The effects of exercise training interventions on the health profile of inactive premenopausal women

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Submitted by Luke John Connolly to the University of Exeter as a thesis for the degree of Doctor of Philosophy in Sport and Health Sciences

February 2018

I certify that all material in this thesis which is not my own work has been identified and that no material has previously been submitted and approved for the award of a degree by this or any other University

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Abstract

A physically inactive lifestyle is associated with increased morbidity of non-communicable diseases, with such diseases representing the leading cause of death worldwide. It is well documented that regular participation in physical activity is associated with an improvement in a number of established health markers. However, it has been reported that 34-39 % of UK women aged 25-54 y fail to meet the minimum physical activity recommendations and many conventional exercise training interventions and initiatives are failing to meaningfully increase physical activity levels and adherence in previously inactive premenopausal women. A common barrier preventing premenopausal women from initiating and maintaining increased habitual physical activity is a ‘lack of time’. Physical activity initiation and maintenance can also be affected by the exercise environment with some individuals preferring to exercise alone while others prefer to exercise within a supervised or group environment. Increasing evidence suggests that high-intensity interval training (HIIT) performed independently, under supervision or within a group environment can provide a time-efficient alternative for improving several health markers in different populations. However, limited research has examined the effects of HIIT on health markers in inactive women and the effects of different methods of HIIT on overall health status. Therefore, the purpose of this thesis was to identify how alternative and smaller volumes of higher-intensity exercise influence enjoyment, adherence rates and health markers in previously inactive premenopausal women following 12-16 wks of training.

Chapter 4 examined the effects of 16 wks of short duration small-sided football training and whole-body vibration (WBV) training on body composition, aerobic fitness and muscle oxidative capacity of previously inactive premenopausal women. Results from this study demonstrated that short duration small-sided football elicited superior health benefits, which included a reduction in body fat percentage and submaximal exercise heart rate (HR) as well as a decrease in PCr depletion for a given work rate during one-legged knee-extension exercise, compared to WBV training. Chapter 5 demonstrated that 15 wks of high-intensity swim training was an effective and time-efficient alternative exercise modality for the improvement of insulin sensitivity, glucose control and plasma soluble intracellular and vascular cell adhesion molecules compared to prolonged

continuous swim training for previously inactive premenopausal women. Chapter 6 revealed that 12 wks of self-paced high-intensity interval and prolonged continuous cycling training both increased cardiorespiratory fitness and cognitive function and reduced resting HR in previously inactive premenopausal women. On the other hand, reductions in resting blood pressure (BP), submaximal HR and body mass and increases in mental well-being were training-type-specific. Finally, Chapter 7 identified that a novel 12 wk home-based DVD-directed exercise programme for previously inactive premenopausal women, encompassing movements commonly found within football training, was beneficial for the improvement of high-density lipoprotein cholesterol concentration and mental well-being when carried out at a moderate- to high-intensity.

The exercise training interventions were well tolerated and adhered to by participants and resulted in improvements to some established health markers. However, the improved health profile of premenopausal women after the various training interventions was not uniform, with several training specific adaptations being manifest. Collectively, the combined training studies (*n*=175 participants) provide some support for shorter-duration, higher-intensity physical exercise training, including football, swimming, cycling and home-based DVD-directed exercise training, but not whole-body vibration training, to improve key health markers in previously inactive premenopausal women. The findings presented in this thesis demonstrate that several HIIT exercise modalities appear to be effective and feasible alternatives to prolonged continuous exercise training for improving health markers in previously inactive premenopausal women.

Acknowledgements

Foremost, I want to express my sincere thanks to Professor Peter Krustrup for giving me the opportunity to undertake this PhD. I value and appreciate all the time and energy you spent on assisting me with my personal development throughout my PhD and allowing me the opportunity to work with world-renowned researchers such as Dr. Jens Jung Nielsen, Dr. Martin Thomassen and Dr. Nikolai Nordsborg at the University of Copenhagen, Denmark. I will always admire the way in which you are able to balance your work and personal life with so many projects on the go.

My sincere thanks are also extended to Professor Andy Jones and Dr. Stephen Bailey for taking me under their wing following Peter's unanticipated return to Denmark. Without your guidance and expertise, I do not think I would have been able to complete my PhD. Andy, your passion for what you do and enthusiasm for research has encouraged me more than you know. Your frequent 'tweets' and 'posts' are always interesting. Stevo, I will always appreciate your frequent reassurance and willingness to help and I'll always admire your eye for detail. Thank you also for your advice and input in the final thesis. Dr. Anni Vanhatalo, I want to express my deepest thanks for assisting me through the final stages of my PhD following the irreplaceable departure of Dr. Stephen Bailey from Sport and Health Sciences at the University of Exeter.

Dr. Magni Mohr, thank you for your insightfulness and expertise throughout my PhD which has led to several collaborations and publications. I have valued your straightforward, organised and detailed approach to research. Suzanne Scott, similar to a Yo-Yo, we've certainly had our ups and downs throughout our time as PhD students but I want to thank you for your insightfulness and support throughout and having confidence in me to prosper in all that I do. You're certainly my **FAV**ourite person to turn to in moments of doubt. Dr. Jonathan Fulford and Dr. Sarah Jackman, thank you for all your energy and effort spent in helping not only with my first study but continued support and assistance throughout my PhD. In particular, Jon, thank you for your assistance with data collection and data analysis using magnetic resonance spectroscopy.

A special thanks also goes out to a number of postgraduate students who have assisted me with my training studies. Adam Linoby, Paul Morgan, Sean Kilroe, Nadine Sammy, Carmelina Morencos, Craig Willis, Dr. Chris Thompson and Becca Lear, without your help, I would not have been to run so many training sessions. To my work colleagues David Childs, Sam Bailey, Mike Cooke and Jamie Blackwell, thank you for providing me with technical support throughout my PhD but also with the selfless amount of time and space you have provided me to continue writing while juggling work and home life but also your genuine friendship over the past couple of years.

A special appreciation also goes out to my parents, sister and Chris Smietanka for their encouragement, frequent pep talks and confidence that they had within me which is what has kept me going. You provided me with strength and helped me more than you know. To my grandparents, who sadly are no longer with us, thank you for your support and having a genuine interest in what I do. Thank you for all of the love and encouragement you have given me. As busy as I was, family always come first. I hope you are proud that I have reached this goal that I set out to complete.

To my wife Gemma, thanks for keeping my feet grounded and showing me there is more to life than just work. I want to express my deepest thanks for your patience, kindness, support and willingness to listen when I needed it the most. You're the strongest person I know. To my daughter Lyla, your imminent arrival through the latter stages of my PhD certainly kept me on track as I imagined that rest and sleep would be a thing of the past. So far, you are yet to prove me wrong. But I wouldn't change it for the world. Everything I do from here on is for you.

Lastly, this thesis would not have been possible without my participants. Thank you for volunteering your time to be a part of these studies. I cannot thank you enough!

Declaration

The material contained within this thesis is original work conducted and written by the author. The following publications and communications are a direct consequence of the work.

Publications and conference communications

Publications

Connolly, L. J., Bailey, S. J., Krustrup, P., Fulford, J., Smietanka, C., & Jones, A. M. (2017). Effects of self-paced interval and continuous training on health markers in women. *European Journal of Applied Physiology*. doi:10.1007/s00421-017-3715-9

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Connolly, L. J., Scott, S., Mohr, M., Ermidis, G., Julian, R., Bangsbo, J., Jackman, S. R., Bowtell, J. L., Davies, R. C., Hopkins, S. J., Seymour, R., Knapp, K., Krustrup, P., & Fulford, J. (2014). Effects of small-volume soccer and vibration training on body composition, aerobic fitness, and muscular PCr kinetics for inactive women aged 20–45. *Journal of Sport and Health Science, 3*(4), 284-292. doi:10.1016/j.jshs.2014.07.003

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Connolly, L. J., Scott, S., Mohr, M., Ermidis, G., Julian, R., Bangsbo, J., Jackman, S. R., Bowtell, J. L., Davies, R. C., Hopkins, S. J., Seymour, R., Knapp, K., Krustrup, P., & Fulford, J. (2015). Effects of small-volume soccer and vibration training on body composition, aerobic fitness, and muscular PCr kinetics for inactive women aged 20–45. 8th *Postgraduate Research Conference, Exeter, UK*

Connolly, L. J., Scott, S., Mohr, M., Ermidis, G., Julian, R., Bangsbo, J., Jackman, S. R., Bowtell, J. L., Davies, R. C., Hopkins, S. J., Seymour, R., Knapp, K., Krustrup, P., & Fulford, J. (2015). Effects of small-volume soccer and vibration training on body composition, aerobic fitness, and muscular PCr kinetics for inactive women aged 20–45. 8th *World Congress on Science & Football, Copenhagen, Denmark*

Connolly, L. J., Scott, S., Mohr, M., Ermidis, G., Julian, R., Bangsbo, J., Jackman, S. R., Bowtell, J. L., Davies, R. C., Hopkins, S. J., Seymour, R., Knapp, K., Krustrup, P., & Fulford, J. (2014). Effects of small-volume soccer and vibration training on body composition, aerobic fitness, and muscular PCr kinetics for inactive women aged 20–45. *BASES Student Conference, Portsmouth, UK*

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Mohr, M., Krustrup, P., **Connolly, L**., Weihe, P., Iuliano, E., Aquino, G., Saltin, B., & Nordsborg, N. B. (2015). Effects of exercise training mode on oxidative capacity in human arm and leg skeletal muscle: 819 Board #215 May 27, 3:30 PM – 5:00 PM. *Medicine and Science in Sports and Exercise, 47(5S)*

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Symbols and abbreviations

Δ	Difference
μ	Microliters
[ ]	Concentration
°C	Degrees Celsius
^{31}P-MRS	^{31}Phosphorous nuclear magnetic resonance spectroscopy
ACSM	American College of Sports Medicine
ADA	American Diabetes Association
ANOVA	Analysis of variance
ATP	Adenosine triphosphate
AUC	Area under the curve
BDNF	Brain-derived neurotrophic factor
BMD	Bone mineral density
BMI	Body mass index
BP	Blood pressure
CHD	Coronary heart disease
CI	Confidence interval
Cm	Centimetre
CNS	Central nervous system
CO_2	Carbon dioxide
CON	Control
CT	Continuous training
CV	Coefficient of variation
CVD	Cardiovascular disease
EDTA	Ethylenediaminetetraacetic Acid
EEG	Electroencephalography
FG	Fasting glucose (tables only)
FI	Fasting insulin (tables only)
FM	Fat mass (tables only)
GEQ	Groningen enjoyment questionnaire
GLUT-4	Glucose transporter protein 4
h	Hour
Hb	Haemoglobin (tables only)
HIIT	High-intensity interval training
HDL	High-density lipoprotein
HOMA-IR	Homeostatic model assessment of insulin resistance
HR	Heart rate
HR_{max}	Maximal heart rate
HR_{peak}	Peak heart rate
HRR	Heart rate reserve
iAUC	Incremental area under the curve
IDF	International Diabetes Federation
IHD	Ischaemic heart disease

IPAQ	International physical activity questionnaire
IR	Insulin resistance (tables only)
IS	Insulin sensitivity (tables only)
ISLT	International shopping list task
ISLTR	International shopping list task recall
IU	International units
jMRUI	Java-based magnetic resonance spectroscopy
kcal	Kilocalorie
Kg	Kilograms
kJ	Kilojoules
L	Litres
LCAT	Lecithin-cholesterol acyltransferase
LDL	Low-density lipoprotein
LM	Lean mass (tables only)
LPL	Lipoprotein lipase activity
MAP	Mean arterial pressure
MetS	Metabolic syndrome
mg	Milligram
MICT	Moderate-intensity continuous training
Min	Minute
ml	Millilitre
mmol	Millimole
MOD	Moderate-intensity continuous exercise
n	Number
NCEP	National Cholesterol Education programme
NHS	National Health Service
O_2	Oxygen
OCL	One card learning
OGTT	Oral glucose tolerance test
ONB	One back memory
PCr	Phosphocreatine
pH	Power of hydrogen
P_i	Inorganic phosphate
RCT	Randomised controlled trial
RER	Respiratory exchange ratio
RMR	Resting metabolic rate
RPE	Rating of perceived exertion
RPM	Revolutions per minute
RPP	Rate pressure product
RR	Relative risk
s	Seconds
SD	Standard deviation
SG	Soccer group
SIT	Sprint interval training
SPSS®	Statistical Package for the Social Sciences

tAUC	Total area under the curve
T2D	Type II diabetes
TBM	Total body mass (tables only)
TC	Total cholesterol
TG	Triglyceride
TWOB	Two back memory
UK	United Kingdom
$\dot{V}CO_2$	Carbon dioxide output
$\dot{V}_E$	Pulmonary ventilation
VG	Vibration group
$\dot{V}O_2$	Oxygen consumption
$\dot{V}O_{2max}$	Maximal oxygen uptake
$\dot{V}O_{2peak}$	Peak oxygen uptake
W	Watt
WBV	Whole-body vibration training
WEMWBS	Warwick-Edinburgh mental well-being scale
WHO	World Health Organization
wk	Week
W_{peak}	Peak power output (tables only)
y	Year
YYIE1	Yo-Yo intermittent endurance test level 1

Definitions

Throughout this thesis the terms physical activity will be defined as follows:

Physical inactivity:

'an activity level insufficient to meet current recommendations' (I. M. Lee et al., 2012) (pp3)

Sedentary behaviour:

'activities requiring seated or reclining postures which do not require an energy expenditure above resting levels, typically 1-1.5 METs' (Pate, O'Neill, & Lobelo, 2008) (pp174)

Physical activity:

'any bodily movement produced by skeletal muscle that results in energy expenditure above resting level' (Caspersen, Powell, & Christenson, 1985) (pp126)

Exercise:

'physical activity that is planned, structured, repetitive, and purposive in the sense that improvement or maintenance of one or more components of physical fitness is an objective' (Caspersen et al., 1985) (pp128)

Chapter 1

Introduction

It is clear that the lifestyle in today's modern 'westernised' society predisposes to increased incidence of non-communicable diseases (NCDs) (Hu et al., 2008; I. M. Lee et al., 2012), leading to a heightened risk of premature morbidity and mortality (Bauer, Briss, Goodman, & Bowman, 2014). For developed countries, changes in professional workload and transportation, and the increase in television screen time have led to a large portion of the day being spent sedentary (Allender, Scarborough, Kaur, & Rayner, 2008). Coupled with an ever increasing easy access to calorie dense foods (French, Story, & Jeffery, 2001), these factors are considered to be integral to the NCD epidemic (Owen, Sparling, Healy, Dunstan, & Matthews, 2010). The World Health Organization (WHO) defines NCDs as chronic diseases that are non-infectious and non-transmissible among individuals. Currently, NCDs are the leading cause of death worldwide, responsible for 38 million of the world's 56 million deaths in 2012 (World Health Organization, 2014, 2015). According to the WHO, cardiovascular diseases (CVD) (such as heart disease and stroke), cancers, chronic respiratory diseases (such as chronic obstructive pulmonary disease and asthma) and type II diabetes (T2D) are the four main types of NCDs. In addition, mental illnesses, which are mainly driven by unhealthy lifestyle behaviours, are linked to an insufficient volume of physical activity (World Health Organization, 2015). However, compared with their infectious disease counterparts, cost-effective interventions to prevent and treat NCDs are severely underfunded (Allen, 2017b). Strikingly, deaths caused by NCDs are 28 times higher than that of human immunodeficiency virus yet receive 17 times less funding (Allen, 2017a).

1.1 Prevalence of physical inactivity

Globally, it was estimated that 23 % of adults (aged 18 and over) were inactive (World Health Organization, 2016c) in 2010. By 2012, 26 % of women were estimated to be inactive in England which was higher than the 19 % of men who were estimated to be inactive over the same time period (Townsend, Wickramasinghe, Williams, Bhatnagar, & Rayner, 2015). Physical inactivity, coupled with increased intake of energy enriched foods, can lead to intermediate risk factors such as overweight/obesity, hypertension, dyslipidaemia and hyperglycaemia, which are clinical markers for the metabolic syndrome (MetS) that can lead to CVD (World Health Organization, 2015). Therefore, it is not surprising that physical inactivity represents the fourth leading cause of death worldwide (Kohl et al., 2012) and has been estimated to account for 3.3 million deaths (11-19 % of all deaths from NCDs) each year in the UK (I. M. Lee et al., 2012; World Health Organization, 2009). A large cohort study has also suggested that physical inactivity contributes to premature death more so than obesity (Ekelund et al., 2015).

Poor cardiorespiratory fitness, arising as a consequence of physical inactivity is a major contributor to the increasing prevalence of some NCDs such as heart and pulmonary diseases; MetS related disorders; and muscle, bone and joint disorders (Krustrup, Aagaard, et al., 2010). Genetics (~50 %) and environmental (~50 %) factors both help explain the variance in cardiorespiratory fitness of an individual, usually defined as the maximal rate of oxygen uptake ($\dot{V}O_{2max}$) during an incremental exercise test (Bouchard et al., 1999). The main environmental factor to alter cardiorespiratory fitness is physical activity (Church, 2009).

1.2 Prevalence of non-communicable diseases

Prevalence of overweight and obesity

Overweight and obesity is a considerable public health problem. In 2014, 39 % of adults worldwide were overweight (body mass index (BMI) ≥ 25 Kg/m^2) (30 % of men and 40 % of women) and 13 % were obese (BMI ≥30 kg/m2) (11 % of men and 15 % of women) (World Health Organization, 2016b). Obesity is also a public health problem for the UK. Recent statistics from the Health Survey for England reported that, in 2015, 27 % of adults were obese and 41 % of men and 31 % of women were overweight (Moody, 2016). In addition, statistics from the Scottish Health Survey reported that, in 2014, 65 % of adults were overweight and 28 % were obese (L. Brown et al., 2014). Furthermore, this survey revealed that, although men (69 %) are more likely to be overweight compared to women (61%), women (29 %) are more likely to be obese compared to men (26 %) with the highest prevalence between the ages of 55-74 (L. Brown et al., 2014). While deaths related to obesity are difficult to estimate, it has been reported that there are at least 2.8 million overweight/obesity-related deaths around the world each year (World Health Organization, 2010) and 30,000 deaths in the UK (National Audit Office, 2001). The accumulation of excess adiposity, in particular visceral fat, has been associated with further health risk factors such as hypertension, dyslipidemia, T2D and CVD (Lebovitz & Banerji, 2005; Pischon et al., 2008).

Prevalence of hypertension

In 2008, it was estimated that around 40 % of individuals had a blood pressure (BP) above normal (>120/80 mmHg), contributing to an estimated 7.5 million deaths worldwide (World Health Organization, 2012b). The prevalence of hypertension is broadly similar in men and women and is projected to increase to 1.5 billion adults, 29 % of men and 30 % of women by 2025 (Kearney et al., 2005; Kearney, Whelton, Reynolds, Whelton, & He, 2004). Data from the 2014 Health Survey for England revealed that 32 % of men and 27 % of women suffered from hypertension (Health and Social Care Information Centre, 2015) and it is estimated that in the UK there are 62,000 deaths each year from stroke and heart attacks due to poor BP control (He & MacGregor, 2003).

Prevalence of abnormal lipids

Globally, 39 % of adults (37 % male and 40 % female) were estimated to have higher than normal cholesterol levels (>5.18 mmol/l) with 2.6 million deaths annually in 2008 attributable to high cholesterol levels (World Health Organization, 2010). Prevalence of raised cholesterol was also the highest in the WHO region of Europe (54 %) (World Health Organization, 2010). In addition, the INTERHEART case-control study estimated that 45 % of heart attacks in Western Europe were due to abnormal blood lipids (Yusuf et al., 2004) and data from 2008 reported that 58 % of men and 61 % of women exhibited a higher than normal total cholesterol (TC) levels in the UK, which increased to 76 % for women from the ages of 45 to 54 (Townsend et al., 2012). Furthermore, 7 % of men and 2 % of women were estimated to have lower than normal high-density lipoprotein (HDL) cholesterol levels (<1.04 mmol/l) in England in 2008 (Townsend et al., 2012). Younger women tend to have a more favourable lipid profile compared to men, but cholesterol rises after the menopausal transition to higher levels than men (K. A. Matthews et al., 1989). Therefore it appears particularly important to maintain normal cholesterol levels leading towards the menopausal transition.

Prevalence of diabetes

Distinct global estimates of the prevalence for type I diabetes and T2D does not exist due to the difficulty of distinguishing between the two, although the majority of individuals with diabetes are affected by T2D (World Health Organization, 2016a). The prevalence of individuals with diabetes has risen from 108 million in 1980 to 422 million in 2008 (World Health Organization, 2016a) with 3.5 million people in the UK diagnosed with diabetes (Diabetes UK, 2016). Diabetes is thought to have caused 1.5 million deaths in 2012 but higher-than-optimal blood [glucose] was thought to be responsible for an additional 2.2 million deaths due to an increased risk of cardiovascular and other diseases (World Health Organization, 2016a). It is also estimated that of the 75,000 people with diabetes in the UK, 24,000 die early (Health and Social Care Information Centre, 2013). In 2012, high blood [glucose], including diabetes, was the eighth leading cause of death among both sexes but the fifth leading cause of death in women (World Health Organization, 2016a). The increased rate of cognitive decline and some specific cancers has also been associated with diabetes (Wong et al., 2013). There is also substantial evidence that diabetes is a more potent risk factor for coronary heart disease (CHD) and stroke in women than in men (Huxley, Barzi, & Woodward, 2006; S. A. E. Peters, Huxley, & Woodward, 2014). Indeed, following a pooled analysis of over 850,000 individuals and 28,000 coronary events, it was shown that the presence of diabetes nearly tripled the risk of CHD in women compared to double the risk in men with the relative risk (RR) for CHD being 44 % greater in women with diabetes than in similarly affected men (Huxley et al., 2006). In addition, a meta-analysis by S. A. E. Peters et al. (2014) of over 750,000 individuals and more than 12,500 strokes reported that the relative effect of diabetes on stroke risk was 27 % greater in women compared with men. As the detrimental effects of glucose already occur at glycaemic levels below the threshold for the diagnosis of diabetes, it might be that the transition from normoglycaemia to impaired glucose tolerance is more detrimental in women than in men. Consequently, it is of major interest to develop and implement interventions to maintain normal glucose levels in apparently healthy women.

Prevalence of cardiovascular disease

The number one cause of death globally in 2012 was CVD which was responsible for 17.5 million deaths (World Health Organization, 2014). In the UK, CVD represented the second most common cause of death (27 % of all deaths) and CHD represented the single largest cause of death (15 % of males and 10 % of females) in 2014 (Townsend, Bhatnagar, Wilkins, Wickramasinghe, & Rayner, 2015). Moreover, in 2013/14, around 1.7 million episodes related to CVD took place in NHS hospitals (Townsend, Bhatnagar, et al., 2015). It is expected that the number of CVD-related mortalities, mainly from CHD and stroke, will increase to 23.3 million by 2030 (Mathers & Loncar, 2006).

Prevalence of cognitive decline

As a person ages, their cognitive abilities gradually deteriorate. However, as we live longer, it is likely that the number of individuals who suffer with cognitive impairment or dementia will increase (Brayne et al., 2006). Cognitive impairment and dementia are increasing globally (World Health Organization, 2008b) and it has been estimated that 35.6 million people are living with dementia worldwide and that this figure will double every 20 y (World Health Organization, 2012a). In addition, mild cognitive impairment is thought to affect 850,000 individuals in the UK (Ray & Davidson, 2014). It has been suggested that coronary risk factors are associated with cognitive impairment, dementia and Alzheimer's disease (Grodstein, 2007) and hypertension, dyslipidaemia and T2D are possible risk factors for cognitive decline in later life (Grodstein, 2007). However, increases in physical activity have shown promise for decreasing the risk of cognitive decline.

1.3 Economic burden

As well as the debilitating effect that physical inactivity places on the health of an individual, there is also a significant financial strain placed upon public health care systems (Allender, Foster, Scarborough, & Rayner, 2007; Oldridge, 2008; Pratt, Norris, Lobelo, Roux, & Wang, 2014). In 2006/2007 the estimated cost of physical inactivity to the National Health Service (NHS) was £0.9 billion, which was part of the £5 billion spent on overweight and obesity-related ill health (Scarborough et al., 2011). The estimated costs of obesity for European countries are displayed in Figure 1.1. In 2009, treatment of CVD was thought to have cost the healthcare system in the UK around £8.6 billion (Townsend et al., 2012). In addition, hypertension is thought to cost the NHS over £2 billion each year (Public Health England, 2014). It is also estimated that it costs the NHS £10 billion a year to treat diabetes and its co-morbidities (Diabetes UK, 2014) while dementia costs the UK

£26 billion a year with mild dementia costing £26,210 a year per person which then rises to £39,294 and £41,187 for developments to moderate and severe dementia (Scrutton & Brancati, 2016).

