008; TjØnna *et al*., 2008). In addition, HIIT interventions ranging from 6 to 16 weeks had minimal effects on the body composition of adults with healthy BMI values (20-25kg/m^{-2}) (Kessler *et al.,* 2012; Ciolac *et al.,* 2010; Musa *et al.,* 2009; Burgomaster *et al.,* 2008; WislØff *et al.,* 2007).

Since energy expenditure is essential in the reduction of fat mass, it can be argued that if the two programs are isocaloric (Mitranun *et al.,* 2014; Moreira *et al.,* 2008; Schjerve *et al.,* 2008; TjØnna *et al.,* 2008) and there is no dietary intervention combined with the training program, then both should have the same effect on body composition (Hwang *et al.,* 2011). Thus, both HIIT and MCAT interventions performed 3 times per week for 12 weeks have produced similar results with regards to body composition in overweight or obese adults (Moreira *et al.,* 2008; Schjerve *et al*., 2008), those with metabolic syndrome (TjØnna *et al.,* 2008) and T2DM patients (Mitranun *et al.,* 2014). Despite these comparable changes noted throughout the literature, HIIT has resulted in a greater reduction in abdominal obesity despite minimal changes in body mass (Whyte *et al.,* 2010; Trapp *et al.,* 2008; Boudou *et al.,* 2003; Tremblay *et al.,* 1994). This is important as abdominal obesity is seen as an independent risk factor for insulin resistance (Sowers, 2003). However, a study by Keating *et al.* (2014) in overweight adults whose main goal was to improve fat distribution, demonstrated that despite no significant reductions in body mass with 12 weeks of either HIIT or MCAT, the latter group demonstrated a reduction in body fat percentage and android fat while no changes were noted in the HIIT group.

These contrasting findings in the literature may be explained by different views on the mechanism of fat loss. It is well-known that aerobic exercise significantly increases hormone-stimulated adipose lipolysis and therefore increases the availability of circulating fatty acids (Burguera *et al.,* 2000). This increase combined with the sustained increase in metabolic rate associated with aerobic exercise leads to an enhanced uptake and oxidation of fatty acids in working muscle (Burguera *et al.,* 2000). Evidently visceral adipose tissue lipolysis has an increased sensitivity to these hormonal changes (Arner *et al.,* 1990) and as HIIT significantly increases catecholamines and growth hormone (Trapp *et al.,* 2008) which stimulates lipolysis, this suggests that HIIT may be more effective in reducing visceral fat (Boutcher *et al.,* 2011; Irving *et al.,* 2008). However, Keating *et al.* (2014) argues that although lipolysis and fatty acid availability is enhanced after HIIT it does not necessarily mean than there will be an increase in fatty acid oxidation and ultimately fat loss. It is suggested that the total amount of fat oxidation occurring during and after exercise which depends on fatty acid availability, metabolic rate and duration of exercise may still be lower in HIIT than in traditional prolonged aerobic exercise (Keating *et al.*, 2014). Thereby, concluding that MCAT, and not HIIT, will improve fat distribution and overall body composition. These contradictions provide the need for more research concerning the mechanism of fat loss associated with HIIT and if this mechanism is consistent across different populations (young, obese, older adults).

The effect of HIIT on body composition may also be dependent on age, as younger individuals have demonstrated the ability to lose a greater amount of body fat percentage than older individuals (Hazell *et al.,* 2014; Racil *et al.,* 2013; Heydari *et al.,* 2012; Kessler *et al.,* 2012; Macpherson *et al.,* 2011; TjØnna *et al.,* 2009; Trapp *et al.,* 2008). Several of these interventions have implemented shorter HIIT sessions which consisted of 8-30 second work intervals at 90-100% VO_{2max} for a period of 8-15 weeks, indicating that younger individuals can achieve favourable changes in body composition by engaging in shorter HIIT sessions. Although the results concerning body composition are contradictory, there has been sufficient evidence to suggest that overweight and obese individuals, as well as younger adults have a better response to HIIT in terms of body composition, relative to healthy older adults or those with chronic diseases. These inconsistencies may be due to older adults and those with chronic diseases not being able to attain or maintain the exercise intensity or duration required to reduce body fat. In addition, overweight and obese individuals have greater starting body mass values and body fat percentages which may lead to greater changes over time.

In conclusion, studies performed over the last five years have reported conflicting findings on the changes in body composition following a HIIT program. The majority of studies that have implemented long duration HIIT (12-16 weeks) found minimal changes in body mass but with significant reductions in abdominal obesity. This decrease in visceral fat combined with the cardiovascular benefits associated with HIIT, advocate HIIT as an effective exercise mode to reduce cardio-metabolic risk factors. Hence, considering previous research, consistent changes in body composition may depend on increasing the length of the exercise intervention, energy expenditure and improving diet (Matinhomaee *et al.,* 2014) which may in turn decrease central fat mass and improve lipid profiles (Hwang *et al.,* 2011).

2. HIIT and insulin sensitivity

Muscle insulin resistance plays a pivotal pathophysiological role in T2DM and is associated with major health problems including obesity and coronary artery disease (Gibala & Little, 2010). There is an approximate 8% age-related decline in insulin sensitivity per decade (DiPietro *et al.*, 2006). This decline may be attributed to changes occurring due to ageing; such as increased adiposity, decreased lean mass and reduced physical activity (DiPietro *et al*., 2006; Short *et al.,* 2003).

Exercise intensity plays a major role in the improvement of insulin-stimulated glucose disposal (DiPietro *et al*., 2006), predisposing younger individuals to greater improvements in insulin sensitivity relative to older adults, as they are able to exercise at higher intensities. These high intensities are often not achieved by older adults due to fear of injury or reduced aerobic capacity (DiPietro *et al.*, 2006). For these reasons moderate intensity training has been prescribed to the older population (Hood *et al.,* 2011), as it is presumed to be a safer option where one is able to achieve sufficient health benefits (DiPietro *et al.*, 2006). Moderate intensity training is believed to improve insulin sensitivity and glycaemic control by exercise-induced increases in muscle oxidative and glucose transport capacities (Gibala & Little, 2010). However, an older adult would have to perform moderate intensity exercise every day to achieve improvements in insulin sensitivity (Gibala & Little, 2010). Many of these individuals do not even meet the public health guidelines of 150 minutes per week of moderate intensity aerobic exercise or a minimum of 75 minutes per week of vigorous-intensity aerobic exercise (Kilpatrick *et al.,* 2014). Given the lack of exercise the required exercise-induced increases in muscle oxidative and glucose transport capacities may not be achieved. Attention has now focused to HIIT and SIT and their ability to induce similar physiological adaptations despite a lower total exercise volume (Gibala & Little, 2010).

Originally moderate intensity aerobic training was found to significantly improve insulin action following exercise, but this improvement was found to be minimal when insulin action was tested 96 hours after training (Short *et al.,* 2003; Hughes *et al.,* 1993). However, it seems that high intensity training has the ability to improve insulin action for a longer time period following the completion of an exercise bout, relative to MCAT. DiPietro *et al.* (2006) showed a 21% improvement in insulin action 72 hours following high intensity training, while only a 16% improvement was recorded after moderate intensity training in healthy older women.

Ageing causes the exercise training effect on insulin sensitivity to decay more rapidly following a bout of exercise but HIIT may be able to delay this degree of decay. This information suggests that older adults have to either exercise more regularly or increase their exercise intensity to ensure necessary increases in insulin sensitivity. Based on this, if only MCAT is implemented, the same volume of energy expenditure would have to be achieved every day in order to maintain the desired health benefits (DiPietro *et al.*, 2006).

As few as 6 sessions of SIT has shown to be a sufficient stimulus to increase muscle oxidative and glucose transport capacities thereby improving insulin sensitivity in young, healthy individuals, previously sedentary adults, recreationally active young adults and sedentary overweight and obese men (Gibala & Little, 2010; Richards *et al.,* 2010; Whyte *et al.,* 2010; Gibala *et al.,* 2007). Whyte *et al.* (2013) demonstrated that a single SIT session did not elicit significant changes in insulin sensitivity compared to an accumulation of SIT sessions over a 2 week period in overweight and obese men. Therefore, the improvement in insulin sensitivity was a training adaptation rather than the effect of the last exercise session (Whyte *et al.,* 2013; Richards *et al.,* 2010). This indicates that regular SIT is advocated as a time-efficient protocol to induce positive changes in insulin sensitivity. Regular interval training will promote long-term adaptations to improve glycaemic control in young healthy adults as well as middle-aged overweight and obese men (Whyte *et al.,* 2013; Richards *et* *al.,* 2010). However, limited evidence exists concerning the effect of aerobic interval training on insulin sensitivity in healthy older adults.

This type of aerobic interval training (SIT) although effective and time efficient requires a high level of motivation as these protocols can lead to extreme fatigue (Hood *et al.*, 2011). These programs are therefore not ideal for older and overweight or obese individuals. However, several studies have used modified SIT and HIIT protocols in sedentary, type 2 diabetics and metabolic syndrome adults (Shaban *et al.,* 2014; Hood *et al*., 2011; TjØnna *et al.,* 2008) and have found significant improvements in insulin sensitivity. This evidence suggests that SIT and HIIT has the potential to improve overall glycaemic control and insulin sensitivity across different population groups but further research is required for the older population.

There is sufficient evidence to suggest that HIIT and SIT are positive training methods for individuals diagnosed with chronic diseases to improve insulin action (Shaban *et al.,* 2014; TjØnna *et al.,* 2008). Although the exact mechanism to improve insulin action with HIIT is still not fully understood, the degree of responsiveness to HIIT to improve insulin sensitivity is dependent on the initial degree of insulin resistance. Older adults with the greatest degree of insulin impairment will exhibit the largest improvement (DiPietro *et al.,* 2006). Evidence has shown that SIT sessions implemented for a period of 2 weeks have shown the greatest effect on improving insulin sensitivity but due to this type of interval training being extremely exhausting, exercise adherence may be a problem. It is advisable to investigate if HIIT of longer duration would induce favourable changes in insulin action in older adults.

3. HIIT and fasting plasma glucose

Evidence shows that SIT interventions lasting less than 12 weeks in participants with normal and elevated glucose baseline values have resulted in no significant change in fasting plasma glucose levels in young, healthy adults, overweight and obese men and CAD patients (Richards *et al.,* 2010; Whyte *et al*., 2010; Babraj *et al.,* 2009; Moholdt *et al.,* 2009). In contrast, HIIT interventions lasting longer than twelve weeks have reported inconsistencies concerning changes in fasting plasma glucose (Kessler *et al.,* 2012). Some interventions ranging between 12-16 weeks reported no change in fasting plasma glucose with either HIIT or MCAT in young women and obese adults (Ciolac *et al.,* 2010; Schjerve *et al.,* 2008), while others reported similar reductions in fasting plasma glucose after 12 weeks of either HIIT or MCAT in sedentary men and overweight adults (Nybo *et al.,* 2010; Moreira *et al.,* 2008). For instance, TjØnna *et al.* (2008) and WislØff *et al.* (2007) showed a reduction in fasting plasma glucose in response to HIIT only in metabolic syndrome patients and HF patients. These contradictions in the literature may be attributed to starting values of fasting plasma glucose prior to the intervention as those with elevated levels experienced the greatest amount of change (Kessler *et al.,* 2012). The literature suggests that changes in fasting plasma glucose are a training effect and HIIT interventions longer than 12 weeks with longer work intervals are necessary to elicit a significant improvement. These inconsistencies necessitate the need to establish the effect of HIIT in healthy, older adults on fasting plasma glucose to prevent the development of T2DM during ageing.

In conclusion, SIT effectively improves insulin sensitivity compared to HIIT in various population groups but results regarding fasting plasma glucose are inconsistent. Limited evidence suggests that longer HIIT interventions are required to induce changes. The majority of studies that have reported reductions in fasting plasma glucose have been in younger or middle-aged populations (Kessler *et al.,* 2012), with minimal evidence advocating the benefits of HIIT in older, healthy population groups. The results of these studies are inconclusive and further research is warranted to determine if HIIT is an alternative to promote glycaemic control in the ageing population.

4. HIIT and blood lipids

There are six behaviours that favourably improve blood lipid levels; these include 1) weight loss, 2) regular aerobic exercise, 3) increased dietary intake of water-soluble fibres, 4) increased dietary intake of polyunsaturated-to-saturated fatty acid ratio and monounsaturated fatty acids, 5) increased dietary intake of unique polyunsaturated fatty acids in fish oils and 6) moderate alcohol consumption (McArdle *et al.,* 2010). Hence, exercise is one of many factors that are able to alter blood lipid levels.

Stein *et al*. (1990) reported that aerobic exercise at 75% of maximum heart rate results in a 19% increase in high-density lipoprotein cholesterol (HDL-C), relative to 10% at 85% of maximum heart rate and no increase at 65% of maximum heart rate. A significant reduction in low-density lipoprotein cholesterol (LDL-C) was seen at 75% of maximum heart rate only (Stein *et al*., 1990) suggesting that there is an optimal aerobic threshold to induce changes in lipoproteins. However, the findings on the effect of aerobic exercise on lipid levels are not consistent across studies (Stein *et al*., 1990).

Several studies have assessed the effect of HIIT on serum lipid outcomes; this includes total cholesterol, LDL-C, HDL-C and triglycerides (TG) (Ciolac *et al.,* 2010; Musa *et al.,* 2009; TjØnna *et al.,* 2009; TjØnna *et al.,* 2008; WislØff *et al.,* 2007). HIIT has improved HDL-C by 3.8%-25% in overweight adolescents, metabolic syndrome patients, HF patients and young men and women, but a minimum of 8 weeks of HIIT was required to induce these changes (Kessler *et al*., 2012; Ciolac *et al.,* 2010; Musa *et al*., 2009; TjØnna *et al*., 2009; TjØnna *et al*., 2008). Most of these studies have focused on younger individuals (Racil *et al.,* 2013; Ciolac *et al.,* 2010; Musa *et al*., 2009; TjØnna *et al*., 2009), although these favourable results have also been shown in older individuals with metabolic syndrome, type 2 diabetic patients and HF patients with low initial HDL-C values (<1.04mmol/l) (Mitranun *et al.,* 2014; TjØnna *et al*., 2008; WislØff *et al.,* 2007). However, there is no concrete evidence that a HIIT or SIT protocol will improve HDL-C across different populations. For this reason, evidence is needed to justify the use of HIIT in older populations and its effect on HDL-C.

It has been shown that HIIT interventions with work intervals of 1-4 minutes lasting 8-16 weeks have a minimal effect on total cholesterol in sedentary men, HF patients, overweight and obese adults, young men and women (Iellamo *et al.,* 2012; Ciolac *et al.,* 2010; Nybo *et al*., 2010; Musa *et al.,* 2009; Wallman *et al*., 2009; Schjerve *et al*., 2008; WislØff *et al*., 2007). The majority of studies investigating the effect of HIIT on total cholesterol have been completed on individuals with normal starting values and therefore minimal change is expected. For this reason, further research is required to determine the influence of HIIT in adults with slightly elevated blood lipids as well as those diagnosed with dyslipidaemia.

The effect of HIIT on changes in LDL-C have been trivial in sedentary men, CAD patients and overweight adults (Nybo *et al*., 2010; Moholdt *et al*., 2009; Wallman *et al*., 2009). LDL-C has shown to decrease with MCAT and resistance training in middle-age adults, but no significant effects were observed after HIIT (Schjerve *et* *al.,* 2008). However, Ciolac *et al.* (2010) and Ouerghi *et al.* (2014) did observe a trend for reduced LDL-C values after HIIT in young women and men (Ouerghi *et al.,* 2014; Ciolac *et al.,* 2010). This is important as individuals with slightly elevated LDL-C values are able to participate in HIIT and achieve a positive outcome. However, this has only been seen in younger individuals and its uncertain if this trend will continue as an individual ages.

Similar to the lack of change observed in total and LDL-C, changes in triglyceride values with HIIT have been negligible in T2DM patients, CAD patients, overweight and obese adults, metabolic syndrome and HF patients (Mitranun *et al.,* 2014 ; Moholdt *et al*., 2009; Wallman *et al*., 2009; Moreira *et al*., 2008; Schjerve *et al*., 2008; TjØnna *et al*., 2008; WislØff *et al*., 2007). As mentioned before, the participants in these studies had normal baseline values (< 1.70mmol/l), necessitating the need to investigate the effect of HIIT in older adults where blood lipids are slightly elevated due to the ageing process.

Based on this evidence, total cholesterol, LDL-C and TG seem to be minimally affected by HIIT; however, the majority of the participants in the studies had healthy baseline values with regards to total cholesterol, LDL-C, TG and HDL-C. In contrast HDL-C has shown to positively improve with HIIT despite most studies being focused on younger individuals and those with low starting values.

Considering the above findings, it is evident that changes in blood lipid levels are highly complex and require a realm of factors to positively alter the values. In general, HIIT exerts the greatest effect on HDL-C, but significant changes in body mass, body composition and diet may be warranted to improve total cholesterol, LDL-C and TG (Kessler *et al.,* 2012). Therefore HIIT acting independently will lead to none or very small changes in blood lipid levels. Long term aerobic exercise has very small effects on LDL-C, however, regular exercise might improve the quality of the circulating lipoprotein by promoting a less oxidized form of LDL-C to reduce artherosclerosis risk (McArdle *et al.,* 2010).

5. HIIT and functional capacity

Functional capacity outcomes are important during ageing. An improvement in functionality and mobility may be more significant in older adults, as these factors enhance physical independence and overall quality of life (Koufaki *et al*., 2014). Only a few studies have examined the effects of HIIT on functionality (Adamson *et al.,* 2014; Koufaki *et al*., 2014; Freyssin *et al.,* 2012; Nilsson *et al*., 2008). Measures of functionality in these studies included the 6 minute walk test, timed-up-and-go test, sit to stand test, 50 metre loaded walk test and gait speed analysis and were performed on HF patients and middle-aged adults. These tests are generally used in older adults and those with metabolic or heart disease and are able to evaluate leg strength, leg endurance as well as static and dynamic balance.

A HIIT program consisting of work intervals of 6s to 5 minutes as well as a MCAT program, both ranging 8-24 weeks, have been found to improve overall functionality (Adamson *et al.,* 2014; Koufaki *et al*., 2014; Freyssin *et al.,* 2012; Nilsson *et al*., 2008), however, HIIT has demonstrated a greater clinical significance in HF patients (Freyssin *et al.,* 2012) This suggests that measures of functional capacity may be able to evaluate cardiovascular and pulmonary responses during exercise and possibly predict increased risk of mortality and morbidity from heart disease (Freyssin *et al.,* 2012). These improvements are significant as they enhance a person’s ability to continually complete activities of daily living as one grows older (Koufaki *et al*., 2014). Studies assessing the effect of HIIT on functional capacity have mainly been performed in HF patients as these individuals suffer from dyspnoea and severe fatigue during exercise (Fleg *et al.,* 2000).

Therefore, significant gaps exist in the literature concerning the effect of HIIT on functional capacity and activities of daily living across different population groups including overweight and obese individuals, patients diagnosed with the metabolic syndrome and older adults. Uncertainty surrounds the effect of HIIT in older populations and whether this training will improve or reduce overall functionality as there is always an increased risk of muscle soreness and musculoskeletal injuries with high intensity exercise. Older adults also tend to view muscle soreness that is associated with exercise negatively, which may reduce overall physical function (Schutzer & Graves, 2004).

6. HIIT and cardiorespiratory fitness

Cardiorespiratory endurance has long been regarded as one of the major components of physical fitness (Helgerud *et al.*, 2007). Research has shown that VO_{2max} declines by approximately 1% a year in adult men and women; this decline is accelerated in men especially during their advancing years (McArdle *et al.,* 2010). Furthermore, the regression in VO_{2max} in ageing men occurs almost twice as fast in sedentary men when compared to those who engage in physical activity (McArdle *et al.,* 2010). Studies that have examined men who differed considerably in age, aerobic power, body composition and lifestyle have reported that those who have remained constant in their physical activity for a 10 year period had no decline in aerobic power (McArdle *et al.,* 2010). Although influenced by genetics, cardiovascular fitness is increased through exercise training, regardless of age, gender, race and initial fitness level (O' Donovan *et al*, 2005).

Research has suggested that improvements in cardiorespiratory fitness are similar between HIIT and MCAT if the two interventions are isocaloric (O'Donovan *et al*, 2005). Studies lasting 4 to 8 weeks have demonstrated a similar increase in VO_{2max} between HIIT and MCAT groups in young men and women, CAD patients and overweight adults (Macpherson *et al*., 2011; Moholdt *et al*., 2009; Wallman *et al*., 2009; Burgomaster *et al*., 2008). Whereas, studies lasting 8 weeks to 6 months have found a significant increase in aerobic capacity following a HIIT intervention relative to an isocaloric MCAT (Kessler *et al*., 2012). This includes CAD and HF patients (WislØff *et al*., 2007; Rognmo *et al*., 2004), young adults (Ciolac *et al*., 2010; Nybo *et al*., 2010; Helgerud *et al*., 2007), obese adults (Schjerve *et al*., 2008) and adults diagnosed with the metabolic syndrome (TjØnna *et al*., 2008). Improvements in aerobic capacity in clinical populations have ranged from 17.9-46% (Schjerve *et al.,* 2008; TjØnna *et al.,* 2008; WislØff *et al.,* 2007; Rognmo *et al.,* 2004), whereas younger individuals have noted a 7.2-15% improvement in aerobic capacity (Ciolac *et al.,* 2010; Nybo *et al.,* 2010; Helgerud *et al.,* 2007). These superior improvements in clinical and older populations relative to younger populations may be due to low starting values as a result of age, physical inactivity or cardio-metabolic diseases.