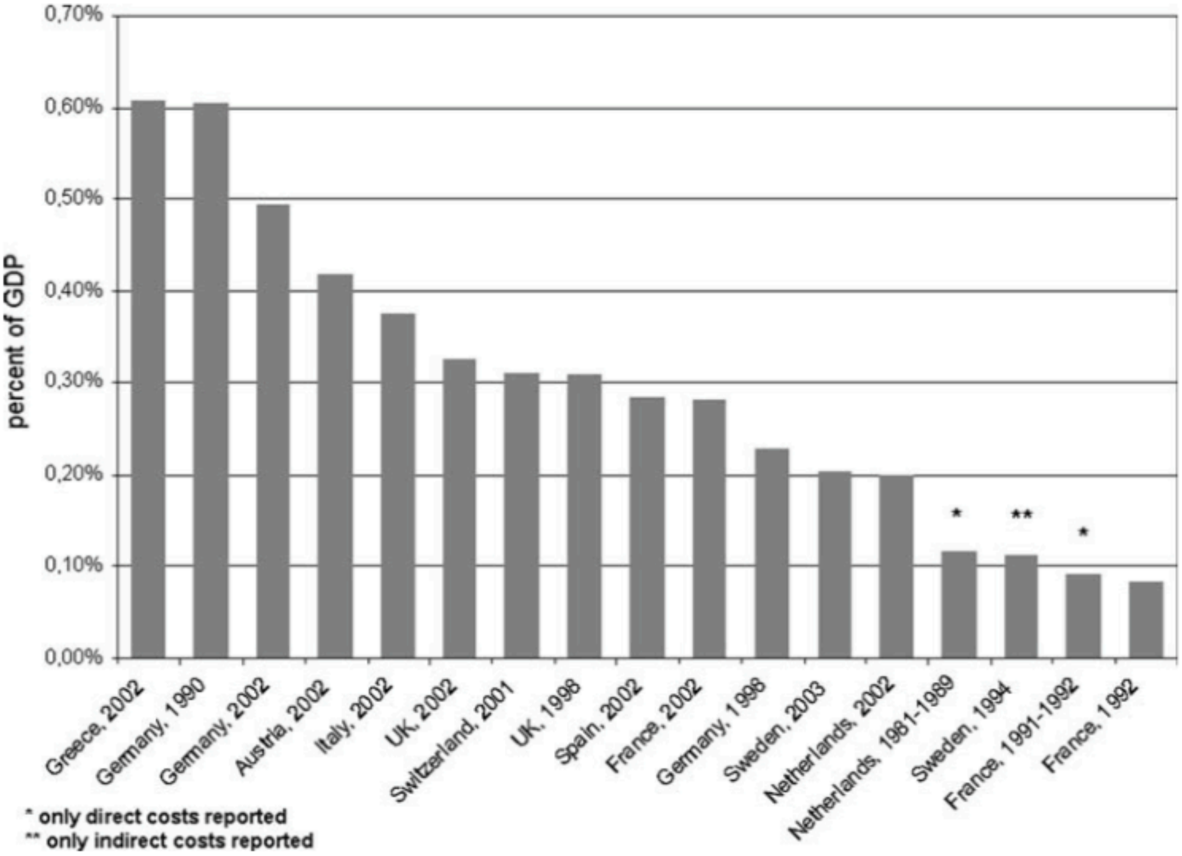


Figure 1.1 Country-specific costs attributable to obesity as a percentage of national gross domestic product (GDP). Reproduced from Muller-Riemenschneider, Reinhold, Berghofer, and Willich (2008) with permission.

1.4 Treatment and sex differences

Although CVD was the number one cause of death throughout the world for males and females in 2012 (World Health Organization, 2014), the risk of heart disease in women is often underestimated due to the misperception that females are ‘protected’ against CVD (Maas & Appelman, 2010). It is assumed that exposure to endogenous oestrogens during the fertile period of life delays the manifestation and progression of NCDs in women as oestrogen has a positive regulatory effect on several metabolic factors such as lipid and inflammatory markers (Maas & Appelman, 2010). This can lead to women receiving less aggressive treatment for cardiovascular risk factors and less frequently referred to CVD prevention programmes compared to men (Ll Lloyd, 2009; Mosca et al., 2005). However, data from the National Health and Nutrition Examination Surveys (NHANES) have shown that over the past 20 y the occurrence of myocardial infarctions has increased in women aged between 35 and 54 y while decreasing in age-matched men (Towfighi, Zheng, & Ovbiagele, 2009). Middle-aged women are particularly susceptible to develop NCDs and associated co-morbidities, but regular physical activity is known to mitigate the development of NCD risk factors (M. A. Ribeiro, Martins, & Carvalho, 2014). This emphasises the need for the promotion and maintenance of physical activity for women as sedentary behaviour tends to increase as leisure-time physical activity declines as women move towards menopause (Chomistek et al., 2013).

Whilst it is appreciated that physical activity prevalence continues to reduce beyond the menopause (Townsend, Wickramasinghe, et al., 2015) it is also clear that women of all age groups would benefit from increased participation in physical activity. However, hormonal changes, such as low plasma oestrogen and elevated luteinizing hormone levels following the menopause (Maas & Appelman, 2010), might influence the effects of physical acitivity interventions in postmenopausal women. Indeed, these hormonal changes could negatively affect key health markers in postmenopausal women including the cardiovascular (Pardhe et al., 2017) and musculoskeletal (Roman-Blas et al., 2009) systems, and their subsequent adapations to an increase in physical activity, compared to premenopausal women. Therefore, to provide more bespoke evidence on the effects of physical acitivity this thesis focused on premenopausal women to provide exercise training recommednations for the prevention and treatment of several key health markers and noncommunicable disease risk factors.

1.5 Physical activity

To reduce the burden of NCDs on global health, current public health advice stresses the importance of preventing, detecting and correcting modifiable risk factors such as physical inactivity. Increasing participation in regular physical activity is one of the first actions required and is recognised as an important strategy to prevent and treat many NCDs (B. K. Pedersen & Saltin, 2006). There is also a growing awareness that more emphasis should be placed on addressing physical inactivity to prevent NCD risk factors from accumulating (Thyfault & Krogh-Madsen, 2011). This has led to a united worldwide effort to promote and increase participation in physical activity in the general population.

1.6 Physical activity guidelines

Since 1975, position stands and recommended guidelines for participation in physical activity have been published and continue to be revised with the release of updated literature (Blair, LaMonte, & Nichaman, 2004). Currently, there are clear physical activity guidelines for adults which stipulate the completion of 150 min of moderate-intensity aerobic activity or 75 min of vigorous-intensity aerobic activity per wk to improve public health as well as strength exercises on two or more days a wk (Department of Health, 2011; Garber et al., 2011). The UK government aim for 70 % of the population to be reasonably active (30 min of moderate-intensity exercise five times per wk) by 2020 (Chief Medical Officer, 2004). However, current literature suggests that the general population are not meeting the recommended levels of physical activity to prevent and treat NCDs as 33 % of men and 45 % of women are failing to comply with physical activity recommendations (Townsend, Wickramasinghe, et al., 2015). In addition, there is evidence of a 40 % reduction in physical activity for women upon reaching middle-age (McArthur, Dumas, Woodend, Beach, & Stacey, 2014). Moreover, the proportion of women meeting physical activity recommendations falls from 66 % to 55 % between the ages of 35 to 64 y (Townsend, Wickramasinghe, et al., 2015). Therefore, meeting the UK governments targets by 2020 has been regarded as ambitious (Allender, Cowburn, & Foster, 2006). Reasons as to why this is the case are extensive and multifactorial, but developing interventions to overcome physical inactivity is of major economic and public health importance.

1.7 Physical activity and sex differences

Both men and women undertake physical activity for a number of reasons but the most popular tend to be an attempt to become fitter and/or lose weight and body fat (Prichard & Tiggemann, 2008; Vartanian, Wharton, & Green, 2012). Although an improvement in cardiovascular fitness is more important than changes in physical looks (Gaesser, 2017), appearance can become more important for women (Strelan, Mehaffey, & Tiggemann, 2003). However, many exercise interventions do not lead to changes in physical appearance or weight (Grediagin, Cody, Rupp, Benardot, & Shern, 1995), which in turn can lead to diminished adherence to the intervention due to a lack of interest or time (Welch, McNaughton, Hunter, Hume, & Crawford, 2009). However, it has been reported that it is more difficult for women to reduce their body weight compared to men (Gleim, 1993).

Women tend to have a lower energy expenditure for a given task compared to men as women typically have smaller body sizes, less fat-free mass and lower resting metabolic rates (Pollock et al., 1998; Westerterp, 1998). Therefore, it is important to develop exercise interventions and programmes that will produce health benefits in a safe and efficient manner for women which may bring about satisfying changes in body composition which may increase adherence to exercise. Additionally, it is important to educate the individual that many health benefits are difficult to visualize and being fit while still overweight is more beneficial than being leaner but unfit (O'Donovan, Kearney, Sherwood, & Hillsdon, 2012). This may further increase the individual’s motivation and adherence to exercise. To further sustain compliance, it seems wise to bring about health benefits in the most time-efficient but safest way possible.

1.8 Moderate-intensity continuous training (MICT)

Traditionally, MICT performed between 50-70% of maximal HR (HR_{max}) for 30-60 min has been recommended as a sufficient and effective strategy to improve the physical activity levels of individuals who are not meeting the recommended physical activity guidelines. This recommendation is underpinned by an abundance of literature which has suggested that, when performed for a sufficient duration, regular MICT can improve clinically relevant risk factors associated to NCDs (Ciolac et al., 2010; Kelley, Kelley, & Tran, 2004; Kong, Fan, et al., 2016; Mohr, Nordsborg, et al., 2014; Moreira, Souza, Schwingel, Sa, & Zoppi, 2008; Trapp, Chisholm, Freund, & Boutcher, 2008). However, one of the most commonly cited barriers to meeting the recommended physical activity guidelines is a lack of time (Trost, Owen, Bauman, Sallis, & Brown, 2002; Welch et al., 2009), something which conflicts with the use of MICT exercise to induce health benefits for the individual. Accordingly, more time-efficient exercise strategies to evoke health improvements have been recommended, developed and analysed extensively over the last ten years (Gibala, Little, Macdonald, & Hawley, 2012).

1.9 High-intensity interval training (HIIT)

Interestingly, previous studies have reported HIIT and sprint-interval training (SIT) to be equivalent and in some cases superior to MICT in providing improvements of health markers related to NCDs (Gibala et al., 2012; Hood, Little, Tarnopolsky, Myslik, & Gibala, 2011; Wisloff, Ellingsen, & Kemi, 2009). HIIT encompasses repeated (~10) short bouts (~60 s) of near maximal (80-100% of HR_{max}) exercise interspersed with short periods (~60 s) of rest or active recovery. Additionally, SIT encompasses repeated (4-6) short bouts (~30 s) of workloads greater than what is required to elicit 100% of $\dot{V}O_{2max}$ interspersed with short periods (~2 min) of rest or active recovery (Gibala, Gillen, & Percival, 2014; K. S. Weston, Wisloff, & Coombes, 2014). While HIIT may be time efficient and, in some case, advantageous to MICT for some health markers, it is argued that some HIIT protocols may be unsuitable for inactive individuals (Francois & Little, 2015). Despite these concerns, several studies have reported significant improvements in health markers in clinical populations (T2D and heart failure patients) following HIIT with minimal adverse effects (Little et al., 2011; Wisloff et al., 2007). In addition, longer intervals or strict work rates used in some HIIT protocols allow minimal variation in session intensity which may adversely impact participant enjoyment and adherence (Foster et al., 2015; Kong, Fan, et al., 2016; Trapp et al., 2008). On the other hand, there are reports of HIIT being more enjoyable than MICT exercise (Bartlett et al., 2011). Another issue that arises from laboratory based exercise protocols is the ease with which the general public can replicate certain protocols outdoors, in their own homes or at a fitness centre. Even less is known about the potential of HIIT on health related markers when participants are allowed to self-select their exercise intensities, as would typically occur if exercising outdoors, in their own homes or fitness centres. Since allowing inactive individuals to self-select their exercise intensity during MICT leads to improvements in affective and perceptual responses (Dasilva et al., 2011), self-paced exercise training interventions might be superior in the longer term, provided they can elicit comparable health benefits to carefully controlled laboratory studies.

Previous research employing SIT and HIIT for improving health related markers has mainly been carried out on healthy, active or recreationally active individuals (Astorino, Allen, Roberson, & Jurancich, 2012; Babraj et al., 2009; Bayati, Farzad, Gharakhanlou, & Agha-Alinejad, 2011; Burgomaster et al., 2007; Burgomaster et al., 2008; Burgomaster, Hughes, Heigenhauser, Bradwell, & Gibala, 2005; Gibala et al., 2006; Gunnarsson & Bangsbo, 2012; Hazell, Hamilton, Olver, & Lemon, 2014; MacDougall et al., 1998; Nalcakan, 2014; Rakobowchuk et al., 2008; Richards et al., 2010). On the other hand, fewer studies have examined the use of HIIT on inactive individuals with increased weight (Astorino et al., 2012; Heydari, Freund, & Boutcher, 2012; Sandvei et al., 2012; Tjonna et al., 2008; Trilk, Singhal, Bigelman, & Cureton, 2011; Whyte, Gill, & Cathcart, 2010) and even fewer have examined only female participants. Therefore, the optimal exercise prescription methods for women remains unclear. This is important because, as previously mentioned, women are less physically active than their male counterparts with middle-aged women being particularly susceptible to developing NCDs and co-morbidities (M. A. Ribeiro et al., 2014; Townsend, Bhatnagar, et al., 2015).

Other forms of high-intensity interval training

Cycling and running are two of the most popular modes of exercise used when undertaking HIIT but short bouts of high-intensity activity can be found in team sports such as recreational football (M. T. Pedersen, Randers, Skotte, & Krustrup, 2009). Recreational football has been successfully implemented for use with inactive men and women which has led to a number of health benefits (Krustrup & Bangsbo, 2015). Previous research employing 12-16 wks of 1 h recreational football sessions completed twice-weekly has been shown to improve a number of health markers for both inactive men (Andersen, Randers, et al., 2010; Krustrup, Christensen, et al., 2010; Krustrup et al., 2009; Randers, Nielsen, et al., 2010) and women (Andersen, Hansen, et al., 2010; Bangsbo et al., 2010; Barene, Krustrup, Jackman, Brekke, & Holtermann, 2014; Helge et al., 2010; Krustrup, Hansen, Andersen, et al., 2010; Krustrup, Hansen, Randers, et al., 2010; M. T. Pedersen et al., 2009) with little or no previous experience of participation in football. However, it is unclear whether recreational football with a shorter time commitment is similarly effective at improving health markers.

Home-based exercise

While HIIT and SIT are effective at enhancing health in different population groups, it should be acknowledged that these exercise modalities are commonly undertaken in an exercise environment in which certain individuals may not feel comfortable and confident to undertake the activity on their own in front of other people such as in a fitness centre environment (Pridgeon & Grogan, 2012; Yin, 2001). This is particularly the case for inactive overweight women (Ball, D, & Owen, 2000). Furthermore, issues such as transport, work, family and/or childcare commitments may also prevent women from participating in pre-arranged exercise programmes away from home (Welch et al., 2009). Therefore, providing home-based moderate- to high-intensity exercise sessions may provide an alternative choice for those individuals who are unable to exercise away from home or would prefer to exercise on their own, in a familiar and safe environment. In turn this could positively impact women's ability to meet recommended physical activity guidelines and, subsequently, their overall health profile.

1.10 Thesis rationale

Based on the literature cited above, it is clear that further research is required to increase participation in, and adherence to, physical activity for inactive premenopausal women. Indeed, given that 34-39 % of women aged between 25-54 y in the UK are not achieving the recommended minimum amount of physical activity (Townsend, Wickramasinghe, et al., 2015), and given that inactive premenopausal women are at a higher risk of NCD morbidity compared to their male counterparts (Parker, Kalasky, & Proctor, 2010), the development and implementation of exercise interventions with high compliance and proven health benefits is required. Since inactive premenopausal women often cite a 'lack of time' for their physically inactive lifestyle, the development of time-efficient interventions to improve health outcomes appears to be particularly pertinent for this population. However, it is also of importance to compare contemporary time-efficient exercise strategies to more traditional prolonged continuous exercise training interventions to ensure comparable or greater health benefits in the former compared to the latter. Therefore, this thesis investigated the potential health benefits of time-efficient high-intensity exercise modalities against their more traditional moderate-intensity counterparts on health markers related to NCDs for previously inactive premenopausal women. This knowledge may help inform exercise prescription guidelines to enhance the adherence to, and health benefits elicited from, physical exercise in previously inactive premenopausal women.

Chapter 2

Literature Review

2.1 Introduction

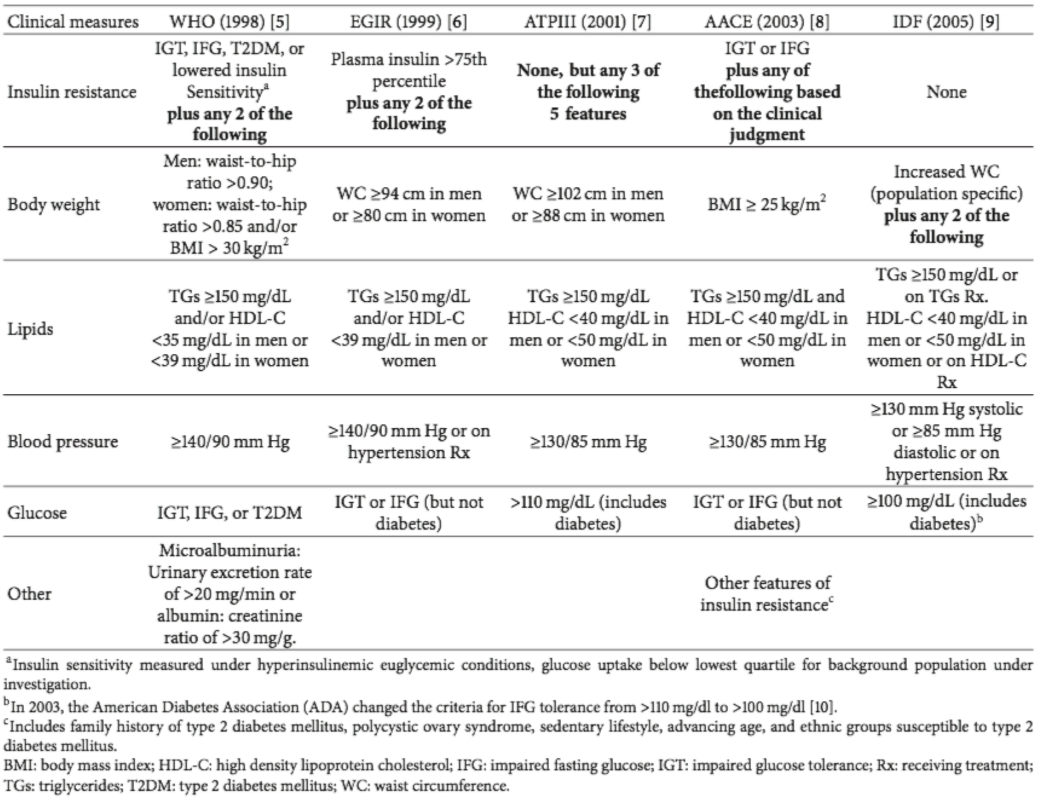
The following section provides a rationale and foundation for this thesis. This section begins with an overview of the health consequences related to physical inactivity and the potential underpinning mechanisms, with particular emphasis on premenopausal women. This is followed by a review of the barriers to satisfying the physical activity guidelines and how moderate-intensity training may help prevent and treat NCD risk factors attributable to physical inactivity. Finally, this section will provide a thorough review on the potential for shorter duration but higher intensity intermittent exercise to elicit comparable, or sometimes greater, health outcomes for premenopausal women in a more time-efficient manner.

2.2 Physical inactivity and risk factors for non-communicable diseases

2.2.1 Metabolic Syndrome

The metabolic syndrome (MetS) is a clustering of complications that can directly increase the risk of T2D, CVD and all-cause mortality (Atlantis et al., 2009). The International Diabetes Federation (IDF) estimates that around 25 % of the world's adult population have the MetS (International Diabetes Federation, 2006) and 25% of the European population have the MetS (Grundy, 2008). The most commonly used criteria for defining and diagnosing the MetS used by the IDF and other groups around the world are summarised in Table 2.1. The criteria are based on co-morbidities which include obesity, glucose intolerance, atherogenic dyslipidaemia, hypertension, and proinflammatory and prothrombotic states (Kaur, 2014). Although men and women share most classic health profile risk factors related to physical inactivity, it should be noted that the criteria for diagnosing the MetS from its constituents is sex-specific (Regitz-Zagrosek, Lehmkuhl, & Mahmoodzadeh, 2007) and will be covered in the sections below.

Table 2.1 Criteria for diagnosis of the Metabolic Syndrome.



Clinical measures	WHO (1998) [5]	EGIR (1999) [6]	ATPIII (2001) [7]	AACE (2003) [8]	IDF (2005) [9]
Insulin resistance	IGT, IFG, T2DM, or lowered insulin Sensitivity[a] **plus any 2 of the following**	Plasma insulin >75th percentile **plus any 2 of the following**	**None, but any 3 of the following 5 features**	IGT or IFG **plus any of thefollowing based on the clinical judgment**	None
Body weight	Men: waist-to-hip ratio >0.90; women: waist-to-hip ratio >0.85 and/or BMI > 30 kg/m^2	WC ≥94 cm in men or ≥80 cm in women	WC ≥102 cm in men or ≥88 cm in women	BMI ≥ 25 kg/m^2	Increased WC (population specific) **plus any 2 of the following**
Lipids	TGs ≥150 mg/dL and/or HDL-C <35 mg/dL in men or <39 mg/dL in women	TGs ≥150 mg/dL and/or HDL-C <39 mg/dL in men or women	TGs ≥150 mg/dL HDL-C <40 mg/dL in men or <50 mg/dL in women	TGs ≥150 mg/dL and HDL-C <40 mg/dL in men or <50 mg/dL in women	TGs ≥150 mg/dL or on TGs Rx. HDL-C <40 mg/dL in men or <50 mg/dL in women or on HDL-C Rx
Blood pressure	≥140/90 mm Hg	≥140/90 mm Hg or on hypertension Rx	≥130/85 mm Hg	≥130/85 mm Hg	≥130 mm Hg systolic or ≥85 mm Hg diastolic or on hypertension Rx
Glucose	IGT, IFG, or T2DM	IGT or IFG (but not diabetes)	>110 mg/dL (includes diabetes)	IGT or IFG (but not diabetes)	≥100 mg/dL (includes diabetes)[b]
Other	Microalbuminuria: Urinary excretion rate of >20 mg/min or albumin: creatinine ratio of >30 mg/g.			Other features of insulin resistance[c]	

[a] Insulin sensitivity measured under hyperinsulinemic euglycemic conditions, glucose uptake below lowest quartile for background population under investigation.

[b] In 2003, the American Diabetes Association (ADA) changed the criteria for IFG tolerance from >110 mg/dl to >100 mg/dl [10].

[c] Includes family history of type 2 diabetes mellitus, polycystic ovary syndrome, sedentary lifestyle, advancing age, and ethnic groups susceptible to type 2 diabetes mellitus.

BMI: body mass index; HDL-C: high density lipoprotein cholesterol; IFG: impaired fasting glucose; IGT: impaired glucose tolerance; Rx: receiving treatment; TGs: triglycerides; T2DM: type 2 diabetes mellitus; WC: waist circumference.

Source: Kaur (2014).

2.2.2 Overweight and obesity

Obesity is a multi-factorial condition which essentially develops as an individual's energy expenditure is consistently lower than their energy intake producing an energy imbalance leading to an accumulation of excess body fat (Papas et al., 2007). This is an issue as an elevated body weight has been associated with a number of diseases and metabolic abnormalities such as insulin resistance, T2D, hypertension, dyslipidaemia, CHD, musculoskeletal issues and psychological disorders (Pi-Sunyer, 2002; Slentz, Houmard, & Kraus, 2009). For example, follow-up data collected from the original 5209 participants of the Framingham Heart Study over 44 y, revealed that the age-adjusted RR for CVD was respectively increased by 21 % (RR 1.21, 95 % CI, 1.05 to 1.40) and 20 % (RR 1.20, 95 % CI, 1.03 to 1.41) in overweight men and women, and 46 % (RR 1.46, 95 % CI, 1.20 to 1.77) and 64 % (RR 1.64, 95 % CI, 1.37 to 1.98) in obese men and women, compared to stable weight individuals. RR is the ratio of the probability of an event occurring in an exposed group to the probability of the event occurring in a non-exposed group.

Although the occurrence of overweight and obesity could simply prevail because individuals are eating more, weight gain has routinely been shown to be highest in those individuals who are physically inactive or who become inactive. For example, Haapanen, Miilunpalo, Pasanen, Oja, and Vuori (1997) followed 2,695 women and 2,564 men over a 10 y period and concluded that the men and women who undertook no regular weekly exercise at the end of the follow-up had an odds ratio of 2.59 (95 % confidence interval (CI), 1.69 to 3.97) and 2.67 (95 % CI, 1.65 to 4.32), respectively, for a clinically significant body mass gain in comparison with the most active groups. This has led to many developed countries being termed as having an "obesogenic" environment (Lake & Townshend, 2006). In contrast, weight loss has been observed to lower the severity of CHD risk factors. For example, in the study by Eilat-Adar, Eldar, and Goldbourt (2005), a weight loss of 4.5 kg over 6 months was associated with a 43 % reduction in the risk-factor-adjusted odds ratio for CHD (odds ratio 0.57, 95 % CI, 0.39 to 0.84).