It has been demonstrated that individuals who train at 90-95% of maximal heart rate during a HIIT intervention achieve greater improvements in VO_{2max} and stroke volume when compared with the effect of isocaloric exercise programs at lower intensities but longer duration (Helgerud *et al.,* 2007). This concludes that improvements in VO_{2max} and stroke volume are intensity dependent. These increases are important because VO_{2max} seems to be a better prognostic marker for cardiovascular disease than any other established risk factor (WislØff, *et al.,* 2009).

As mentioned previously, exercising at a high percentage of VO_{2max} has demonstrated positive effects in clinical populations (CAD, HF metabolic syndrome and T2DM) (Mitranun *et al.,* 2014; TjØnna *et al*., 2008). Although no official cause-effect relationship has been established, it was found that poor aerobic capacity is a common factor underlying cardiovascular and metabolic disease (TjØnna *et al.,* 2008). This is because VO_{2max} is a strong independent predictor of mortality in patients with coronary artery disease and HF (Guiraud *et al.,* 2012). Exercising at this high intensity has also been shown to aid in the prevention of cardiovascular risk factors such as diabetes, dyslipidaemia, being overweight and hypertension (Guiraud *et al*., 2012).

In conclusion, HIIT interventions lasting longer than 8 weeks have resulted in greater improvements in cardiorespiratory fitness compared to longer continuous aerobic training programs. This is vital as cardiovascular protection is of utmost importance in older adults and improving aerobic capacity should be the focus of exercise sessions in healthy, older adults. Although HIIT has been advocated in numerous population groups, there are still gaps in the literature as to whether older, healthy adults would be able to achieve these significant increases in VO_{2max} and if these exercise intensities would be tolerable in this population group.

7. HIIT and quality of Life

Although much research has examined the physical effects of HIIT, few studies have observed the changes that occur in quality of life (Kilpatrick *et al.,* 2014). Advancing age increases an adult's susceptibility to many chronic conditions, disability and reduced quality of life (Wanderley *et al.,* 2015).

HIIT has been found to improve overall quality of life (Fu *et al.,* 2011; Molmen-Hansen *et al.,* 2011; Nilsson *et al.,* 2008; WislØff *et al.,* 2007) be more enjoyable than MCAT (Jung *et al.,* 2015; Martinez *et al.,* 2013; Bartlett *et al.,* 2011; TjØnna *et al*., 2008) and reduce levels of anxiety and depression (Freyssin *et al.,* 2012) in hypertensive patients, HF patients, metabolic syndrome patients, pre-diabetic adults, overweight adults and recreationally active men. Enhanced quality of life during ageing is of primary concern as it leads to an increased sense of independence, reduced sense of pain, increased vitality and energy and increased happiness, enjoyment and contentment. Further research needs to determine if HIIT is able to improve all aspects of quality of life and to investigate whether HIIT will lead to greater exercise adherence in the healthy older population as the majority of studies have been completed in adults with metabolic and heart disease where an increase in quality of life is warranted.

F. Gender-specific effects of HIIT

Men and women are able to achieve similar adaptations to chronic endurance and resistance training (Astorino *et al.,* 2011). The gender-specific adaptations of HIIT have not been extensively investigated and large gaps exist in the literature with respect to the differences, if any, in training adaptations experienced by men and women to HIIT.

Significantly more aerobic interval training studies have been performed on men compared to women. SIT completed over a period of 2 weeks improved insulin action in young men (Whyte *et al.,* 2010; Babraj *et al.,* 2009), significantly increased maximal oxygen uptake (Whyte *et al.,* 2010) and reduced waist and hip circumference in young, overweight men (Whyte *et al.,* 2010). In addition 8-12 weeks of HIIT effectively reduced abdominal fat, total body fat, body mass, improved aerobic power in overweight men (Matinhomaee *et al.,* 2014; Heydari *et al.,* 2012) and increased HDL-C in young men (Musa *et al.,* 2009). In comparison, 6 weeks of HIIT had no effect on insulin sensitivity in overweight women (Gillen *et al.,* 2013). However, a 16 week HIIT program significantly improved insulin, insulin sensitivity and cardiorespiratory fitness in young women (Ciolac *et al.,* 2010). In addition, favourable changes were seen in type 2 diabetic women with regards to body mass, waist circumference and glucose tolerance following 15 weeks of HIIT. This suggests that longer HIIT interventions may be necessary to induce metabolic and hemodynamic changes in women.

Limited studies have compared the gender-specific differences in response to HIIT. Metcalfe *et al.* (2011) reported that 6 weeks of SIT performed three time per week resulted in similar gains in aerobic capacity in healthy men and women, but improvements in insulin sensitivity were seen in men only (Metcalfe *et al.,* 2011). This may be attributed to women breaking down 42% less glycogen in type 1 fibres during a single Wingate sprint (Gibala *et al.,* 2014). Astorino *et al.* (2011) reported that improvements in VO_{2max}, power output and substrate oxidation was similar between men and women who completed six SIT sessions over a two week period. These studies concluded that improvements in aerobic capacity are similar in men and women who are matched for VO_{2max} and physical activity, but additional studies are warranted to determine if this is true for all health-related outcome measures.

Although many studies have included mixed cohorts of men and women and have investigated the effect of SIT and HIIT on health-related outcomes, they have not described the gender-specific responses to interval training (Hood *et al.,* 2011; Richards *et al.,* 2010; Burgomaster *et al.,* 2008). In addition many studies investigating the effect of longer duration HIIT on chronic diseases have included both men and women, but these studies focused primarily on the effect of HIIT on the disease rather than the individual responses of men and women (Mitranun *et al.,* 2014; Freyssin *et al.,* 2012; TjØnna *et al.,* 2008; WislØff *et al.,* 2007; Rognmo *et al.,* 2004). No studies using longer duration HIIT have been completed that have investigated the gender-specific response to HIIT in older adults. This necessitates further research to determine if both men and women will have similar improvements with HIIT with regards to body composition, insulin sensitivity, fasting plasma glucose, functional capacity, cardiorespiratory fitness and quality of life.

G. Conclusion

In summary, HIIT provides numerous physiological and psychological benefits. The primary improvements associated with HIIT are the superior increase in aerobic capacity and insulin sensitivity, whereas evidence concerning body composition and blood lipids is conflicting and inconclusive. HIIT programs implemented 3 times per week for a period of 12-16 weeks have shown to be most beneficial in improving cardiorespiratory fitness and abdominal obesity in HF and metabolic syndrome patients as well as obese adults. In comparison, SIT programs implemented 3 times per week for a period of 2 weeks have shown significant improvements in insulin sensitivity in young, healthy and overweight adults. Longer duration HIIT has also shown to improve HDL-C in young adults as well as those with low baseline HDL-C values, whereas no significant improvements have been seen with regards to LDL-C, total cholesterol and TG across all population groups. Lastly, HIIT exceeding 12 weeks improved functional capacity and quality of life, with the majority of research focusing on HF patients. Although HIIT has been shown to improve body composition, insulin sensitivity, cardiorespiratory fitness and functional capacity, these studies have either focused on clinical populations, younger individuals or middle-aged adults. Despite all the advantages associated with implementing HIIT, the extent of research is lacking with regards to the effect of this training method in healthy, older adults as well as gender-specific response to HIIT. Evidence dictates that HIIT should be incorporated into an exercise program for older adults but more research is needed to determine if HIIT is a viable exercise alternative in older, healthy adults and if this training method will elicit similar improvements in health-related outcomes relative to moderate intensity continuous aerobic training. Therefore this study was aimed to determine if HIIT was able to elicit these same improvements in health outcomes in healthy, older adults and whether these benefits would exceed those obtained through moderate continuous aerobic training.

CHAPTER 3

METHODOLOGY

A. Introduction

High intensity interval training (HIIT) is no longer limited to elite athletes and has been successfully implemented in sedentary and chronic disease populations (TjØnna *et al.,* 2008; WislØff *et al.,* 2007). The positive training effects of HIIT has been well described, however, the focus of much of the research has been on adults with cardio-metabolic disease. Thus minimal evidence supports the use of HIIT in healthy, older adults.

B. Research Design

The study followed a pre - post intervention design. Participants were randomly allocated to either a HIIT group or a Moderate Continuous Aerobic Training group (MCAT). All outcome variables were measured before and after a 16 week supervised intervention.

This study proposal was approved by the Ethics Committee for Human Research at Stellenbosch University (HS891/2013). Participation in this study was completely voluntary and participants were aware that they were free to withdraw at any time. Participants completed an informed consent form (Appendix A) prior to the first day of testing. The testing procedures and exercise sessions were thoroughly explained to each individual and they were encouraged to ask questions. All testing procedures and exercise sessions were monitored by a qualified biokineticist who was equipped to perform CPR (cardiopulmonary resuscitation) and basic life support. Participants were informed that they could stop the testing on the treadmill or the exercise sessions at any point and were instructed on how to use the emergency stop on the treadmill. Those participating in the HIIT intervention were fitted with a safety harness that was attached to the treadmill.

C. Participants

Men and women between the ages of 50 and 75 years were targeted for this study. Participants were recruited via the Stellenbosch University website as well as advertisements placed in and around Stellenbosch**.** All volunteers were screened for co-morbidities and were stratified into a risk category according to ACSM guidelines for exercise testing (ACSM, 2010) (Appendix B). Prior to pre-participation screening, interested volunteers were requested to complete a Physical Activity Readiness Questionnaire (PAR-Q) (Appendix C) to determine if there were any diagnosed risk factors or diseases. This was sent to the potential participant via email or the questionnaire was communicated telephonically. If any exclusion criteria were met during this process, the individual was informed that they would not be able to participate and they were thanked for their interest. Pre-participation screening was implemented to identify those participants that met the inclusion criteria.

Individuals were included in the study if:

1. They were between the age of 50 and 75 years;
2. They had a BMI of < 35 $kg.m^{-2}$;
3. They had medical clearance from their physician (if required after screening);
4. They had previously performed recreational physical activities such as walking, biking, hiking and swimming;
5. They underwent and passed the preliminary screening procedure.

Individuals were excluded from the study if:

1. They did not comply with the regulations preceding the tests;

2. They had end organ damage (damage to major organs that are fed by the circulatory system);
3. They had one or more signs or symptoms, or a diagnosis of cardiovascular, pulmonary or metabolic diseases;
4. They had orthopaedic or musculoskeletal problems that could affect their exercise ability;
5. They had a BMI of less than 18.5 $kg.m^{-2}$;
6. They had 3 or more risk factors according to the ACSM guidelines for exercise testing (ACSM, 2010);
7. They had been participating in at least 30 minutes of moderate intensity physical activity (64%-76% of maximal heart rate) on at least 3 days of the week for 3 months prior to commencement of the study.

D. Experimental design

Fig. 3.1 illustrates the experimental design and timeline of the study. While 33 participants expressed interest in the study, 26 qualified to participate, 2 participants withdrew from the study, resulting in 24 participants that completed the intervention.

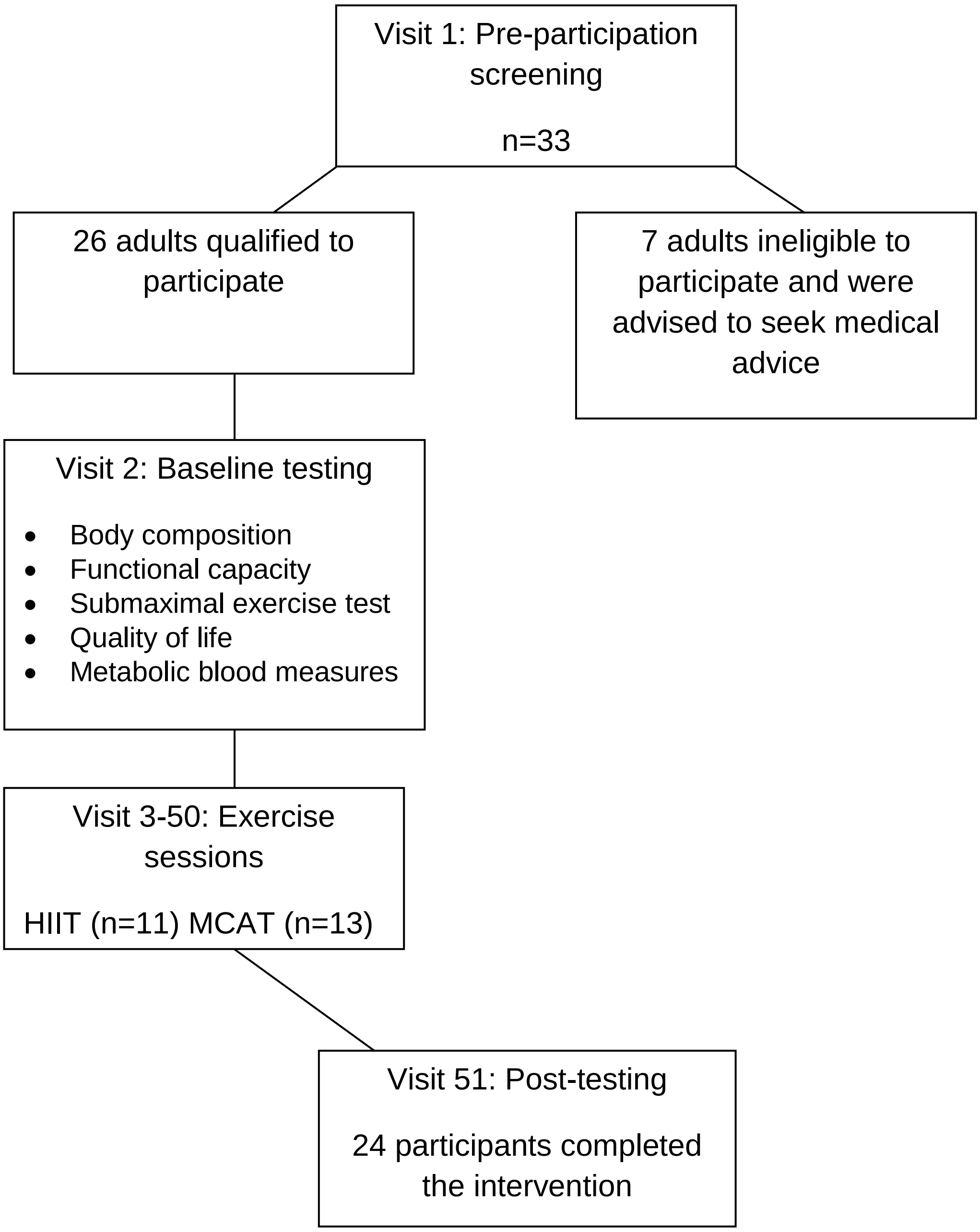

Figure 3.1: Timeline of intervention

E. Laboratory visits

1. Visit 1: Pre-participation screening

The participants' first visit to the laboratory included screening tests to determine if they were eligible to participate. Co-morbidities were screened by means of cholesterol and glucose tests, anthropometry (stature, body mass, waist and hip circumference) and cardiovascular measures (resting blood pressure and resting ECG) (Appendix D). Table 3.1 depicts the criteria for the screening tests.

Table 3.1: ACSM (2010) guidelines for exercise prescription

Pre-participation screening measures	**Cut-off points**
BMI	>35kg.m^{-2}
Waist-to-hip-ratio	Men > 1.03 Women >0.90
Non-fasting plasma glucose	> 11.10mmol/l
Non-fasting total cholesterol	>6.2mmol/l
Resting ECG	Any abnormal ECG readings

(ACSM, 2010)

2. Visit 2: Baseline testing

Participants that passed the pre-participation screening, returned to the laboratory on a separate day for baseline (pre) testing (Appendix E). Participants were asked to void their bladders immediately prior to testing and to refrain from exercise and drinking diuretics like caffeine or alcohol for at least eight hours before the tests. The participants were also requested to refrain from smoking four hours before the measurements were taken. Written informed consent was completed prior to participation in baseline testing.

Baseline testing included; resting blood pressure, functional testing (timed-up-and-go test), body composition assessments (stature, body mass, waist and hip circumferences, sagittal abdominal diameter and percentage body fat), a submaximal exercise test (Bruce protocol) and metabolic blood measures (lipogram and insulin resistance). Participants were also requested to complete the SF-36v2 questionnaire (quality of life) (Appendix F). Testing was completed in the following order;

1. Quality of life questionnaire
2. Resting blood pressure
3. Body composition measures
4. Functional testing
5. Submaximal exercise test
6. Participants were given a Pathcare form (Appendix G) at the end of baseline testing and were instructed to have a blood sample taken within 2 days.

At the end of this session, participants were randomly allocated to either the HIIT or MCAT group using a randomized block design. This random allocation was completed by placing two different colour cards in a bag. One colour represented HIIT (13 cards) and the other MCAT (13 cards). Participants were requested to blindly pick a card to establish their participation group. Participants were asked to maintain their current lifestyle, and to not alter their level of physical activity and diet during participation of the study.

3. Visit 3-50: Exercise sessions

All HIIT and MCAT exercise sessions were supervised by qualified biokineticists or student biokineticists. All persons that supervised the sessions were instructed to monitor the participant's heart rate, as well as the speed and incline of the treadmill, and to ensure that the individuals always trained at the correct pre-determined intensity. Both exercise groups completed 3 exercise sessions per week for a total of 16 weeks. All sessions were completed on a treadmill in either the Stellenbosch Exercise Physiology Laboratory or in the Stellenbosch Biokinetics Centre. Rating of perceived exertion (0-10) (Appendix H) was recorded after each interval during the HIIT session and every 10 minutes during the MCAT session.

4. Visit 51: Post-testing

Post-testing was completed 24-48 hours after the last exercise session. All procedures completed during baseline testing were repeated. The participants were reminded of the pre-test requirements when the appointment was made for the final assessments.

F. Measurement and testing protocol

1. Anthropometry

Standing height was measured with a sliding steel anthropometer (Siber-Hegner GPM, Switzerland), with the participant standing with their heels together while the back of the heels, buttocks, and upper part of the back were touching the scale and head facing forward. Measurements were taken to the nearest 0.1 cm.

Body mass was measured with a calibrated electronic scale (UWE BW - 150, 1997 model, Brisbane Australia), with participants wearing comfortable exercise clothing. Body mass was recorded to the nearest 0.1 kilogram (kg). The height and body mass measurements were used to determine body mass index (BMI) as body mass (kg)/height (m^2). All measurements were taken by the same investigator in order to ensure test-retest reliability.

Waist and hip circumferences were measured with a spring loaded, non-extensible anthropometric tape measure (*Rosscraft*, Canada), in a relaxed standing position with the arms folded across the thorax and legs together according to ISAK (International Standards for Anthropometric Assessment) protocols (2011). The same investigator took the measurements and used the cross-hand technique (Stewart *et al.,* 2011).

Sagittal abdominal diameter (SAD) was measured in the supine position using a Holtain-Kahn abdominal calliper during baseline and post-testing sessions by the same investigator. Measurements were recorded to the nearest 0.1 cm.

2. Bioelectrical Impedance Analysis

Body fat percentage was measured using Bioelectric Impedance Analysis (BIA) through a portable Bodystat device (Quadscan 400, Isle of Man, United Kingdom). Through BIA a small electrical current is sent through the body (800uA at 50 kHz) via four limb electrodes. This current measures the resistance and reactance of the surrounding body tissue and the measurement technique is based on the principle that adipose tissue measures higher resistances than non-adipose tissue (Duren *et al.,* 2008).

The participants were instructed to avoid caffeine and alcohol eight hours and smoking four hours prior to the testing and to empty their bladders immediately before the testing. Participants removed their right shoe and sock, jewellery and lay supine on a plinth, with arms and legs spread apart to avoid them touching each other. Participants were instructed to relax and breathe normally. The dorsal side of the right hand and foot were thoroughly cleaned with an alcohol swab to ensure firm adhesion with the electrode.

The four electrodes were placed on the following anatomical points on the right side of the body: the dorsal side of the right hand, one centimetre proximal to the knuckle of the middle finger; the dorsal side of the wrist between the heads of the radius and ulna; the dorsal foot between the hallux and the third phalange; and the fourth electrode was placed between the medial and lateral malleoli.