BMI is one method to help define the terms overweight and obesity and helps classify the severity of the condition. BMI expresses total body mass with respect to height and is calculated as:

$$\text{BMI (kg/m}^2\text{)} = \text{total body mass (kg) / height (m}^2\text{)} \qquad \text{(Equation 1.1)}$$

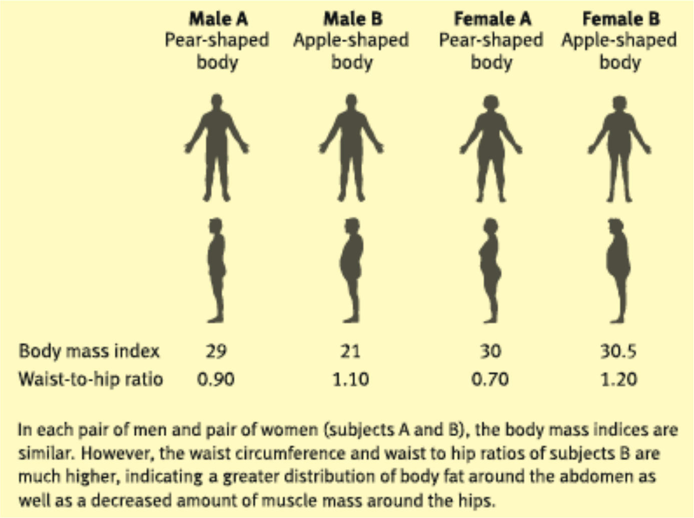
Table 2.2 highlights the international classification of overweight and obesity. BMI provides a quick and simple measure of adiposity. However, the use of BMI as a diagnostic tool for moderate obesity and leaner individuals has been questioned as it is unable to differentiate between lean mass and fat mass which can lead to misclassification (Romero-Corral et al., 2006; Romero-Corral et al., 2008). Studies which incorporate magnetic resonance imaging (MRI) are used as the reference method for measuring whole-body and regional adipose tissue volumes *in vivo* (Ross et al., 1994). However, this process can be time-consuming and costly. Further detail of body fat measurements used within this thesis are described in detail within the methods section.

Table 2.2 International classification of overweight and obesity. Adapted from World Health Organization (2017)

Classification	**BMI (kg/m^2)**	
	Principal cut-off points	**Additional cut-off points**
Underweight	**<18.50**	**<18.50**
Severe thinness	<16.00	<16.00
Moderate thinness	16.00 - 16.99	16.00 - 16.99
Mild thinness	17.00 - 18.49	17.00 - 18.49
Normal range	**18.50 - 24.99**	**18.50 - 22.99** **23.00 - 24.99**
Overweight	**≥25.00**	**≥25.00**
Pre-obese	25.00 - 29.99	25.00 - 27.49 27.50 - 29.99
Obese	**≥30.00**	**≥30.00**
Obese class I	30.00 - 34.99	30.00 - 32.49 32.50 - 34.99
Obese class II	35.00 - 39.99	35.00 - 37.49 37.50 - 39.99
Obese class III	≥40.00	≥40.00

BMI: body mass index.

It is apparent that not all obese individuals have the same risk of developing features of the MetS (Lafontan & Berlan, 2003). The distribution of fat (even within a normal BMI range) plays a major role in the appearance of health risks with visceral fat, the fat stored within the abdominal cavity, more closely associated with metabolic and cardiovascular problems compared to lower-body adipose tissue (Lafontan & Berlan, 2003; Pi-Sunyer, 2002). Problems seem to occur when intra-abdominal fat becomes used as fat storage (Figure 2.1) and excessive amounts of cytokines (adipokines) such as leptin, adiponectin, resistin, interleukins and tumour necrosis factor alpha are secreted by an expanded intra-abdominal fat mass (Han & Lean, 2015).



In each pair of men and pair of women (subjects A and B), the body mass indices are similar. However, the waist circumference and waist to hip ratios of subjects B are much higher, indicating a greater distribution of body fat around the abdomen as well as a decreased amount of muscle mass around the hips.

Figure 2.1 Variation in human body fat distribution in men and women. Reproduced from Han and Lean (2015) with permission.

Although women tend to have a higher body fat percentage compared to men, partly due to the presence of oestrogen, premenopausal women appear to accumulate more peripheral adiposity and gluteal fat, which may provide a relatively safe lipid reservoir for excess energy (Karastergiou, Smith, Greenberg, & Fried, 2012). However, for those individuals who are inactive, women are more likely to accumulate fat at a faster rate than their male counterparts as males are more likely to have a greater percentage of muscle mass compared with fat mass which contributes to a higher resting and total energy expenditure (R. L. Williams, Wood, Collins, & Callister, 2015). Therefore, given that men and women store fat at different rates and in different areas, some body composition results need to be treated with caution.

Given the rising rate and unfavourable health consequences of obesity, low-cost prevention measures are still urgently required (Papas et al., 2007). The most common method to evoke a negative energy balance for weight loss or weight maintenance is diet with women more likely to control their body weight by means of dieting rather than exercise (Kiefer, Rathmanner, & Kunze, 2005). However, dieting does not provide a long-term solution as weight loss through dieting is eventually regained (Sumithran & Proietto, 2013). Conversely, individuals are able to increase their physical activity levels, the only component on the energy expenditure side of the energy balance equation which is under voluntary control. The difficulty is determining how much additional physical activity is required for weight loss to reduce health risks.

It is apparent that there is a requirement to find a weight loss programme that works effectively for inactive premenopausal women. It has been reported that a weight loss of between 5 and 10 % of baseline weight is sufficient to reduce health risks (Wing et al., 2011). Cost-effective exercise interventions, if adhered to, have shown positive changes in adiposity in overweight premenopausal women following MICT (Keating et al., 2014) and HIIT (Boutcher, 2011). However, it is still debated what type of training is more favourable for abdominal weight loss. This will be discussed in further detail in later sections of the thesis.

2.2.3 Cardiorespiratory fitness

Cardiorespiratory fitness, commonly assessed by measuring the $\dot{V}O_{2max}$ during an incremental exercise test to volitional exhaustion, is an important health metric that has been proposed to be an independent and strong, if not stronger, predictor of mortality relative to other established risk factors such as hypertension, smoking, high cholesterol and T2D (Arena & Cahalin, 2014; Myers et al., 2002; Ross et al., 2016).

Although cardiorespiratory fitness is partly determined by genetic factors (~50 %), with an observed decline in $\dot{V}O_{2max}$ of 5-10% per decade of life among untrained individuals (Fleg et al., 2005), it is also determined by environmental factors (~50 %) such as physical activity (Bouchard et al., 1999). For example, in a cohort of 10,224 men and 3120 women from the Aerobics Centre Longitudinal Study followed for 8 y, Blair et al. (1989) demonstrated that those individuals in the lowest quintiles of physical fitness, had a 140 % (RR 2.4, 95 % CI, 2.0-5.8) and 270 % (RR 3.7, 95 % CI, 2.2 to 9.8) increased risk of death from any cause compared with the top quintile for fitness in men and women. Fitness was assessed by time to exhaustion in a treadmill test with treadmill-time quintiles determined for each age and sex group. In absolute terms, men showed a greater decline in $\dot{V}O_{2max}$ but when expressed in relative terms the sex difference disappeared (Zoeller, 2008). In addition, findings reported from a meta-analysis of over 103,000 men and women demonstrated that those individuals in the lowest fitness category had a 70 % higher all-cause (RR 1.70, 95 % CI, 1.51-1.92) and 56 % higher CVD (RR 1.56, 95 % CI, 1.39-1.75) mortality rate compared to those in the highest fitness category (Kodama et al., 2009).

Following an increase in cardiorespiratory fitness, it has been demonstrated that a large proportion of the lowered risk of all-cause mortality is attributable to a reduction in the risk of CVD mortality (C. D. Lee, Blair, & Jackson, 1999; D. C. Lee et al., 2011) even in populations who already present with other risk factors for CVD such as overweight and obesity (C. D. Lee et al., 1999), hypertension (Sui, LaMonte, & Blair, 2007), diabetes (Church, LaMonte, Barlow, & Blair, 2005), and smoking (C. D. Lee & Blair, 2002). This is important as the meta-analysis of Kodama et al. (2009) reported that a 1-MET higher level of $\dot{V}O_{2max}$ was associated with a 13% (RR 0.87, 95 % CI, 0.84 to 0.90) and 15% (RR 0.85, 95 % CI, 0.82-0.88) decrease in risk of all-cause mortality and CVD, respectively, which is similar to the 17 % decrease in mortality (hazard ratio 0.83, 95 % CI, 0.81 to 0.84) reported for women (54 y) (Al-Mallah et al., 2016).

From a clinical perspective, based on risk estimates of the constituents of the MetS according to the National Cholesterol Education programme (NCEP, 2002), a 1-MET increment in $\dot{V}O_{2max}$ translates to a decrease of 7 cm, 5 mmHg, 1 mmol/L and 1 mmol/L in waist circumference (de Koning, Merchant, Pogue, & Anand, 2007), systolic BP (Lewington et al., 2002), triglyceride (TG) level (in men) (Hokanson & Austin, 1996) and fasting plasma glucose (Coutinho, Gerstein, Wang, & Yusuf, 1999), respectively, and an increase of 0.2 mmol/L in HDL cholesterol (D. J. Gordon et al., 1989).

Large longitudinal studies have shown that previously sedentary and inactive individuals can improve their $\dot{V}O_{2max}$ following a period of aerobic training (Garber et al., 2011; Wenger & Bell, 1986). However, the beneficial effects of regular exercise may depend on the intensity and amount of work performed during training (Kemi et al., 2005; Kessler, Sisson, & Short, 2012; Swain & Franklin, 2002), factors which are discussed in further detail later on.

2.2.4 Impaired glucose tolerance and insulin resistance

Impaired glucose tolerance is a pre-diabetic state of hyperglycaemia between normal glucose tolerance and diabetes (Table 2.3), where insulin is unable to control hepatic glucose uptake and influence glucose in adipose tissue and skeletal muscle (Eckel, 2007).

Table 2.3 Diagnostic criteria for normal glucose tolerance, impaired fasting glucose/impaired glucose tolerance and diabetes mellitus. Adapted from American Diabetes (2015)

	Fasting plasma glucose (mmol/l)	**2 hr post 75g oral glucose tolerance test (mmol/l)**
Normal glucose tolerance	<6.1	<7.8
Impaired fasting glucose/impaired glucose tolerance	≥ 6.1 to 7.0	7.8 < 11.1
Diabetes mellitus	≥ 7.0	≥ 11.1

In the presence of elevated glucose levels, insulin is secreted to restore blood nutrient homeostasis through the coordination of several multi-tissue metabolic processes. In skeletal muscle, insulin stimulates glucose uptake, oxidation and glycogen synthesis (Wilcox, 2005). Insulin also aids endothelial cells to stimulate nitric oxide and endothelin-1 production, adjust blood flow dynamics and enhance its own delivery to each of these tissues (Barrett, Wang, Upchurch, & Liu, 2011). A chronic increase in insulin leads to insulin resistance which is defined by Park et al. (2005) as a fasting insulin level ≥ 9.98 μIU/ml or a Homeostatic Model Assessment (HOMA-IR) ≥ 2.56. The development of insulin resistance is a strong predictor of the future development of T2D including microvascular and macrovascular damage (DeFronzo & Tripathy, 2009). Insulin resistance is considered one of the earliest mechanisms of the MetS as it has been found in young adults free of other metabolic abnormalities such as dyslipidaemia, high BP, high fasting blood [glucose], and obesity (Dvorak, DeNino, Ades, & Poehlman, 1999).

Compared with individuals with no T2D, insulin resistance has been associated with a 250 % (RR 3.50, 95 % CI, 2.70 to 4.53) greater relative cardiovascular risk in women and 106 % in men (2.06, 95 % CI, 1.81 to 2.34), respectively, and it was concluded that the relative risk for cardiovascular complications associated with diabetes was 50 % higher in women compared to men (Huxley et al., 2006). The effectiveness of insulin's action can be characterised in terms of insulin sensitivity and insulin responsiveness. Insulin sensitivity relates to the [insulin] needed to provoke a half-maximal metabolic effect whereas insulin responsiveness describes the magnitude of the effect that is induced by the insulin concentration that is maximally effective (Holloszy, 2005).

The ‘gold standard’ technique for the measurement of insulin secretion and resistance is by using the hyperinsulinemic euglycaemic clamp technique (DeFronzo, Tobin, & Andres, 1979) which is a direct method of insulin infusion. However, indirect methods that measure insulin concentration such as HOMA-IR, fasting glucose/insulin ratio, and quantitative insulin sensitivity check index (QUICKI) have been used due to their less invasive, relatively easy administration. These methods have shown good correlation to the hyperinsulinemic euglycemic clamp (Lorenzo et al., 2010; D. R. Matthews et al., 1985; Quon, 2001). The HOMA-IR model was developed in 1985 and has been widely used for the estimation of insulin resistance within epidemiological and clinical studies due to its ease of measurement of fasting glucose and fasting insulin concentrations (D. R. Matthews et al., 1985). The relationship between glucose and insulin at baseline reflects the balance between hepatic glucose output and insulin secretion, which is maintained by a feedback loop between the liver and pancreatic β-cells. In population studies, insulin resistance is defined as a greater or equal to the 75th percentile of the surrogate IR measure distribution in individuals without diabetes mellitus (Balkau & Charles, 1999). However, limitations do exist with using surrogate measures of insulin resistance. For example, HOMA-IR does not reflect the true function of dynamic pancreatic β-cell insulin secretion and is only a prediction of glucose-stimulated insulin secretion from fasting steady-state data (Muniyappa, Lee, Chen, & Quon, 2008). Due to the detrimental impact of insulin resistance on several diseases and metabolic disorders, there is a continued requirement to establish beneficial interventions to decrease insulin resistance.

At the metabolic and molecular levels, the causes of skeletal muscle insulin resistance are numerous and complex and one of the pathological drivers for these defects is suggested to be physical inactivity (Thyfault & Krogh-Madsen, 2011). A reduction in insulin sensitivity has repeatedly been shown following periods of complete inactivity of as little as 3 days (Alibegovic et al., 2010; Hamburg et al., 2007; Lipman et al., 1972) as well as models of reduced physical activity through a reduction in average daily step count from ~10,000/day to ~1500/day over a period of 14 days in healthy men who were recreationally active with the authors reporting a 17 % reduction in insulin sensitivity (Krogh-Madsen et al., 2010). In a 16 y follow-up, Rana, Li, Manson, and Hu (2007) reported the relative risk of adiposity compared with physical inactivity and risk of T2D in 4,030 incident cases for women. Compared to women who had a healthy weight and were physically active, the relative risk of T2D for those women who were obese and inactive was 16.75 (95 % CI, 13.99 to 20.04), 10.74 (95 % CI, 10.74 to 13.18) for those who were active but obese and 2.08 (95 % CI, 1.66 to 2.61) for those who were lean but inactive.

Increasing insulin sensitivity has been related to a decrease in the subsequent effects of obesity and chronic disease which is important for chronic disease prevention (Facchini, Hua, Abbasi, & Raven, 2001). In a large prospective study of 5990 males, each increase in 500 kcal in energy expenditure per wk was associated with a decreased incidence risk of T2D of 6 % (RR 0.94, 95 % CI, 0.90 to 0.98) (Helmrich, Ragland, Leung, & Paffenbarger, 1991). Notably, this finding was most beneficial for those individuals with a high BMI. In addition, a review of randomised controlled trials (RCTs) also concluded that modest weight loss through diet and exercise reduced the incidence of T2D among high-risk individuals by ~40-60 % over 3-4 y (Williamson, Vinicor, Bowman, Centers For Disease, & Prevention Primary Prevention Working, 2004).

It is well known that exercise enhances insulin action in overweight and obese adults, however, the exercise type, intensity and duration most beneficial for improving insulin action in previously inactive premenopausal women is still debated (Dube, Allison, Rousson, Goodpaster, & Amati, 2012; Houmard et al., 2004) and will be covered in further detail later. With the prevalence of diabetes outlined in Chapter 1, the need for insulin resistance reversal is undeniable and warrants further investigation for specific populations.

2.2.5 Lipid abnormalities

Lipoproteins and total lipids play an essential role in maintaining cardiovascular health and are of major interest with regards to vascular plaque formation and BP. The term ‘lipid profile’ describes the varying level of lipids in the blood. The lipids that are most easily and routinely measured are HDL, low-density lipoproteins (LDL), TC and TG. LDL cholesterol has a much higher TG component than HDL cholesterol (Buttar, Li, & Ravi, 2005). The IDF criteria for the MetS regarding lipid abnormalities is characterised by high TG and low HDL (Han & Lean, 2015). Table 2.4 highlights the classification of LDL, TC, and HDL cholesterol reported by the National Cholesterol Education Program (NCEP) (2002).

Table 2.4 Classification of LDL, total, and HDL cholesterol. Adapted from National Cholesterol Education Program (NCEP) (2002)

	Classification
LDL cholesterol (mmol/l)	
<2.59	Optimal
2.59 - 3.34	Near optimal/above optimal
3.35 - 4.11	Borderline high
4.12 - 4.89	High
≥4.92	Very high
Total cholesterol (mmol/l)	
<5.18	Desirable
5.18 - 6.19	Borderline high
≥6.20	High
HDL cholesterol (mmol/l)	
<1.04	Low
≥1.55	High

LDL is deposited in arterial blood vessels and, when floating freely in the vascular system, tends to have its highest atherogenicity (Buttar et al., 2005). Vascular walls of individuals with coronary artery disease and endothelial dysfunction commonly display higher lipid content than individuals with normal endothelial function (Choi et al., 2013). The deposition of LDL in the vascular walls of individuals is a concern due to its association with systemic inflammation and the formation of plaque (Buyukyazi et al., 2010). A build-up of plaque inside the artery can make it difficult for blood to flow freely and, with its continuation in growth, could lead to an artery gradually becoming blocked or a piece breaking off causing a clot that may rapidly block the artery. On the other hand, HDL has been shown to have protective cardiac benefits due to its role in reverse cholesterol transport, collecting excess LDL that has been deposited in the vascular tissue, which is then carried back to the liver for metabolic degradation (De Nardo et al., 2014; Meagher, 2004). Increased HDL has also been associated with enhanced mitochondrial ATP synthesis and glucose uptake implicating its role in muscle mitochondrial metabolism, glucose homeostasis and fat oxidation (Lehti et al., 2013). Maintaining a balanced blood lipid profile is clinically important in minimising the formation of arterial blood vessel plaques and thrombi (Buttar et al., 2005).

Men have been shown to have a less favourable lipid profile compared to age-matched women between 20 and 50 y as expressed by higher plasma LDL and lower HDL partly due to the greater rate of lipoprotein transport in women (Despres et al., 2000). Plasma HDL levels are higher in women than in men by 0.3 mmol/l with an average concentration of 1.2 mmol/l in men and 1.4 mmol/l in women (Knopp et al., 2005). However, when accompanied by obesity and diabetes, greater lipoprotein abnormalities are found in women (Knopp et al., 2005). There is strong evidence that increased cholesterol is associated with an increased risk of ischaemic heart disease (IHD). For example, Yarnell et al. (2001) measured fasting TG, TC and HDL in 4362 men (45-63 y) and monitored them over 10 y. It was concluded that the highest observed incidence of IHD (22.6 %) was found in the group with the highest risk category for all three lipids (high TG and TC and low HDL) with 4.7 % incidence in the group with the lowest expected risk. This highlights the need for quality interventions aimed at reducing cholesterol levels.

Previous studies have reported that a 0.6 mmol/L reduction in serum cholesterol can reduce the incidence of IHD by 54 % (RR 0.46, 95 % CI, 0.38 to 0.55) at the age of 40 y (Law, Wald, & Thompson, 1994). In addition, analyses from the Prospective Studies Collaboration on almost 900,000 individuals and over 33,000 coronary deaths demonstrated that, in both men and women (40-49 y) a 1 mmol/L lowering of TC was associated with about a half (hazard ratio 0.44, 95 % CI, 0.42 to 0.48) lower IHD mortality (Lewington et al., 2007). Furthermore, a meta-analysis of 14 randomised clinical trials of statins reported that a reduction of 1.0 mmol/L in LDL can decrease the risk of major vascular events by 21% (RR 0.79, 95 % CI, 0.77 to 0.81) (Baigent et al., 2005). However, it is known that statins can compromise skeletal muscle function (Parker et al., 2013) so alternative methods for improving the blood lipid profile of the individual are clearly warranted.

There is some evidence from meta-analysis to support aerobic exercise in improving TC (2 %), HDL (2-3 %), LDL (3 %) and TG (5-9 %) (Kelley & Kelley, 2006; Kelley et al., 2004). Buttar et al. (2005) attempted to show the effects of exercise on blood lipid profiles by summarising the results from several studies, concluding that routine exercise (3-5 days per wk) markedly lowers the amount of LDL (up to 0.3 mmol/l) and increases HDL (up to 0.1 mmol/l). However, the studies summarised varied in gender, age and exercise type and intensity undertaken which make it difficult to extrapolate recommendations for premenopausal women. More specifically, Kraus et al. (2002) have shown improvements in the lipid profile of sedentary men and women (aged 40 to 65) but results were related to the amount of exercise undertaken irrespective of the exercise intensity. It is still unclear whether exercise intensity or duration provokes the most beneficial change in lipid profile in inactive premenopausal women which warrants further investigation and will be covered in more detail later on.

2.2.6 Cell adhesion molecules

The normal endothelium maintains vasodilatory properties of arteries, regulates vascular homeostasis, and inhibits inflammation, cell adhesion and intravascular coagulation (Anderson, 1999). When exposed to disturbances in endothelial shear stress, biomechanical forces from hypertension and the presence of other cardiovascular risk factors, the endothelium loses its normal cardioprotective properties. Endothelial dysfunction is associated with metabolic disease and is considered one of the earliest pathophysiological processes in the progression to atherosclerosis (Cassidy, Thoma, Houghton, & Trenell, 2017).

This early phase of atherosclerosis involves the recruitment of inflammatory cells from the circulation and their transendothelial migration. This process is predominantly mediated by cell adhesion molecules, which are expressed on the vascular endothelium and on circulating leukocytes in response to several inflammatory stimuli (Blankenberg, Barbaux, & Tiret, 2003).

Two markers of endothelial dysfunction that have been shown to predict CVD in healthy populations (Mulvihill, Foley, Crean, & Walsh, 2002) and various settings of disease (N. G. Chen, Azhar, Abbasi, Carantoni, & Reaven, 2000; Kim, Montagnani, Koh, & Quon, 2006) include soluble intracellular cell adhesion molecule 1 (sICAM-1) and soluble vascular cell adhesion molecule 1 (sVCAM-1) (Weyer et al., 2002), which are mediators of platelet rolling and cell attachment (Marsh & Coombes, 2005). sICAM-1 is widely expressed at a basal level and can be up-regulated by pro-inflammatory cytokines in leukocytes and endothelial cells (Blankenberg et al., 2003). sICAM-1 mediates adhesion of leukocytes to activated endothelium by establishing strong bonds with integrins and inducing a firm arrest of inflammatory cells at the vascular surface and contributes in leukocyte extravasation (Blankenberg et al., 2003). sVCAM-1 is transcriptionally induced on endothelial cells but can also be expressed by other cell types such as macrophages and myoblasts with sVCAM-1 contributing to the recruitment of blood cells by activated endothelium and promoting firm adhesion (Blankenberg et al., 2003).

Levels of soluble adhesion molecules have also been shown to correlate to other cardiovascular risk factors such as hypertension (DeSouza, Dengel, Macko, Cox, & Seals, 1997; Preston et al., 2002), low HDL cholesterol (Calabresi et al., 2002), hypercholesterolemia (Hackman et al., 1996) and hypertriglyceridemia (Abe et al., 1998). In 28, 263 postmenopausal women, Ridker, Hennekens, Buring, and Rifai (2000) reported that the RR of cardiovascular events for women with the highest baseline plasma levels of sICAM-1 as compared with the lowest was 2.6 (95 % CI, 1.3 to 5.1). In addition, Hwang et al. (1997) reported that the level of sICAM-1 was a significant predictor of incident CHD with the odds of incident CHD increased by 1.88 (95 % CI, 1.41 to 2.50) for each standard deviation (SD) increase in sICAM-1 level compared to control subjects. It is assumed that exposure to endogenous oestrogens during the fertile period of life delays the manifestation of atherosclerotic disease in women (Thomassen, Christensen, Gunnarsson, Nybo, & Bangsbo, 2010). However, signs of atherosclerosis can already be found in women before menopause especially in the presence of several other CHD risk factors (Sutton-Tyrrell et al., 1998). Therefore, effective interventions are still required for inactive premenopausal women.

It is well known that aerobic exercise training has a preventive effect on atherosclerosis (Green, 2009; Thijssen et al., 2010), thus, exercise interventions targeting an improvement in endothelial function are clearly warranted for inactive women approaching the menopause period. However, there is still conflicting evidence as to whether MICT or HIIT training is more beneficial for the improvement in endothelial function (Schjerve et al., 2008; Tjonna et al., 2008; Wisloff et al., 2007) which will be discussed in further detail below.

2.2.7 Hypertension

With regard to BP, systolic/diastolic readings of 120/80 mmHg are considered normal. However, the more constricted or narrow a blood vessel becomes, the greater the resistance produced on blood flow and the higher the BP. If BP readings consistently exceed these values and remain around 140/90 mmHg, a person is considered to have hypertension (Table 2.5) (Chobanian et al., 2003).

Table 2.5 Classification of blood pressure for adults. Adapted from Chobanian et al. (2003)

Systolic mmHg	Diastolic mmHg	Classification
<120	and <80	**Normal**
120-139	or 80-89	**Prehypertension**
140-159	or 90-99	**Stage 1 Hypertension**
≥160	≥100	**Stage 2 Hypertension**

Hypertension is frequently associated with several metabolic abnormalities including glucose intolerance, dyslipidaemia, inflammatory factors and obesity mainly of an abdominal distribution (Ferrannini & Natali, 1991; Han & Lean, 2015). Obesity can have a direct effect on haemodynamics leading to an increase in blood volume, stroke volume, and cardiac output at rest (Poirier et al., 2006) which may arise from an increase in fatty acids which influences vasoconstriction through endothelial dysfunction, an increase in oxidative stress or vascular cell growth (Tripathy et al., 2003). Vasan et al. (2001) have reported that moderate/borderline hypertension (<140/90 mmHg) causes more endothelial dysfunction and cardiovascular complications in women than in men and systolic BP has also been shown to rise more steeply in ageing women compared with men, (Burt et al., 1995; Dubey, Oparil, Imthurn, & Jackson, 2002).

Results from the Framingham Heart study have found that men and women (35-64 y) with high-normal BP at baseline examination had a higher incidence of CVD on 10 y follow-up (4 % in women and 8 % in men) with a higher risk-factor-adjusted hazard ratio for CVD found in women (2.5, 95 % CI, 1.6 to 4.1) than men (1.6, 95 % CI 1.1 to 2.2) compared with normotensives (Vasan et al., 2001). In addition, a report from the Women's Health Initiative of 60,785 postmenopausal women during a 7.7 y follow-up suggested that the risk of a myocardial infarction and stroke was increased by 76 % (hazard ratio 1.76, 95 % CI, 1.40 to 2.22) and 93 % (hazard ratio 1.93, 95 % CI, 1.49 to 2.50) for pre-hypertensives and 186 % (hazard ratio 2.86, 95 % CI, 2.28 to 3.59) and 262 % (hazard ratio 3.62, 95 % CI, 2.82 to 4.66) for hypertensives compared with normotensive women, respectively (Hsia et al., 2007). It has also been estimated that a 3.8 (95 % CI, -4.97 to -2.72) and 2.6 (95 % CI, -3.35 to -1.81) mmHg reduction in systolic and diastolic BP can reduce cardiac morbidity, stroke and all-cause mortality by 5, 8 and 14 % in the average population (Whelton, Chin, Xin, & He, 2002).

It is evident that individuals who lead an inactive life are susceptible to an increase in BP but the detrimental effects are reversible. With the large prevalence and economic burden, it is important to establish methods to reduce the risk of hypertension in premenopausal women. Increasing physical activity levels through aerobic exercise has been reported to improve resting parasympathetic activity and HR variability, which may be essential for training-induced autonomic regulation and lowering of the CVD risk (Carter, Banister, & Blaber, 2003). For example, a meta-analysis by Fagard (2006) reported significant reductions in systolic (-3 mmHg) and diastolic (-2.4 mmHg) BP following aerobic endurance training in inactive adults. Similarly, a meta-analysis performed on 53 trials for systolic BP and 50 trials for diastolic BP following aerobic exercise interventions found reductions in systolic and diastolic BP of 3.8 and 2.5 mmHg (S. P. Whelton et al., 2002). Importantly, of 3,148 healthy individuals, those who maintained or improved their fitness levels had a 26 % (RR 0.72, 95 % CI, 0.59 to 0.88) and 28 % (RR 0.72, 95 % CI, 0.59 to 0.88) lower risk of incident hypertension compared with those who lost fitness (D. C. Lee et al., 2012). Approximately 34 % of hypertension incidence could theoretically be prevented for individuals who increase their fitness from low to moderate or moderate to high (Carnethon et al., 2010).

Reduced submaximal HR and enhanced stroke volume provide further evidence of cardiovascular training adaptations (Bassett & Howley, 2000; Blomqvist & Saltin, 1983; Carter et al., 2003). MICT has been traditionally recommended for hypertension prevention and treatment. However, HIIT has more recently been suggested to be beneficial for the prevention and controlling of hypertension (Ciolac, 2012). Although there is substantial evidence supporting the ability for MICT and HIIT exercise of various durations and intensities to significantly reduce or control BP, the optimum type and amount recommended is still debated for premenopausal women.

2.2.8 Cognitive function

Ageing is accompanied by a gradual decline of the central nervous system (CNS) function (Dustman et al., 1984) as well as deteriorations in intellect, memory, attention and perception (R. Peters, 2006). Although cognitive decline is much more apparent and debilitating in older individuals, there is evidence that this decline is apparent in middle-aged adults (45-49 y) (Singh-Manoux et al., 2012). It has been suggested that decrements in cognitive function and electrophysiological activity of older individuals, such as suppressed electroencephalography (EEG) and evoked potential activity, may in part, result from the brain being mildly hypoxic. Indeed, it has been reported that reduced cerebral oxygenation and the associated decline in brain function in old age may be associated with the increasing presence of atherosclerosis and an inability to efficiently transport and utilise oxygen due to a physically inactive lifestyle (Waldstein, 2000). In addition, glucose intolerance is associated with cognitive impairments, which appear to occur in a continuum, worsening as glucose intolerance increases (Messier, Awad-Shimoon, Gagnon, Desrochers, & Tsiakas, 2011). Impaired glucose regulation, assessed indirectly, has been shown to negatively affect verbal declarative memory performance in younger (Awad, Gagnon, Desrochers, Tsiakas, & Messier, 2002; Messier et al., 2011; Messier, Desrochers, & Gagnon, 1999) and older non-diabetic participants after ingesting a glucose load and it is apparent that these deficits increase with age (Messier, Gagnon, & Knott, 1997).

Several longitudinal studies have reported that the risk of dementia, cognitive impairment, cognitive decline, and Alzheimer's disease is higher in those that live a physically inactive lifestyle compared to those engaging in regular exercise (Angevaren et al., 2007; Lista & Sorrentino, 2010). For example, Laurin, Verreault, Lindsay, MacPherson, and Rockwood (2001) assessed the association between physical activity and the risk of cognitive impairment and dementia in over 9000 individuals (65 y or older) over a 5 y period. Following adjustment for age, sex and education, high levels of physical activity were associated with reduced risks of cognitive impairment (odds ratio 0.58, 95 % CI, 0.41 to 0.83), Alzheimer's disease (odds ratio 0.50, 95 % CI, 0.28 to 0.90) and dementia of any type (odds ratio 0.63, 95 % CI, 0.40 to 0.98). Upregulation of brain-derived neurotrophic factor (BDNF) during exercise has been linked to an acute improvement in cognitive function post exercise and to chronic improvements in cognitive function via neurovascular remodelling including neuro/synaptogenesis and angiogenesis, (Hillman, Erickson, & Kramer, 2008).

Although it is widely accepted that engaging in regular exercise can offset the gradual decline in cognitive function with age by maintaining and, in some cases, enhancing multiple aspects of cognitive function, the type and duration of exercise most beneficial following chronic exercise interventions have received limited consideration. Moreover, even less consideration has been given to middle-aged premenopausal women. Consequently, the development of exercise interventions to maintain or enhance cognitive function for previously inactive middle-aged women is an important research avenue to investigate as cognitive decline is evident in middle-aged adults (Singh-Manoux et al., 2012) and is increasingly prevalent with the MetS (Yates, Sweat, Yau, Turchiano, & Convit, 2012). Examples on the effects of MICT and HIIT on aspects of cognitive function will be discussed in further detail later.

2.2.9 Mental well-being

Mental well-being is a multidimensional concept capturing hedonic, pleasant (or unpleasant) sensations and eudaimonic aspects which focuses on meaning and self-realisation of mental health and functioning (Gale, Deary, & Stafford, 2014). Maintaining positive psychological well-being is considered a crucial part of healthy ageing as having a stronger sense of well-being is represented by a reduced risk of premature mortality in a healthy population (combined hazard ratio 0.82, 95 % CI, 0.76 to 0.89) as reported in a meta-analysis of 35 studies (Chida & Steptoe, 2008). In addition, positive psychological well-being has also been associated with a reduced risk of incident CHD in a 5 y follow-up of 7,942 individuals after controlling for cardiovascular risk factors and ill-being (Boehm, Peterson, Kivimaki, & Kubzansky, 2011). For each SD increase in emotional vitality and optimism, there was a 10 % (hazard ratio 0.90, 95 % CI, 0.80 to 1.01) and 13 % (hazard ratio 0.87, 95 % CI 0.78 to 0.98) decrease in the risk of CHD.

In addition, although most variation in cognitive function is explained by age, and most variation in well-being is explained by depression, there is evidence of an association between cognitive function and well-being in older individuals with lower well-being affecting cognitive performance (Allerhand, Gale, & Deary, 2014). Having a stronger sense of purpose in life has also been associated with a reduced risk of incident Alzheimer's disease (hazard ratio 0.48, 95 % CI 0.33 to 0.69) and mild cognitive impairment (hazard ratio 0.71, 95 % CI 0.53 to 0.95) following a 7 y follow-up of 900 older individuals (Boyle, Buchman, Barnes, & Bennett, 2010). Therefore, it is of great interest to identify potentially modifiable factors associated with mental well-being at an earlier age which may help offset the risk factors outlined above and in turn protect cognitive performance against the adverse effects of lower well-being.

Physical activity is an important modifiable factor and it is evident that exercise training has a positive effect on mood and mental well-being (through reduced stress, anxiety and depression) (Black et al., 2015). For example, Black et al. (2015) investigated the associations of physical activity and mental well-being in a cohort of 930 older individuals (60-64 y) and concluded that those who walked for > 1 h per wk had mean mental well-being scores 1.47 (95 % CI, 0.60 to 2.34) points higher than those who reported no walking. This is of clinical interest as exercise training may be useful in the management of depressed individuals (Carek, Laibstain, & Carek, 2011; Craft & Perna, 2004) and may also help individuals to cope with stress more effectively (Strohle, 2009) and to recover from the adverse effects of negative life events (Roth & Holmes, 1987).

However, there is inconsistency in the form of exercise which is most beneficial for improving mental well-being which will be discussed in further detail later. As exercise adherence tends to be low for middle-aged women (McArthur et al., 2014), examining the effects of exercise on well-being might permit the development of training methods that encourage a more persistent behaviour change.

2.3 Interrelation of risk factors for health

It is apparent that physical inactivity not only places the individual at increased risk of NCD's but also places a large burden on society, which represents a major public health problem. More importantly, many of the risk factors highlighted above are interrelated and all reversible. For example, although insulin-resistant individuals are not always obese, they commonly have an abnormal fat distribution that is characterised predominantly by upper body fat (Kaur, 2014). Some research suggests that obesity is strongly associated with and is a possible causal factor of insulin resistance (Freidenberg, Reichart, Olefsky, & Henry, 1988). Furthermore, there is evidence that inflammation can lead to the development of hypertension and that oxidative stress and endothelial dysfunction are involved in the inflammatory cascade (Dinh, Drummond, Sobey, & Chrissobolis, 2014).

Therefore, lowering one risk factor could lead to the reduction in several other risk factors. This emphasises the need to develop effective strategies for the prevention and treatment of NCD's. From a public health perspective, modifiable factors that reduce the risk of mortality among inactive individuals would be of great interest. To date, the two main approaches to optimally control risk factors associated with the MetS and other NCD's are lifestyle modification and medication (Ren & Kelley, 2009). Typically, the first recommended step for the management of the MetS is lifestyle modification.

2.4 Exercise for the prevention and treatment of non-communicable diseases

A review of the literature provided by B. K. Pedersen and Saltin (2006) demonstrated how exercise can, in some cases, be just as effective as medical treatment for the prevention and treatment of NCD's. Figure 2.2 provides a model depicting the relationship between physical loading, areas of fitness and the risk of lifestyle diseases. However, the large variation in type, intensity, duration and frequency of exercise undertaken within interventional studies make it difficult to establish the most beneficial physical activity regimes to provide for inactive premenopausal women.

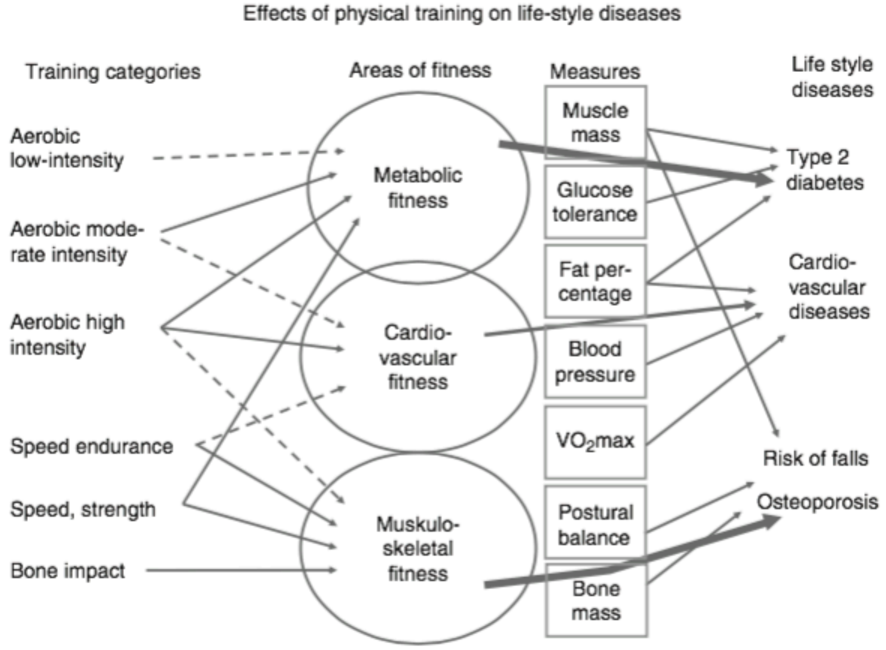


Figure 2.2 Overview of the impact of different types of training on various fitness capacities and their relationship to the risk of certain lifestyle diseases. Full lines denote comprehensive effects and/or well-known relationships. Dotted lines denote sub-optimal yet positive effects. Reproduced from Krustrup, Aagaard, et al. (2010) with permission.

2.4.1 Barriers to participation in physical activity

The risk factors to health outlined above provide a clear rationale for participating in physical activity. However, over 45 % of women are not meeting physical activity recommendations which is higher than the 33 % of men who are not meeting these guidelines (Townsend, Wickramasinghe, et al., 2015). One of the reasons reported for adults in the UK not meeting physical activity guidelines includes the lack of willingness from health care professions and the individuals themselves to look at situations where exercise prescription may be as beneficial as drug prescription (Church & Blair, 2009). In addition, lack of time due to work or family commitments is one of the most commonly cited issues preventing women from meeting physical activity recommendations (Welch et al., 2009) as well as travel and financial restrictions (Napolitano, Papandonatos, Borradaile, Whiteley, & Marcus, 2011). In addition, individuals may not have time to attend externally scheduled training which may act as a barrier to exercise. This is particularly relevant in pre-menopausal women due to work and family commitments which may impact on resources and time available to travel and attend a structured exercise programme (W. J. Brown & Trost, 2003; Sternfield, Ainsworth, & Quesenberry, 1999). This might account, at least in part, for the estimated dropout rate of 50 % within the first few months of participation in clinical trials (Dishman & Buckworth, 1996;

White, Ransdell, Vener, & Flohr, 2005). This would suggest that prescribing long duration exercise may not be the best solution for maintaining participation.

Although exercise choices could be provided based on the most important risk factors for health that need addressing, enjoyment of the activity should also be taken into consideration to sustain adherence. Therefore, focus should be placed on finding novel ways in which motivation and long-term adherence are upheld while participating in regular exercise (Hawley & Holloszy, 2009). It has recently been postulated that HIIT may offer a time-efficient alternative to high volume aerobic exercise training. However, a number of studies have demonstrated an inverse relationship between exercise intensity and adherence with participant dropout increasing with higher intensities of exercise and moderate-intensity aerobic exercise reported to be pleasurable among the majority of participating individuals (K. L. Cox, Burke, Gorely, Beilin, & Puddey, 2003; Perri et al., 2002).

A meta-analysis of interventions for increasing exercise found that participant adherence to such interventions are considerably higher when the intensity is lower (i.e., ≤50% $\dot{V}O_{2max}$) rather than higher (Dishman & Buckworth, 1996). Although the form of exercise that should be recommended is still debated, recommending a low to moderate intensity exercise programme and eventually progressing to a higher intensity programme when appropriate may be the best way forward (Guiraud et al., 2010; Rognmo, Hetland, Helgerud, Hoff, & Slordahl, 2004). However, performing exercise at a low intensity requires a substantial time commitment to improve health markers (Kong, Fan, et al., 2016). In addition, prolonged high intensity exercise is not ideal for overweight and obese individuals with cardiovascular risks which may be detrimental to adherence (Thompson, Townsend, Boughey, Patterson, & Bassett, 1998). However, short duration high-intensity training interspersed with recovery periods may prove to be of significant benefit to inactive individuals. This method of exercise is applicable to overweight, obese, healthy and fit individuals allowing them to work at intervals of higher intensity than they would otherwise be able to by incorporating recovery periods of lower intensity during the exercise workout. There is evidence that HIIT is perceived to be more enjoyable than MICT for active men (Bartlett et al., 2011) but less is known for premenopausal women.

The remainder of the literature review will focus on recommended physical activity guidelines followed by an appreciation and thorough review of the more traditional MICT, high-intensity interval/intermittent exercise and variations of this exercise training method. The health benefits, enjoyment and adherence to these interventions will also be addressed.

2.4.2 Physical activity guidelines

The current physical activity guidelines set out by the Department of Health (2011) recommend the accumulation of 150 min of moderate-intensity activity or 75 min of vigorous-intensity activity per wk. In addition, the American College of Sports Medicine (ACSM) and American Heart Association (AHA) recommend the accumulation of 150 to 250 min of moderate physical activity per wk to assist in weight loss and improve health (Donnelly et al., 2009). Physical activity undertaken is suggested to be completed in bouts of at least 10 min duration over the course of the day.

It is important to note there are no strict definitions on the duration of interventions classed as short-, medium- or long-term in the literature, therefore for the purpose of this thesis, interventions ranging from 1 to 4 wks are classed as "short-term", 1-4 months are classed as "medium-term" whilst any exceeding 4 months in length are referred to as "long-term". In addition, an abundance of previous literature is available on the acute and chronic effects of exercise training for inactive and active males. Where possible, this literature review will focus on premenopausal females who do not regularly participate in structured exercise. However, for comparative reasons other populations of interest may be discussed.

2.4.3 Moderate-intensity continuous training

MICT is characterised by a constant physical activity at a submaximal intensity in which the body's physiological processes achieve a steady state and there are no intermittent breaks within the exercise session. MICT involves exercising at around 50-70 % of maximal HR_{max} or 60-65 % of $\dot{V}O_{2max}$ and is routinely recommended to novice exercisers or older individuals (Achten, Gleeson, & Jeukendrup, 2002). Cross-sectional and interventional studies have repeatedly shown that MICT can improve risk factors for NCD's in men and women (Houmard et al., 2004) which will be outlined below with regards to several risk factors to health.

2.4.3.1 Body composition

After reviewing the literature summarised in Table 2.6, it is apparent that improvements in body composition, including reductions in total body mass (3 %), BF % (3-5 %) and android (3 %) and gynoid (2-3 %) fat, as well as increases in lean mass, have been reported for overweight and obese women following moderate-intensity walking and continuous cycling performed for 30-50 min, 3-4 times weekly for 8-12 wks (Sawyer et al., 2016; Schjerve et al., 2008; Wallman, Plant, Rakimov, & Maiorana, 2009). On a few occasions, reductions in total body mass (2 %), BF% (3-7 %) and waist (2 %) and hip (1 %) measurements and an increase in lean mass (1 %) have also been reported for sedentary (inactive) women with a lower baseline bodyweight (72-75 kg) following at least 20 min of moderate-intensity continuous cycling or running at least 3 times weekly for 5-14 wks (Kong, Sun, Liu, & Shi, 2016; Moreira et al., 2008). However, it cannot be discounted that these changes occurred due to changes in dietary intake as diet was not directly controlled. For those interventions reporting improvements in body composition, the data are in line with a review conducted by Ross and Janssen (2001) on the effects of exercise on body composition of obese adults which suggested that MICT is able to reduce body mass by 0.2 kg per wk for a total body mass loss of 2.3 kg over 12 wks. However, as highlighted in a systematic review and meta-analysis performed by Keating, Johnson, Mielke, and Coombes (2017) it could be argued that MICT does not produce clinically meaningful reductions in body fat and body mass. Clinically meaningful reductions in body mass are considered to start at 3 % for glycaemic measures and TG and 5 % for BP and HDL and LDL cholesterol (Ryan & Heaner, 2014).

For leaner adults (61-79 kg), it is more common for little or no changes in body composition to occur following MICT. For example, Leon et al. (2000) and Sandvei et al. (2012) reported no change in total body mass, BMI, BF% or lean mass in sedentary (inactive) adults (69-72 kg) following 3 weekly moderate-intensity continuous cycling or running sessions for 8-20 wks. This may lead participants to become demotivated if they are unable to quantitatively view a reduction in body mass or body fat.

In summary, it is apparent that beneficial changes in body composition are possible following MICT, however, these changes are commonly reported for those individuals with higher baseline values with some studies reporting conflicting results. It is also apparent that such interventions require at least 3-5 training session per wk lasting 30-60 min. Several authors argue that the fat loss brought about by this type of training is usually less than expected and results are typically disappointing (De Feo, 2013; Ross et al., 2004; Stiegler & Cunliffe, 2006), which could lead to an increase in participant drop out as participants are not able to physically see any changes. The disappointing reductions in total body mass and fat mass could be due to the lack of control on energy intake (Barwell, Malkova, Leggate, & Gill, 2009). In addition, much of the literature reviewed also requires participants to adhere to stringent exercise intensities which may negatively affect adherence whereas there seems to be a lack of data on how self-pacing and self-directing exercise may improve body composition outcomes in previously inactive premenopausal women.