Once the electrodes were placed in its correct positions, the Bodystat device was attached to the electrodes and a low electrical current was transmitted through the body. Values for body fat percentage and lean mass were recorded from the BIA software and the participants were classified according to the following table:

Table 3.2: Risk classification of body fat percentages of older adults according to ACSM (2010)

	Health risk	**60-79 years**
Men		
	Elevated	< 13%
	Average	13%-24%
	Elevated	25%-29%
	High	≥ 30%
Women		
	Elevated	<24%
	Average	24%-35%
	Elevated	36%-41%
	High	≥ 42%

(ACSM, 2010)

3. Cardiovascular measurements

3.1 Blood pressure

Resting blood pressure was measured by qualified biokineticists during all testing sessions and was taken according to the guidelines set by the ACSM (2010). The participants sat quietly in a chair with their back supported for a period of at least five minutes. Both feet were on the floor and their left arm was supported at heart level, and any clothing obstructing the upper arm was removed. The appropriate blood pressure cuff size was determined by ensuring that the bladder inside of the cuff encircled at least 80% of the upper arm. Two measurements were taken at least one minute apart and the average of the two measurements was recorded. If the two measurements differed by more than 5 mmHg then a third measurement was required and the average was recorded.

3.2 Resting Electrocardiogram (ECG)

A resting ECG was administered during the pre-participation screening. A 12-lead ECG (ELI 250, Milwaukee, U.S.A.) was used to determine if there were any underlying cardiovascular anomalies. The participant was instructed to lie supine on a plinth in the anatomical position. Prior to placing the electrodes, area on the skin was prepared by removing any excess hair and using alcohol swabs to clean the area to ensure adhesion. A total of 6 electrodes were placed on the chest area (V1-V6) and 4 were placed on the limbs (RA, LA, F, N) as follows:

Table 3.3: Electrode placement

Lead	**Electrode Placement**
V1	Fourth intercostal space just to the right of the sternal border
V2	Fourth intercostal space just to the left of the sternal border
V3	At the midpoint of a straight line between V2 and V4
V4	On the midclavicular line in the fifth intercostal space
V5	On the anterior axillary line and on a horizontal plane through V4
V6	On the midaxillary line and on a horizontal plane through V4 and V5
RA	On the right wrist or deltoid
LA	On the left wrist or deltoid
F	On the left ankle medially
N	On the right ankle medially

The ECG reports were examined by a physician who then made a final decision on the in- or exclusion of the participant. Those who were excluded from the study were referred to their general practitioner for further testing.

4. Self-administered questionnaire

The Short Form Health Survey Version 2 (SF-36v2) is a multipurpose health survey with 36 questions. This survey has been shown to be useful in both general and specific populations and is easy to administer (Davenport *et al.,* 2011). It provides information concerning an individual's perceived mental and physical quality of life. The SF-36v2 assesses eight health concepts which include:

- Physical functioning (limitations on normal physical activities such as stair climbing, lifting objects, bending, kneeling and walking a moderate distance);
- Role-physical (limitations on work function or everyday responsibilities that is caused by physical health problems);
- Bodily pain (the severity of pain and how it interferes with daily functioning);
- General health (physical health status);
- Vitality (a subjective feeling of energy and fatigue);
- Social functioning (the quality and quantity of social interactions);
- Role-emotional (limitations in work function that is distinct from those caused by physical health problems);
- Mental health (dimensions of anxiety, depression, loss of behavioural or emotional control and psychological well-being).

Each question provides a score that when added gives each section a total score (0-100). The lower the score the more disability is experienced by the individual. Scores for the psychometrically-based physical component summary (PCS) and the mental component summary (MCS) were also provided. The standard version of the SF-36v2 Health Survey was used to assess each participant's quality of life. The questionnaires were administered pre and post intervention.

5. Functional assessment

The Timed-Up-and-Go test (TUG) was previously used to determine frailty in the elderly (Podsiadlo & Richardson, 1991). However, it is now commonly used in several population groups (elderly, obese, respiratory and heart disease) to determine functional capacity (Shumway-Cook *et al.,* 2000). This test is easy to administer and assesses a person's mobility as it requires the use of both static and dynamic balance.

Prior to the test, participants were asked to wear comfortable exercise shoes. The participants were instructed to sit on a chair with back support but without arm rests. On the command "Go", the participant stood up from the chair, walked 3 metres forward, turned around a cone and walked back to the chair. Timing started when the command was given and stopped when the participant's buttocks was placed on the chair. Participants were informed to complete the task as fast as possible without running. Each participant performed 3 trials and the best time was recorded in seconds to two decimal places.

6. Cardiorespiratory fitness

The participant's submaximal exercise capacity was assessed on the h/p/cosmos Saturn treadmill (Nussdorf-Truanstein, Germany) using the Bruce protocol. The metabolic data was collected using the Cosmed metabolic system (Cosmed Quark b^2 2000, Italy) and software which calculated and recorded the exercise intensity, as well as selected cardiorespiratory parameters throughout the test. A telemetric heart rate monitor (POLAR®, Polar Electro Oy, Finland) was integrated with the gas analyzer and recorded heart rate in beats per minute (bpm).

The gas analysers were calibrated according to the manufacturer's manual (Cosmed Quark b^2 2000, Italy) with atmospheric gas and known gas concentrations of 16% oxygen, 4% carbon dioxide and a balance of nitrogen. The turbine flow meter was calibrated with a 3 litre syringe. All calibration took place the morning before testing commenced. The Karvonen formula was used to calculate the participant's target heart rate (THR) set at 75% of their maximum; THR=((HR max-HR rest) x %intensity) + HR rest.

Prior to initiation of the test, all participants were instructed on how to use the emergency stop button and were informed that they could terminate the test at any point. Participants were also attached to the treadmill via a safety harness.

The test started at an incline of 10 degrees and a speed of 2.7 km/h. The incline and speed were increased incrementally every 3 minutes until the target heart rate was reached. Participants then actively cooled down for 5 minutes at 2.7 km/h (no gradient). Heart rate and rating of perceived exertion (RPE) were recorded at the end of each stage. RPE is a valuable indicator for monitoring a participant's exercise tolerance (ACSM, 2010). Borg developed the RPE scale to subjectively rate an individual's whole-body feel during exercise. Borg's category-ratio scale of 0-10 (modified Borg scale) was used and was a good indication of impending fatigue (ACSM, 2010). No talking was allowed during the test unless to communicate feelings of severe discomfort or fatigue.

The test was terminated when the participants reached their target heart rate or when one of the termination criteria for stopping an exercise test was visible (ACSM, 2010). These included;

1. Onset of angina or angina-like symptoms;
2. A drop in systolic blood pressure greater than 10mm Hg from baseline despite an increase in exercise intensity;
3. A significant rise in systolic blood pressure greater than 250 mmHg or diastolic blood pressure greater than 115 mmHg;
4. Abnormal shortness of breath, wheezing, leg cramps or claudication;

5. Signs of poor perfusion: light-headedness, confusion, ataxia, pallor, cyanosis, nausea or cold and clammy skin;
6. Failure of heart rate to increase with an increase in exercise intensity;
7. Noticeable change in heart rhythm;
8. Participant requests to stop;
9. Physical or verbal manifestations of severe fatigue;
10. Failure of the testing equipment.

A predicted VO_{2max} score was calculated for each participant pre and post intervention. The equation used for women was VO_{2max} (ml/kg/min) = 4.38(T) -3.9 (Pollock *et al.,* 1982) and for men VO_{2max} (ml/kg/min) = 14.8 – (1.379 x T) + (0.451 x T^2) – (0.012 x T^3) (Foster *et al.,* 1984).

“T” is the total time of the test expressed in minutes and fractions of a minute

7. Metabolic blood measures

During pre-participation screening, total cholesterol and glucose tests were performed. A qualified biokineticist used a disposable finger prick to collect a drop of blood from the ring finger of the non-dominant hand using a cholesterol or glucose strip (Roche Diagnostics) that was inserted into a portable device (Accutrend (R) plus, 2007, Roche Diagnostics).

On the same day that participants completed baseline testing and post-testing, they were issued with a form for Pathcare Centre (Stellenbosch). In the next 24-48 hours the participant was instructed to visit Pathcare Centre (Stellenbosch) to complete a lipogram and insulin resistance blood test.

The participants were instructed to fast eight hours prior to the testing and to have the test done first thing in the morning. The lipogram provided results including total cholesterol, LDL-C, HDL-C and TG.

The insulin resistance test was completed on the same day as the lipogram and provided results including fasting plasma insulin levels and fasting plasma glucose levels. These two values were used to determine insulin sensitivity (HOMA-IR method) using the formula; fasting insulin concentration (μU/mL) x fasting glucose concentration (mmol/L)/22.5 (Keskin *et al.,* 2005).

G. Exercise intervention

The intervention took place over a period of 16 weeks and was completed under supervision in the Sport Physiology Laboratory and the Stellenbosch Biokinetics Centre. Both groups performed 3 exercise sessions per week with a single rest day between sessions.

The HIIT exercise sessions were completed on the h/p/cosmos Saturn treadmill which is fitted with a safety harness and emergency stop. Participants were instructed on what they can expect and how to use the emergency button. Each participant completed 4 intervals of 4 minutes each at 90-95% of their age-predicted HRmax. After each 4-minute interval the participants walked slowly on the treadmill for 3 minutes at 50-70% of their age-predicted HRmax for an active recovery. The workout was preceded by a 5-minute warm-up at 70% of their age-predicted HRmax, while a cool-down of 5 minutes concluded the session. Heart rate was monitored continuously and recorded throughout (Suunto Oy 11/2007, Finland). A qualified biokineticist monitored every exercise session and adjusted the speed and incline accordingly to achieve desired heart rate range. The total duration of the HIIT session amounted to 35 minutes.

The participants in the MCAT group exercised continuously for 47 minutes at a moderate intensity, which was set at 70-75% of their age-predicted HRmax. This exercise duration and intensity is isocaloric to the previously described HIIT session (TjØnna *et al., 2008*). Heart rate was monitored throughout the session (Suunto Oy 11/2007, Finland). Participants were instructed to adjust speed or incline during their exercise session in order to maintain their heart rate in the desired range. Age-predicted heart max was calculated using the formula: (220-age) x % intensity (90-95% for HIIT and 70-75% for MCAT). RPE was recorded at the end of every interval during the HIIT sessions and every 10 minutes during the MCAT sessions.

All participants that qualified to partake in the study completed a total of 51 visits to finish the intervention.

H. Statistical analysis

The statistical analysis of the data was performed using Microsoft Office Excel (Windows®, 2010, USA), GraphPad Prism 6.0 and STATISTICA 12.0 (Statsoft®, 2013, USA). The descriptive statistics of the participants were reported as means ($\bar{x}$) and standard deviations (±SD). Differences in means within the HIIT and MCAT groups were compared by the paired t-test. Time x group interaction effects were determined using 2 x 2 ANOVA. The level of significance was set at $p < 0.05$ for all analysis.

Practically significant differences between the two groups were assessed using Cohen's effect sizes. The effect sizes were interpreted according to the following criteria: trivial practically significant effect < 0.20, small practically significant effect ≥

0.20, moderate practically significant effect ≥ 0.50, large practically significant effect ≥ 0.80, very large practically significant effect ≥ 1.20 (Rice & Harris, 2005).

Reliability was determined for the SF-36 version 2 using Cronbach's α and the questionnaire was considered reliable if Cronbach's α was greater than 0.70.

CHAPTER 4

RESULTS

A. Descriptive characteristics

1. Participants

Twenty-four older adult participants (6 men and 18 women) were included in the study. The participants were healthy, older adults with a mean age of 62.8 ± 6.5 years. Participants were classified as healthy according to ACSM guidelines for exercise testing (2010) and reported neither presence nor history of pulmonary, metabolic or cardiovascular disease. The American College of Sports Medicine (ACSM) classifies an individual as underweight with a BMI lower than 18.5 $kg.m^{-2}$, normal weight with a BMI between 18.5 and 24.9$kg.m^{-2}$, overweight between 25.0 and 29.9$kg.m^{-2}$ and obese with a BMI greater than 30$kg.m^{-2}$ (ACSM, 2010). The participants had a mean BMI of 26.5 ± 4.2$kg.m^{-2}$ which would classify them as overweight according to ACSM (2010). However, it has been suggested that older adults only have an increased cardiovascular disease risk with a BMI greater than 30$kg.m^{-2}$ (Tsigos *et al.,* 2013), which would indicate that these adults are still classified as healthy. Although according to the participants' body fat percentage (men 29.2 ± 4.6% and women 40.3 ± 6.2%) they would be placed at an elevated health risk for their age (ACSM, 2010). As these adults were previously sedentary, both the men and women had a combined initial predicted VO_{2max} of 21.9 ± 11.3 ml/kg/min which is classified as very poor for both men and women (ACSM, 2010).

Prior to the commencement of the study, all participants confirmed that they were not currently engaged in any type of structured exercise program and were free of any orthopaedic injury. Of the 33 participants screened prior to participation, 26 were approved to participate and 24 participants completed the 16 week study. Slight muscular discomfort was experienced by some individuals following the initial sessions, however, no participant requested to stop during the exercise sessions. Two individuals withdrew from the study. One of these individuals injured a hip during an unrelated event and another had a previous injury that she did not report prior to the study. All other participants reported no adverse effects and the exercise sessions were well tolerated.

Table 4.1 illustrates the baseline physical and physiological characteristics of the participants. No statistically significant differences existed between the groups at baseline ($p > 0.05$).

Table 4.1: Physical and physiological characteristics (mean ± SD, range) of the HIIT and MCAT groups.

Variables	HIIT Mean ± SD	MCAT Mean ± SD	Range
n	11	13	
Gender	M=3 F=8	M=3 F=10	
Age (years)	64.3 ± 7.1	61.6 ± 6.0	52.0 – 77.0
Height (cm)	165.6 ± 9.0	163.5 ± 8.9	148.0 – 179.0
Body mass (kg)	73.2 ± 15.4	71.0 ± 14.9	50.5 – 99.1
BMI (kg/m^{-2})	26.5 ± 4.1	26.5 ± 4.4	21.3 – 36.
Body fat (%)	37.3 ± 7.9	37.2 ± 7.8	25.0 – 51.7

HIIT=high intensity interval training; MCAT=moderate continuous aerobic training; n=number of participants; cm=centimetre; kg=kilogram; BMI=body mass index; kg/m^{-2}=kilogram per metre squared; %=percentage.

2. The effect of HIIT and MCAT on body composition

Table 4.2 represents the measures of body composition before and after the 16 week intervention for both groups. There was a trivial practically significant change in BM in both the HIIT and MCAT groups (ES = 0.07 and 0.15, respectively), although the decrease was statistically significant for the latter group (2.2 kg; p = 0.0003). Both groups had statistically significant decreases in %BF (HIIT: 1.9% vs

MCAT: 2.2%), sagittal abdominal diameter (HIIT: 1.7 cm vs MCAT: 1.6 cm), waist circumference (HIIT: 4.1cm vs MCAT: 4.4 cm) and hip circumference (HIIT: 5cm vs MCAT: 5.1cm) following the training intervention ($p < 0.05$).

Table 4.2: Change in body composition (mean ± SD) in HIIT and MCAT groups

Variables	HIIT Pre Mean ± SD	HIIT Post Mean ± SD	MCAT Pre Mean ± SD	MCAT Post Mean ± SD
Body mass (kg)	73.2 ± 15.4	72.2 ± 15.1[a]	71.0 ± 14.9	68.8 ± 14.2*[a]
Body fat (%)	37.3 ± 7.9	35.4 ± 7.0*[b]	37.2 ± 7.8	35.0 ± 7.0*[b]
Sagittal abdominal diameter (cm)	21.1 ± 3.5	19.4 ± 3.1*[c]	20.6 ± 2.6	19.0 ± 3.0*[c]
Waist circumference (cm)	84.5 ± 13.1	80.4 ± 12.5*[b]	81.7 ± 10.8	77.3 ± 10.3*[b]
Hip circumference (cm)	103.4 ± 10.9	98.4 ± 8.5*[c]	103.3 ± 11.1	98.2 ± 10.7*[b]

*HIIT=high intensity interval training; MCAT=moderate continuous aerobic training; Pre=Pre-intervention; Post=Post-intervention; kg=kilogram; %=percentage; cm=centimetre. * =statistically significant difference between pre and post ($p < 0.05$). [a] =trivial practically significant effect within groups (ES = < 0.20); [b] =small practically significant effect within groups (ES = ≥ 0.20); [c] =moderate practically significant effect within groups (ES = ≥ 0.50).*

Figure 4.1 compares the magnitude of change between the two groups in body mass and body fat percentage following the intervention. The MCAT group lost significantly more BM than the HIIT group and this difference was of large practical significance (ES = 0.8). The time x group interaction effect of body mass was not significant (p = 0.08). In comparison, both the HIIT and MCAT group lost a significant amount of body fat and this difference was of small practical significance (ES = 0.27). The time x group interaction effect of body fat percentage was also not statistically significant ($p > 0.05$).

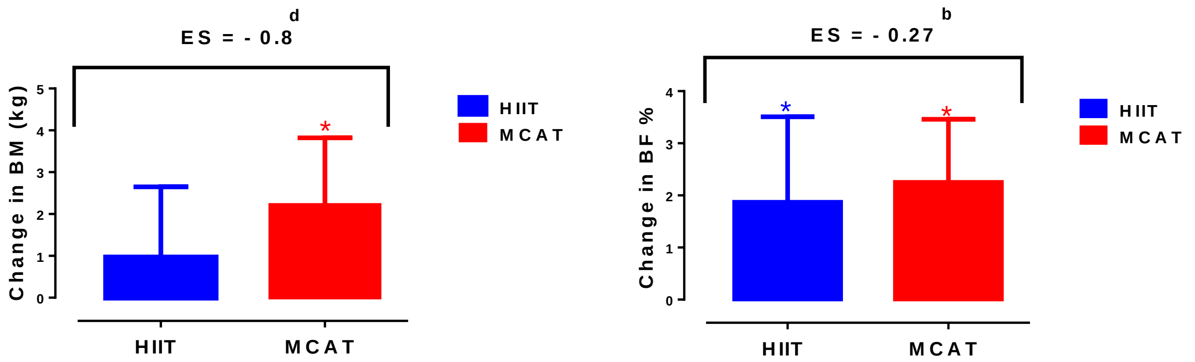

Figure 4.1: Comparison of the change in body mass (BM) and body fat percentage (BF) over 16 weeks between the HIIT and MCAT groups. Results are indicated as mean + SD.
** = Statistically significant difference between pre and post (p < 0.05)*
[b] *= Small practically significant effect between groups (ES = ≥ 0.20)*
[d] *= Large practically significant effect between groups (ES = ≥ 0.8)*

Figure 4.2 illustrates the change in sagittal abdominal diameter following the intervention between the two groups. Although there were statistically significant changes of 1.7cm in the HIIT group (p = 0.0005; ES =0.51) and 1.6 cm in the MCAT group (p =0.00; ES = 0.57), the difference between groups was not practically significant (p > 0.05; ES = 0.07). In addition, there was no time x group interaction effect (p > 0.05).

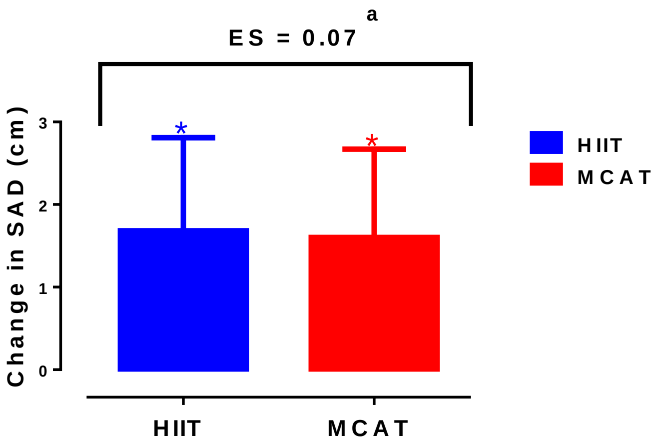

Figure 4.2: Comparison of the change in sagittal abdominal diameter (SAD) over 16 weeks between the HIIT and MCAT groups. Results are indicated as mean + SD.
** = Statistically significant difference between pre and post (p < 0.05)*
[a] *=Trivial practically significant effect between groups (ES = < 0.20)*

Figure 4.3 compares the magnitude of change in waist and hip circumference following the intervention. Both the HIIT and MCAT groups had significantly lower waist and hip circumferences following the intervention ($p < 0.05$; ES > 0.2). However, the differences between the groups were only of trivial practical significance (ES = -0.09 and -0.01, respectively). In addition, the time x group interaction effect for both these variables was not statistically significant ($p > 0.05$).