Table 2.6 Characteristics of reviewed moderate-intensity continuous training studies on body composition

Study	**Participants**	**Intervention group baseline Age (years) BMI (kg/m^2) TBM (kg)**	**Number in intervention group**	**Intervention protocol**	**Mode of exercise**	**Length (weeks)**	**Effects on body composition**
Ciolac et al. (2010)	44 F premenopausal Inactive	Age: 27 BMI: 24.3 TBM: 64	11 F	Protocol: 40 min walking Training intensity: 60-70 % $\dot{V}O_{2max}$ Sessions per week: 3 Weekly training time commitment: 180 min	Treadmill	16	←→ TBM ←→BMI ←→WC ←→ W-to-H ratio
Dalleck, Borresen, Wallenta, Zahler, and Boyd (2008)	15 F Premenopausal Overweight Sedentary (inactive)	Age: 37 BMI: 26.1 TBM: 72	15 F	Protocol: Expend a net 1,000 kcal per week Training intensity: 50 % $\dot{V}O_2R$ Sessions per week: 3-4 Weekly training time commitment: ~90 min	Indoor running track	10	←→ TBM ←→ BMI ↓ 5 % BF %
Grediagin et al. (1995)	12 F Premenopausal Overweight Inactive	Age: 31 BMI: 26.2 TBM: 68	6 F	Protocol: Duration sufficient to expend 300 kcal Training intensity: 50 % $\dot{V}O_{2peak}$ Sessions per week: 4 Weekly training time commitment: Variable	Treadmill	12	↓ 2 % TBM ↓ 2 % BMI ←→ LM ←→ BF %
		Age: 30 BMI: 24 TBM: 68	6 F	Protocol: Duration sufficient to expend 300 kcal Training intensity: 80 % $\dot{V}O_{2peak}$ Sessions per week: 4 Weekly training time commitment: Variable			←→ TBM ←→ BMI ←→ LM ←→ BF %
Higgins, Fedewa, Hathaway, Schmidt, and Evans (2016)	52 F Premenopausal Overweight/obese	Age: 20 BMI: — TBM: 83	29 F	Protocol: 20-30 min continuous Training intensity: 60-70 % HRR Sessions per week: 3 Weekly training time commitment: 90 min	Cycle ergometer	6	←→ TBM ←→ LM ↑ 2 % leg LM ←→ FM ←→ BF % ←→ Android fat
Kong, Fan, et al. (2016)	26 F Premenopausal Overweight	Age: 21 BMI: 25.5 TBM: 68	13 F	Protocol: 40 min continuous cycling at 60 rpm Training intensity: 60-80 % $\dot{V}O_{2peak}$ Sessions per week: 4	Cycle ergometer	5	↓ 2 % TBM ↓ 2 % BMI ←→ LM ↓ 5 % FM

				Weekly training time commitment: ~150 min			↓ 3 % BF %
Krustrup, Hansen, Andersen, et al. (2010)	28 F Premenopausal Inactive	Age: 40 BMI: 25.1 TBM: 70 $\dot{V}O_{2max}$: 34.5	10 F	Protocol: 60 min continuous Training intensity: 82 % HR_{max} Sessions per week: 2 Weekly training time commitment: 120 min	Running	64	↔ TBM ↔ BMI ↔LM ↔ FM ↔ BF % ↔ Android FM (%) ↔ Gynoid FM (%)
Krustrup, Hansen, Randers, et al. (2010)	50 F Premenopausal Inactive	Age: 37 BMI: 23.1 TBM: 67	17 F	Protocol: 60 min continuous Training intensity: 82% HR_{max} Sessions per week: 2 Weekly training time commitment: 120 min	Running	4	↔ TBM ↔ BMI ↔ LM ↔ FM ↔ BF % ↓ 3 % Android fat (%) ↔ Gynoid fat (%)
						16	↔ TBM ↔ BMI ↑ 3 % LM ↓ 5 % FM ↓ 5 % BF % ↓ 6 % Android fat (%) ↔ Gynoid fat (%)
Lemura et al. (2000)	48 F Premenopausal Sedentary (inactive)	Age: 21 BMI: 22.9 TBM: 63	12 F	Protocol: 30 min continuous Training intensity: 70-75 % HR_{max} Sessions per week: 3 Weekly training time commitment: ~90-135 min	Cycle ergometer Rowing ergometer Treadmill	16	↔ TBM ↓ 6 % BMI ↔ LM ↓ 13 % BF %
Leon et al. (2000)	299 M 376 F Stage of menopause not reported Overweight	Age: 34 BMI: 26.2 TBM: 69	376 F	Protocol: 30-50 min continuous Training intensity: 55-75 % of $\dot{V}O_{2max}$ Sessions per week: 3 Weekly training time commitment: ~90-150 min	Cycle ergometer	20	↔ TBM

	Sedentary							
Moreira et al. (2008)	8 M 14 F Stage of menopause not reported Overweight Sedentary	Age: 40 BMI: 27.5 TBM: 74.8	Not reported	Protocol: 20-60 min continuous Training intensity: 10% lower than anaerobic threshold Sessions per week: 3 Weekly training time commitment 60-180 min	Cycle ergometer	12	↓ 2 % TBM ↑ 1 % LM ↓ 3 % BF % ↓ 2 % Waist ↓ 1 % Hip
Robinson et al. (2015)	7 M 32 F Stage of menopause not reported Overweight/obese Inactive	Age: 52 BMI: 31.4 TBM: 88	4 M 14 F	Protocol: 20-50 min continuous Training intensity: 60-65 % HR_{peak} Sessions per wk: 5 Weekly training time commitment: Variable	Cycle ergometer Treadmill walking Outdoor walking Elliptical trainer	2	↓ 2 % TBM ↔ BMI
Ross et al. (2004)	54 F Premenopausal Obese (required to maintain weight)	Age: 41 BMI: 32.9 TBM: 88.1	12 F	Protocol: Required to expend 500 kcal Training intensity: Brisk walking/light jogging Sessions per week: 7 Weekly training time commitment: Variable	Treadmill	14	↔ TBM ↔ BMI ↑ 4 % LM ↓ 7 % FM ↔ WC ↓ 6 % Total subcutaneous fat ↓ 10 % Abdominal fat
Sandvei et al. (2012)	8 M 15 F Premenopausal Inactive	Age: 18-35 BMI: 23.5 TBM: 72	12 Ratio of M:F not reported	Protocol: 30-60 min continuous Training intensity: 70-80% HR_{peak} Sessions per week: 3 Weekly training time commitment: ~90-180 min	Running	8	↔ TBM ↔ BMI ↔ LM ↔ BF %
Santiago, Leon, and Serfass (1995)	27 F Stage of menopause not reported Sedentary	Age: 31 BMI: 24.1 TBM: 64	16 F	Protocol: continuous (4.8 km) Training intensity: 72 % HR_{max} Sessions per week: 4 Weekly training time commitment: variable	Treadmill	40	↔ TBM ↔ BF %

Sawyer et al. (2016)	18 Ratio of M:F not reported Obese	Age: 35 BMI: 34.5 TBM: 100	9 Ratio of M:F not reported	Protocol: 30 min continuous Training intensity: 70-75 % HR_{max} Sessions per week: 3 Weekly training time commitment: ~90 min	Cycle ergometer	8	←→ TBM ←→ BMI ←→ LM ←→ FM ↓ 2 % BF % ↓ 1 % WC ←→ Android fat % ↓ 2 % Gynoid fat (%)
Schjerve et al. (2008)	8 M 32 F Stage of menopause not reported Obese	Age: 44 BMI: 36.7 TBM: 104	2 M 11 F	Protocol: 47 min continuous Training intensity: 60-70 % HR_{max} Sessions per week: 3 Weekly training time commitment: 141 min	Treadmill	12	↓ 3 % TBM ↓ 3 % BMI ↓ 3 % BF % ←→ W-to-H ratio
Shepherd et al. (2015)	26 M 52 F Stage of menopause not reported Inactive	Age: 44 BMI: 27.7 TBM: 78	14 M 22 F	Protocol: 30-45 min continuous cycling Training intensity: 70% HR_{max} Sessions per wk: 3 Weekly training time commitment: 128 min	Instructor-led group cycling class	10	↓ 1 % TBM ↓ 1 % BMI ↓ 3 % FM
Tjonna et al. (2008)	13 M 15 F Stage of menopause not reported Overweight MetS patients	Age: 52 BMI: 29.4 Body mass: 91	4 M 4 F	Protocol: 47 min continuous walking/ running "uphill" Training intensity: 70% of HR_{max} Sessions per week: 3 Weekly training time commitment: ~150 min	Treadmill	16	↓ 4 % TBM ↓ 4 % BMI ↓ 6 % Waist ←→ W-to-H ratio
Trapp et al. (2008)	45 F Premenopausal Inactive	Age: 21 BMI: 22.4 TBM: 60	15 F	Protocol: 40 min continuous Training intensity: 60 % $\dot{V}O_{2peak}$ Sessions per week: 3 Weekly training time commitment: ~150 min	Cycle ergometer	15	←→ TBM ←→ FM ←→ BF %
Tremblay, Simoneau, and Bouchard (1994)	13 M 14 F Premenopausal	Age:18-32 BMI: — TBM: 61	8 M 9 F	Protocol: 30-45 min continuous Training intensity: 60-85 % HRR Sessions per week: 4-5 Weekly training time commitment: ~120-225 min	Cycle ergometer	20	←→ TBM ←→ Sum of 6 skinfolds ↓ 12 % Sum of 3 trunk skinfolds
Wallman et al. (2009)	6 M 18 F	Age: 45 BMI: 30.1 TBM: 91	6 ratio of M:F not reported	Protocol: For a duration that resulted in the same amount of energy expenditure (J) as the performed by	Cycle ergometer	8	←→TBM ↓ 3 % Android FM ↓ 3 % Gynoid FM

	Stage of menopause not reported Overweight and obese Not participated in regular exercise for 6 months			their matched partner in the HIIT arm of the study. Training intensity: 50-65 % $\dot{V}O_{2peak}$ Sessions per week: 4 Weekly training time commitment: Varied			
Wiklund et al. (2014)	90 F premenopausal Overweight and obese Sedentary	Age: 42 BMI: 28.4 TBM: 79	39 F	Protocol: 30-60 min walking Training intensity: 60-75% HR_{max} Sessions per week: 3 Weekly training time commitment: ~90-120 min	Nordic walking (walking with poles)	6	←→ TBM ←→ BMI ←→ LM ←→ Visceral fat area

Abbreviations: BF %: body fat percentage, BMI: Body mass index, FM: fat mass, F: female, HRR: heart rate reserve, kcal: kilocalorie, LM: lean mass, M: male, HR_{max}: maximal heart rate, $\dot{V}O_{2max}$: maximal oxygen uptake, $\dot{V}O_2R$: oxygen uptake reserve, $\dot{V}O_{2peak}$: peak oxygen uptake, TBM: total body mass, W-to-H: Waist-to-hip ratio.

2.4.3.2 Cardiorespiratory fitness

From reviewing the literature outlined in Table 2.7 based on sedentary (inactive) adults, it is apparent that improvements in $\dot{V}O_{2peak}$ (4-19 %) have consistently been reported following 6-20 wks of 20-60 min continuous exercise carried out 3-5 times per wk at an intensity of around 55-75 % of $\dot{V}O_{2peak}$ or 70-80 % of HR_{max} (Burgomaster et al., 2008; Leon et al., 2000; Macpherson, Hazell, Olver, Paterson, & Lemon, 2010; Robinson et al., 2015; Sandvei et al., 2012). These improvements were reported for individuals with baseline $\dot{V}O_{2max}$ values between 22 and 48 $ml \cdot kg^{-1} \cdot min^{-1}$. Similarly, improvements in $\dot{V}O_{2max}$ (4-19 %) have also been reported for sedentary adults with a larger baseline bodyweight (90-104 kg) following MICT interventions with baseline $\dot{V}O_{2max}$ values between 24 and 33 $ml \cdot kg^{-1} \cdot min^{-1}$ (Roxburgh, Nolan, Weatherwax, & Dalleck, 2014; Sawyer et al., 2016; Schjerve et al., 2008; Wallman et al., 2009). Exercise was performed using a combination of cycle ergometers, treadmill, elliptical trainer and walking outdoors.

Considering sedentary premenopausal women alone, improvements in $\dot{V}O_{2peak}$ (7-26 %) have also been reported following 5-16 wks of 3-4 weekly 20-40 min MICT at an intensity of 50-80 % $\dot{V}O_{2peak}$ (Ciolac et al., 2010; Dalleck et al., 2008; Kong, Fan, et al., 2016; Trapp et al., 2008) or 60-70 % of HR_{max} (Higgins et al., 2016; Lemura et al., 2000) with baseline $\dot{V}O_{2max}$ values ranging from 27 to 35 $ml \cdot kg^{-1} \cdot min^{-1}$. In addition, Bangsbo et al. (2010) reported a 6 and 10 % improvement in $\dot{V}O_{2peak}$ in inactive premenopausal women with a baseline $\dot{V}O_{2peak}$ of 35 $ml \cdot kg^{-1} \cdot min^{-1}$ following 4 and 16 wks of twice weekly 60 min continuous running at 83 % of HR_{max}.

In summary, MICT interventions consistently appear to improve the cardiorespiratory fitness of previously inactive adults with baseline $\dot{V}O_{2peak}$ ranging from 22 to 48 $ml \cdot kg^{-1} \cdot min^{-1}$. These improvements tend to appear when training intensity is at least 50 % of $\dot{V}O_{2peak}$ or 60 % of HR_{max} but individuals are required to exercise at least 3 times a wk with training time commitments ranging from 1.5 to 4.5 h per wk which may be an issue for those individuals with time constraints. However, less is know whether the same benefits are achievable when the training modality or time commitment is changed for previously inactive premenopausal women and this warrants further investigation.

Table 2.7 Characteristics of reviewed moderate-intensity continuous training studies on cardiorespiratory fitness

Study	**Participants**	**Intervention group baseline characteristics** **Age (y)** **BMI (kg/m^2)** **TBM (kg)** **$\dot{V}O_{2peak/max}$ (ml·kg^{-1}·min^{-1})**	**Number in intervention group**	**Intervention**	**Mode of exercise**	**Length (weeks)**	**Effects on $\dot{V}O_{2peak/max}$**
Bangsbo et al. (2010)	65 F Premenopausal Inactive	Age: 19-47 BMI: — TBM: 71 $\dot{V}O_{2peak}$: 35	18 F	Protocol: 60 min continuous Training intensity: 82 % HR_{max} Sessions per week: 2 Weekly training time commitment: 120 min	Running	4 16	↑ 6 % $\dot{V}O_{2peak}$ ↑ 10 % $\dot{V}O_{2peak}$
Burgomaster et al. (2008)	10 M 10 F Premenopausal Active but untrained	Age: 23 BMI: — TBM: 75 $\dot{V}O_{2peak}$: 41	5 M 5 F	Protocol:40–60 min continuous Training intensity: ~65 % $\dot{V}O_{2peak}$ Sessions per week: 5 Weekly training time commitment: ~270 min	Cycle ergometer	6	↑ 9 % $\dot{V}O_{2peak}$
Ciolac et al. (2010)	44 F premenopausal Inactive	Age: 27 BMI: 24.3 TBM: 64 $\dot{V}O_{2max}$: 32	11 F	Protocol: 40 min walking Training intensity: 60-70 % $\dot{V}O_{2max}$ Sessions per week: 3 Weekly training time commitment: 180 min	Treadmill	16	↑ 8 % $\dot{V}O_{2max}$
Dalleck et al. (2008)	15 F Premenopausal Overweight Sedentary	Age: 37 BMI: 26.1 TBM: 72 $\dot{V}O_{2max}$: 35	15 F	Protocol: Expend a net 1,000 kcal per week Training intensity: 50 % $\dot{V}O_2R$ Sessions per week: 3-4 Weekly training time commitment: ~90 min	Indoor running track	10	↑ 7 % $\dot{V}O_{2max}$
Foster et al. (2015)	23 M 42 F Sedentary	Age: 20 BMI: — TBM: 67-94 $\dot{V}O_{2max}$: 34	19 ratio of M:F not reported	Protocol: 20 min continuous Training intensity: Power output calculated to require a $\dot{V}O_2$ of 90% of ventilatory threshold. Sessions per week: 3 Weekly training time commitment: 60 min	Cycle ergometer	8	↑ 19 % $\dot{V}O_{2max}$

Grediagin et al. (1995)	12 F Premenopausal Overweight Inactive	Age: 31 BMI: 26.2 TBM: 68 $\dot{V}O_{2max}$: 31	6 F	Protocol: Duration sufficient to expend 300 kcal Training intensity: 50 % $\dot{V}O_{2peak}$ Sessions per week: 4 Weekly training time commitment: Variable	Treadmill	12	←→ $\dot{V}O_{2max}$
		Age: 30 BMI: 24 TBM: 68 $\dot{V}O_{2max}$: 32	6 F	Protocol: Duration sufficient to expend 300 kcal Training intensity: 80 % $\dot{V}O_{2peak}$ Sessions per week: 4 Weekly training time commitment: Variable			
Higgins et al. (2016)	52 F Premenopausal Overweight/obese	Age: 20 BMI: — TBM: 83 $\dot{V}O_{2max}$: 27	29 F	Protocol: 20-30 min continuous Training intensity: 60-70 % HRR Sessions per week: 3 Weekly training time commitment: 90 min	Cycle ergometer	6	↑ 7 % $\dot{V}O_{2max}$
Kong, Fan, et al. (2016)	26 F Premenopausal Overweight	Age: 21 BMI: 25.5 TBM: 68 $\dot{V}O_{2max}$: 32	13 F	Protocol: 40 min continuous cycling at 60 rpm Training intensity: 60-80 % $\dot{V}O_{2peak}$ Sessions per week: 4 Weekly training time commitment: ~150 min	Cycle ergometer	5	↑ 12 % $\dot{V}O_{2max}$
Krustrup, Hansen, Andersen, et al. (2010)	28 F Premenopausal Overweight Inactive	Age: 40 BMI: 25.1 TBM: 70 $\dot{V}O_{2max}$: 34.5	10 F	Protocol: 60 min continuous Training intensity: 82 % HR_{max} Sessions per week: 2 Weekly training time commitment: 120 min	Running	64	↑ 12 % $\dot{V}O_{2max}$
Lemura et al. (2000)	48 F Premenopausal Sedentary (inactive)	Age: 21 BMI: 22.9 TBM: 63 $\dot{V}O_{2max}$: 34	12 F	Protocol: 30 min continuous Training intensity: 70-75 % HR_{max} Sessions per week: 3 Weekly training time commitment: ~90-135 min	Cycle ergometer Rowing ergometer Treadmill	16	↑ 26 % $\dot{V}O_{2max}$
Leon et al. (2000)	299 M 376 F Stage of menopause not reported Overweight	Age: 34 BMI: 26.2 TBM: 69 $\dot{V}O_{2max}$: 27	376 F	Protocol: 30-50 min continuous Training intensity: 55-75 % of $\dot{V}O_{2max}$ Sessions per week: 3 Weekly training time commitment: ~90-150 min	Cycle ergometer	20	↑ 19 % $\dot{V}O_{2max}$

	Sedentary						
Macpherson et al. (2010)	12 M 8 F Recreationally active	Age: 23 BMI: 24.2 TBM: 76 $\dot{V}O_{2max}$: 44	6 M 4 F	Protocol: 30-60 min continuous Training intensity: 65 % $\dot{V}O_{2max}$ Sessions per week: 3 Weekly training time commitment: 180 min	Non-motorised treadmill	6	↑ 13 % $\dot{V}O_{2peak}$
Robinson et al. (2015)	7 M 32 F Stage of menopause not reported Overweight/obese Inactive	Age: 52 BMI: 31.4 TBM: 88 $\dot{V}O_{2peak}$: 20.6	4 M 14 F	Protocol: 20-50 min continuous Training intensity: 60-65 % HR_{peak} Sessions per wk: 5 Weekly training time commitment: Variable	Cycle ergometer Treadmill walking Outdoor walking Elliptical trainer	2	↑ 7 % $\dot{V}O_{2peak}$
Ross et al. (2004)	54 F Premenopausal Obese	Age: 41 BMI: 32.9 TBM: 88.1 $\dot{V}O_{2max}$: 2.2 ($l \cdot min^{-1}$)	12 F	Protocol: Required to expend 500 kcal Training intensity: Brisk walking/light jogging Sessions per week: 7 Weekly training time commitment: Variable	Treadmill	14	↑ 23 % $\dot{V}O_{2max}$
Roxburgh et al. (2014)	10 M 19 F Premenopausal Overweight Sedentary	Age: 37 BMI: 29.6 TBM: 90 $\dot{V}O_{2max}$: 33	6 ratio of M:F not reported	Protocol: 15 min walking, 15 min cycling Training intensity: 45-60 % $\dot{V}O_2R$ Sessions per week: 5 Weekly training time commitment: 150 min	Treadmill Cycle ergometer	12	↑ 4 % $\dot{V}O_{2max}$
Sandvei et al. (2012)	8 M 15 F Premenopausal Inactive	Age: 18-35 BMI: 23.5 TBM: 72 $\dot{V}O_{2max}$: 48	12 Ratio of M:F not reported	Protocol: 30-60 min continuous Training intensity: 70-80% HR_{peak} Sessions per week: 3 Weekly training time commitment: ~90-180 min	Running	8	↑ 4 % $\dot{V}O_{2max}$
Santiago et al. (1995)	27 F Stage of menopause not reported Sedentary	Age: 31 BMI: 24.1 TBM: 64 $\dot{V}O_{2max}$: 32	16 F	Protocol: continuous (4.8 km) Training intensity: 72 % HR_{max} Sessions per week: 4 Weekly training time commitment: variable	Treadmill	40	↑ 22 % $\dot{V}O_{2max}$

Sawyer et al. (2016)	18 Ratio of M:F not reported Obese	Age: 35 BMI: 34.5 TBM: 100 $\dot{V}$O2max: 22	9 Ratio of M:F not reported	Protocol: 30 min continuous Training intensity: 70-75 % HR_{max} Sessions per week: 3 Weekly training time commitment: ~90 min	Cycle ergometer	8	↑ 14 % $\dot{V}O_{2max}$
Schjerve et al. (2008)	8 M 32 F Stage of menopause not reported Obese	Age: 44 BMI: 36.7 TBM: 104 $\dot{V}O_{2max}$: 25	2 M 11 F	Protocol: 47 min continuous Training intensity: 60-70 % HR_{max} Sessions per week: 3 Weekly training time commitment: 141 min	Treadmill	12	↑ 16 % $\dot{V}O_{2max}$
Shepherd et al. (2015)	26 M 52 F Stage of menopause not reported Inactive	Age: 44 BMI: 27.7 TBM: 78 $\dot{V}O_{2max}$: 32	14 M 22 F	Protocol: 30-45 min continuous cycling Training intensity: 70% HR_{max} Sessions per wk: 3 Weekly training time commitment: 128 min	Instructor-led group cycling class	10	↑ 8 % $\dot{V}O_{2max}$
Tjonna et al. (2008)	13 M 15 F Stage of menopause not reported Overweight MetS patients	Age: 52 BMI: 29.4 Body mass: 91 $\dot{V}O_{2max}$: 36	4 M 4 F	Protocol: 47 min continuous walking/ running “uphill” Training intensity: 70% of HR_{max} Sessions per week: 3 Weekly training time commitment: ~150 min	Treadmill	16	↑ 14 % $\dot{V}O_{2max}$
Trapp et al. (2008)	45 F Premenopausal Inactive	Age: 21 BMI: 22.4 TBM: 60 $\dot{V}O_{2peak}$: 31	15 F	Protocol: 40 min continuous Training intensity: 60 % $\dot{V}O_{2peak}$ Sessions per week: 3 Weekly training time commitment: ~150 min	Cycle ergometer	15	↑ 18 % $\dot{V}O_{2peak}$
Wallman et al. (2009)	6 M 18 F Stage of menopause not reported Overweight and obese Not participated in regular exercise for 6 months	Age: 45 BMI: 30.1 TBM: 91 $\dot{V}O_{2max}$: 24	6 ratio of M:F not reported	Protocol: For a duration that resulted in the same amount of energy expenditure (J) as the performed by their matched partner in the HIIT arm of the study. Training intensity: 50-65 % $\dot{V}O_{2peak}$ Sessions per week: 4 Weekly training time commitment: Varied	Cycle ergometer	8	↑ 17 % $\dot{V}O_{2peak}$

Wiklund et al. (2014)	90 F Premenopausal Overweight and obese Sedentary	Age: 42 BMI: 28.4 TBM: 79 V̇O2max: 32	39 F	Protocol: 30-60 min walking Training intensity: 60-75% HR$_{max}$ Sessions per week: 3 Weekly training time commitment: ~90-120 in	Nordic walking (walking with poles)	6	←→ V̇O$_{2max}$

Abbreviations: BMI: Body mass index, F: female, HRR: heart rate reserve, M: male, kcal: kilocalorie, HR$_{max}$: maximal heart rate, V̇O$_{2max}$: maximal oxygen uptake, MetS: metabolic syndrome, V̇O$_2$R: oxygen uptake reserve, HR$_{peak}$: peak heart rate, V̇O$_{2peak}$: peak oxygen uptake, TBM: total body mass.

2.4.3.3 Insulin and glucose

From reviewing the literature outlined in Table 2.8, it is apparent that some, but not all, MICT interventions have a positive effect on blood [insulin] and [glucose] for sedentary adults. For example, Robinson et al. (2015) reported an improvement in fasting blood [glucose] (5 %) but not [insulin] or insulin sensitivity following just 10 sessions of MICT over 2 wks at 60-65 % of HR_{peak} for inactive overweight/obese adults. In addition, improvements in insulin sensitivity (27 %), fasting [insulin] (28 %) and [glucose] (4 %) have been reported following similar exercise interventions lasting 8-16 wks (Ciolac et al., 2010; Sandvei et al., 2012). Shepherd et al. (2015) also reported reductions in fasting [insulin] (9 %) and insulin sensitivity (10 %) but no change in fasting [glucose] following an instructor-led group moderate-intensity cycling class for inactive adults (42 y) following 3 sessions a wk for 10 wks of 30-45 min cycling at 70% of HR_{max}.

A similar theme is apparent when considering sedentary premenopausal women (21-42 y) alone. For example, improvements in fasting [insulin] (9-19 %), [glucose] (6-10 %) and insulin sensitivity (11-28 %) have been reported following 6-15 wks of 3-4 weekly 30-60 min sessions of MICT (Dalleck et al., 2008; Trapp et al., 2008; Wiklund et al., 2014). In addition, Krustrup, Hansen, Randers, et al. (2010) reported a 12 % reduction in fasting blood [glucose] following 4 wks of twice weekly 60 min continuous running at 82 % of HR_{max} for inactive women. However, no change was reported for fasting [insulin] or [glucose] following an OGTT and no further changes were apparent when the training was extended to 16 wks and 16 months (Krustrup, Hansen, Andersen, et al., 2010). There were also no such changes in fasting blood [glucose] for premenopausal women who participated in 14 wks of brisk walking/light jogging 7 times per wk (Ross et al., 2004)

In summary, MICT interventions of at least 60 % of HR_{peak} or 60 % of $\dot{V}O_{2peak}$ appear to have some beneficial effects on fasting [glucose], [insulin] and insulin sensitivity in previously inactive women but the magnitude of change seems to be related to baseline values as outlined in Table 2.8. Variation in training programme intensity and duration also make it difficult to distinguish the most beneficial type of exercise for previously inactive premenopausal women and this warrants further investigation.