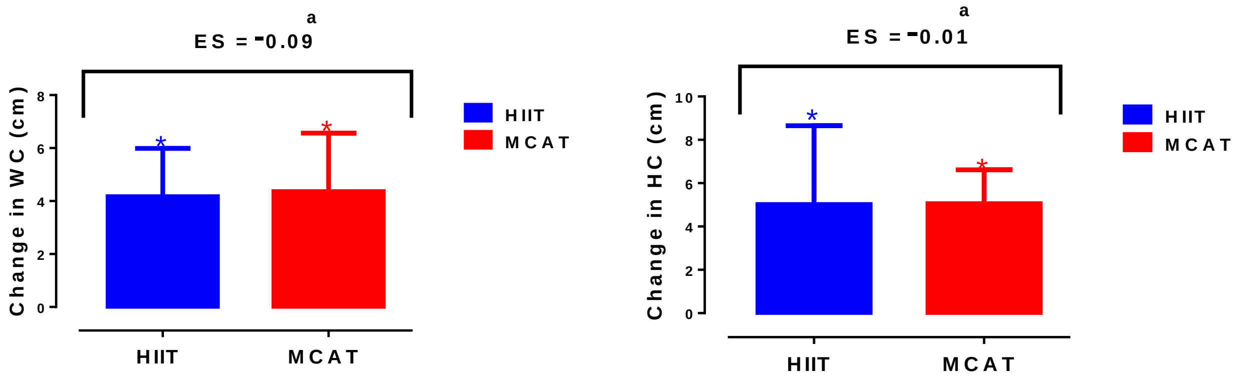

Figure 4.3: Comparison of the change in waist circumference (WC) and hip circumference (HC) over 16 weeks between the HIIT and MCAT groups. Results are indicated as mean ± SD.
* =*Statistically significant difference between pre and post (p < 0.05)*
[a] =*Trivial practically significant effect between groups (ES = < 0.20)*

3. The effect of HIIT and MCAT on metabolic blood measures

Table 4.3 represents the measures of insulin resistance before and after the 16 week intervention for both the HIIT and MCAT group. There was a small (ES=0.36) and trivial (ES=0.09) practically significant change in fasting insulin in the HIIT (0.8 mIU/L) and MCAT group (0.4 mIU/L), respectively; these reductions were not statistically significant ($p > 0.05$).

Fasting plasma glucose was significantly lower following the HIIT intervention only (HIIT: 0.3mmol/ vs MCAT: 0.1mmol/l). The HIIT and MCAT group had a 0.1 and 0.2 increase in the glucose: insulin ratio respectively ($p > 0.05$; ES =0.22 and 0.32, respectively) and there was a small practically significant change in the insulin sensitivity (HOMA-IR) in the HIIT group, compared to a trivial practically significant change in the MCAT group ($p > 0.05$; HIIT: ES = 0.21 vs MCAT: ES = 0.08).

Table 4.3: Change in insulin resistance measures (mean ± SD) in HIIT and MCAT groups

Variables	HIIT Pre Mean ± SD	HIIT Post Mean ± SD	MCAT Pre Mean ± SD	MCAT Post Mean ± SD
Insulin fasting (mIU/L)	5.8 ± 2.2	5.0 ± 2.2[b]	6.5 ± 4.1	6.1 ± 5.1[a]
P-glucose fasting (mmol/l)	5.6 ± 1.3	5.3 ± 1.2*[b]	5.0 ± 0.6	4.9 ± 0.7[a]
Glucose: insulin ratio	1.1 ± 0.4	1.2 ± 0.5[b]	1.0 ± 0.4	1.2 ± 0.8[b]
Insulin sensitivity (HOMA-IR)	1.5 ± 1.0	1.3 ± 0.9[b]	1.5 ± 1.2	1.4 ± 1.4[a]

*HIIT=high intensity interval training; MCAT=moderate continuous aerobic training; Pre=Pre-intervention; Post=Post-intervention; (mIU/L)=milli-international units per litre; (mmol/l), millimoles per litre. * =statistically significant difference between pre and post ($p < 0.05$). [a] =trivial practically significant effect within group (ES = < 0.20) ; [b] =small practically significant effect within groups (ES = ≥ 0.20).*

Figure 4.4 compares the change in fasting insulin between the two groups following the intervention. Although, the HIIT group had a greater reduction in fasting insulin, the magnitude of the difference between the two groups was of small practical significance (ES = 0.21). In addition, the time x group interaction effect for fasting insulin was not significant ($p > 0.05$).

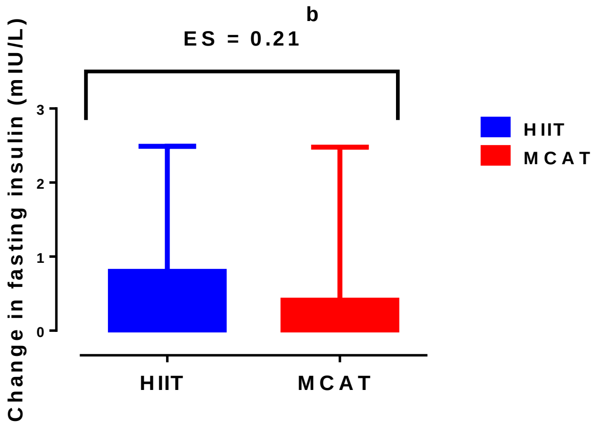

Figure 4.4: Comparison of the change in fasting insulin over 16 weeks between the HIIT and MCAT groups. Results are indicated as mean + SD.
[b] *=Small practically significant effect between groups (ES = ≥ 0.20)*

Figure 4.5 demonstrates the magnitude of change in fasting plasma glucose following the intervention. Only the HIIT group achieved a statistically significant change in fasting plasma glucose (HIIT: 0.3 mmol/l; p = 0.02 vs MCAT: 0.1 mmol/l; p =0.58) and the difference between the two groups was of moderate practical significance (ES = 0.6). The time x group interaction effect for fasting plasma glucose was not significant (p > 0.05).

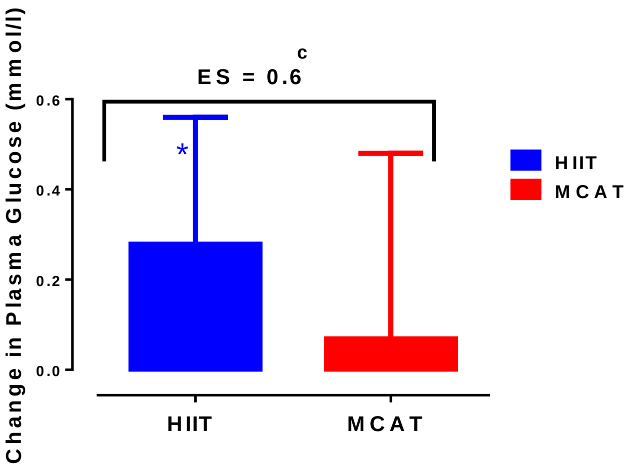

Figure 4.5: Comparison of the change in fasting plasma glucose over 16 weeks between the HIIT and MCAT groups. Results are indicated as mean + SD.
* *=Statistically significant difference between pre and post (p < 0.05)*
[C] *=Moderate practically significant effect between groups (ES ≥ 0.50)*

Figure 4.6 represents the change in glucose: insulin ratio and insulin sensitivity following the intervention. Neither group had a statistically significant change in these variables (p > 0.05). However, there was a small practically significant difference in both the glucose: insulin ratio and insulin sensitivity between the HIIT and MCAT groups following the intervention (ES = 0.-22 and 0.33, respectively). There was no time x group interaction effect for glucose: insulin ratio and insulin sensitivity (p > 0.05).

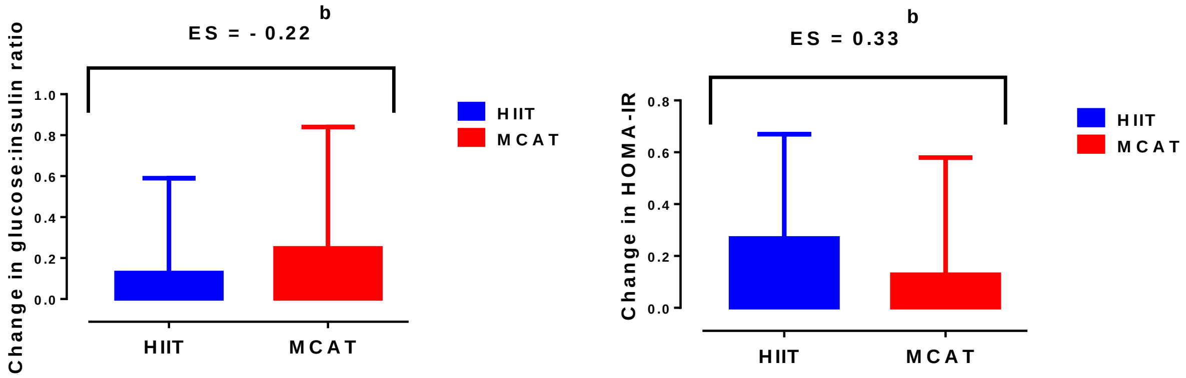

Figure 4.6: Comparison of the change in glucose: insulin ratio and insulin sensitivity (HOMA-IR) over 16 weeks between the HIIT and MCAT groups. Results are indicated as mean ± SD.
[b] *=Small practically significant effect between groups (ES = ≥ 0.20)*

Table 4.4 represents the measures of blood lipids before and after the 16 week intervention for both the HIIT and MCAT groups. Total cholesterol was lowered in the HIIT group (0.3mmol/l; p > 0.05; ES = 0.29), compared to an increase in the MCAT group (0.1mmol/l; p > 0.05; ES = -0.11) following the intervention. Similarly the MCAT group demonstrated an increase in LDL-C (0.1mmol/l; p > 0.05; ES = -0.12), in comparison to a decrease in the HIIT group (0.2mmol/l; p > 0.05; ES = 0.21). There was no statistically or practically significant change in HDL-C in either group (p > 0.05; ES < 0.20). The HIIT group had a trivial practically significant change in TG compared to the MCAT group which had a small practically significant change in TG

(HIIT: 0.1mmol/l; ES = 0.16vs MCAT: 0.1mmol/l; ES = 0.28) and a trivial practically significant change in the cholesterol : HDL ratio (HIIT: 0.1mmol vs MCAT: 0.0mmol/l; ES < 0.2, in both cases).

Table 4.4: Change in blood lipids (mean ± SD) in HIIT and MCAT groups

Variables	HIIT Pre Mean ± SD	HIIT Post Mean ± SD	MCAT Pre Mean ± SD	MCAT Post Mean ± SD
Total-cholesterol (mmol/l)	5.9 ± 1.1	5.6 ± 1.0[b]	5.5 ± 0.6	5.6 ± 1.1[a]
LDL-C(mmol/l)	3.7 ± 1.0	3.5 ± 0.9[b]	3.3 ± 0.7	3.4 ± 1.0[a]
HDL-C (mmol/l)	1.7 ± 0.3	1.7 ± 0.4[a]	1.7 ± 0.4	1.7 ± 0.4[a]
Triglycerides (mmol/l)	1.2 ± 0.7	1.1 ± 0.5[a]	1.1 ± 0.4	1.0 ± 0.3[b]
Cholesterol : HDL ratio	3.6 ± 0.9	3.5 ± 0.9[a]	3.3 ± 0.9	3.3 ± 0.9[a]

HIIT=high intensity interval training; MCAT=moderate continuous aerobic training; Pre=Pre-intervention; Post=Post-intervention; T-cholesterol=Total cholesterol; HDL=High-density lipoprotein; LDL=Low-density lipoprotein; mmol/l=millimoles per litre. [a] =trivial practically significant effect within groups (ES = < 0.20) ; [b] =small practically significant effect within groups (ES = ≥ 0.20).

Figure 4.7 illustrates the change in total cholesterol and LDL-C following the intervention in the HIIT and MCAT groups. Although both total and LDL-C decreased following HIIT, this change was not statistically significant (p>0.05). There was, however, a small practically significant difference between the groups for both total and LDL-C (ES = 0.41 and 0.41, respectively). In comparison, both total and LDL-C increased following the MCAT intervention (0.1mmol for both variables). There was no time x group interaction effect for total and LDL-C (p > 0.05).

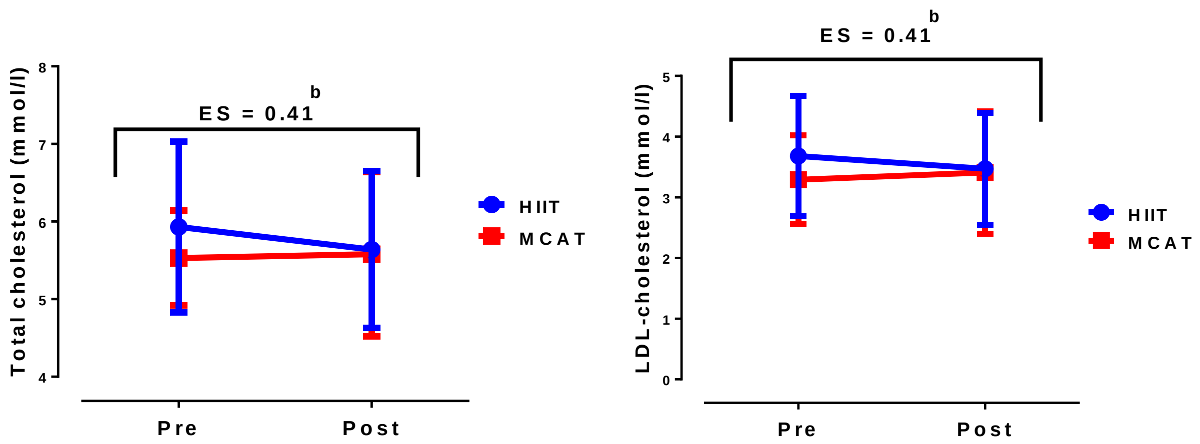

Figure 4.7: Change in total cholesterol and LDL-C over 16 weeks between the HIIT and MCAT groups. Results are indicated as mean $\pm$ SD.
[b] *=Small practically significant effect between groups (ES = ≥ 0.20)*

Figure 4.8 illustrates the minimal change in HDL-C following the intervention in both the HIIT and MCAT groups. Neither group experienced a statistically or practically significant increase in HDL-C. The difference in the magnitude of change between the two groups was also of trivial practical significance (ES =0.06). In addition, the time x group interaction effect for HDL-C was not significant ($p > 0.05$).

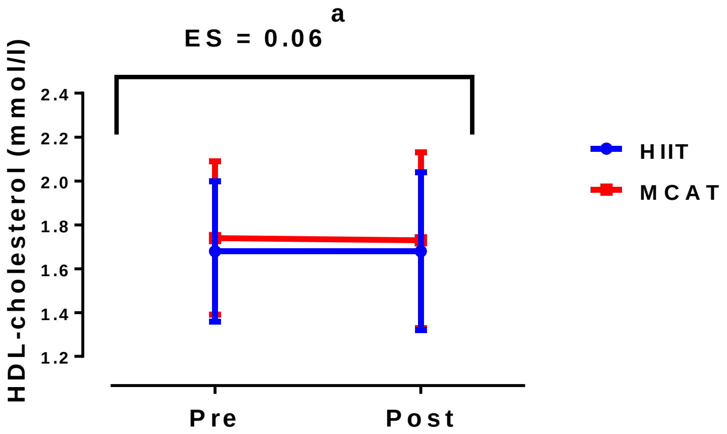

Figure 4.8: Change in HDL-C over 16 weeks between the HIIT and MCAT groups. Results are indicated as mean $\pm$ SD.
[a] *=Trivial practically significant effect between groups (ES = < 0.20)*

Figure 4.9 represents the change in triglyceride levels following the intervention in the HIIT and MCAT groups. There was a slight, but non-significant decrease in triglyceride levels in both groups, with the difference between the groups achieving a small practical significance (ES = 0.23). There was no time x group interaction effect for triglyceride levels ($p > 0.05$).

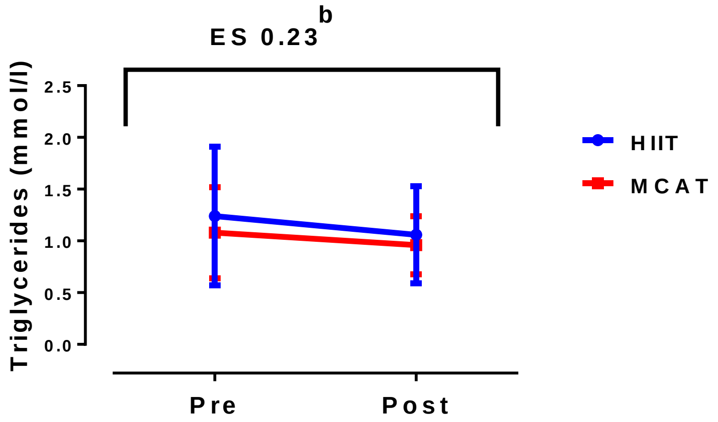

Figure 4.9: Change in triglycerides over 16 weeks between the HIIT and MCAT groups. Results are indicated as mean ± SD.
[b] *=Small practically significant effect between groups (ES = ≥ 0.20)*

4. The effect of HIIT and MCAT on functional capacity

Table 4.5 illustrates functional capacity as measured with the timed-up-and-go test (TUG) before and after the 16 week intervention. There were statistically significant reductions in the TUG test time in both the HIIT and MCAT groups following the intervention (HIIT: 0.3s vs MCAT: 0.2s; $p < 0.05$; ES = 0.40. and 0.27, respectively).

Table 4.5: Change in functional capacity (mean ± SD) in HIIT and MCAT groups

Variables	HIIT Pre Mean ± SD	HIIT Post Mean ± SD	MCAT Pre Mean ± SD	MCAT Post Mean ± SD
TUG (s)	5.6 ± 0.8	5.3 ± 0.7*[b]	5.6 ± 0.7	5.4 ± 0.8*[b]

*HIIT=High Intensity Interval Training; MCAT=Moderate Continuous Aerobic Training; TUG= Timed up and go; s=seconds. * =statistically significant difference between pre and post (p < 0.05).* [b] *=small practically significant effect within groups (ES = ≥ 0.20).*

Figure 4.10 illustrates the change in the TUG time following the intervention in both the HIIT and MCAT groups. Although both groups experienced a statistically significant improvement in TUG time, the magnitude of difference between the two groups were of small practical significance (ES = 0.30). There was no time x group interaction effect for the TUG test (p > 0.05).

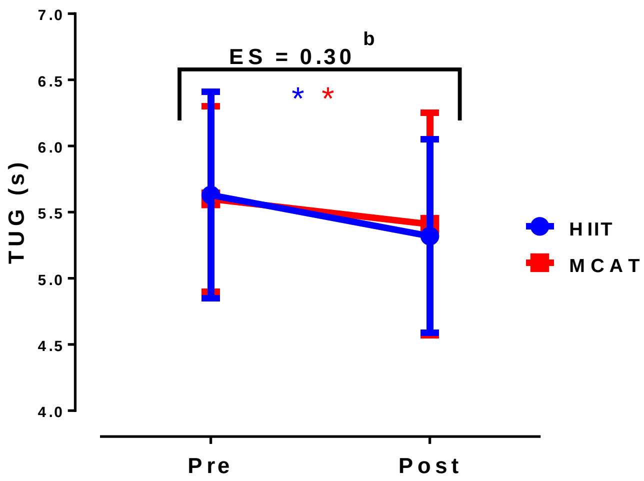

Figure 4.10: Change in timed-up-and-go over 16 weeks between the HIIT and MCAT groups. Results are indicated as mean + SD.
* =*Statistically significant difference between pre and post (p < 0.05)*
[b] =*small practically significant effect between groups (ES = ≥ 0.20)*

5. The effect of HIIT and MCAT on cardiorespiratory fitness

Table 4.6 illustrates the results for cardiorespiratory fitness depicted by the Bruce protocol termination time and predicted $VO2_{max}$ before and after the 16 week intervention. The HIIT group demonstrated a statistically significant and large practically significant improvement in termination time following the intervention (90.9s; p = 0.004; ES = 0.86). In comparison, the MCAT group demonstrated only a small practically significant improvement, which was not statistically significant (24.8s; p > 0.05; ES = 0.21). Similarly, the HIIT intervention resulted in a statistically and practically improved predicted VO_{2max} (7.6 ml/kg/min; p = 0.01; ES = 0.84), compared to a trivial practically significant change in the MCAT group (1.8ml/kg/min; p > 0.05; ES = 0.18).

Table 4.6: Change in cardiorespiratory fitness (mean ± SD) in HIIT and MCAT groups

Variables	HIIT Pre Mean ± SD	HIIT Post Mean ± SD	MCAT Pre Mean ± SD	MCAT Post Mean ± SD
Termination time (s)	276.6 ± 118.3	367. 5 ± 91.1*[d]	305.2 ± 145.3	330.0 ± 89.9 [b]
Predicted VO_{2max} (ml/kg/min)	20.8 ± 10.1	28.4 ± 7.9*[d]	22.7 ± 12.6	24.5 ± 6.5[a]

*HIIT= high intensity interval training; MCAT=moderate continuous aerobic training; Pre=Pre-intervention; Post=Post-intervention; S=seconds; * =statistically significant difference between pre and post (p < 0.05). [a] =trivial practically significant effect within groups (ES = < 0.20); [b] =small practically significant effect within groups (ES = ≥ 0.20); [d] =large practically significant effect within groups (ES = ≥0.80).*

Figure 4.11 compares the magnitude of change in termination time following the intervention between the two groups. The participants in the HIIT group experienced a 33 ± 23% improvement in termination time compared to 8 ± 38% in the MCAT group and this difference was of moderate practical significance (ES = 0.71). The time x group interaction effect was not statistically significant (p = 0.1).