Table 2.8 Characteristics of reviewed moderate-intensity continuous training studies on fasting glucose, insulin and insulin sensitivity

Study	**Participants**	**Intervention group baseline characteristics** **Age (years)** **BMI (kg/m^2)** **TBM (kg)** **FG ($mmol \times l^{-1}$)** **FI ($\mu IU \times ml^{-1}$)** **IS**	**Number in intervention group**	**Intervention**	**Mode of exercise**	**Length (weeks)**	**Effects on FG, FI and IS**
Ciolac et al. (2010)	44 F premenopausal Inactive	Age: 27 BMI: 24.3 TBM: 64 FG: 4.7 FI: 9.0 IS (HOMA-IR): 1.88	11 F	Protocol: 40 min walking Training intensity: 60-70 % $\dot{V}O_{2max}$ Sessions per week: 3 Weekly training time commitment: 180 min	Treadmill	16	←→ FG ↓ 28 % FI ↑ 27 % IS
Dalleck et al. (2008)	15 F Premenopausal Overweight Sedentary	Age: 37 BMI: 26.1 TBM: 72 FG: 4.7	15 F	Protocol: Expend a net 1,000 kcal per week Training intensity: 50 % $\dot{V}O_2R$ Sessions per week: 3-4 Weekly training time commitment: ~90 min	Indoor running track	10	↓ 6 % FG
Kong, Sun, et al. (2016)	18 F Premenopausal Obese	Age: 20 BMI: 26.2 TBM: 69 FG: 4.6	13 F	Protocol: 40 min continuous cycling at 60 rpm Training intensity: 65 % $\dot{V}O_{2peak}$ with resistance increased with lowered HR Sessions per week: 4 Weekly training time commitment: 160 min	Cycle ergometer	5	←→ FG
Krustrup, Hansen, Andersen, et al. (2010)	28 F Premenopausal Overweight Inactive	Age: 40 BMI: 25.1 TBM: 70 FG: 5.47	10 F	Protocol: 60 min continuous Training intensity: 82 % HR_{max} Sessions per week: 2 Weekly training time commitment: 120 min	Running	64	←→ FG
Krustrup, Hansen, Randers, et al. (2010)	50 F Premenopausal Inactive	Age: 37 BMI: 23.1 TBM: 67 FG: 5.7	17 F	Protocol: 60 min continuous Training intensity: 82 % HR_{max} Sessions per week: 2 Weekly training time commitment: 120 min	Running	4 16	↓ 12 % FG ←→ FI ←→ OGTT ←→ FG ←→ FI ←→ OGTT

Moreira et al. (2008)	8 M 14 F Stage of menopause not reported Overweight Sedentary	Age: 40 BMI: 27.5 TBM: 74.8 FG: ~4.2	Not reported	Protocol: 20-60 min continuous Training intensity: 10% lower than anaerobic threshold Sessions per week: 3 Weekly training time commitment 60-180 min	Cycle ergometer	12	↓ ~4 % FG
Robinson et al. (2015)	7 M 32 F Stage of menopause not reported Overweight/obese Inactive	Age: 52 BMI: 31.4 TBM: 88 FG: 5.9 FI: 12.2	4 M 14 F	Protocol: 20-50 min continuous Training intensity: 60-65 % HR_{peak} Sessions per wk: 5 Weekly training time commitment: Variable	Cycle ergometer Treadmill walking Outdoor walking Elliptical trainer	2	↓ 5 % FG ←→ FI ←→ IS
Ross et al. (2004)	54 F Premenopausal Obese (required to maintain weight)	Age: 41 BMI: 32.9 TBM: 88.1 FG: 5.28 FI: 6.06	12 F	Protocol: Required to expend 500 kcal Training intensity: Brisk walking/light jogging Sessions per week: 7 Weekly training time commitment: Variable	Treadmill	14	←→ FG ←→FI ←→ OGTT
Sandvei et al. (2012)	8 M 15 F Premenopausal Inactive	Age: 18-35 BMI: 23.5 TBM: 72 FG: 5.50 FI: 6.62 IS: 15.09 (HOMA-IR)	12 Ratio of M:F not reported	Protocol: 30-60 min continuous Training intensity: 70-80% HR_{peak} Sessions per week: 3 Weekly training time commitment: ~90-180 min	Running	8	↓4% FG ←→ Glucose at 120 min OGTT ←→ Glucose AUC ←→FI ←→HOMA-IR
Sawyer et al. (2016)	18 Ratio of M:F not reported Obese	Age: 35 BMI: 34.5 TBM: 100 FG: 5.14 FI: 19.6 IS: 4.5 (HOMA-IR)	9 Ratio of M:F not reported	Protocol: 30 min continuous Training intensity: 70-75 % HR_{max} Sessions per week: 3 Weekly training time commitment: ~90 min	Cycle ergometer	8	←→FG ←→ FI ←→ IS

Schjerve et al. (2008)	8 M 32 F Stage of menopause not reported Obese	Age: 44 BMI: 36.7 TBM: 104 FG: 6.2	2 M 11 F	Protocol: 47 min continuous Training intensity: 60-70 % HR_{max} Sessions per week: 3 Weekly training time commitment: 141 min	Treadmill	12	←→ FG
Shepherd et al. (2015)	26 M 52 F Stage of menopause not reported Inactive	Age: 44 BMI: 27.7 TBM: 78 FG: 5.5 FI: 27.8 IS: 7.3 (HOMA-IR)	14 M 22 F	Protocol: 30-45 min continuous cycling Training intensity: 70% HR_{max} Sessions per wk: 3 Weekly training time commitment: 128 min	Instructor-led group cycling class	10	←→ FG ↓ 9 % FI ↑ 10 % IS
Tjonna et al. (2008)	13 M 15 F Stage of menopause not reported Overweight MetS patients	Age: 52 BMI: 29.4 Body mass: 91 FG: 6.1 FI: 15 IS: 64.4 (HOMA %)	4 M 4 F	Protocol: 47 min continuous walking/ running "uphill" Training intensity: 70% of HR_{max} Sessions per week: 3 Weekly training time commitment: ~150 min	Treadmill	16	←→ FG ←→ FI ←→ HOMA-IR
Trapp et al. (2008)	45 F Premenopausal Inactive	Age: 21 BMI: 22.4 TBM: 60 FG: 4.2 FI: 11.1 IS: 2.2 (HOMA-IR)	15 F	Protocol: 40 min continuous Training intensity: 60 % $\dot{V}O_{2peak}$ Sessions per week: 3 Weekly training time commitment: ~150 min	Cycle ergometer	15	↓ 9 % FI ↓ 11 % IS
Wiklund et al. (2014)	90 F Premenopausal Overweight and obese Sedentary	Age: 42 BMI: 28.4 TBM: 79 FG: 5.2 FI: 8.3 IS: 1.8 (HOMA-IR)	39 F	Protocol: 30-60 min walking Training intensity: 60-75% HR_{max} Sessions per week: 3 Weekly training time commitment: ~90-120 in	Nordic walking (walking with poles)	6	↓ 10 % FG ↓ 19 % FI ↓ 28 % IS

Abbreviations: AUC: area under the curve, BMI: Body mass index, FG: fasting glucose, FI: fasting insulin, F: female, HR: heart rate, HOMA-IR: homeostatic model assessment of insulin resistance, IS: insulin sensitivity, M: male, HR_{max}: maximal heart rate, $\dot{V}O_{2max}$: maximal oxygen uptake, OGTT: Oral glucose tolerance test, $\dot{V}O_{2peak}$: peak oxygen uptake, TBM: total body mass.

2.4.3.4 Lipid profile

Following the summarisation of literature in Table 2.9, when considering sedentary adults, 12-20 wks of 3 weekly 20-60 min cycling or running sessions at 55-75 % of $\dot{V}O_{2max}$, or 60-70 % of HR_{max} appears sufficient to increase [HDL] (3 %) and reduce [LDL] (8 %) and [TC] (16 %) (Leon et al., 2000; Moreira et al., 2008; Schjerve et al., 2008). In addition, similar results have been reported following instructor-led group moderate-intensity cycling class for inactive adults following 3 sessions a wk for 10 wks of 30-45 min cycling at 70 % of HR_{max}. Furthermore, when considering sedentary premenopausal women alone, 10-16 wks of 3-4 weekly sessions of MICT at 50 % of $\dot{V}O_2$ reserve was sufficient to increase [HDL] (6-29 %) and reduce [TG] (14 %) (Dalleck et al., 2008; Lemura et al., 2000). These results are in agreement with a meta-analysis of RCTs assessing changes in lipid profile for women (>18 y) following aerobic exercise interventions which reported that following at least 8 wks of exercise, significant improvements were evident for [TG] (-5 %), [HDL] (+3 %), [LDL] (-3 %) and [TC] (- 2 %) (Kelley et al., 2004).

Conversely, some MICT interventions ranging from 6-40 wks of 3-4 weekly 30-60 min sessions have been insufficient in improving the lipid profile of inactive premenopausal women (Ciolac et al., 2010; Krustrup, Hansen, Randers, et al., 2010; Sandvei et al., 2012; Sawyer et al., 2016; Tjonna et al., 2008; Wallman et al., 2009; Wiklund et al., 2014). Likewise, 5 wks of four 40 min weekly cycling sessions did not change the lipid profile of 26 inactive obese premenopausal women when exercising at 60-80 % of $\dot{V}O_{2peak}$ (Kong, Fan, et al., 2016).

Previous studies examining the effects of exercise intensity on blood lipid concentrations have reported conflicting results. While meta-analyses suggest improvements in the lipid profile of women following moderate-intensity exercise, isolated randomised control trials do not present overly convincing results which may be due to the baseline values of lipids and lack of dietary control. Nonetheless, as standard management of abnormal blood lipids is drug therapy, and moderate-intensity exercise may have some benefits on blood lipids, it would be preferable to initially recommend moderate-intensity exercise to those at risk of abnormal blood lipids. However, it is debated whether HIIT may be more beneficial, which will be discussed in further detail later.

Table 2.9 Characteristics of reviewed moderate-intensity continuous training studies on lipid profile

Study	**Participants**	**Intervention group baseline characteristics** **Age (y)** **BMI (kg/m^2)** **TBM (kg)** **TC (mmol/L)** **HDL (mmol/L)** **LDL (mmol/L)** **TG (mmol/L)**	**Number in intervention group**	**Intervention**	**Mode of exercise**	**Length (weeks)**	**Effects on blood lipids**
Ciolac et al. (2010)	44 F premenopausal Inactive	Age: 27 BMI: 24.3 TBM: 64 TC: 4.60 HDL: 1.47 LDL: 2.78 TG: 1.82	11 F	Protocol: 40 min walking Training intensity: 60-70 % $\dot{V}O_{2max}$ Sessions per week: 3 Weekly training time commitment: 180 min	Treadmill	16	←→ TC ←→ HDL ←→ LDL ←→ TG
Dalleck et al. (2008)	15 F Premenopausal Overweight Sedentary	Age: 37 BMI: 26.1 TBM: 72 TC: 5.44 HDL: 1.40 LDL: 1.41 TG: 2.54	15 F	Protocol: Expend a net 1,000 kcal per week Training intensity: 50 % $\dot{V}O_2R$ Sessions per week: 3-4 Weekly training time commitment: ~90 min	Indoor running track	10	←→ TC ↑ 6 % HDL ←→ LDL ←→ TG
Kong, Fan, et al. (2016)	26 F Premenopausal Overweight	Age: 21 BMI: 25.5 TBM: 68 TC: 4.3 HDL: 1.3 LDL: 2.4 TG: 0.9	13 F	Protocol: 40 min continuous cycling at 60 rpm Training intensity: 60-80 % $\dot{V}O_{2peak}$ Sessions per week: 4 Weekly training time commitment: ~150 min	Cycle ergometer	5	←→ TC ←→ LDL ←→ HDL ←→ TG
Kraus et al. (2002)	98 M 70 F Stage of menopause not reported Overweight	Age: 54 BMI: 29.2 TBM: 90 TC: 5.00 HDL: 1.04 LDL: 3.15 TG: 5.10	14 M 5 F	Protocol: 12 miles per week Training intensity: 40-55 % $\dot{V}O_{2peak}$ Sessions per week: 3 Weekly training time commitment: ~190 min	Cycle ergometer Treadmill Elliptical trainer	40	←→ TC ←→ HDL ←→ LDL ←→ TG

Krustrup, Hansen, Randers, et al. (2010)	50 F Premenopausal Inactive	Age: 37 BMI: 23.1 TBM: 67 TC: 4.4 HDL: 1.6 LDL: 2.5 TG: 0.68	17 F	Protocol: 60 min continuous Training intensity: 82% HR$_{max}$ Sessions per week: 2 Weekly training time commitment: 120 min	Running	4 16	←→ TC ←→ HDL ←→ LDL ←→ TG ←→ TC ←→ HDL ←→ LDL ←→ TG
Lemura et al. (2000)	48 F Premenopausal Sedentary (inactive)	Age: 21 BMI: 22.9 TBM: 63 TC: 5.2 HDL: 1.4 LDL: 2.6 TG: 1.4	12 F	Protocol: 30 min continuous Training intensity: 70-75 % HR$_{max}$ Sessions per week: 3 Weekly training time commitment: ~90-135 min	Cycle ergometer Rowing ergometer Treadmill	16	←→ TC ↑ 29 % HDL ←→ LDL ↓ 14 % TG
Leon et al. (2000)	299 M 376 F Stage of menopause not reported Overweight Sedentary	Age: 34 BMI: 26.2 TBM: 69 TC: 4.35 HDL: 1.15 LDL: 2.99 TG: 2.48	376 F	Protocol: 30-50 min continuous Training intensity: 55-75 % of $\dot{V}O_{2max}$ Sessions per week: 3 Weekly training time commitment: ~90-150 min	Cycle ergometer	20	←→TC ↑ 3 % HDL ←→LDL ←→TG
Moreira et al. (2008)	8 M 14 F Stage of menopause not reported Overweight Sedentary	Age: 40 BMI: 27.5 TBM: 74.8 TC: 4.66 TG: 5.18	Not reported	Protocol: 20-60 min continuous Training intensity: 10% lower than anaerobic threshold Sessions per week: 3 Weekly training time commitment 60-180 min	Cycle ergometer	12	↓16 % TC ←→TG
Sandvei et al. (2012)	8 M 15 F Premenopausal Inactive	Age: 18-35 BMI: 23.5 TBM: 72 TC: 4.1 HDL: 1.4 LDL: 2.7 TG: 0.70	12 Ratio of M:F not reported	Protocol: 30-60 min continuous Training intensity: 70-80% HR$_{peak}$ Sessions per week: 3 Weekly training time commitment: ~90-180 min	Running	8	←→TC ←→HDL ←→LDL ←→TG

Santiago et al. (1995)	27 F Stage of menopause not reported Sedentary	Age: 31 BMI: 24.1 TBM: 64 TC: 4.70 HDL: 1.68 LDL: 2.69 TG: 0.74	16 F	Protocol: continuous (4.8 km) Training intensity: 72 % HR_{max} Sessions per week: 4 Weekly training time commitment: variable	Treadmill	40	←→TC ←→HDL ←→LDL ←→TG
Sawyer et al. (2016)	18 Ratio of M:F not reported Obese	Age: 35 BMI: 34.5 TBM: 100 TC: 4.14 HDL: 1.17 LDL: 2.50 TG: 3.58	9 Ratio of M:F not reported	Protocol: 30 min continuous Training intensity: 70-75 % HR_{max} Sessions per week: 3 Weekly training time commitment: ~90 min	Cycle ergometer	8	←→TC ←→HDL ←→LDL ←→TG
Schjerve et al. (2008)	8 M 32 F Stage of menopause not reported Obese	Age: 44 BMI: 36.7 TBM: 104 TC: 5.8 HDL: 1.4 TG: 1.5	2 M 11 F	Protocol: 47 min continuous Training intensity: 60-70 % HR_{max} Sessions per week: 3 Weekly training time commitment: 141 min	Treadmill	12	←→TC ←→HDL ↓ ~8 % LDL ←→TG
Shepherd et al. (2015)	26 M 52 F Stage of menopause not reported Inactive	Age: 44 BMI: 27.7 TBM: 78 TC: 5.4 HDL: 1.24 LDL: 2.9 TG: 1.34	14 M 22 F	Protocol: 30-45 min continuous cycling Training intensity: 70% HR_{max} Sessions per wk: 3 Weekly training time commitment: 128 min	Instructor-led group cycling class	10	↓ 7 % TC ↑ 11 % HDL ↓ 10 % LDL ←→ TG
Tjonna et al. (2008)	13 M 15 F Stage of menopause not reported Overweight MetS patients	Age: 52 BMI: 29.4 Body mass: 91 TC: — HDL: 0.74 TG: 1.47	4 M 4 F	Protocol: 47 min continuous walking/ running "uphill" Training intensity: 70% of HR_{max} Sessions per week: 3 Weekly training time commitment: ~150 min	Treadmill	16	←→ HDL ←→ TG

Wallman et al. (2009)	6 M 18 F Stage of menopause not reported Overweight and obese Not participated in regular exercise for 6 months	Age: 45 BMI: 30.1 TBM: 91 TC: 4.7 HDL: 1.7 LDL: 2.3 TG: 1.7	6 ratio of M:F not reported	Protocol: For a duration that resulted in the same amount of energy expenditure (J) as the performed by their matched partner in the HIIT arm of the study. Training intensity: 50-65 % $\dot{V}O_{2peak}$ Sessions per week: 4 Weekly training time commitment: Varied	Cycle ergometer	8	←→TC ←→HDL ←→LDL ←→TG
Wiklund et al. (2014)	90 F premenopausal Overweight and obese Sedentary	Age: 42 BMI: 28.4 TBM: 79 TC: 4.9 HDL: 1.5 LDL: 2.6 TG: 1.2	39 F	Protocol: 30-60 min walking Training intensity: 60-75% HR_{max} Sessions per week: 3 Weekly training time commitment: ~90-120 min	Nordic walking (walking with poles)	6	←→TC ←→HDL ←→LDL ←→TG

Abbreviations: BMI: Body mass index, F: female, M: male, kcal: kilocalorie, HR_{max}: maximal heart rate, $\dot{V}O_{2max}$: maximal oxygen uptake, MetS: metabolic syndrome, $\dot{V}O_2R$: oxygen uptake reserve, HR_{peak}: peak heart rate, $\dot{V}O_{2peak}$: peak oxygen uptake, TBM: total body mass.

2.4.3.5 Blood pressure

From reviewing the literature outlined in Table 2.10, when considering sedentary adults, MICT exercise of ~50 min performed 3 times per wk for 12-16 wks at 60-70 % of HR_{max} appears sufficient to reduce systolic (3 %), diastolic BP (8-9 %) and mean arterial pressure (MAP) (7 %) (Schjerve et al., 2008; Shepherd et al., 2015; Tjonna et al., 2008). The exercise interventions applied in these studies comprised treadmill running or instructor-led group cycling and it should be noted that both baseline systolic and diastolic BP were above normal in these studies. Robinson et al. (2015) have reported small reductions in MAP (2 %) following just 10 sessions of 20-50 min MICT at 60-65 % of HR_{peak} for inactive overweight/obese adults, however, systolic BP appeared to be higher than normal at baseline.

Additionally, 10 wks of running 3-4 times per wk at 50 % of $\dot{V}O_2$ reserve was sufficient to reduce systolic BP (6 %) and diastolic (9 %) BP for sedentary premenopausal women (37 y) with a baseline BP of 118/75 mmHg (Dalleck et al., 2008). However no such changes have been reported following similar interventions for inactive premenopausal women when BP at baseline is either normal or lower than normal (Ciolac et al., 2010; Krustrup, Hansen, Randers, et al., 2010). However, when training was extended to 16 wks, a 6 % reduction in systolic BP was apparent for the participants of Krustrup, Hansen, Randers, et al. (2010) with normal blood pressure vales at baseline.

Cleary, the benefits of MICT appear to be more pronounced in hypertensive compared to normotensive individuals. However, previous literature on the effects of MICT on BP in previously inactive premenopausal women is sparse with conflicting evidence, mainly due to differences in baseline BP. Further research is required to establish the magnitude of the effect of MICT on resting BP in previously inactive premenopausal women as well as alternative exercise modalities and intensities.

Table 2.10 Characteristics of reviewed moderate-intensity continuous training studies on blood pressure

Study	Participants	Intervention group baseline Age (years) BMI (kg/m^2) TBM (kg) Resting SBP (mmHg) Resting DBP (mmHg)	Number in intervention group	Intervention	Mode of exercise	Length (weeks)	Effects on BP
Ciolac et al. (2010)	44 F premenopausal Inactive	Age: 27 BMI: 24.3 TBM: 64 SBP: 106 DBP: 65	11 F	Protocol: 40 min walking Training intensity: 60-70 % $\dot{V}O_{2max}$ Sessions per week: 3 Weekly training time commitment: 180 min	Treadmill	16	←→ DBP ←→ SBP
Dalleck et al. (2008)	15 F Premenopausal Overweight Sedentary (inactive)	Age: 37 BMI: 26.1 TBM: 72 SBP: 118 DBP: 75	15 F	Protocol: Expend a net 1,000 kcal per week Training intensity: 50 % $\dot{V}O_2R$ Sessions per week: 3-4 Weekly training time commitment: ~90 min	Indoor running track	10	↓ 6 % SBP ↓ 9 % DBP
Krustrup, Hansen, Andersen, et al. (2010)	28 F Premenopausal Inactive	Age: 40 BMI: 25.1 TBM: 70 SBP: 110 DBP: 69	10 F	Protocol: 60 min continuous Training intensity: 82 % HR_{max} Sessions per week: 2 Weekly training time commitment: 120 min	Running	64	←→ DBP ←→ SBP
Krustrup, Hansen, Randers, et al. (2010)	50 F Premenopausal Inactive	Age: 37 BMI: 23.1 TBM: 67 SBP: 112 DBP: 71	17 F	Protocol: 60 min continuous Training intensity: 82% HR_{max} Sessions per week: 2 Weekly training time commitment: 120 min	Running	4	←→ SBP ←→ DBP ←→MAP
						16	↓ 6 % SBP ←→ DBP

							←→ MAP
Robinson et al. (2015)	7 M 32 F Stage of menopause not reported Overweight/obese Inactive	Age: 52 BMI: 31.4 TBM: 88 SBP: 131 DBP: 82	4 M 14 F	Protocol: 20-50 min continuous Training intensity: 60-65 % HR_{peak} Sessions per wk: 5 Weekly training time commitment: Variable	Cycle ergometer Treadmill walking Outdoor walking Elliptical trainer	2	↓ 2 % MAP
Schjerve et al. (2008)	8 M 32 F Stage of menopause not reported Obese	Age: 44 BMI: 36.7 TBM: 104 SBP: — DBP: ~90	2 M 11 F	Protocol: 47 min continuous Training intensity: 60-70 % HR_{max} Sessions per week: 3 Weekly training time commitment: 141 min	Treadmill	12	←→ SBP ↓ 9 % DBP
Shepherd et al. (2015)	26 M 52 F Stage of menopause not reported Inactive	Age: 44 BMI: 27.7 TBM: 78 SBP: 127 DBP: 78	14 M 22 F	Protocol: 30-45 min continuous cycling Training intensity: 70% HR_{max} Sessions per wk: 3 Weekly training time commitment: 128 min	Instructor-led group cycling class	10	↓ 3 % SBP ←→ DBP
Tjonna et al. (2008)	13 M 15 F Stage of menopause not reported Overweight MetS patients	Age: 52 BMI: 29.4 Body mass: 91 SBP: 131 DBP88	4 M 4 F	Protocol: 47 min continuous walking/ running "uphill" Training intensity: 70% of HR_{max} Sessions per week: 3 Weekly training time commitment: ~150 min	Treadmill	16	↓ 8 % SBP ←→ DBP ↓ 7 % MAP

Abbreviations: BMI: Body mass index, BP: blood pressure, DBP: diastolic blood pressure F: female, kcal: kilocalorie, M: male, MAP: mean arterial pressure, HR_{max}: maximal heart rate, $\dot{V}O_{2max}$: maximal oxygen uptake, $\dot{V}O_2R$: oxygen uptake reserve, $\dot{V}O_{2peak}$: peak oxygen uptake, SBP: systolic BP, TBM: total body mass.

2.4.3.6 Cognitive Function

Cross-sectional (A. D. Brown et al., 2010; Chodzko-Zajko & Moore, 1994) and prospective observational studies (Singh-Manoux, Hillsdon, Brunner, & Marmot, 2005; Yaffe, Barnes, Nevitt, Lui, & Covinsky, 2001) generally indicate that physically active individuals exhibit better cognitive function than their inactive peers. In addition, participation in moderate-intensity exercise has repeatedly been shown to be beneficial to the cognitive function of older individuals (Johnson et al., 2016; Young, Angevaren, Rusted, & Tabet, 2015). This is strengthened by results from a 5-y follow-up from the Northern Manhattan Study of 876 individuals (70 y) reporting that a greater cognitive decline was independently associated with low levels of leisure-time physical activity (Willey et al., 2016). However, RCTs have reported inconsistent results (Colcombe & Kramer, 2003; Smith et al., 2010).

There is evidence that processing speed, attention and memory are positively associated with physical activity levels (Smith et al., 2010). E. P. Cox et al. (2016) carried out a systematic review on the relationship between physical activity and cognitive function in healthy young to middle-aged adults with significant effects of physical activity on cognitive function found in 12 of 14 studies reviewed. However, only 8 studies utilised validated instruments for the measurement of physical activity and often failed to include physical activity domains. It is evident that aerobic fitness produces beneficial effects on cognitive function, however, very little data is available on the effect of MICT on cognitive function of middle-aged premenopausal women following a prolonged period of training. Also, it is still unclear which form of physical activity elicits the greatest benefits on cognitive performance. Adequate physical activity for this age range may potentially have immediate benefits on cognitive function, resulting in a higher quality of life whilst potentially delaying age-related cognitive decline. If chronic MICT is shown to benefit cognition in healthy young to middle-aged adults, it would be advisable to undertake adequate physical activity before cognitive decline steepens through ageing (Harada, Natelson Love, & Triebel, 2013). However, to what extent this compares to chronic HIIT for inactive middle-aged premenopausal women is also unknown.

2.4.3.7 Mental well-being

Systematic reviews and meta-analyses of healthy older adults without clinical disorders have reported beneficial effects of participation in short-term exercise interventions on aspects of mental well-being, including positive affect (Netz, Wu, Becker, & Tenenbaum, 2005; Rosenbaum & Sherrington, 2011). Netz et al. (2005) reported a significant effect of exercise on well-being enhancement with moderate-intensity providing the strongest effects on self-efficacy. Improvements in cardiovascular status, strength and functional capacity were also linked to well-being improvement. Similarly, a large number of clinical studies have reported decreases in depressive symptoms, negative affect, and sleep disturbances following MICT (Dinas, Koutedakis, & Flouris, 2011). Cramer, Nieman, and Lee (1991) attempted to assess the relationship between MICT consisting of 5 x 45 min sessions of brisk walking at 62 % of $\dot{V}O_{2max}$ per wk for 15 wks and psychological well-being and mood state in sedentary mildly obese women (25-45 y) with the authors concluding that general well-being was significantly improved following MICT.

Conversely, following a 12-wk MICT intervention for obese female participants (45 y), no significant improvement in general well-being was reported (Nieman, Custer, Butterworth, Utter, & Henson, 2000). However, those participants that exercised in conjunction with moderate energy restriction significantly improved general well-being which may be related to weight loss. The exercise intervention consisted of walking 5 times per wk for 45 min per session at 60-80 % of HR_{max}. In addition, Shepherd et al. (2015) assessed the use of 10 wks of MICT in a gym setting for inactive adults (42 y) carried out as 30-45 min cycling at 70 % of HR_{max} three times weekly. However, life satisfaction did not change following the intervention. Beneficial effects on health perceptions, positive and negative affect and subjective vitality were reported following MICT.

Although physical activity is widely promoted for the benefit of mental well-being, previous research primarily relates to the associations with negative mental health or clinical populations (C3 Collaborating for Health, 2012; Loprinzi, 2013). Conversely, less is known about the effects of MICT on mental well-being in inactive premenopausal women with no known mental disorders. This warrants further research in conjunction with the use of various exercise durations and intensities.

2.4.3.8 Conclusion on moderate-intensity continuous training

Based on the literature reviewed above it is apparent that, upon meeting the physical activity recommendations, MICT for previously inactive premenopausal women improves body composition, cardiorespiratory fitness, glucose tolerance, insulin resistance, blood lipids, inflammatory markers, BP, cognitive function and well-being. Improvements in the above health profile parameters appear to be amplified for those individuals with higher than normal baseline values. MICT is appealing for use with inactive individuals since adherence may be increased with light- and moderate-intensity activities (Parfitt, Rose, & Burgess, 2006). On the other hand, although the lower intensity of exercise may appeal to some individuals, time constraints and enjoyment may result in reduced benefits. More recently there has been growing interest in HIIT as an alternative to traditional MICT due to the time efficient training sessions and the ability to elicit clinically relevant improvements in established NCD risk factors (Gibala et al., 2012). Therefore alternative choices and durations of exercise should be examined more closely with their health effects compared to those attained following MICT.

2.4.4 High-intensity interval training

HIIT is an exercise protocol that may provide an alternative time-efficient intervention to reduce several risk factors for NCD’s (Ferrari Bravo et al., 2008; Gibala & McGee, 2008; Kessler et al., 2012; Wisloff et al., 2009). HIIT often requires the completion of short-duration high-intensity intervals for which power output cannot be maintained for a prolonged period of time. In order to repeatedly work at high intensities, the individual must be given time to recover between intervals. Throughout this thesis, as proposed by K. S. Weston et al. (2014), the term ‘HIIT’ will be used to encompass all literature pertaining to protocols in which the training stimulus is ‘near maximal’ or the target intensity is 80-100 % of HR_{max}. In addition, SIT encompasses all literature pertaining to protocols in which the target intensities are greater than that required to elicit 100 % of $\dot{V}O_{2max}$ (K. S. Weston et al., 2014). In some cases, there may be value in providing a description of the complete protocol and, where appropriate, this will be used when describing the results of specific studies. The most common HIIT and SIT protocols are highlighted in Figure 2.3.

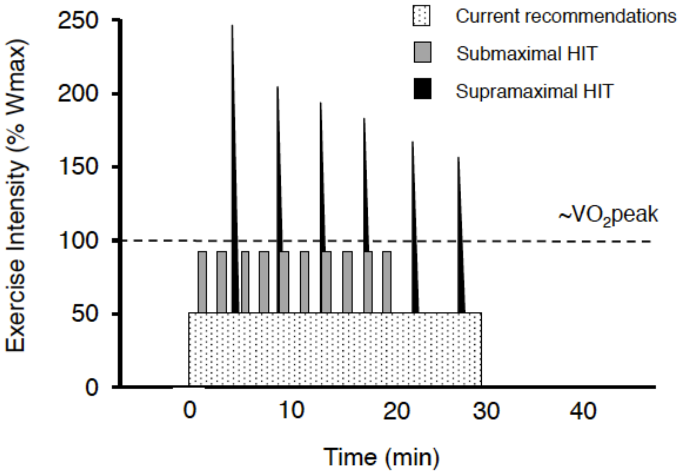


Figure 2.3 Schematic of common HIIT protocols vs. current recommendations. Supramaximal HIIT is also referred to as SIT. Source: Gibala et al. (2014)

Traditional SIT protocols, such as Wingate-style intervals consisting of 4-6 bouts of 30 s sprints interspersed with longer duration rest periods on a cycle ergometer were primarily designed for the purposes of improving performance among athletic populations (Figure 2.3). The benefits of this type of training have been analysed extensively due to the important findings related to health and wellness (Burgomaster et al., 2008; Burgomaster et al., 2005; Gibala et al., 2012). However, individuals have often reported sensations of nausea and light-headiness following this type of protocol (Richards et al., 2010). Some researchers have questioned the safety of those protocols for at-risk populations and low adherence may be expected for untrained individuals and novice exercisers.

Traditional HIIT protocols normally consist of longer intervals ranging from 1-4 min performed at intensities around 80-95 % of HR_{max} (Kessler et al., 2012). Other variations of HIIT protocols utilise intensities relative to an individual’s performance on a $\dot{V}O_{2max}$ test, and include approximately one min sprint and recovery intervals with participants reaching near-maximal heart rates on completion of 10 intervals (Little, Safdar, Wilkin, Tarnopolsky, & Gibala, 2010) (Figure 2.3). HIIT protocols have been used in both young and older healthy participants as well as clinical populations leading to significant health benefits which will be outlined below.

2.4.4.1 Body composition

From reviewing the literature outlined in Table 2.11, it is apparent that improvements in body composition are possible following HIIT but the type of body composition constituent, the exercise protocol and participant baseline characteristics may have an influence on the outcome. For example, reductions in total body mass (1.5 kg), fat mass (2.5 kg) and BF % (2.7 %) have been reported following 15 wks of 60 x 8 s intervals of all-out maximal cycling efforts (Trapp et al., 2008). However, no such changes in body composition were reported following a similar protocol for females when carried out for 5 wks (Kong, Fan, et al., 2016). The shorter intervention duration may have prevented changes in body composition. Furthermore, this type of SIT requires the participants to sprint 60 times per session which some researchers have argued places too much strain on an inactive individual and could negatively affect adherence (Heinrich, Patel, O'Neal, & Heinrich, 2014).

Reductions in fat mass (4-12 %), BF% (2-7 %) and lean mass (1 %) have also been reported in sedentary and recreationally active adults (76-97 kg) employing longer intervals over 2-6 wks using 4-7 x 30 s sprint intervals on a cycle ergometer or non-motorised treadmill interspersed with 4 min recovery performed 3 times weekly (Hazell et al., 2014; Higgins et al., 2016; Macpherson et al., 2010; Richards et al., 2010; Trilk et al., 2011). However, Macpherson et al. (2010) did report that the reduction in fat mass was evident only in males. Conversely, little to no change in total body mass, BMI, fat mass, lean mass and android fat % has been reported for sedentary (inactive) adults (60-117 kg) following 1-10 x 10-60 s near maximal sprints interspersed with 1-6 min recovery performed 3 times weekly for 6-8 wks (Metcalfe, Babraj, Fawkner, & Vollaard, 2012; Sandvei et al., 2012; Sawyer et al., 2016). The lack of significant changes may be due to the small number of sprints in the protocol used by Metcalfe et al. (2012). Another major issue is that diet was not controlled in any of the studies outlined above.

Further conflict of body composition results appears when the high-intensity intervals are extended beyond 1 min. For example, for sedentary adults (80 kg), improvements in total body mass (1 %), lean mass % (1 %), BF % (2 %), waist (1 %) and hip (4 %) circumferences have been reported following 12 wks of cycling for 2 min at an intensity 20 % above anaerobic threshold interspersed with 1 min rest for 20-60 min 3 times per wk (Moreira et al., 2008). Conversely, when considering younger recreationally active females (20 y, 59 kg), no change in total body mass was apparent following 5 wks of 6-10 x 2 min intervals at 120-140 % of the baseline peak power at lactate threshold, interspersed with one min rest (Edge, Bishop, & Goodman, 2006) which may be due to the lowered total body mass at baseline. Extending the high-intervals to 4 min has also been shown to improve total body mass (2-3 %), BMI (2 %), BF % (2 %), and waist (5%) and hip (4 %) circumferences following 12-16 wks for sedentary adults (47-59 y, 96-114 kg) (Schjerve et al., 2008; Tjonna et al., 2008) when carried out 3 times per wk.

Although beneficial adaptations in body composition following HIIT and SIT are prevalent in individuals with no previous experience of high-intensity exercise, based on the literature outlined in this literature review, there is little conclusive evidence that HIIT provides superior weight loss compared to MICT (De Feo, 2013). This is line with the systematic review and meta-analysis by Keating et al. (2017) who concluded that neither HIIT/SIT nor MICT produced clinically meaningful reductions in body fat. Although the studies reviewed above have reported weight loss ranging from 1-3 %, it could be argued that the weight loss is not of clinical significance. Evidence suggests that weight loss of at least 3 % (for glycaemic measures and TG) and 5 % (for blood pressure and HDL and LDL cholesterol) is required to be considered clinically meaningful (Ryan & Heaner, 2014). However, as there is potential for HIIT to provide equivalent adaptations in body composition compared to MICT, this is of particular interest considering that the total exercise time for HIIT is much lower than that of MICT protocols. The length of the high-intensity intervals, as well as the intervention length, may also have an influence on the potential improvements in body composition which need to be taken into consideration when planning a HIIT programme. Sensitivity to adaptations in body composition tend to be greater for those individuals with higher baseline body composition with many previous studies employing both males and females with little data available on previously inactive middle-aged premenopausal women.

Table 2.11 Characteristics of reviewed high-intensity interval and sprint interval training studies on body composition

Study	Participants	Intervention group baseline Age (years) BMI (kg/m^2) TBM (kg)	Number in intervention group	Intervention protocol	Mode of exercise	Length (weeks)	Effects on body composition
Ciolac et al. (2010)	44 F premenopausal Inactive	Age: 24 BMI: 23.5 TBM: 62	11 F	Protocol: 2 min walking / 1 min running for 40 min Training intensity: 50-60 % $\dot{V}O_{2max}$ /80-90 % $\dot{V}O_{2max}$ Sessions per week: 3 Weekly training time commitment: 180 min	Treadmill	16	←→ TBM ←→BMI ←→WC ←→ W-to-H ratio
Edge et al. (2006)	16 F Premenopausal recreationally active	Age: 20 BMI: 21.4 TBM: 59	8 F	Protocol: 6-10 x 2 min intervals interspersed with 1 min recovery Training intensity: 120-140 % of baseline peak power at lactate threshold Sessions per week: 3 Weekly training time commitment: ~ 90 min	Cycle ergometer	5	←→ TBM
Hazell et al. (2014)	15 F Premenopausal Recreationally active	Age: 23 BMI: 22.6 TBM: 61	15 F	Protocol: 4-6 x 30 s intervals interspersed with 4 min active recovery Training intensity: maximal effort sprints Sessions per week: 3 Weekly training time commitment: ~ 60 min	Non-motorised treadmill	6	↓ 1 % TBM ↑ 1 % LM ↓ 8 % FM ↓ 7 % BF % ↓ 4 % WC
Higgins et al. (2016)	52 F Premenopausal Overweight/obese	Age: 20 BMI: — TBM: 82	23 F	Protocol: 5-7 x 30 s intervals interspersed with 4 min rest Training intensity: ‘All out max effort’ Sessions per week: 3 Weekly training time commitment: ~110 min	Cycle ergometer	6	←→ TBM ←→ LM ↑ 2 % leg LM ↓ 4 % FM ↓ 2 % BF % ↓ 7 % Android fat

Kong, Fan, et al. (2016)	26 F Premenopausal Overweight	Age: 22 BMI: 25.8 TBM: 69	13 F	60 x 8 s intervals interspersed with 12 s rest Training intensity: ‘All out max effort’ Sessions per week: 4 Weekly training time commitment: ~66 min	Cycle ergometer	5	←→ TBM ←→ LM ←→ FM ←→ BF %
Macpherson et al. (2010)	12 M 8 F Premenopausal Recreationally active	Age: 24 BMI: 25.1 TBM: 76	6 M 4 F	Protocol: 4-6 x 30 s intervals interspersed with 4 min recovery Training intensity: All-out sprints Sessions per week: 3 Weekly training time commitment: ~80 min	Non-motorised treadmill	6	←→ TBM ↑ 1 % LM ↓ 12 % FM (male only)
Metcalfe et al. (2012)	13 M 16 F Premenopausal Sedentary	Age: 24 BMI: 22.8 TBM: 60	8 F	Protocol: 1-2 x 10-20 s intervals with remainder of session performed at low intensity (60 W) Training intensity: 7.5 % of body weight Sessions per week: 3 Weekly training time: 30 min	Cycle ergometer	6	←→ TBM ←→ BMI
Moreira et al. (2008)	8 M 14 F Stage of menopause not reported Sedentary	Age: 40 BMI: 28.3 TBM: 80	Not reported	Protocol: 20-60 min of 2 min intervals interspersed with 1 min rest Training intensity: 20% above anaerobic threshold Sessions per week: 3 Weekly training time commitment 60-180 min	Cycle ergometer	12	↓ 1 % TBM ↑ 1 % LM % ↓ 2 % BF % ↓ 1 % Waist ↓ 4 % Hip
Richards et al. (2010)	5 M 7 F Premenopausal Sedentary or recreationally active	Age: 29 BMI: 26.2 TBM: 76	5 M 7 F	Protocol: 4-7 x 30 s intervals interspersed with 4 min rest Training intensity: maximal efforts Sessions per week: 3 Weekly training time commitment: ~95 min	Cycle ergometer	2	←→ TBM
Robinson et al. (2015)	7 M 32 F Stage of menopause not reported Overweight/obese Inactive	Age: 52 BMI: 32.9 TBM: 89	3 M 17 F	Protocol: 4-10 x 1 min intervals interspersed with 1 min rest Training intensity: ~90% of HR_{peak} Sessions per wk: 5 Weekly training time commitment: variable	Cycle ergometer Treadmill walking Outdoor walking	2	↓ 1 % TBM ↓ 1 % BMI

					Elliptical trainer		
Sandvei et al. (2012)	8 M 15 F Premenopausal Inactive	Age: 18-35 BMI: 23 TBM: 70	11 ratio of M:F not reported	Protocol: 5-10 x 30 s intervals interspersed with 3-6 min rest Training intensity: Near maximal sprints Sessions per week: 3 Weekly training time commitment: ~7.5-15 min	Running	8	←→ TBM ←→ BMI ←→ LM ←→ % BF
Sawyer et al. (2016)	18 Ratio of M:F not reported Obese	Age: 35 BMI: 37.4 TBM: 117	9 ratio of M:F not reported	Protocol: 10 x 1 min intervals interspersed with 1 min recovery Training intensity: 90-95 % HR_{max} Sessions per week: 3 Weekly training time commitment: ~30 min	Cycle ergometers	8	←→ TBM ←→ BMI ←→ LM ←→ FM ↓ 2 % BF % ↓ 2 % WC ←→ Android fat % ↓ 3 % Gynoid fat %
Schjerve et al. (2008)	8 M 32 F Stage of menopause not reported Obese	Age: 47 BMI: 36.6 TBM: 114	3 M 11 F	Protocol: 4 x 4 min intervals interspersed with 3 min active rest Training intensity: 85-85% HR_{max} Sessions per week: 3 Weekly training time commitment: 48 min	Treadmill	12	↓ 2 % TBM ↓ 2 % BMI ↓ 2 % BF % ←→ W-to-H ratio
Shepherd et al. (2015)	26 M 52 F Inactive	Age: 42 BMI: 27.7 TBM: 79	15 M 31 F	Protocol: repeated 15-60 s sprints interspersed with 45-120 s rest Training intensity: >90% HR_{max} Sessions per wk:3 Weekly training time commitment: 55 min	Instructor-led group cycling class	10	↓ 1 % TBM ↓ 1 % BMI ↓ 3 % FM
Tjonna et al. (2008)	13 M 15 F Stage of menopause not reported MetS patients	Age: 50 BMI: 32.1 TBM: 96	4 M 7 F	Protocol: 4 x 4 min intervals interspersed with 3 min active recovery Training intensity: 90% of HR_{max} Sessions per week: 3 Weekly training time commitment: ~48 min	Treadmill	16	↓ 3 % TBM ↓ 2 % BMI ↓ 5 % Waist ←→ W-to-H ratio
Trapp et al. (2008)	45 F Premenopausal Inactive	Age: 22 BMI: 24.4 TBM: 63	15 F	Protocol: 60 x 8 s intervals interspersed with 12 s rest. Training intensity: ‘All out’ max effort Sessions per week: 3	Cycle ergometer	15	↓ 1.5 kg TBM ↓ 2.5 kg FM ↓ 2.7 % BF

				Weekly training time commitment: ~24 min			
Trilk et al. (2011)	28 F Stage of menopause not reported Overweight/obese Sedentary	Age: 30 BMI: 35.7 TBM: 97	14 F	Protocol: 4-7 x 30 s intervals interspersed with 4 min recovery Training intensity: 5% TBM as resistance Sessions per week: 3 Weekly training time commitment: 18-32 min	Cycle ergometer	4	←→ TBM ←→ BMI ←→ BF%
Wallman et al. (2009)	6 M 18 F Stage of menopause not reported Overweight and obese Inactive	Age: 41 BMI: 31.4 TBM: 91	6 ratio of M:F not reported	Protocol: 30 min of 1 min intervals interspersed with 2 min recovery Training intensity: 90 % and 30 % of $\dot{V}O_{2peak}$ Sessions per week: 4 Weekly training time commitment: 120 min	Cycle ergometer	8	←→ TBM ↓ 8 % Android FM ↓ 4 % Gynoid FM

Abbreviations: BF %: body fat percentage, BMI: Body mass index, BP: blood pressure, DBP: diastolic blood pressure, FM: fat mass, F: female, LM: lean mass, M: male, HR_{max}: maximal heart rate, $\dot{V}O_{2max}$: maximal oxygen uptake, MetS: Metabolic syndrome, $\dot{V}O_{2peak}$: peak oxygen uptake, SBP: systolic BP, TBM: total body mass, W-to-H: waist-to-hip.

2.4.4.2 Cardiorespiratory fitness

From reviewing the literature outlined in Table 2.12 and in line with several meta-analyses (Gist, Fedewa, Dishman, & Cureton, 2014; Scribbans, Vecsey, Hankinson, Foster, & Gurd, 2016; Sloth, Sloth, Overgaard, & Dalgas, 2013; M. Weston, Taylor, Batterham, & Hopkins, 2014), there appears to be good evidence that HIIT may significantly improve the cardiorespiratory fitness of sedentary and recreationally trained individuals. However, the optimal duration of the training session and intervention still remains unknown.

For example, previous studies of sedentary and recreationally trained adults have demonstrated that two wks of SIT performed as 4-7 x 30 s sprint intervals interspersed with 4 min recovery or 4-10 x 60 s sprints interspersed with 60 s recovery was sufficient to improve cycling time to exhaustion and time trial performance (Gibala et al., 2006) and $\dot{V}O_{2peak}$ (7 %) (Robinson et al., 2015). Improvements in $\dot{V}O_{2peak}$ (5-14 %) have also been reported for overweight females and sedentary (inactive) adults following similar protocols ranging from 6-10 wks of cycling or treadmill training (Burgomaster et al., 2005; Hazell et al., 2014; Higgins et al., 2016; Macpherson et al., 2010; Sandvei et al., 2012; Shepherd et al., 2015). This is of interest as the SIT groups have reported exercising for a total training volume that was ~90 % lower than that of MICT groups. However, this SIT protocol requires the participants to repeatedly perform "all-out" sprints for 30 s and although participants' ratings of perceived exertion (RPE) have ranged from 4-8 on a 10-point scale, this type of protocol may still be too intense for older inactive individuals to sustain.

Improvements in $\dot{V}O_{2peak}$ (7-30 %) have also been reported for sedentary overweight/obese females when the high-intensity intervals were reduced to 8 s (Kong, Fan, et al., 2016; Trapp et al., 2008; Trilk et al., 2011). However, these 4-6 wk interventions still required 60 intervals per session interspersed with 12 s rest which may be unsustainable over a longer intervention period for inactive women inexperienced with HIIT. Unfortunately, no data exist on the enjoyment levels during or following this type of HIIT. To combat the issue of repetitive high-intensity intervals, Metcalfe et al. (2012) and Metcalfe, Tardif, Thompson, and Vollaard (2016) employed a HIIT intervention for sedentary adults using only 1-2 10-20 s maximal cycling efforts per session over 6 wks of 3 weekly 10 min sessions. The small number of sprints was sufficient to improve $\dot{V}O_{2peak}$ (12 %) in sedentary adults with no differences between male and females. However, a reduction in intervals may reduce the potential to improve other health profile parameters such as insulin sensitivity and glucose tolerance.

Talanian, Galloway, Heigenhauser, Bonen, and Spriet (2007) and Perry, Heigenhauser, Bonen, and Spriet (2008) have reported improvements in $\dot{V}O_{2peak}$ (9-13 %) following a lower intensity variation of HIIT that does not require "all out" effort. The young recreationally active women completed 10 x 4 min bouts of cycling at 90 % of $\dot{V}O_{2peak}$ interspersed with 2 min recovery. Improvements in $\dot{V}O_{2max}$ (33 %) have also been reported following a reduction in the number of intervals (4 x 4 min at 80-85 % of HR_{max} interspersed with 3 min recovery) for obese adults (47 y) when performed 3 times per wk for 12 wks. Such protocols may address issues of tolerability in inactive individuals as participants exercise at approximately one half of the exercise intensity usually performed during traditional HIIT. However, the total time per session is considerably increased which may be detrimental for those individuals with time constraints. For inactive individuals, the 10-20-30 HIIT protocol used by Gunnarsson and Bangsbo (2012) may be more tolerable and alleviate the time spent sprinting within a HIIT session. In this protocol, participants were asked to run at a low-intensity (<30 % of maximal intensity) for 30 s, moderate-intensity for 20 s (<60 % of maximal intensity) and high-intensity (>90 % of maximal intensity) for 10 s which was repeated 5 times before a rest interval of 2 min. This 5-min block was repeated a maximum of 5 times so participants were only required to sprint 25 times per session. Seven wks of 10-20-30 training was shown to increase $\dot{V}O_{2peak}$ (4 %) in moderately trained individuals (34 y). However, this type of protocol has not been used with inactive premenopausal women.

From reviewing the various HIIT protocols above, it is clear that HIIT is a useful and time-efficient training strategy compared to MICT to improve the cardiorespiratory fitness of sedentary and recreationally trained individuals with improvements in $\dot{V}O_{2peak}$ ranging from 5 to 30 %. The range of improvements appears to vary based on the baseline data of the participants with larger improvements reported for inactive individuals. The improvements in cardiorespiratory fitness can be viewed as clinically significant as a 1-MET increase in exercise capacity has been shown to reduce all-cause mortality and CVD mortality by 15 and 19 %, respectively (D. C. Lee et al., 2011). However, there appears to be a lack of literature based on inactive premenopausal women and it is still unclear whether there is one type of HIIT protocol which is superior to the others. It is apparent that beneficial effects on cardiorespiratory fitness are noticeable following just 2 wks of training. However there is relatively little literature available on whether further improvements are attainable following interventions lasting longer than 10 wks and how this might affect training enjoyment and adherence.