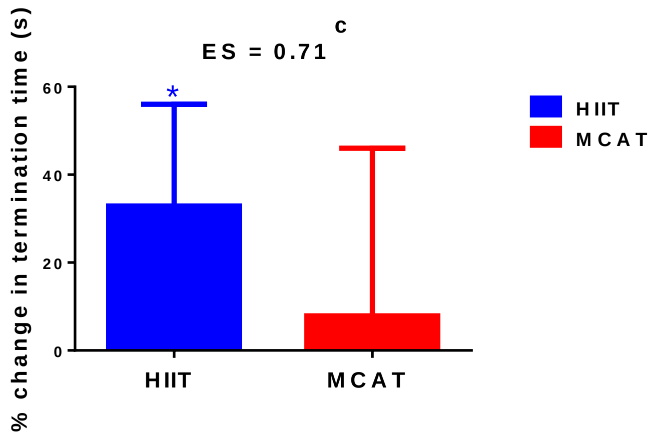

Figure 4.11: Comparison of the percentage change in termination time over 16 weeks between the HIIT and MCAT groups. Results are indicated as mean ± SD.
** =Statistically significant difference between pre and post (p < 0.05)*
[c] =moderate practically significant effect between groups (ES = ≥ 0.50)

Figure 4.12 shows the magnitude of change in predicted VO_{2max} for both groups following the intervention. All participants in the HIIT group improved their predicted VO_{2max}, while 5 out of 13 participants in the MCAT group actually performed poorer after the intervention. The difference between the two groups was of moderate practical significance (ES = 0.62). The time x group interaction effect was not statistically significant ($p > 0.05$).

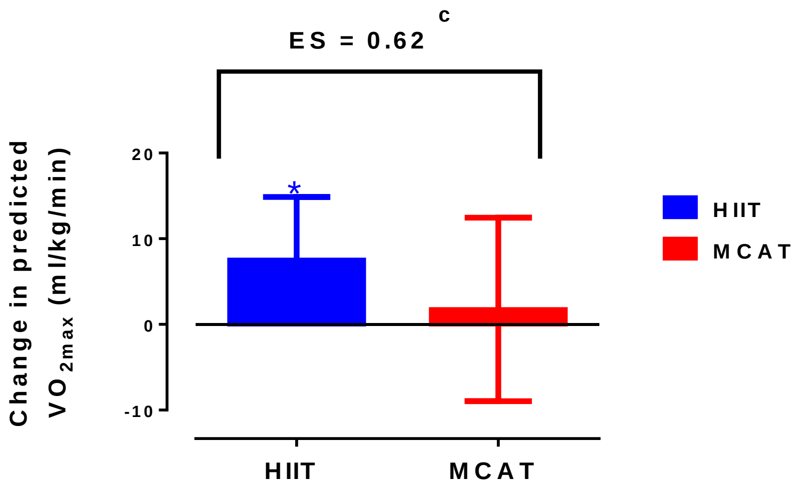

Figure 4.12: Comparison of the change in predicted VO_{2max} over 16 weeks between the HIIT and MCAT groups. Results are indicated as mean ± SD.
* =*Statistically significant difference between pre and post ($p < 0.05$)*
[c] =*moderate practically significant effect between groups (ES = ≥ 0.50)*

6. The effect of HIIT and MCAT on quality of Life

The SF 36 version 2 was found to be reliable in this population group (Cronbach's α = 0.84 ± 0.04). *Table 4.7* illustrates pre and post measures of quality of life that occurred within the groups following the 16 week intervention. No statistically significant change was seen in either group with regards to physical functioning (HIIT: 1.0 vs MCAT: 0.5), bodily pain (HIIT: -3.6 vs MCAT: 2.6), general health (HIIT: 1.1 vs MCAT: 3.2) and the physical component summary (HIIT: -0.7 vs MCAT: 1.0). Only the MCAT group demonstrated a statistically significant improvement ($p < 0.05$) in role/physical (3.3), vitality/energy (6), social functioning (5.4) and mental health (5.7), compared to the HIIT group who experienced a statistically significant improvement ($p < 0.05$) in role/emotional (2.4). In addition, both groups demonstrated a statistically significant improvement in the mental component summary (HIIT: 3.8 vs MCAT: 6.9; $p < 0.05$).

Table 4.7: Change in quality of life score (mean ± SD) in HIIT and MCAT groups

Subscales of SF-36v2	**HIIT Pre Mean ± SD**	**HIIT Post Mean ± SD**	**MCAT Pre Mean ± SD**	**MCAT Post Mean ± SD**
Physical functioning	54.4 ± 2.9	55.4 ± 2.2	51.1 ± 6.6	51.6 ± 5.4
Role/physical	54.4 ± 3.5	56.3 ± 1.2	51.4 ± 6.6	54.7 ± 5.1*
Bodily pain	55.4 ± 8.2	51.8 ± 9.3	51.7 ± 5.2	54.3 ± 8.1
General health	56.3 ± 5.6	57.4 ± 5.7	52.1 ± 7.7	55.3 ± 7.8
Vitality/energy	56.8 ± 3.3	59.9 ± 6.7	51.8 ± 7.2	57.8 ± 7.4*
Social functioning	52.7 ± 7.6	56.1 ± 1.9	47.3 ± 8.7	52.7 ± 7.7*
Role/emotional	52.5 ± 4.4	54.9 ± 2.8*	47.5 ± 8.4	52.3 ± 7.0
Mental health	56.3 ± 5.2	58.8 ± 6.1	50.2 ± 6.6	55.9 ± 5.7*
Physical component summary	55.0 ± 3.2	54.3 ± 4.6	52.5 ± 6.3	53.5 ± 6.6
Mental component summary	54.3 ± 4.8	58.1 ± 5.7*	48.1 ± 8.1	55.0 ± 7.0*

*HIIT=high intensity interval training; MCAT=moderate continuous aerobic training; Pre=Pre-intervention; Post=Post-intervention; %, percentage. * =statistically significant difference between pre and post (p < 0.05)*

Figure 4.13, illustrates the magnitude of change in all subscales of the SF-36v2 for the two groups following the intervention and Table 4.8 summarizes the effect sizes of the differences between the two groups. There was a trivial practically significant difference in physical functioning between HIIT and MCAT (ES = 0.15), however, the difference was not statistically significant ($p > 0.05$). Role/physical, vitality/energy, social functioning, mental health/emotional wellbeing, physical component summary and mental component summary all demonstrated a small practically significant change between the two groups, with all of these subscales improving to a greater extent in the MCAT group ($p < 0.05$). The HIIT group demonstrated a small practical, but statistically significant change in role/emotional and the mental component summary. Subjective measures of bodily pain and the physical component summary were worsened following the HIIT intervention, although the differences between the groups were not statistically significant ($p > 0.05$).

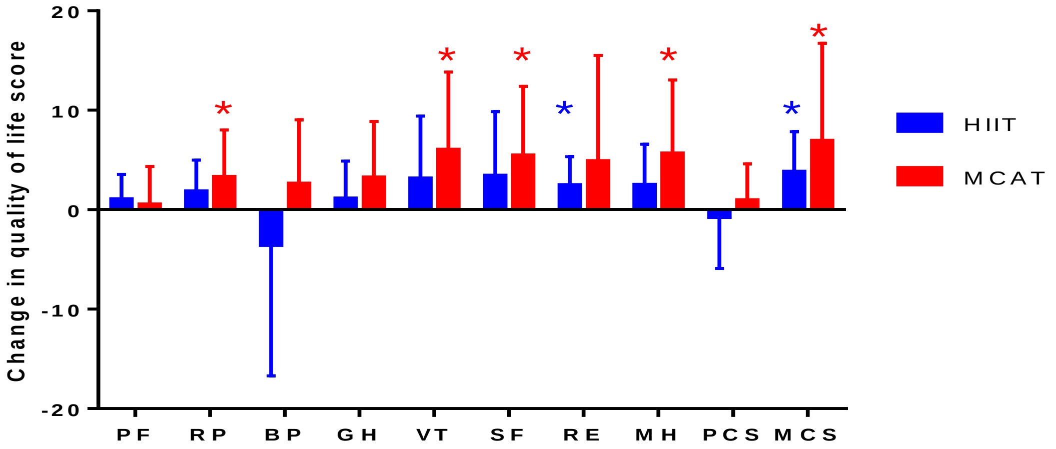

Figure 4.13: Comparison of the change in quality of life over 16 weeks between the HIIT and MCAT groups. Results are indicated as mean ± SD.
PF=physical functioning; RP=role/physical; Bp=bodily pain; GH=general health; VT= vitality/energy; SF=social functioning; RE=role/emotional; MH=mental health; PCS=physical component summary; MCS=mental component summary
* =*Statistically significant difference between pre and post (p < 0.05)*

Table 4.8 represents the effect size of the differences between the HIIT and MCAT groups. In addition there was a moderate practically significant effect in bodily pain between the two groups (ES = 0.64) indicating that bodily pain improved to a greater with MCAT relative to HIIT. There were no statistically significant interaction effects for any of the subscales of the SF-36v2 ($p > 0.05$).

Table 4.8: Effect sizes of quality of Life

Subscales of SF-36v2	HIIT vs MCAT Effect size
Physical functioning	0.15[a]
Role/physical	-0.34[b]
Bodily pain	-0.64[c]
General health	-0.43[b]
Vitality/energy	-0.40[b]
social functioning	-0.30[b]
Role/emotional	-0.29[b]
Mental health/emotional well (MH)	-0.50[b]
Physical component summary (PCS)	-0.38[b]
Mental component summary (MCS)	-0.38[b]

ES=Effect size; [a] =trivial practically significant effect between groups (ES = < 0.20); [b] =small practically significant effect between groups (ES = ≥ 0.20); [c] =moderate practically significant effect between groups (ES = ≥ 0.50).

CHAPTER 5

DISCUSSION

A. Introduction

Many studies have established the ability of HIIT to effectively improve health-related outcomes, including aerobic capacity, insulin sensitivity, body composition and HDL-C (Whyte *et al.,* 2010; Moreira *et al*., 2008; Schjerve *et al.,* 2008; TjØnna *et al*., 2008; WislØff *et al.,* 2007). However, limited evidence exists regarding the influence of HIIT on these health-related outcomes in older adults. The purpose of this study was to determine the effects of a high intensity interval training (HIIT) program on various health-related outcomes in older adults. Furthermore, the effects of HIIT relative to moderate continuous aerobic training (MCAT) were also examined.

The main finding of this study was that several health-related outcomes in older adults were significantly improved after 16 weeks of HIIT and these improvements were similar or superior to those improvements experienced with MCAT. Insulin resistance, functional capacity and cardiorespiratory fitness were significantly more improved in healthy, older adults in comparison to an isocaloric MCAT program.

Results were presented as both p-values for statistical significance and effect sizes (ES) for practical significance. As this study focused on health-related outcomes, any improvements in these variables in older adults are of practical significance, despite several outcomes not achieving statistical significance.

The two training programs in the present study were isocaloric; this is to ensure that the results obtained from the study can be attributed to the two different exercise intensities implemented (HIIT: 90-95% age-predicted HRmax vs MCAT: 70-75%

age-predicted HR max). In addition, this study can be directly compared to others which have used similar isocaloric HIIT and MCAT programs in type 2 diabetics, young women, obese adults, metabolic syndrome patients, HF and CAD patients (Mitranun *et al.,* 2014; Ciolac *et al.,* 2010; Schjerve *et al.,* 2008; TjØnna *et al.,* 2008; WislØff *et al.,* 2007; Rognmo *et al.,* 2004).

B. Health-related outcomes

1. The effect of HIIT and MCAT on body composition

It is well documented that regular aerobic exercise training reduces body mass by increasing the amount of calories expended (Swift *et al.,* 2014). On the other hand, studies on HIIT and MCAT programs performed 3-4 times per week for a period of 8-16 weeks in healthy men and women, metabolic syndrome patients and overweight and obese adults have demonstrated inconsistencies in their findings concerning body composition, specifically body mass (Keating *et al.,* 2014; Wallman *et al.,* 2009; Schjerve *et al.,* 2008; TjØnna *et al.,* 2008; Trapp *et al.,* 2008; Helgerud *et al.,* 2007). Keating *et al.* (2014) and Wallman *et al.* (2009) found no significant reduction in body mass with either HIIT or MCAT in overweight adults. This lack of change may be attributed to a progressive increase in HIIT and MCAT exercise session length over 12 weeks, with participants only maximising calorie expenditure in week 5. (HIIT: 20-24 minutes vs MCAT: 36-45 minutes) (Keating *et al.,* 2014). Additionally the exercise intervention may not have been long enough (8 weeks) (Wallman *et al.,* 2009). In comparison, Trapp *et al.* (2008) found a significant reduction in body mass with 15 weeks of HIIT compared to MCAT in young women. Although there was no statistically significant difference in calorie expenditure between the two interventions, the HIIT group expended on average 834.5 ± 11.3kJ per session compared to 809.7 ± 74.0kJ in the MCAT group, therefore resulting in greater calorie expenditure over time with HIIT. Furthermore, Schjerve *et al.* (2008) and TjØnna *et al.* (2008) found a significant reduction in body mass in both the HIIT and MCAT group with a 12-16 week intervention in obese adults and metabolic syndrome patients. As expected, this comparable decrease may be attributed to the HIIT and MCAT programs being isocaloric. However, this was not the case in the present study, where the body mass of the HIIT participants was not significantly reduced despite the two protocols being isocaloric, whereas the MCAT group achieved a significant body mass loss of 2.2kg.

This lack of significant change in body mass in the HIIT group may be attributed to an increase in muscle mass (Boudou *et al.,* 2003). As Mitranun *et al.* (2014) reported a significant increase in quadriceps and hamstrings muscle strength with 12 weeks of treadmill based HIIT in type 2 diabetic patients. Although a measurement of muscle mass and strength was not included in this study, the HIIT and MCAT participants had similar reductions in body fat percentage and abdominal diameter following the intervention. This suggests that leg muscle mass was increased due to the nature of treadmill incline running and walking during the HIIT program, therefore compensating for the lack of change in body mass.

In addition, there was no dietary intervention in this study and although the participants were informed to maintain their current diet, this was not controlled. Therefore, alterations in diet may have played a pivotal role in the body mass results yielded from this study. Gremeaux *et al.* (2012) demonstrated that a HIIT program combined with nine months of nutritional counselling significantly improved body mass, BMI and waist circumference in obese adults. A combined HIIT and dietary plan may be necessary to induce consistent favourable changes in the body mass of older adults.

Although the MCAT group did reduce body mass significantly, evidence has indicated younger individuals as well as obese adult's exhibit an even greater reduction in body mass with aerobic exercise. HIIT and MCAT interventions performed 2-3 times per week for a total of 12-15 weeks have demonstrated significant changes in body mass in younger populations (Racil *et al.,* 2013; TjØnna *et al.,* 2009) and obese individuals diagnosed with the metabolic syndrome (TjØnna *et al.,* 2008). Although participants in the present study were classified as overweight (BMI ≥ 25kg/m^{-2}), they were not considered to be at health risk, as it is suggested that the mortality risk in older adults increases with a BMI greater than 30kg/m^{-2} compared to 25kg/m^{-2} in younger populations (Tsigos *et al.,* 2013). This suggests that minimal change is required in this population group, as being slightly overweight offers a protective effect against cardiovascular mortality in older adults (Hainer & Aldhoon-Hainerova, 2013). This phenomenon is referred to as the obesity paradox. A meta-analysis of 40 studies revealed significantly lower risks for total mortality and cardiovascular mortality in overweight, older adults (Hainer & Aldhoon-Hainerova, 2013).

Both the HIIT and MCAT groups in the present study demonstrated a statistically significant reduction in total body fat percentage (1.9% and 2.2%, respectively). This is in contrast to several studies in healthy adults and HF patients that have reported no change in body composition following HIIT (Ciolac *et al.,* 2010; Musa *et al.,* 2009; Burgomaster *et al.,* 2008; WislØff *et al.,* 2007). This may be due to some HIIT interventions being too short (Musa *et al.,* 2009; Burgomaster *et al.,* 2008), as a minimum of twelve sessions is seemingly necessary to induce changes in body composition (Kessler *et al.,* 2012). Furthermore, most of these studies were implemented in adults with healthy BMI values (20-25kg/m^{-2}) (Ciolac *et al.,* 2010;

WislØff *et al.,* 2007). Therefore minimal change is expected as obese adults experience the greatest improvement in body composition with HIIT (Kessler *et al.,* 2012).

The findings of the present study are consistent with limited previous research that has shown similar improvements in total body fat percentage with 12-16 weeks of HIIT and an isocaloric MCAT program in patients with T2DM (Mitranun *et al.,* 2014), overweight adults (Moreira *et al,* 2008), obese adults (Schjerve *et al*., 2008), and adults diagnosed with metabolic syndrome (TjØnna *et al.,* 2008). Although a reduction in total body fat percentage is able to reduce cardiovascular mortality, a greater focus should be on reducing abdominal adiposity in older adults (Sowers, 2003).

Thus, a key finding in the present study was the significant reduction in sagittal abdominal diameter (HIIT: 1.7cm vs MCAT: 1.6cm) and waist circumference (HIIT: 4.1cm vs MCAT: 4.4cm) in both the HIIT and MCAT groups. This finding is in agreement with TjØnna *et al.* (2008) who found a comparable reduction in waist circumference (HIIT: 5cm vs MCAT: 6cm) in response to 16 weeks of HIIT and an isocaloric MCAT program in metabolic syndrome patients. In comparison, several other studies have also demonstrated a significant change in abdominal obesity with HIIT in young women and overweight men. These studies, however, did not include a comparable, isocaloric MCAT program (Heydari *et al.,* 2012; Whyte *et al.,* 2010; Trapp *et al.,* 2008), or the exercise training was supplemented with a dietary intervention (Dunn *et al.,* 2009).

Visceral adiposity, which is strongly associated with waist circumference, is considered more pathogenic than subcutaneous adiposity, and is correlated with an increase in cardiovascular disease risk factors and all-cause mortality (Gremeaux *et al.,* 2012). Tsigos *et al*. (2013) also described waist circumference as an independent predictor of adverse health in the older population. In addition, Gustat *et al.* (2000) has demonstrated that SAD has a strong association with glucose intolerance and insulin resistance and identified SAD as an independent predictor of hyperglycaemia and insulinaemia.

The mechanism for improving body composition is not fully understood. It is well-known that aerobic exercise is associated with increased levels of adiponectin which assists in fatty acid breakdown (TjØnna *et al.,* 2008) and this increase is true for both MCAT and HIIT. Increased circulating adiponectin levels associated with both HIIT and MCAT may be the reason for the comparable reduction in intra-abdominal obesity depicted by SAD and waist circumference (Weston *et al.,* 2014). In addition, the HIIT induced fat loss may be attributed to an increased exercise and post-exercise fat oxidation and a reduced post-exercise appetite (Boutcher *et al.,* 2011). Both Burgomaster *et al.* (2008) and Talanian *et al.* (2006) demonstrated that 2-6 weeks of low volume HIIT is able to increase the capacity for whole body and skeletal muscle fatty acid oxidation.

It was also suggested that HIIT may result in a suppressed appetite (Boutcher *et al.,* 2011). This suppression may be attributed to an elevated release of corticotropin releasing factor (CRF), a potent appetite suppressor that is associated with hard exercise (Boutcher *et al.,* 2011). Individuals have also subjectively reported reduced hunger following intense aerobic exercise (Bilski *et al.,* 2009). As no studies have investigated the effects of HIIT on appetite control, this topic warrants further research.

Despite minimal change in body mass and no controlled dietary intervention, this study demonstrated that regular participation in HIIT is able to significantly improve abdominal obesity similarly to MCAT. This is of primary importance as an excess deposition of body fat particularly in the abdominal area is recognised as being an independent risk factor for insulin resistance, cardiovascular disease and death. HIIT is therefore considered to be as beneficial as MCAT in improving body fat percentage and abdominal obesity, although a similar outcome for body mass is not always evident. It can be argued that a reduction in body mass should not be the main aim of exercise training in older adults, but that greater focus should be placed on decreasing visceral adiposity resulting in a reduced risk for cardiovascular and metabolic diseases (Darmon *et al.,* 2013).

2. Effect of HIIT and MCAT on insulin resistance

2.1 Fasting insulin and Insulin sensitivity

Evidence suggests that abnormalities in insulin and glucose metabolism can exist in healthy individuals (Ciolac *et al.,* 2010). This is particularly true for ageing adults, that have normal BMI values and waist circumferences, but who don’t engage in sufficient levels of physical activity. Healthy, older adults with elevated insulin and glucose levels combined with low exercise rates are considered at high risk for developing T2DM. The question was therefore asked whether a HIIT intervention would elicit favourable changes in glucose metabolism in a healthy older adult population.

It has been suggested that individuals with a greater degree of insulin resistance have a better metabolic response to exercise (Gremeaux *et al.,* 2012). In the present study, despite the MCAT group displaying higher insulin levels at baseline compared to the HIIT group (6.5 and 5.8mIU/L, respectively), the latter group surprisingly experienced a greater reduction in fasting insulin (HIIT: 0.8 mIU/L vs MCAT: 0.4 mIU/L; ES = 0.21), thereby corresponding to a reduced mortality rate. It is suggested that although the results were not significant with HIIT, HIIT may lead to an increase in insulin signalling and insulin action in muscle which results from a decreased intracellular accumulation of TG and increased fatty acid oxidation (Ciolac *et al.,* 2010; TjØnna *et al.,* 2008). This suggests that HIIT has the potential to improve insulin metabolism to a greater extent relative to MCAT in healthy older adults, thereby reducing the risk of developing T2DM. This finding also suggests that the effect of exercise on insulin action in muscle is dependent on the intensity of the exercise, as an equal amount of work was done by the participants in the two groups.

Neither HIIT nor MCAT had a significant effect on insulin sensitivity as assessed by HOMA-IR, which is in contrast with previous research (Hood *et al.,* 2011; Ciolac *et al.,* 2010; Richards *et al.,* 2010; Whyte *et al.,* 2010; Babraj *et al.,* 2009; TjØnna *et al.,* 2009; TjØnna *et al.,* 2008). However, previous studies have mainly investigated the effect of low volume HIIT, which implemented 4-6 maximal sprints in six sessions over a two week period (Hood *et al.,* 2011; Richards *et al.,* 2010; Whyte *et al.,* 2010; Babraj *et al.,* 2009) suggesting that maximal effort sprint intervals may be necessary to induce favourable changes in insulin sensitivity, especially in those who are not insulin resistant. Thus, another reason for the lack of improvement in the present study may be attributed to the normal insulin sensitivity (HOMA-IR < 2.5) at baseline in both the HIIT (1.5 ± 1.0) and MCAT (1.5 ± 1.2) groups, as greater improvements in insulin resistance have been shown in individuals with greater insulin and metabolic abnormalities. Both Mitranun *et al.* (2014) and TjØnna *et al.* (2008) reported a significant improvement in insulin sensitivity in type 2 diabetic patients and metabolic syndrome patients with a greater degree of insulin resistance following 12-16 weeks of HIIT. In addition, previous studies have shown significant improvements in insulin sensitivity following 12-16 weeks of HIIT in younger individuals (Ciolac *et al.,* 2010; TjØnna *et al.,* 2009). This suggests that healthy older adults should participate in long-term HIIT to maintain healthy glucose control and to prevent the development of insulinaemia and hyperglycaemia. However, older adults with abnormal glucose and insulin levels may need to participate in short term SIT to gain control of these elevated levels, however this mode of HIIT needs to be further investigated to determine if it is tolerable in the ageing population.

The findings of this study may possibly also be affected by the time participants took to complete their blood tests following post-testing. Although participants were instructed to complete these tests within 24 hours, this was not always the case. The effect of exercise on insulin sensitivity wanes over time and insulin sensitivity improves for only 24-48 hours after the last bout of exercise (Rynders & Weltman, 2014).

Although the changes in insulin sensitivity were not statistically significant, participants in the HIIT group had a greater practically significant improvement in insulin sensitivity relative to MCAT (ES = 0.33). Thus, HIIT is potentially able to enhance insulin action to a greater extent relative to MCAT in older adults, suggesting HIIT as an alternative form of exercise to improve metabolic health in older adults that possess risks for insulin resistance.

2.2 Fasting plasma glucose

Although there were no significant differences between the two groups at baseline, the HIIT group had slightly elevated levels of fasting plasma glucose (5.6 mmol/l) compared to normal values in the MCAT group (5.0 mmol/l). After the HIIT intervention, the participants' slightly elevated values were reduced to normal values (< 5.5mmol/l), demonstrating that HIIT, as applied in this study, is sufficient to induce favourable changes in glucose metabolism, therefore decreasing the risk of developing T2DM (Turner *et al.,* 1998).

These findings were in accordance with Iellamo *et al.* (2012) and WislØff *et al.* (2007) in which HIIT improved glucose metabolism to a greater extent relative to MCAT in HF patients despite the two programs being isocaloric. The improvement may be attributed to an increased expression of GLUT- 4 following HIIT (Whitehurst, 2012). An increase in GLUT- 4 results in an enhanced transportation of glucose, therefore decreasing the development of the growing epidemic of T2DM. These findings again stress the importance of the intensity in exercise training and suggest that traditional low-to-moderate exercise intensity programs are not a strong enough stimulus to affect changes in glucose metabolism.

This study is among a few to demonstrate a significant improvement in glucose metabolism with HIIT in healthy older adults (Bruseghini *et al.,* 2015), as previous research showing improvements have focused on clinical populations (Iellamo *et al.,* 2012; WislØff *et al.,* 2007). This is of utmost importance as the incidence of insulin resistance and T2DM in older adults is continually increasing (Katzmarzyk *et al.,* 2004), and this study suggests that HIIT may be able to postpone or avoid the development of this disease.

In conclusion, HIIT significantly improve fasting plasma glucose relative to MCAT. Furthermore, the results were not significant for fasting insulin and insulin sensitivity, as the participants had normal baseline values, but HIIT still elicited a greater practically significant improvement in these variables relative to MCAT. This indicates that both healthy older adults and those with abnormal insulin metabolism will benefit from participating in HIIT.

3. The effect of HIIT and MCAT on blood lipids

3.1 Total cholesterol, LDL-cholesterol and triglycerides

Elevated cholesterol levels, particularly LDL-C, is a strong risk factor for cardiovascular disease and reducing LDL-C should be the primary target for older adults diagnosed with dyslipidaemia (ACSM, 2010). In the present study, neither HIIT nor MCAT resulted in a significant decrease in total cholesterol (HIIT: 0.3mmol/l vs MCAT: -0.1mmol/l) and LDL-C (HIIT: 0.2mmol/l vs MCAT: -0.1mmol/l). This is in accordance with previous research which has implemented similar isocaloric HIIT and MCAT programs for 8-12 weeks in young women, CAD patients, overweight adults and HF patients (Ciolac *et al.,* 2010; Moholdt *et al.,* 2009; Wallman *et al*., 2009; WislØff *et al*., 2007). In addition 8-12 weeks of HIIT performed by young and middle-aged men with no comparable isocaloric MCAT protocol also did not cause significant changes in total cholesterol and LDL-C (Nybo *et al.,* 2010; Musa *et al.,* 2009).

In the present study, participants in both groups had elevated total cholesterol and LDL-C values at baseline, placing them at an increased risk for cardiovascular and metabolic disease (ACSM, 2010). Despite no significant reductions in either group, HIIT resulted in a greater practically significant reduction in total cholesterol and

LDL-C (ES = 0.41, 0.41, respectively), whereas participants in the MCAT group ended the intervention period with higher values. The latter is in contrast with previous studies where it was reported that greater improvements in these variables followed continuous aerobic training compared with an isocaloric HIIT program in overweight and obese adults and HF patients (Iellamo *et al.,* 2012; Moreira *et al.,* 2008; Schjerve *et al*., 2008). A possible reason for the difference in the findings may be that previous studies focussed on young to middle aged adults, whereas this study involved older adults. Perhaps older adults need exercise at higher intensities, including weight loss to affect changes in cholesterol metabolism.

The greater practical effect of HIIT on reducing total and LDL-C in the present study, although not statistically significant, suggests that HIIT may be effective to reduce elevated cholesterol values in older adults, leading to an improvement in the overall metabolic profile. Improvements in cholesterol levels were previously reported by Ouerghi *et al.* (2014) and Ciolac *et al.* (2010) in young men and women who completed 12-16 weeks of HIIT. Therefore, the findings of this study suggest that this trend may continue during ageing and older adults with mild forms of dyslipidaemia who are able to participate in HIIT can improve their health status.

Despite the reduction in total and LDL-C with HIIT, neither training intervention had any significant effect on triglyceride values. This is in agreement with previous studies that have implemented similar isocaloric HIIT and MCAT programs for 8-16 weeks in young women, CAD patients, overweight and obese adults, metabolic syndrome patients and found no significant change (Ciolac *et al.,* 2010; Moholdt *et al.,* 2009; Wallman *et al.,* 2009; Schjerve *et al.,* 2008; TjØnna *et al.,* 2008; WislØff *et al.,* 2007). There is increasing evidence that elevated triglyceride levels have a strong association with cardiovascular disease risk (ACSM, 2010). However, both groups in the present study had healthy values (<1.70mmol/l) at baseline, similar to those in previous studies; hence no change was expected. The present study therefore suggests that exercise in the form, intensity and duration of the present study has no effect on triglyceride values within normal ranges in older adults. However, this does not mean that HIIT would not have an effect in older adults with elevated triglyceride levels.

As no significant change was found in total cholesterol, LDL-C or TG, the lack of dietary intervention in the current study may have played a crucial role. HIIT combined with significant weight loss, as well as an increased ingestion of water-soluble fibres, polyunsaturated-to-saturated fatty acid ratio and monounsaturated fatty acids, polyunsaturated fatty acids in fish oils and moderate alcohol consumption may be necessary to ensure consistent changes in blood lipids. A meta-analysis of 70 studies indicated that weight reduction is strongly associated with an improvement in total cholesterol, LDL-C and TG in adult men and women (Dattilo & Kris-Etherton, 1992). In addition, Gremeaux *et al.* (2012) demonstrated significant improvements in the blood lipid profile in obese individuals that presented with risk factors for the metabolic syndrome. A nine month combined HIIT and lifestyle modification program that included a dietary intervention was implemented to induce these favourable changes. This suggests that HIIT combined with a significant improvement in body fat percentage and abdominal obesity may not be sufficient to elicit consistent changes in total cholesterol, LDL-C and TG in older adults compared to middle-aged or younger adults, but that the addition of a dietary intervention is crucial to favourably change these variables.

3.2 HDL-cholesterol

Aerobic exercise has often been prescribed as part of a multi-treatment strategy to improve HDL-C (McArdle *et al.,* 2010). However, the present study demonstrated no change in HDL-C values with either HIIT or MCAT. The participants in the present study did present with high HDL-C values at baseline (> 1.55mmol/l), which suggests that improvements in HDL-C with HIIT occur only in those with low HLD-C values (Mitranun *et al.,* 2014; TjØnna *et al*., 2008; WislØff *et al.,* 2007) and in younger populations (Racil *et al.,* 2013; Musa *et al*., 2009; TjØnna *et al*., 2009).

TjØnna *et al.* (2008) reported a 25% increase in HDL-C with 16 weeks of HIIT only, compared to an isocaloric MCAT program in metabolic syndrome patients with low HDL-C levels (<1.04 mmol/l). In addition, Racil *et al.* (2013) showed a significant increase in HDL-C with both HIIT and MCAT in adolescent boys and girls, but these two programs were not isocaloric. Musa *et al.* (2009) and TjØnna *et al.* (2009) demonstrated that 8-12 weeks of HIIT is sufficient to induce favourable changes in HDL-C in adolescent boys and girls, as well as young men. However, these studies did not have a comparable isocaloric MCAT program; indicting further research is warranted to compare the effects of isocaloric HIIT and MCAT in younger individuals.

The mechanism by which aerobic exercise increases HDL-C is not fully understood (Thompson & Rader, 2001), but it is believed that exercise leads to an increase in lipoprotein lipase activity (Thompson & Rader, 2001). However, research has indicated that HDL-C does not improve to the extent as once believed following aerobic training, as an increase of only 0.03mmol/l on average was reported by 66 previously completed training studies (Thompson & Rader, 2001).

Although no significant improvements occurred in any measures of cholesterol, there was a trend towards improvements in total cholesterol and LDL-C in response to HIIT in older adults. This should be taken into consideration as many older adults demonstrate increased dyslipidaemia as a result of ageing (Humayun *et al.,* 2009) and this study suggests that HIIT is able to reduce these levels to a healthy value. Although both HIIT and MCAT had no influence on HDL-C, the participants had high baseline values which necessitate the need for further research to determine the effects of HIIT in older adults with low HDL-C, as evidence suggests that HIIT will elicit an improvement. The findings of this study suggest that HIIT has the potential to reduce cardiovascular risk factors which may decrease the incidence of the development of metabolic diseases in the ageing population.

4. The Effect of HIIT and MCAT on functional capacity

Improving and maintaining functional capacity is of primary concern to prevent a physical decline during ageing (Adamson *et al.,* 2014). In the present study both HIIT and MCAT demonstrated a significant improvement in functional capacity as measured with the timed-up-and-go test (TUG) (HIIT: 0.3s vs MCAT: 0.2s). Although both training programs led to statistically significant improvements, there was a greater practical significance with HIIT (ES = 0.3). This is relevant as it indicates that older adults who participate in HIIT are able to improve and maintain their physical function and mobility during ageing. This enables older adults to remain independent by increasing the ability to perform activities of daily living.

The findings of this study are in agreement with Adamson *et al.* (2014) and Nilsson *et al.* (2008) who reported that eight weeks of HIIT was able to significantly improve functional capacity as measured with the six minute walk test, TUG, sit to stand test and the 50m load walk test in middle aged adults and HF patients. However, these two studies did not include a MCAT group, so it was not possible to classify HIIT as a superior training program to improve functional capacity. In addition, Koufaki *et al.* (2014) and Freyssin *et al.* (2012) reported a significant improvement in functional capacity with 8-24 weeks of HIIT and MCAT in HF patients as measured through the six minute walk test, sit to stand test and gait speed analysis. Although both of these studies included HIIT and MCAT programs, they were not isocaloric.

This suggests that the present study is the first to demonstrate an improvement in functional capacity after 16 weeks of isocaloric HIIT and MCAT in healthy, older adults. The practical improvement in functional capacity with HIIT may be attributed to a potential increase in leg strength that is associated with running and walking at an incline. This increased strength would enable the HIIT participants to get up, and walk faster during the timed-up-and-go test. Limited evidence exists regarding HIIT and its effect on functional capacity in healthy older adults. The present study suggests that although both interval and continuous aerobic training improved functionality, HIIT elicited a greater practical change.

5. The effect of HIIT and MCAT on cardiorespiratory fitness

Improving cardiorespiratory fitness is a vital component of a healthy lifestyle since low fitness levels correlate with an increased risk of premature death particularly from cardiovascular disease as well as all causes (ACSM, 2010). Cardiorespiratory fitness, as measured in this study by the Bruce protocol, was significantly improved with HIIT, relative to MCAT. The HIIT group achieved a 36% improvement in predicted VO_{2max} compared to a 7.7% non-significant increase with MCAT. These findings are comparable to similar isocaloric HIIT and MCAT programs (Schjerve *et al.,* 2008; TjØnna *et al.,* 2008; WislØff *et al.,* 2007) that have reported a 35%, 33% and 46% improvement in VO_{2max} respectively with HIIT, relative to a 16%, 16% and

14% improvement in VO_{2max} with MCAT respectively, in obese adults, HF and metabolic syndrome patients.

As expected, both groups improved their cardiorespiratory fitness and this finding is supported by the literature (Freyssin *et al.,* 2012; Iellamo *et al.,* 2012; Fu *et al.,* 2011; Molmen-Hansen *et al.,* 2011; Moholdt *et al.,* 2009; Rognmo *et al.,* 2004) which reported that 4-12 weeks of an isocaloric HIIT and MCAT program is able to significantly improve cardiorespiratory fitness in patients with HF, CAD and hypertension. In addition, Freyssin *et al.* (2012) reported a significant increase in VO_{2peak} with eight weeks of HIIT only when compared to a MCAT program in HF patients, although the two programs did not result in equal energy expenditure.

Although both groups in the present study improved cardiorespiratory fitness, the HIIT group had a greater practically significant improvement in predicted VO_{2max} and exercise termination time than the MCAT group (ES = 0.62 and 0.71, respectively). These practical improvements in predicted VO_{2max} with HIIT are of primary importance for older adults as evidence points to the fact that cardiovascular fitness plays a pivotal role in protecting health and mortality (TjØnna *et al.,* 2008). Furthermore, it has been demonstrated that 1-MET (3.5ml/kg/min) improvement in cardiorespiratory fitness is representative of a 10-25% increase in survival (Weston *et al.* 2014). This justifies the notion that improvements in cardiorespiratory fitness should be the primary goal of an exercise program in older adults.

The significant improvements in predicted VO_{2max} with HIIT in the present study may be attributed to a combination of central and peripheral adaptations that have enhanced the availability, extraction and utilization of oxygen (Weston *et al*., 2014). In addition, HIIT has consistently shown to increase mitochondrial enzyme activity in skeletal muscle, thereby enhancing its oxidative capacity (Adamson *et al.,* 2014). HIIT also seems to exert the greatest response on VO_{2max} in the less fit (Weston *et al.,* 2014) and this was seen in the present study, as the participants had baseline predicted VO_{2max} scores of 21.9 ± 11.3 ml/kg/min which is considered very poor in this age group (ACSM, 2010). This is in agreement with Schjerve *et al.* (2008) and WislØff *et al.* (2007) who proposed that large increases in VO_{2max} with HIIT, in comparison to an isocaloric MCAT program, are attributed to low baseline scores in HF patients and obese adults.

The present study confirms that training intensity, rather than training volume is the key component in improving cardiorespiratory fitness which is the underlying training principle behind HIIT. Further evidence is warranted to determine if older adults would be able to achieve these superior improvements in a shorter time span, as previous evidence indicates that increases in cardiorespiratory fitness with HIIT occur in only 50-60% of the time taken for the same gain via continuous aerobic exercise in middle-aged adults (Keating *et al.,* 2014).

In conclusion, the improvement in cardiorespiratory fitness with HIIT has relevant practical significance, as the protective effect of cardiorespiratory fitness occurs even in the presence of cardiovascular risk factors, indicating that there are no age restrictions to start exercising and to improve your lifestyle even as an older adult.

6. The Effect of HIIT and MCAT on quality of life

Both HIIT and MCAT resulted in significant improvements in several aspects of quality of life. Participants in the HIIT group reported significant improvements in role-emotional and the mental component summary. This translates to an improvement in emotional wellness in the work environment as well as an overall improvement in mental health and emotional well-being. In comparison, participants in the MCAT group reported significant improvements in role-physical, vitality and energy, social functioning, mental health and mental component summary. This translates to an improvement in physical aspects of the work environment, an improvement in energy levels, fatigue, quality and quantity of social interactions and overall mental health and emotional well-being. This indicates that MCAT was able to improve more subscales of the SF-36v2 compared to the HIIT group, thereby contributing to an enhanced overall quality of life. Interestingly, the MCAT group also reported a moderate practically significant improvement in bodily pain after the intervention (ES = -0.64), while the HIIT group experienced a worsening in bodily pain.

The findings of the present study are in contrast with previous research which found that HIIT improved quality of life more than MCAT (Fu *et al.,* 2011; Molmen-Hansen *et al.,* 2011; WislØff *et al.,* 2007) in heart disease patients. This improvement may be attributed to participants finding more intensive physical training to be more rewarding (WislØff *et al.,* 2007). The opposite was true for the present study and this difference may be attributed to the age of the participants and the potential for recovery. The lack of significant improvement in quality of life may be due to an increased incidence of bodily pain or muscle soreness as a result of HIIT. As recovery between sessions was only one full day, the incidence of bodily pain experienced by the HIIT group may have reduced overall physicality as indicated by the physical component summary, thereby contributing to a reduced quality of life, despite an improvement in the mental component summary. Recent evidence suggests that middle-aged adults are able to significantly improve aerobic capacity, physical function and glucose control by completing two sessions of HIIT per week compared to three (Adamson *et al.,* 2014). This would allow older adults sufficient recovery time while still attaining the associated health benefits of HIIT.

Another explanation for the lack of change in quality of life scores with HIIT may be that despite the MCAT group improving significantly in several subscales of quality of life, the baseline values of the HIIT group were higher in comparison to the MCAT group at baseline. In addition, all the post-testing values of the HIIT group were greater relative to the MCAT group, with the exception of bodily pain. This indicates that the HIIT group did improve in quality of life, but baseline scores were already high so minimal change was expected, whereas the MCAT group had lower baseline values allowing for greater change over time. In addition, post intervention scores for the HIIT group were still greater than age-related norms for all subscales (Ware *et al.,* 2001). This demonstrates that with the exception of bodily pain, HIIT did not reduce quality of life, as the participants in this study were healthy and exhibited above average quality of life scores (Ware *et al.,* 2001). This suggests that HIIT may have a greater impact on improving quality of life in older adults with poor scores including those diagnosed with cardiovascular, metabolic, pulmonary and mental diseases.

In conclusion, although HIIT and MCAT did improve several aspects of quality of life, future HIIT training programs should account for longer recovery time in older adults, which will improve overall functionality, increase vitality and energy and promote an enhanced quality of life.

C. Safety in HIIT

The present study found HIIT to be safe, efficient and low-risk for healthy older adults. This finding was supported by four studies that found no adverse effects following 8-16 weeks of HIIT in HF patients, and CAD patients (Freyssin *et al.,* 2012; Moholdt *et al.,* 2009; Wisloff *et al.,* 2007; Rognmo *et al.,* 2004). Rognmo *et al.* (2012) investigated the safety of HIIT compared to MCAT in 4846 coronary artery disease patients. The results indicated that there is a low risk of a cardiovascular event occurring during both HIIT and MCAT, as there was one fatal cardiac event during MCAT and 2 non-fatal cardiac events during HIIT (Rognmo *et al.,* 2012).

HIIT has previously been deemed controversial by healthcare professionals for the treatment of high-risk patients (Weston *et al.,* 2014). However, no adverse effects have been reported in comparison to significant gains and therefore HIIT can be advocated for a large range of special populations including older adults. However, participants in previous studies were considered stable and therefore HIIT may not be appropriate for certain disease groups. In summary, when participants are screened appropriately and there is sufficient communication with the patient’s doctor, HIIT can be a safe training option for high-risk individuals and older adults.

D. Transforming HIIT to a “real world” setting

This study suggested HIIT as a sustainable alternative form of exercise to induce favourable changes in body composition, metabolic blood measures, cardiorespiratory fitness and functional capacity in healthy older adults. However, these improvements were achieved in a laboratory setting, which raises the question as to whether these same favourable changes would be achieved if HIIT is taken out of the laboratory and into the “real world”.

This notion was assessed by Lunt *et al.* (2014) who implemented isocaloric HIIT and MCAT protocols as well as a maximal volitional intensity training program in middle-aged adults who were at a high risk for cardio-metabolic disease. Supervised exercise sessions for 12 weeks were completed in parks and community areas and each participant wore a heart rate monitor to attain and maintain the desired exercise intensity. Although a small change in body composition was noted across the three groups, improvements in VO_{2max} were modest after the intervention, with the HIIT group achieving the greatest change of 10%. These minimal changes were attributed to low adherence rates and high incidence of injuries, as the participants were previously sedentary and not accustomed to high exercise intensities. Although this study demonstrated that HIIT can be translated to a “real world” setting, it was not completely successful and warrants the need for further research. In comparison, participants in the present study verbalised their intentions to continue HIIT after the intervention with many of them requesting their personalised HIIT program. In addition the exercise sessions were tolerable and adherence rates were high. This suggests that a familiarisation period of 8 to 12 weeks is warranted before previously sedentary, overweight and older adults engage in unsupervised HIIT programs outside the laboratory. This would ensure correct technique and prevent overtraining thereby reducing the risk for musculoskeletal injuries. In addition, a familiarisation period would elicit cardiovascular and body composition improvements which may motivate the individual to continue. Lastly, it would allow older, overweight adults or those with cardio-metabolic diseases to experience training at high exercise intensities under supervision which may prevent future adverse events. In conclusion, there is evidence to suggest that HIIT can be transformed into a “real world” setting, but a familiarisation period should be included to educate and motivate participants thereby promoting greater long-term exercise adherence.

E. Conclusion

Overall, HIIT demonstrated improvements in health-related outcomes of older adults. HIIT did not only improve body composition to a similar extent as MCAT, but also succeeded in inducing greater improvements in blood lipids, glucose metabolism, cardiorespiratory fitness and functional capacity relative to MCAT.

The ability of HIIT to improve abdominal obesity, cardiorespiratory fitness and enhance glucose metabolism in older adults, are the findings of most practical significance for this population. The improvement of these variables is of primary concern as each variable can be considered an independent risk factor for cardio-metabolic disease and mortality. In combination with these findings, HIIT demonstrated the ability to practically improve the lipid profile and functional capacity of these older adults relative to MCAT. This not only decreases the risk of heart disease but also increases activities of daily living and independence which is a primary concern for the ageing population.

The key variable that improved with MCAT to a greater extent relative to HIIT was quality of life; however, this may be attributed to minimal recovery time between HIIT sessions and reduced energy levels following the training. Recent evidence suggests that older adults are able to achieve these health benefits by participating in two HIIT sessions per week compared to three.

In addition, there was no significant time x group interaction effects between HIIT and MCAT for any of the outcome variables. This indicates that the two groups did not change differently across the two time points. This may be attributed to both groups inducing similar changes on the outcome variables during the 16 week intervention. Both groups experienced an improvement or lack thereof in health-related outcomes and neither group demonstrated a superior change in any variable relative to the other group, with the exception of termination time in the Bruce exercise test. Although there was no significant time x group interaction effect for improving termination time on the Bruce protocol at $\alpha = 0.05$ with HIIT, there was a significant time x group interaction effect at $\alpha = 0.1$, indicating a potential effect of HIIT to improve submaximal exercise capacity over time relative to MCAT, warranting further research on the topic. Despite no further significant time x group interaction effects, HIIT demonstrated the ability to elicit statistically and practically significant changes in these outcome variables relative to MCAT in older adults and was capable of improving cardiorespiratory fitness, glucose metabolism and functional capacity to a greater extent relative to MCAT.

In conclusion, 16 weeks of HIIT and MCAT was tolerable and produced favourable results in health-related outcomes in older adults. By engaging in a HIIT program older adults were able to attain significant improvements in body composition, insulin resistance measures, cardiorespiratory fitness and functional capacity that were similar or greater to those experienced in a MCAT program. These benefits promote HIIT as a viable, sustainable alternative training program for older adults.

F. Summary

In accordance with the above results, the following conclusions are presented based on the hypotheses stated in chapter 1;

- **Hypothesis 1:** *HIIT will result in a significant improvement in body composition relative to MCAT*. The present study demonstrated that HIIT was able to achieve similar improvements in body composition relative to MCAT. This included reductions in total body fat percentage and abdominal obesity. Based on the above findings this hypothesis is **rejected**.

- **Hypothesis 2:** *HIIT will result in a significant improvement in measures of insulin resistance relative to MCAT*. The present study demonstrated that HIIT was able to significantly reduce fasting plasma glucose, and have a greater practically significant effect on fasting insulin and insulin sensitivity relative to MCAT. Based on the above findings this hypothesis is **accepted**.
- **Hypothesis 3:** *HIIT will result in a significant improvement in blood lipids relative to MCAT.* Although there was no significant improvement in blood lipids relative to MCAT, HIIT demonstrated a greater practically significant effect in reducing total and LDL-C. Based on the above findings this hypothesis is **accepted.**
- **Hypothesis 4:** *HIIT will result in a significant improvement in functional capacity relative to MCAT*. Both HIIT and MCAT achieved a significant improvement in functional capacity however HIIT demonstrated a greater practically significant effect. Based on the above findings this hypothesis is **accepted**.
- **Hypothesis 5:** *HIIT will result in a significant improvement in cardiorespiratory fitness relative to MCAT*. The present study demonstrated that HIIT results in a significant improvement in predicted VO_{2max} relative to MCAT. Based on the above findings this hypothesis is **accepted**.
- **Hypothesis 6:** *HIIT will result in a significant improvement in quality of life relative to MCAT*. MCAT demonstrated significant improvement in quality of life relative to HIIT. Based on the above findings this hypothesis is **rejected**.

G. Study limitations

The following limitations should be considered when interpreting the results of this study:

Firstly, the sample size was too small, as a larger population group is needed to increase confidence in the observations that were made. Secondly, there was an unequal male to female ratio with only 6 males participating in the study. It would be optimal to have equal male and female participants, so that the effects of HIIT on gender differences could also be established. Thirdly, the use of the Bruce protocol in this study was limiting and possibly underestimated the individual's cardiorespiratory fitness level. The initial incline of the test was set at 10 degrees and many of the participants were not accustomed to this slope as it does not reflect daily walking. This steep incline caused a rapid increase in heart rate which led to individuals reaching their target heart rate prematurely. A more practical measure of cardiorespiratory fitness should have been used or even a maximal exercise test should have been implemented as no adverse effects related to any cardiac events were reported and the HIIT exercise sessions were completed at a near maximal intensity.

Although participants were asked to maintain their current lifestyle, and to not alter their level of physical activity and diet during participation of the study, this was not controlled and compliance rates of these instructions were not tested. A further limitation of this study was the inability to control the length of time after post-testing that participants took to have blood drawn for measures of insulin resistance and the blood lipid profile. Although they were instructed to visit Pathcare 24 hours after post-testing, this was not always the case and this delay may have affected the metabolic blood measures. Lastly, this study did not include a measure of leg muscle mass or strength which may have explained the lack of change in body mass in the HIIT group.

H. Future recommendations

- Future studies need to determine an optimal exercise program for older adults, that would combine MCAT and HIIT and allow for sufficient recovery time between sessions while still gaining superior benefits in health-related outcomes. Future studies should also focus on implementing HIIT in older adults with cardiovascular disease risk factors. As the participants in this study had relatively healthy baseline values with regards to blood lipids and insulin resistance measures, the effect of HIIT on these variables should be investigated independently in older adults who have diagnosed dyslipidaemia or insulin resistance.
- As SIT is becoming more popular in clinical populations, an investigation needs to determine if older adults are able to participate and tolerate this form of intense aerobic interval training and if greater improvements in insulin sensitivity would be noted as it has been across several clinical populations.
- Majority of studies that have focused on HIIT have used different protocols and intensities. It would be helpful to establish an optimal HIIT protocol describing training mode, time, intensity, intervals, and type of recovery that can be used in all populations to reduce differences in results relative to differences in protocols.
- Future studies also need to focus on how to transform a HIIT program into a “real world” setting that would promote correct technique and exercise adherence.

- Lastly, the optimal balance between HIIT and resistance training needs to be determined, as resistance training offers important benefits for the older population. Research needs to focus on determining the optimal combination of HIIT, endurance and resistance training to maximise fitness levels, body composition measures and total body strength.

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APPENDIX A

UNIVERSITEIT•STELLENBOSCH•UNIVERSITY
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STELLENBOSCH UNIVERSITY
CONSENT TO PARTICIPATE IN RESEARCH

THE DOSE-RESPONSE RELATIONSHIP OF MODERATE ENDURANCE AND HIGH INTENSITY EXERCISE ON HEALTH AND FUNCTIONAL RELATED OUTCOMES IN OLDER INDIVIDUALS

You are asked to participate in a research study conducted by Prof E Terblanche (PhD) and Dr P Olivier (PhD) from the Department of Sport Science at Stellenbosch University. Aspects of this research project will form part of the thesis of one Masters in Sport Science student (Ms S Nieuwoudt (15617572) and one PhD in Sport Science student (Carla Coetsee, 15365484) in the Department of Sport Science. You were selected as a possible participant in this study because you are between the ages of 55 and 75 years.

1. PURPOSE OF THE STUDY

The purpose of this study is to obtain an understanding of the relationship between the frequency of exercise and adaptations in health and functional capacity outcomes in older individuals. The question is therefore asked what the minimum amount of exercise is that an individual must do to experience its benefits.

2. PROCEDURES

If you volunteer to participate in the study, we will ask you to do the following during visits to the Sport Physiology Laboratory:

1. measures of resting blood pressure, heart rate, glucose, height and weight, static and dynamic balance;
2. donate a blood sample of 10 mL (taken by a qualified nurse) to determine your cholesterol values;
3. complete questionnaires on your health, activity level and mental well being;
4. a resting ECG test;
5. muscle strength tests of your upper and lower body;
6. the "Timed-Up-and-Go" (TUG) test to determine how quickly you can get up from a chair, walk three meters, turn, walk back and sit on the chair;
7. a walk test on a treadmill during which the speed and slope will increase progressively while your oxygen consumption is measured until you cannot maintain the speed;
8. a test on the computer to determine how quickly you respond to a visual stimulus;
9. complete measures of brain blood flow through stickers on your forehead.

The tests above will be completed over two days. Hereafter you will be randomly allocated to a specific exercise group. We will request you to visit the Biokinetics Centre either once per week or three time per week for an exercise session. The exercise program will last 16 weeks. The sessions will be 30 to 60 minutes each and will consist of moderate to high intensity walking on the treadmill. Every four weeks some of the tests, as indicated above, will be repeated (i.e. balance, functional capacity, muscle strength, brain blood flow and the computer test). On completion of the 16 week exercise program, all the tests above will be repeated.

3. POTENTIAL RISKS AND DISCOMFORTS

There are no serious risks involved in the tests or the exercise program. You may experience dizziness and nausea during the test and exercise sessions on the treadmill. If so, the exercise will be stopped immediately. You may also experience temporary discomfort, like muscle soreness or stiffness, after the first few exercise sessions.

4. POTENTIAL BENEFITS TO SUBJECTS AND/OR TO SOCIETY

The results of all the measurements and tests will be given to you, which will lead to personal enrichment. You can also look forward to improved fitness levels and functional capacity over the course of the 16 week program.

5. PAYMENT FOR PARTICIPATION

You will receive no compensation for your participation in this study. However, if you're in the exercise groups you will receive exercise sessions free of charge for the duration of the intervention period (16 weeks).

Should you incur any research-related injury or incident, all costs will be covered by the Department of Science.

6. CONFIDENTIALITY

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission or as required by law. Confidentiality will be maintained by means of giving participants numbers to identify them so no one will be identified using their names. The data collected will be stored in a computer which is password protected and only the researchers and the postgraduate students will have access to it. This computer will be locked in an office.

You will receive a report on your results on completion of the intervention. The findings of the study (i.e. group results) will be published in scientific journals and confidentiality will be maintained in that your (or any other participant's) name will not be mentioned. Selected results will form part of the research theses of the two postgraduate students. The department will keep the data for a period of 5 years and then it will be destroyed.

7. PARTICIPATION AND WITHDRAWAL

You can choose whether to be in this study or not. If you volunteer to be in this study, you may withdraw at any time without consequences of any kind. You may also refuse to answer any questions you don't want to answer and still remain in the study. The investigator may withdraw you from this research if circumstances arise which warrant doing so. This may happen if you fall ill, get injured or if there are any adverse effects during or after the exercise tests or exercise sessions.

8. IDENTIFICATION OF INVESTIGATORS

If you have any questions or concerns about the research, please feel free to contact any of the following persons:

Prof E. Terblanche (Principle investigator) by 021 808 4817. E-mail: et2@sun.ac.za.
Dr P Olivier (Co-investigator) by 021 808 4718. E-mail: polivier@sun.ac.za
Me Carla Coetsee (PhD-student) by 021 808 2818. E-mail: 15365484@sun.ac.za
Me Sharné Nieuwoudt (MSc-student) by 021 808 2818. E-mail: 15617572@sun.ac.za

9. RIGHTS OF RESEARCH SUBJECTS

You may withdraw your consent at any time and discontinue participation without penalty. You are not waiving any legal claims, rights or remedies because of your participation in this research study. If you have questions regarding your rights as a research subject, contact Ms Maléne Fouché [mfouche@sun.ac.za; 021 808 4622] at the Division for Research Development.

SIGNATURE OF RESEARCH SUBJECT OR LEGAL REPRESENTATIVE

The information above was described to me ______________________________ (name) by ________________________ (researcher) in _________________ (language) and I am in command of this language or it was satisfactorily translated to me. I was given the opportunity to ask questions and these questions were answered to my satisfaction.

I hereby consent voluntarily to participate in this study. I have been given a copy of this form.

____

Name of Subject/Participant

____

Name of Legal Representative (if applicable)

____ _______________

Signature of Subject/Participant or Legal Representative **Date**

SIGNATURE OF INVESTIGATOR

I declare that I explained the information given in this document to ___________________ [*name of the subject/participant]* and/or [*his/her*] representative _____________________ [*name of the* *representative]. [He/she*] was encouraged and given ample time to ask me any questions. This conversation was conducted in [*Afrikaans/*English/*Xhosa/*Other*] and no translator was used.

_______________________________________ ______________

Signature of Investigator **Date**

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INWILLIGING OM DEEL TE NEEM AAN NAVORSING

Die dosis-respons verhouding van matige uithouvermoë oefening en hoë intensiteit oefening op die gesondheid en funksionele kapasiteit van ouer individue

U word gevra om aan 'n navorsingstudie deel te neem van Prof E Terblanche (PhD) en Dr P Olivier (PhD) van die Departement Sportwetenskap, Universiteit Stellenbosch. Aspekte van hierdie navorsingsprojek maak deel uit van die tesisse van een Meesters in Sportwetenskapstudent (Sharné Nieuwoudt 15617572) en een PhD student (Carla Coetsee, 15365484) in die Departement Sportwetenskap U is as moontlike deelnemer aan die studie gekies omdat u tussen die ouderdom van 55 en 75 jaar is.

1. DOEL VAN DIE STUDIE

Die doel van hierdie studie is om ondersoek in te stel na die verband tussen die frekwensie van oefening en die aanpassings wat in die gesondheidsuitkomste en funksionele kapasiteit van ouer volwassenes gemaak word. Die vraag word dus gevra wat die minimum hoeveelheid oefening is wat 'n persoon moet doen om die voordele daarvan te geniet.

2. PROSEDURES

Indien u inwillig om aan die studie deel te neem, vra ons dat u die volgende tydens besoeke aan die Sportfisiologie laboratorium doen:

1. metings van rustende bloeddruk, hartspoed, glukose, lengte en gewig, statiese en dinamiese balans;
2. 'n Bloedmonster van 10 mL verskaf (geneem deur 'n gekwalifiseerde verpleegster) waarmee u cholesterolwaardes bepaal sal word;
3. vraelyste voltooi oor u gesondheid, aktiwiteitsvlak en geestelike welstand;
4. 'n rustende EKG toets;
5. spierkragtoetse van u boonste en onderste ledemate;
6. die "Timed-Up-and-Go" (TUG) toets om te kyk hoe vinnig u kan opstaan uit 'n stoel, 'n afstand van drie meter aflê, omdraai, terugloop en weer gaan sit op die stoel;

7. ’n staptoets op ’n trapmeul waartydens die spoed en helling progressief moeiliker raak en u suurstofverbruik gemeet word totdat u nie langer die spoed kan volhou nie;
8. ’n toets op ’n rekenaar voltooi wat bepaal hoe vinnig u op ’n visuele stimulus reageer;
9. metings van brein bloedvloei voltooi wat met behulp van plakkers op u voorkop gedoen sal word.

Bogenoemde toetse sal oor twee dae voltooi word. Hierna sal u lukraak in ’n spesifieke groep verdeel word. U sal lukraak in ’n spesifieke oefengroep ingedeel word. U sal versoek word om óf 1 keer per week, óf 3 keer per week die Biokinetika Sentrum te besoek vir ’n oefensessie. Hierdie oefenprogram sal 16 weke duur. Die oefensessies sal 30 tot 60 minute duur en sal stapoefening teen ’n matige tot hoë intensiteit op ’n trapmeul behels. Elke vier weke sal sekere van die toetse soos hierbo beskryf, herhaal word (bv. balans, funksionele kapasiteit, brein bloedvloei en die rekenaartoets). Nadat u die oefenprogram van 16 weke voltooi het, sal al die toetse soos hierbo beskryf is, herhaal word.

3. MOONTLIKE RISIKO’S EN ONGEMAKLIKHEID

Daar is geen ernstige risiko’s verbonde aan die toetse of die oefenprogram nie. U mag wel lighoofdigheid en naarheid ervaar tydens die toetse en oefeninge op die trapmeul. Indien wel, sal die oefening dadelik gestaak word. U mag ook tydelike ongemak, soos spierseerheid en spierstyfheid, na die eerste paar oefensessies ervaar.

4. MOONTLIKE VOORDELE VIR PROEFPERSONE EN/OF VIR DIE SAMELEWING

Die uitslae van alle metings en toetse sal aan u bekend gemaak word wat sal lei tot persoonlike verryking. U kan ook uitsien na verbetering in u fiksheids en funksionele kapasiteit oor de verloop va die 16 weke.

5. VERGOEDING VIR DEELNAME

U sal geen vergoeding ontvang vir deelname aan die studie nie. Indien u in een van die oefengroepe ingedeel word, sal u vir 16 weke gratis oefensessies in die Biokinetika Sentrum ontvang.

Indien u enige navorsingsverwante besering of insident opdoen, sal alle koste wat hiermee geassosieer word, deur die Departement Sportwetenskap gedek word.

6. VERTROULIKHEID

Enige inligting wat deur middel van die navorsing verkry word en wat met u in verband gebring kan word, sal vertroulik bly en slegs met u toestemming bekend gemaak word of soos deur die wet vereis. Vertroulikheid sal gehandhaaf word deur middel van die aanwysing van ’n kode vir elke deelnemer. Hierdie kode sal gebruik word eerder as om u naam te gebruik. Data sal op ’n persoonlike rekenaar gehou word wat deur ’n wagwoord beskerm word. Hierdie rekenaar sal slegs vir die navorsers en nagraadse studente toegangklik wees. Die rekenaar sal in ’n kantoor toegesluit word.

Na afloop van die intervensie sal u ’n verslag van u eie resultate ontvang. Die resultate van die studie (groepresultate) sal in wetenskaplike joernale gepubliseer word en vertroulikheid sal gehandhaaf word deurdat u naam (of dié van enige deelnemer) nie genoem sal word nie. Sekere resultate sal deel uitmaak van die navorsingstesisse van die twee studente. Die Departement sal die data vir ’n periode van 5 jaar bewaar en sal dit daarna vernietig.

7. DEELNAME EN ONTTREKKING

U kan self besluit of u aan die studie wil deelneem of nie. Indien u inwillig om aan die studie deel te neem, kan u te eniger tyd u daaraan onttrek sonder enige nadelige gevolge. U kan ook weier om op bepaalde vrae te antwoord, maar steeds aan die studie deelneem. Die navorsers kan u ook aan die studie onttrek indien omstandighede dit vereis. Dit mag bv. gebeur indien u siek word, u ’n besering kry of enige nadelige effekte tydens of na die oefentoetse of oefensessies ervaar.

8. IDENTIFIKASIE VAN ONDERSOEKERS

Indien u enige vrae of besorgdheid omtrent die navorsing het, staan dit u vry om met enige van die volgende persone in verbinding te tree:

Prof E. Terblanche (Hoofnavorser) by 021 808 4817. E-pos: et2@sun.ac.za.
Dr P Olivier (mede-Navorser) by 021 808 4718. E-pos: polivier@sun.ac.za
Me Carla Coetsee (PhD-student) by 021 808 2818. E-pos: 15365484@sun.ac.za
Me Sharné Nieuwoudt (MSc-student) by 021 808 2818. E-pos: 15617572@sun.ac.za

9. REGTE VAN PROEFPERSONE

U kan te eniger tyd u inwilliging terugtrek en u deelname beëindig, sonder enige nadelige gevolge vir u. Deur deel te neem aan die navorsing doen u geensins afstand van enige wetlike regte, eise of regsmiddel nie. Indien u vrae het oor u regte as proefpersoon by navorsing, skakel met Me Maléne Fouché [mfouche@sun.ac.za; 021 808 4622] van die Afdeling Navorsingsontwikkeling.

VERKLARING DEUR PROEFPERSOON OF SY/HAAR REGSVERTEENWOORDIGER

Die bostaande inligting is aan my,_______________________________________, gegee en verduidelik deur ___________________________ in _______________(taal) en ek is dié taal magtig of dit is bevredigend vir my vertaal. Ek is die geleentheid gebied om vrae te stel en my vrae is tot my bevrediging beantwoord.

Ek willig hiermee vrywillig in om deel te neem aan die studie. ’n Afskrif van hierdie vorm is aan my gegee.

____

Naam van proefpersoon/deelnemer

____

Naam van regsverteenwoordiger (indien van toepassing)

____ _____________________

Handtekening van proefpersoon/deelnemer of regsverteenwoordiger Datum

VERKLARING DEUR ONDERSOEKER

Ek verklaar dat ek die inligting in hierdie dokument vervat verduidelik het aan _______________________ en/of sy/haar regsverteenwoordiger _________________________. Hy/sy is aangemoedig en oorgenoeg tyd gegee om vrae aan my te stel. Dié gesprek is in Afrikaans/Engels gevoer en geen vertaler is gebruik nie.

____ _______________

Handtekening van ondersoeker Datum

Goedgekeur Subkomitee A 25 Oktober 2004

APPENDIX B

ATHEROSCLEROTIC CARDIOVASCULAR DISEASE RISK FACTOR THRESHOLDS FOR USE WITH ACSM RISK STRATIFICATION:

POSITIVE RISK FACTORS	DEFINING CRITERIA
Age	Men ≥ 45 years; Women ≥ 55 years.
Family history	Myocardial infarction, coronary revascularization, or sudden death before 55 years of age in father or other male first-degree relative, or before 65 years of age in mother or other female first-degree relative.
Current smoking	Current cigarette smoker or those who quit within the previous six months or exposure to environmental tobacco smoke.
Sedentary lifestyle	Not participating in at least 30 minutes of moderate intensity (40%-60% VO_2R) physical activity on at least three days of the week for at least three months.
Obesity	Body mass index ≥ 30kg.m^{-2} *or* waist girth > 102 cm for men and > 88 cm for women.
Hypertension	Systolic blood pressure ≥ 140 mmHg and/or diastolic ≥ 90 mmHg, confirmed by measurements on at least two separate occasions, *or* on any antihypertensive medication.
Dyslipidemia	Low-density lipoprotein cholesterol ≥ 3.37 mmol.L^{-1} *or* high-density lipoprotein (HDL) cholesterol < 1.04 mmol.L^{-1} *or* on lipid-lowering medication. If total serum cholesterol is all that is available use ≥ 5.18 mmol.L^{-1}.
Prediabetes	Impaired fasting glucose = fasting plasma glucose ≥ 5.50 mmol.L^{-1} but < 6.93 mmol.L^{-1} *or* impaired glucose tolerance = 2-hour values in oral glucose tolerance test ≥ 7.70 mmol.L^{-1} but < 11.00 mmol.L^{-1} confirmed by measurements on at least two separate

	occasions.
NEGATIVE RISK FACTOR	**DEFINING CRITERIA**
High-serum HDL cholesterol	≥ 1.55 $mmol.L^{-1}$

APPENDIX C
HEALTH SCREENING FORM

Afdeling 1 / *Part 1*

Naam en van / *Name and surname:* ________________________________ Ouderdom / *Age*: __________

Geboortedatum / *Date of birth*: _____/_____/_________ Geslag / *Sex*: _____________

Bevolkingsgroep / *Race*: ______________________ ID nr.: ____________________________

Lengte / *Height:* _____________ m Gewig / *Weight:* ___________ kg

Afdeling 2 / *Part 2*

Voltooi die volgende vrae so akkuraat as moontlik. Maak 'n regmerkie in die toepaslike blokkie (ڤ). Dit is tot u eie voordeel om die vrae so eerlik as moontlik te beantwoord. / *Complete the following questions as accurately as possible. Check the applicable block* (ڤ). *It is to your own benefit to complete the questions as honest as possible.*

1. Laaste mediese ondersoek / *Last medical exam:* ___________________________________(Jaar / *Year*)

   Laaste fikshe idstoets / *Last fitness test:* ____ (Jaar / *Year*)

2. Het u 'n geskiedenis van enige van die volgende / *Do you have a history of any of the following?*

   ڤ Hartaanval / *Heart attack*
   ڤ Koronêre trombose / *Coronary thrombosis*
   ڤ Vernoude are / *Narrowing arteries*
   ڤ Hoë cholesterol / *High cholesterol*
   ڤ Hoë bloeddruk / *High blood pressure*
   ڤ Rumatiek koors / *Rheumatic fever*
   ڤ Beroerte aanval / *Stroke*
   ڤ Angina (Borspyne) / *Chest pains*
   ڤ Lekkende hartklep / *Leaking heart valve*
   ڤ Diabetes / *Diabetes*
   ڤ Artritis / *Arthritis*
   ڤ Epilepsie / *Epilepsy*
   ڤ Kardiovaskulêre siekte / *Cardiovascular diseas*
   ڤ Palpitasies / *Palpitations*
   ڤ Pulmonale siekte / *Pulmonary disease*
   ڤ Geswelde enkels / *Ankle edema*
   ڤ Metaboliese siekte / *Metabolic disease*
   ڤ Dispnee (asemnood) / *Dyspnea*
   ڤ Hartgeruis / *Heart murmur*
   ڤ Intermittende klaudikasie / *Intermittent claudication*

3. Het u 'n familiegeskiedenis van een van die volgende / *Do you have a family history of any of the following?*

   ڤ Hartaanval / *Heart attack*
   ڤ Koronêre hartsiekte < 60jr / *Coronary heart disease < 60yrs*
   ڤ Hoë cholesterol / *High cholesterol*
   ڤ Hoë bloeddruk / *High blood pressure*
   ڤ Beroerte aanval / *Stroke*
   ڤ Oorgewig / *Overweight*
   ڤ Suikersiekte / *Diabetes*

4. Het u enige allergieë / *Do you have any allergies?* ڤ Ja / *Yes* ڤ Nee / *No*

   Indien ja, noem dit / *If yes, name it:*____

5. Merk een van die volgende. Gedurende 'n normale dag is ek: / *Check one of the following. During a normal day I am:*

ٯ Nooit gespanne / *Never tense* ٯ Weinig gespanne / *Seldom tense* ٯ Van tyd tot tyd gespanne / *Tense from time to time* ٯ Gereeld gespanne of angstig / *Often tense or anxious*

ٯ Gewoonlik gespanne of angstig / *Normally tense or anxious*

6. Hoe gereeld neem u aan fisieke aktiwiteite of oefening deel / *How often do you participate in physical activity or exercise?*

Keer per week / *Times per week:*________ Duur / *Duration:*__________ Tipe / *Type:*__________________________

____

7. Voel u ooit / *Do you ever experience:*

Kort van asem tydens rus of met ligte oefening? / *Shortness of breath at rest or with mild exertion?*_________

Moeg of kort van asem met daaglikse aktiwiteite? / *Unusual fatigue or shortness of breath with daily activities?*

____

8. Beskryf asseblief u rook geskiedenis / *Please describe you history of smoking:* ___________________________

9. Het u ‘n geskiedenis van enige gewrigs- of spierbeserings / *Do you have a history of any joint or muscle injury?*

ٯ Nek / *Neck* ٯ Bo-rug / *Upper back* ٯ Lae rug / *Lower back* ٯ Heup / *Hip*

ٯ Bobeen / *Thigh* ٯ Knie / *Knee* ٯ Onderbeen / *Lower leg* ٯ Enkel / *Ankle*

ٯ Voet / *Foot* ٯ Skouer / *Shoulder* ٯ Elmboog / *Elbow* ٯ Pols of gewrig / *Wrist or hand*

10. Gebruik u gereelde medikasie / *Are you on regular medication?* ٯ Ja / *Yes* ٯ Nee / *No*

Indien ja, wat is die naam, dosis en die gebruik daarvan / *If yes, what is the name, dosage and use thereof? :*__

Kondisie: bv. Cholesterol	*Medikasie: bv. Lipitor*	*Dosis: bv. 10mg / dag*
____________________	__________________	__________________
____________________	__________________	__________________
____________________	__________________	__________________
____________________	__________________	__________________

11. Het u dokter voorheen aangedui dat u enige ander kondisie het waarvan ons moet kennis neem / *Have your doctor previously indicated any other conditions that we should be aware of?* __________________________________

____

____

12. Is u kleurblind? / *Are you colour blind?*

____

13. Dui asseblief u hoogste kwalifikasie (vlak van opleiding) aan / *Please indicate your highest qualification*

____

____

PAR-Q & YOU

Common sense is your best guide when you answer the following questions. Please read the questions carefully and answer each one. Lees asseblief die volgende vrae deeglik deur en antwoord elkeen.

ڤ Yes ڤ No Het u dokter voorheen aangedui dat u 'n hartsiekte het en dat u slegs fisieke aktiwiteit moet doen soos aanbeveel deur 'n dokter?

Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?

ڤ Yes ڤ No Kry u pyn in u bors wanneer u fisieke aktiwiteit doen?

Do you feel pain in your chest when you do physical activity?

ڤ Yes ڤ No Het u in die afgelope maand borspyn ervaar wanneer u nie fisieke aktiwiteit doen nie?

In the past month, have you had chest pain when you were not doing physical activity?

ڤ Yes ڤ No Verloor u u balans as gevolg van duiseligheid of verloor u ooit u bewussyn?

Do you lose your balance because of dizziness or do you ever lose consciousness?

ڤ Yes ڤ No Het u 'n been- of gewrigsprobleem wat vererger kan word deur 'n verandering in u fisieke aktiwiteit?

Do you have a bone or joint problem that could be made worse by a change in your physical activity?

ڤ Yes ڤ No Neem u huidiglik enige medikasie soos voorgeskryf deur u dokter (bv. Waterpille vir bloeddruk of hartsiektes)?

Is your doctor currently prescribing drugs (for example water pills for blood pressure or heart conditions)?

ڤ Yes ڤ No Is u bewus van enige rede waarom u nie fisieke aktiwiteit kan doen nie?

Do you know of any other reason why you should not do physical activity?

APPENDIX D

SCREENING FORM

Name: ……………………………………………………………………

Date: ……………………………………………………………………

Resting BP (mmHg)		**Resting HR (beats/min)**	
Height (cm)		**Weight (kg)**	
		BMI	
Circumferences:	**Waist**		
	Hip		
Non-fasting Glucose (mmol/L)		**Tot. Cholesterol (mmol/L)**	

MoCA score: __________

ECG interpretation:

____

____

Approve: Yes ☐ No ☐

APPENDIX E

BASELINE AND POST-TESTING

Name: ………

Date: ……………………………………………… **Time: ………………………………………**

Questionnaires (3)

BP	
Height	
Weight	

NIRS & Stroop

TUG in seconds:		
1.		
2.		
3.		
Grip strength in kg:	**Right hand**	**Left hand**
1.		
2.		
3.		

Waist circumference	
Hip circumference	

BIA no. of download:		
Training per week	Very low (0 – 1 x); Low/med (1 – 2 x); Medium (3 – 4 x); Med/high (4 – 5 x); Very high (> 6 x)	
Age		
DATA COLLECTED	**Values**	**Normative ranges**
Weight (kg)		
% Body fat		
% Lean Body Mass	**kcal**	**KJ**
Resting Energy Consumption	**Kcal**	**KJ**
Energy Required		
H2O Content		
BMI		

BFMI		
FFMI		

Abdominal fat (cm)	

Bodymetrix measurement

<u>Bruce Protocol:</u>

Resting BP	
Resting HR	
Target HR [(220-age-RHR) * 0.75 + RHR]	

Stage	**RPE**	**HR**
2.7 km/h - 10°		
4.0 km/h - 12°		
5.4 km/h - 14°		
6.7 km/h - 16°		
8.0 km/h - 18°		

Termination:

Time: ……………………………….. **RPE: ………………………..**

Active rest	**RPE**	**HR**
1 min		
3 min		
5 min		

Blood pressure: ………………………………..

<u>10-RM strength tests:</u>

Leg press	
Bench press	

APPENDIX F

The SF-36v2™ Health Survey

Instructions for Completing the Questionnaire

Please answer every question. Some questions may look like others, but each one is different. Please take the time to read and answer each question carefully by filling in the bubble that best represents your response.

EXAMPLE

This is for your review. Do not answer this question. The questionnaire begins with the section ***Your Health in General*** below.

For each question you will be asked to fill in a bubble in each line:

1. **How strongly do you agree or disagree with each of the following statements?**

	Strongly agree	Agree	Uncertain	Disagree	Strongly disagree
a) I enjoy listening to music.	○	●	○	○	○
b) I enjoy reading magazines.	●	○	○	○	○

Please begin answering the questions now.

Your Health in General

1. **In general, would you say your health is:**

Excellent	Very good	Good	Fair	Poor	
○1	○2	○3	○4	○5	GH01

2. **Compared to one year ago, how would you rate your health in general now?**

Much better now than one year ago	Somewhat better now than one year ago	About the same as one year ago	Somewhat worse now than one year ago	Much worse now than one year ago	
○1	○2	○3	○4	○5	HT

Please turn the page and continue.

3. **The following questions are about activities you might do during a typical day. Does <u>your health now limit you</u> in these activities? If so, how much?**

	Yes, limited a lot	Yes, limited a little	No, not limited at all	
a) **Vigorous activities**, such as running, lifting heavy objects, participating in strenuous sports	O1	O2	O3	PF01
b) **Moderate activities**, such as moving a table, pushing a vacuum cleaner, bowling, or playing golf	O1	O2	O3	PF02
c) Lifting or carrying groceries	O1	O2	O3	PF03
d) Climbing **several** flights of stairs	O1	O2	O3	PF04
e) Climbing **one** flight of stairs	O1	O2	O3	PF05
f) Bending, kneeling, or stooping	O1	O2	O3	PF06
g) Walking **more than a mile**	O1	O2	O3	PF07
h) Walking **several hundred yards**	O1	O2	O3	PF08
i) Walking **one hundred yards**	O1	O2	O3	PF09
j) Bathing or dressing yourself	O1	O2	O3	PF10

4. **During the <u>past 4 weeks</u>, how much of the time have you had any of the following problems with your work or other regular daily activities <u>as a result of your physical health</u>?**

	All of the time	Most of the time	Some of the time	A little of the time	None of the time	
a) Cut down on the **amount of time** you spent on work or other activities	O1	O2	O3	O4	O5	RP01
b) **Accomplished less** than you would like	O1	O2	O3	O4	O5	RP02
c) Were limited in the **kind** of work or other activities	O1	O2	O3	O4	O5	RP03
d) Had **difficulty** performing the work or other activities (for example, it took extra effort)	O1	O2	O3	O4	O5	RP04

5. During the past 4 weeks, how much of the time have you had any of the following problems with your work or other regular daily activities as a result of any emotional problems (such as feeling depressed or anxious)?

	All of the time	Most of the time	Some of the time	A little of the time	None of the time	
a) Cut down on the **amount of time** you spent on work or other activities	O 1	O 2	O 3	O 4	O 5	RE01
b) **Accomplished less** than you would like	O 1	O 2	O 3	O 4	O 5	RE02
c) Did work or other activities **less carefully than usual**	O 1	O 2	O 3	O 4	O 5	RE03

6. During the past 4 weeks, to what extent has your physical health or emotional problems interfered with your normal social activities with family, friends, neighbors, or groups?

Not at all	Slightly	Moderately	Quite a bit	Extremely	
O 1	O 2	O 3	O 4	O 5	SF01

7. How much bodily pain have you had during the past 4 weeks?

None	Very mild	Mild	Moderate	Severe	Very severe	
O 1	O 2	O 3	O 4	O 5	O 6	BP01

8. During the past 4 weeks, how much did pain interfere with your normal work (including both work outside the home and housework)?

Not at all	A little bit	Moderately	Quite a bit	Extremely	
O 1	O 2	O 3	O 4	O 5	BP02

9. These questions are about how you feel and how things have been with you during the past 4 weeks. For each question, please give the one answer that comes closest to the way you have been feeling. How much of the time during the past 4 weeks...

	All of the time	Most of the time	Some of the time	A little of the time	None of the time	
a) did you feel full of life?	O 1	O 2	O 3	O 4	O 5	VT01
b) have you been very nervous?	O 1	O 2	O 3	O 4	O 5	MH01
c) have you felt so down in the dumps that nothing could cheer you up?	O 1	O 2	O 3	O 4	O 5	MH02
d) have you felt calm and peaceful?	O 1	O 2	O 3	O 4	O 5	MH03
e) did you have a lot of energy?	O 1	O 2	O 3	O 4	O 5	VT02
f) have you felt downhearted and depressed?	O 1	O 2	O 3	O 4	O 5	MH04
g) did you feel worn out?	O 1	O 2	O 3	O 4	O 5	VT03
h) have you been happy?	O 1	O 2	O 3	O 4	O 5	MH05
i) did you feel tired?	O 1	O 2	O 3	O 4	O 5	VT04

10. **During the <u>past 4 weeks</u>, how much of the time has your <u>physical health or emotional problems</u> interfered with your social activities (like visiting friends, relatives, etc.)?**

All of the time	Most of the time	Some of the time	A little of the time	None of the time	
O1	O2	O3	O4	O5	SF02

11. **How TRUE or FALSE is <u>each</u> of the following statements for you?**

	Definitely true	Mostly true	Don't know	Mostly false	Definitely false	
a) I seem to get sick a little easier than other people	O1	O2	O3	O4	O5	GH02
b) I am as healthy as anybody I know	O1	O2	O3	O4	O5	GH03
c) I expect my health to get worse	O1	O2	O3	O4	O5	GH04
d) My health is excellent	O1	O2	O3	O4	O5	GH05

APPENDIX G

PathCare PRACTICE NO. 5200539

LOCAL PATHOLOGISTS :
DRS DIETRICH, VOIGT, MIA PARTNERS

PATHOLOGY REQUEST FORM

Tel. : 021 596 3587
Fax : 021 596 3710

SP_DEAL

COMPANY / DOCTOR DETAILS

Referring Company / Doctor	SPORTS SCIENCE PHYSIOLOGICAL DEPARTMENT	PathCare Code	CP SPORTBØ
Attention	DR PIERRE OLIVIER	Tel.	021 808 2818
Address	SPORT PHYSIOLOGICAL LABORATORY, PRIVATE BAG X1, MATIELAND, STELLENBOSCH, 7602		

DATA-CAPTURING INSTRUCTIONS: DO NOT CAPTURE ON PATHREQUESTER

PATIENT / EMPLOYEE DETAILS

Patient Surname			
Patient First Name/s		Gender ☑	M ☐ F ☐
Patient ID No.		Date of Birth	
Employee Reference No.			

I certify that the above information is correct, and give consent for the selected tests to de done | Signature

Collected by	Name		Date	Time
	Signature			

SPECIMEN INSTRUCTIONS

- **B** CITRATE tube must be full (blue stopper)
- **G** SST GEL tube (gold stopper)
- **H** HEPARIN lithium tube (green stopper)
- **Y** ACD tube (yelow stopper)
- **P** EDTA tube (purple stopper) 4ml
- **P6** EDTA tube (purple stopper) 6ml
- **S** Stool specimen
- **DT** Swab in transport medium
- **TE** TRACE ELEMENT (royal blue stopper)
- **U** 25ml random urine specimen
- ☎ Arrange with laboratory
- * On Dry Ice - urines
- ** On Ice
- = Separate asap

SPECIMEN INFORMATION AND COUNT

CITRATE	EDTA 4ml	EDTA 6ml	FLUORIDE	GEL	HEPARIN	STOOL	SWAB	TRACE ELEMENT	URINE	OTHER (please specify)	TEST COUNT

Received by		Date	Time

CLINICAL DATA

TESTS REQUIRED

G A1038 ☐ LIPOGRAM (fasting)

F + G A3936 ☐ INSULIN RESISTANCE (quicki index)

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APPENDIX H

rating	description
0	NOTHING AT ALL
0.5	VERY, VERY LIGHT
1	VERY LIGHT
2	FAIRLY LIGHT
3	MODERATE
4	SOMEWHAT HARD
5	HARD
6	
7	VERY HARD
8	
9	
10	VERY VERY HARD (MAXIMAL)