Table 2.12 Characteristics of reviewed high-intensity interval and sprint interval training studies on cardiorespiratory fitness

Study	**Participants**	**Intervention group baseline characteristics** **Age (y)** **BMI (kg/m^2)** **TBM (kg)** **$\dot{V}O_{2peak/max}$ (ml·kg^{-1}·min^{-1})**	**Number in intervention group**	**Intervention**	**Mode of exercise**	**Length (weeks)**	**Effects on $\dot{V}O_{2peak/max}$**
Burgomaster et al. (2005)	14 M 2 F Premenopausal Recreationally active	Age: 22 BMI: 25.6 TBM: 83 $\dot{V}O_{2peak}$: 45	6 M 2 F	Protocol: 4-7 x 30 s intervals interspersed with 4 min recovery Training intensity: ‘All out’ maximal effort Sessions per week: 3 Weekly training time commitment: ~10 min	Cycle ergometer	2	←→
Burgomaster et al. (2008)	10 F 10 F Premenopausal Active but untrained	Age: 24 BMI: — TBM: 69 $\dot{V}O_{2peak}$: 41	5 M 5 F	Protocol: 4-6 x 30 s intervals interspersed with 4.5 min rest Training intensity: ‘All out’ maximal effort Sessions per week: 3 Weekly training time commitment: ~10 min	Cycle ergometer	6	↑ 7 %
Ciolac et al. (2010)	44 F premenopausal Inactive	Age: 24 BMI: 23.5 TBM: 62 $\dot{V}O_{2peak}$: 29	11 F	Protocol: 2 min walking / 1 min running for 40 min Training intensity: 50-60 % $\dot{V}O_{2max}$ /80-90 % $\dot{V}O_{2max}$ Sessions per week: 3 Weekly training time commitment: 180 min	Treadmill	16	↑ 16 %
Edge et al. (2006)	16 F Premenopausal recreationally active	Age: 20 BMI: 21.4 TBM: 59 $\dot{V}O_{2max}$: 44	8 F	Protocol: 6-10 x 2 min intervals interspersed with 1 min recovery Training intensity: 120-140 % of baseline peak power at lactate threshold Sessions per week: 3 Weekly training time commitment: ~ 90 min	Cycle ergometer	5	↑ 14 %

Foster et al. (2015)	23 M 42 F Sedentary	Age: 20 BMI: — TBM: M: 81, F: 68 $\dot{V}O_{2peak}$: 34	21 ratio of M:F not reported	Protocol: ‘Tabata’ 8 x 20 s intervals interspersed with 10 s rest Training intensity: 170 % $\dot{V}O_{2max}$ Sessions per week: 3 Weekly training time commitment: ~8 min	Cycle ergometer	8	↑ 18 %
		Age: 20 BMI: — TBM: M: 76, F: 72 $\dot{V}O_{2peak}$: 34	15 ratio of M:F not reported	Protocol: ‘Meyer’ 13 x 30 s intervals interspersed with 60 s rest Training intensity: 100 % $\dot{V}O_{2max}$ Sessions per week: 3 Weekly training time commitment: ~26 min			↑ 18 %
Gunnarsson and Bangsbo (2012)	12 M 6 F Premenopausal Moderately trained	Age: 33 BMI: — TBM: 75 $\dot{V}O_{2max}$: 52	7 M 3 F	Protocol: ’10-20-30’ 3-4 x 5 min intervals interspersed with 2 min recovery Training intensity: Low-, moderate-, and high-speed running (<30 %, <60 %, and >90 % of maximal intensity) Sessions per week: 3 Weekly training time commitment: ~ 90 min	Running	7	↑ 4 %
Hazell et al. (2014)	15 F Premenopausal Recreationally active	Age: 23 BMI: 22.6 TBM: 61 $\dot{V}O_{2max}$: 46	15 F	Protocol: 4-6 x 30 s intervals interspersed with 4 min active recovery Training intensity: maximal effort sprints Sessions per week: 3 Weekly training time commitment: ~ 60 min	Non-motorised treadmill	6	↑ 9 %
Higgins et al. (2016)	52 F Premenopausal Overweight/obese	Age: 20 BMI: — TBM: 82 $\dot{V}O_{2max}$: 29	23 F	Protocol: 5-7 x 30 s intervals interspersed with 4 min rest Training intensity: ‘All out max effort’ Sessions per week: 3 Weekly training time commitment: ~110 min	Cycle ergometer	6	↑ 14 %
Kong, Fan, et al. (2016)	26 F Premenopausal Overweight	Age: 22 BMI: 25.8 TBM: 69	13 F	Protocol: 60 x 8 s intervals interspersed with 12 s rest Training intensity: ‘All out max effort’ Sessions per week: 4	Cycle ergometer	5	↑ 9 %

				Weekly training time commitment: ~66 min			
Macpherson et al. (2010)	12 M 8 F Premenopausal Recreationally active	Age: 24 BMI: 25.1 TBM: 76	6 M 4 F	Protocol: 4-6 x 30 s intervals interspersed with 4 min recovery Training intensity: All-out sprints Sessions per week: 3 Weekly training time commitment: ~80 min	Non-motorised treadmill	6	↑ 12 %
Metcalfe et al. (2012)	13 M 16 F Premenopausal Sedentary $\dot{V}O_{2max}$: 33	Age: 24 BMI: 22.8 TBM: 60	8 F	Protocol: 1-2 x 10-20 s intervals with remainder of session performed at low intensity (60 W) Training intensity: 7.5 % of body weight Sessions per week: 3 Weekly training time: 30 min	Cycle ergometer	6	↑ 12 %
Metcalfe et al. (2016)	17 M 18 F Premenopausal Sedentary	Age: 33 BMI: 25.1 TBM: 67 $\dot{V}O_{2max}$: 32	18 F	Protocol: 1-2 x 10-20 s intervals with remainder of session performed at low intensity (60 W) Training intensity: 5 % of body weight Sessions per wk: 3 Weekly training time commitment: 30 min	Cycle ergometer	6	↑ 9 %
Perry et al. (2008)	5 M 3 F Active but not structured training	Age: 24 BMI: 22.6 TBM: 73 $\dot{V}O_{2peak}$: 3.29 (L×min^{-1})	3 F	Protocol: 10 x 4 min intervals interspersed with 2 min rest Training intensity: ~90 % of $\dot{V}$O2peak Sessions per week: 3 Weekly training time: ~180 min	Cycle ergometer	6	↑ 9 %
Robinson et al. (2015)	7 M 32 F Stage of menopause not reported Overweight/obese Inactive	Age: 52 BMI: 32.9 TBM: 89 $\dot{V}O_{2max}$: 20	3 M 17 F	Protocol: 4-10 x 1 min intervals interspersed with 1 min rest Training intensity: ~90 % of HR_{peak} Sessions per wk: 5 Weekly training time commitment: variable	Cycle ergometer Treadmill walking Outdoor walking Elliptical trainer	2	↑ 7 %
Sandvei et al. (2012)	8 M 15 F Premenopausal Inactive	Age: 18-35 BMI: 23 TBM: 70 $\dot{V}O_{2max}$: 51	11 ratio of M:F not reported	Protocol: 5-10 x 30 s intervals interspersed with 3-6 min rest Training intensity: Near maximal sprints Sessions per week: 3 Weekly training time commitment: ~7.5-15 min	Running	8	↑ 5 %

Sawyer et al. (2016)	18 Ratio of M:F not reported Obese	Age: 35 BMI: 37.4 TBM: 117 $\dot{V}O_{2peak}$: 20	9 ratio of M:F not reported	Protocol: 10 x 1 min intervals interspersed with 1 min recovery Training intensity: 90-95 % HR_{max} Sessions per week: 3 Weekly training time commitment: ~30 min	Cycle ergometers	8	↑ 20 %
Schjerve et al. (2008)	8 M 32 F Stage of menopause not reported Obese	Age: 47 BMI: 36.6 TBM: 114 $\dot{V}O_{2peak}$: 24	3 M 11 F	Protocol: 4 x 4 min intervals interspersed with 3 min active rest Training intensity: 85-85 % HR_{max} Sessions per week: 3 Weekly training time commitment: 48 min	Treadmill	12	↑ 33 %
Shepherd et al. (2015)	26 M 52 F Stage of menopause not reported Inactive	Age: 42 BMI: 27.7 TBM: 79 $\dot{V}O_{2peak}$: 24	15 M 31 F	Protocol: repeated 15-60 s sprints interspersed with 45-120 s rest Training intensity: >90 % HR_{max} Sessions per wk:3 Weekly training time commitment: 55 min	Instructor-led group cycling class	10	↑ 9 %
Talanian et al. (2007)	8 F Premenopausal Recreationally active	Age: 22 BMI: — TBM: 65 $\dot{V}O_{2peak}$: 2.36 ($L \times min^{-1}$)	8 F	Protocol: 10 x 4 min intervals interspersed with 2 min rest Training intensity: ~90 % $\dot{V}O_{2peak}$ Sessions per week: 3-4 Weekly training time commitment: 180 min	Cycle ergometer	2	↑ 13 %
Tjonna et al. (2008)	13 M 15 F Stage of menopause not reported MetS patients	Age: 50 BMI: 32.1 TBM: 96 $\dot{V}O_{2max}$: 34	4 M 7 F	Protocol: 4 x 4 min intervals interspersed with 3 min active recovery Training intensity: 90 % of HR_{max} Sessions per week: 3 Weekly training time commitment: ~48 min	Treadmill	16	↑ 30 %
Trapp et al. (2008)	45 F Premenopausal Inactive	Age: 22 BMI: 24.4 TBM: 63 $\dot{V}O_{2max}$: 29	15 F	Protocol: 60 x 8 s intervals interspersed with 12 s rest. Training intensity: ‘All out’ max effort Sessions per week: 3 Weekly training time commitment: ~24 min	Cycle ergometer	15	↑ 23 %

Trilk et al. (2011)	28 F Stage of menopause not reported Overweight/obese Sedentary	Age: 30 BMI: 35.7 TBM: 97 $\dot{V}O_{2peak}$: 22	14 F	Protocol: 4-7 x 30 s intervals interspersed with 4 min recovery Training intensity: 5 % of TBM as resistance Sessions per week: 3 Weekly training time commitment: 18-32 min	Cycle ergometer	4	↑ 12 %
Wallman et al. (2009)	6 M 18 F Stage of menopause not reported Overweight and obese Inactive	Age: 41 BMI: 31.4 TBM: 91 $\dot{V}O_{2peak}$: 23	6 ratio of M:F not reported	Protocol: 30 min of 1 min intervals interspersed with 2 min recovery Training intensity: 90 % and 30 % of $\dot{V}O_{2peak}$ Sessions per week: 4 Weekly training time commitment: 120 min	Cycle ergometer	8	↑ 21 %

Abbreviations: BMI: Body mass index, F: female, M: male, HR_{max}: maximal heart rate, $\dot{V}O_{2max}$: maximal oxygen uptake, MetS: metabolic syndrome $\dot{V}O_{2peak}$: peak oxygen uptake TBM: total body mass.

2.4.4.3 Insulin and glucose

The literature outlined in Table 2.13 suggests there is some evidence that HIIT is an effective method for improving [insulin] and [glucose] in populations either at an elevated risk of developing insulin resistance, such as overweight and obese individuals or in populations already presenting with insulin resistance. For example, Little et al. (2011) examined glycaemic control of individuals with T2D (63 y) following 2 wks of HIIT. Following 3 weekly sessions of 10 x 60 s cycling intervals at 90 % HR_{max} interspersed with 60 s rest, a ~13 % reduction in mean 24-h blood [glucose], as well as a 29 % reduction in the aggregate glucose area under the curve (AUC) was reported.

Improvements in insulin sensitivity and glucose tolerance for those individuals who are overweight but have normal blood [glucose] values at baseline are inconsistent. For example, 2-8 wk studies employing 15-60 s sprints such as Sawyer et al. (2016) and Robinson et al. (2015), no improvement in fasting blood [glucose], [insulin] and insulin sensitivity were reported for inactive overweight adults when assessed 42-72 h after the final training session. Although the baseline values of [insulin] and [glucose] are likely to influence potential changes following training, it could also be argued that potential adaptations may have been missed in the 24 h following the last training session. However, using the gold standard euglycemic hyperinsulinemic clamp technique, Richards et al. (2010) reported improvements in insulin sensitivity (27 %) in inactive adults following 2 wks of 4-7 x 30 s maximal cycling interspersed with 4 min recovery performed three times weekly and assessed 72 h after the last training session. It could also be argued that the sensitivity of the method used may have more of an influence than the timing of data collection.

Following a 6 wk HIIT intervention for healthy but sedentary adults consisting of 1-2 10-20 s maximal effort sprints at 7.5 % body mass three times weekly, glucose AUC increased (6 %) for the female participants with no change in fasting [glucose], [insulin] and insulin AUC (Metcalfe et al., 2012). The low volume of high-intensity exercise may have been insufficient to induce changes in insulin and glucose. However, in a follow up to their previous study on the use of reduced exertion HIIT, Metcalfe et al. (2016) used a similar protocol with 1-2 all-out 10-20 s sprints against a resistance of 5 % body mass in sedentary men and women.

The authors reported no significant changes following the intervention, concluding that no sex difference in responses were apparent. The lack of change in some studies may be due to the fact that females have a 25 % greater aerobic contribution to all-out sprints compared to men (D. W. Hill & Smith, 1993) with 42 % less muscle glycogen breakdown in type 1 fibers (Esbjornsson-Liljedahl, Sundberg, Norman, & Jansson, 1999) leading to a lower blood lactate accumulation following single (Esbjornsson-Liljedahl, Bodin, & Jansson, 2002; Gratas-Delamarche, Le Cam, Delamarche, Monnier, & Koubi, 1994) and repeated 30 s sprints (Esbjornsson-Liljedahl et al., 2002). The reduced rate of glycogenolysis may also be associated with lower basal activities of muscle phosphofructokinase and lactate dehydrogenase which has been reported in women (Esbjornsson Liljedahl, Holm, Sylven, & Jansson, 1996; Jaworowski, Porter, Holmback, Downham, & Lexell, 2002) and which could help explain the relative glycogen sparing that has been reported in women (Esbjornsson-Liljedahl et al., 1999).

Contradictory results such as these warrant further research to determine how much of a role the participant baseline values, timing of data collection following the final training session, length of the training programme as well as the training intensity has on the effectiveness of HIIT on [insulin] and [glucose]. Additionally, there is little evidence on whether or not glycaemic control, as a result of HIIT when directly compared to MICT, can be effective in inactive middle-aged premenopausal women. Thus, studies that aim to improve insulin sensitivity in populations at risk of developing metabolic diseases could potentially be of clinical significance as individuals who exercise for 20-30 min per day demonstrated a 58% reduction in progression of impaired glucose tolerance to T2D (Wilcox, 2005). Furthermore, it is unknown whether these adjustments can be sustained for the long term.

Table 2.13 Characteristics of reviewed high-intensity interval and sprint interval training studies on fasting glucose, insulin and insulin sensitivity

Study	**Participants**	**Intervention group baseline characteristics** **Age (years)** **BMI (kg/m^2)** **TBM (kg)** **FG (mmol/L)** **FI (μIU/ml)** **IS**	**Number in intervention group**	**Intervention**	**Mode of exercise**	**Length (weeks)**	**Effects on FG, FI and IS**
Ciolac et al. (2010)	44 F premenopausal Inactive	Age: 24 BMI: 23.5 TBM: 62 FG: 4.62 FI: 7.9 IS: 1.53 (HOMA)	11 F	Protocol: 2 min walking / 1 min running for 40 min Training intensity: 50-60 % $\dot{V}O_{2max}$ /80-90 % $\dot{V}O_{2max}$ Sessions per week: 3 Weekly training time commitment: 180 min	Treadmill	16	←→ FG ↓ 35 % FI ↓ 31 % IS
Gunnarsson and Bangsbo (2012)	12 M 6 F Premenopausal Moderately trained	Age: 33 BMI: — TBM: 75 FG: 5.1 FI: 5.03	7 M 3 F	Protocol: '10-20-30' 3-4 x 5 min intervals interspersed with 2 min recovery Training intensity: Low-, moderate-, and high-speed running (<30 %, <60 %, and >90 % of maximal intensity) Sessions per week: 3 Weekly training time commitment: ~ 90 min	Running	7	←→ FG ←→ FI
Hood et al. (2011)	4 M 3 F stage of menopause not reported Sedentary	Age: 45 BMI: 27 TBM: — FG: 4.9 FI: 8.1 IS: 13 (HOMA-IR)	4 M 3 F	Protocol: 10 x 1 min intervals interspersed with 1 min recovery Training intensity: 60 % of peak power output achieved during ramp $\dot{V}O_{2peak}$ test Sessions per week: 3 Weekly training time commitment:	Cycle ergometer	2	←→ FG ↓16% FI ↑ ~35% IS
Kong, Fan, et al. (2016)	26 F Premenopausal Overweight	Age: 22 BMI: 25.8 TBM: 69 FG: 4.5	13 F	Protocol: 60 x 8 s intervals interspersed with 12 s rest Training intensity: 'All out max effort' Sessions per week: 4	Cycle ergometer	5	←→ FG

				Weekly training time commitment: ~66 min			
Metcalfe et al. (2012)	13 M 16 F Premenopausal Sedentary	Age: 24 BMI: 22.8 TBM: 60 FG: ~5.0 FI: ~15 IS: ~68 (Cederholm)	8 F	Protocol: 1-2 x 10-20 s intervals with remainder of session performed at low intensity (60 W) Training intensity: 7.5 % of body weight Sessions per week: 3 Weekly training time: 30 min	Cycle ergometer	6	←→ FG ←→ FI ←→ IS ↑ 6% Glucose AUC ←→ Insulin AUC
Metcalfe et al. (2016)	17 M 18 F Premenopausal Sedentary	Age: 33 BMI: 25.1 TBM: 67 FG: 4.96 FI: 5.6 IS: 79 (Cederholm)	18 F	Protocol: 1-2 x 10-20 s intervals with remainder of session performed at low intensity (60 W) Training intensity: 5 % of body weight Sessions per wk: 3 Weekly training time commitment: 30 min	Cycle ergometer	6	←→ FG ←→ FI ←→ IS ←→ Glucose AUC ←→ Insulin AUC
Moreira et al. (2008)	8 M 14 F Stage of menopause not reported Sedentary	Age: 40 BMI: 28.3 TBM: 80 FG: ~3.9	Not reported	Protocol: 20-60 min of 2 min intervals interspersed with 1 min rest Training intensity: 20 % above anaerobic threshold Sessions per week: 3 Weekly training time commitment 60-180 min	Cycle ergometer	12	↓ 14 % FG
Richards et al. (2010)	5 M 7 F Premenopausal Sedentary or recreationally active	Age: 29 BMI: 26.2 TBM: 76 FG: 4.4 FI: 5.4 IS: 6.3 mg/kg/min (hyperinsulinaemic euglycaemic clamp)	5 M 7 F	Protocol: 4-7 x 30 s intervals interspersed with 4 min rest Training intensity: maximal efforts Sessions per week: 3 Weekly training time commitment: ~95 min	Cycle ergometer	2	←→ FG ←→ FI ↑ 27 % IS
Robinson et al. (2015)	7 M 32 F Stage of menopause not reported	Age: 52 BMI: 32.9 TBM: 89 FG: 5.6 FI: 15.7	3 M 17 F	Protocol: 4-10 x 1 min intervals interspersed with 1 min rest Training intensity: ~90 % of HR_{peak} Sessions per wk: 5	Cycle ergometer Treadmill walking	2	←→ FG ←→ FI ←→ IS

	Overweight/obese Inactive			Weekly training time commitment: variable	Outdoor walking Elliptical trainer		
Sandvei et al. (2012)	8 M 15 F Premenopausal Inactive	Age: 18-35 BMI: 23 TBM: 70 FG: 5.3 FI: 5.5 IS: 0.7 (HOMA-IR)	11 ratio of M:F not reported	Protocol: 5-10 x 30 s intervals interspersed with 3-6 min rest Training intensity: Near maximal sprints Sessions per week: 3 Weekly training time commitment: ~7.5-15 min	Running	8	↓ 4 % FG ←→ FI ↓ 6 % Glucose AUC ←→ HOMA-IR
Sawyer et al. (2016)	18 Ratio of M:F not reported Obese	Age: 35 BMI: 37.4 TBM: 117 FG: 5.08 FI: 19.1 IS: 4.8 (HOMA-IR)	9 ratio of M:F not reported	Protocol: 10 x 1 min intervals interspersed with 1 min recovery Training intensity: 90-95 % HR_{max} Sessions per week: 3 Weekly training time commitment: ~30 min	Cycle ergometers	8	←→ FG ←→ FI ←→ IS
Schjerve et al. (2008)	8 M 32 F Stage of menopause not reported Obese	Age: 47 BMI: 36.6 TBM: 114 FG: 5.2	3 M 11 F	Protocol: 4 x 4 min intervals interspersed with 3 min active rest Training intensity: 85-85 % HR_{max} Sessions per week: 3 Weekly training time commitment: 48 min	Treadmill	12	←→ FG
Shepherd et al. (2015)	26 M 52 F Stage of menopause not reported Inactive	Age: 42 BMI: 27.7 TBM: 79 FG: 5.3 FI: 20.8 IS: 5 (HOMA-IR)	15 M 31 F	Protocol: repeated 15-60 s sprints interspersed with 45-120 s rest Training intensity: >90 % HR_{max} Sessions per wk:3 Weekly training time commitment: 55 min	Instructor-led group cycling class	10	←→ FG ↓ 8 % FI ↑ 8 % IS
Tjonna et al. (2008)	13 M 15 F Stage of menopause not reported MetS patients	Age: 50 BMI: 32.1 TBM: 96 FG: 6.9 FI: 16.0 IS: 62.2 % (HOMA %)	4 M 7 F	Protocol: 4 x 4 min intervals interspersed with 3 min active recovery Training intensity: 90 % of HR_{max} Sessions per week: 3 Weekly training time commitment: ~48 min	Treadmill	16	↓ 4 % FG ←→ FI ↑ 22 % IS

Trapp et al. (2008)	45 F Premenopausal Inactive	Age: 22 BMI: 24.4 TBM: 63 FG: 4.2 FI: 19.4 IS: 3.6 (HOMA-IR)	15 F	Protocol: 60 x 8 s intervals interspersed with 12 s rest. Training intensity: 'All out' max effort Sessions per week: 3 Weekly training time commitment: ~24 min	Cycle ergometer	15	↓ 31 % FI ↑ 33 % IS

Abbreviations: AUC: area under the curve, BMI: Body mass index, FG: fasting glucose, FI: fasting insulin, F: female, HOMA-IR: homeostatic model assessment of insulin resistance, IS: insulin sensitivity, M: male, HR_{max}: maximal heart rate, $\dot{V}O_{2max}$: maximal oxygen uptake, $\dot{V}O_{2peak}$: peak oxygen uptake TBM: total body mass.

2.4.4.4 Lipid profile

Following a review of the literature outlined in Table 2.14, it appears that HIIT has little to no effect on the blood lipid profile of inactive and recreationally trained adults with normal blood lipid values at baseline. For example, when considering inactive adults, 8-16 wks of 3 weekly sessions of 1-2 min running or cycling intervals at 80-90 % of $\dot{V}O_{2peak}$ or 90-95 % HR_{max} interspersed with 2 min rest did not significantly change [TC], [LDL], [HDL], or [TG] (Ciolac et al., 2010; Keating et al., 2014; Moreira et al., 2008; Sawyer et al., 2016; Wallman et al., 2009). In addition, Kong, Fan, et al. (2016) also reported no change in [TC], [LDL], [HDL] and [TG] following 5 wks of 3 weekly sessions of 60 x 8 s intervals at maximal intensity interspersed with 12 rest on a cycle ergometer in obese females. The same trend appears with longer high-intensity intervals as Schjerve et al. (2008) also reported no changes in lipid profile in obese adults following 12 wks of 3 weekly sessions of 4 x 4 min running intervals at 80-85 % HR_{max} interspersed with 3 min recovery. The lack of significant changes following HIIT protocols with varying work-to-rest intervals is likely due to the normal values of blood lipids at baseline.

For adults at an elevated risk for NCDs, Tjonna et al. (2008) reported a 20 and 19 % improvement in [HDL] and [adiponectin] following a 16 wk protocol of 4 x 4 min HIIT for individuals with the MetS (50 y). This is in line with previous literature suggesting that HDL cholesterol is the constituent of the lipid profile most likely to improve following physical activity (Mann, Beedie, & Jimenez, 2014). The improvements in HDL are also of clinical significance as every 0.026 mmol/L increase is associated with a 2-3 % risk reduction for CHD (D. J. Gordon et al., 1989)

Notably, an 8 and 10 wk programme incorporating 3 weekly 5-60 intervals for sedentary (inactive) adults was sufficient to reduce [TC] (6-7 %) and [LDL] (10 %) and increase [HDL] (3 %) (Sandvei et al., 2012; Shepherd et al., 2015). In addition, Gunnarsson and Bangsbo (2012) reported a 10 % and 15 % reduction in [TC] and [LDL] following 7 wks of the 10-20-30 HIIT programme for moderately trained adults (33 y) when performed 3 times weekly. It is noteworthy that the improvements reported in Gunnarsson and Bangsbo (2012) and Sandvei et al. (2012) presented baseline values of blood lipids that were no higher than those previously reviewed and were still within a normal range. However, as diet was not directly controlled within these 7-8 wk programmes, it cannot be ruled out that a change in dietary intake may have influenced a change in blood lipid profile.

It is apparent that HIIT does not alter the blood lipid profile to a large extent in inactive and recreationally trained adults with normal blood lipid values at baseline. However, there is evidence from some studies indicating the potential of HIIT to improve several constituents of the blood lipid profile, albeit, without dietary control. With a lack of literature on the effects of different HIIT programmes on the blood lipid profile in previously inactive premenopausal women, further investigation is warranted.

Table 2.14 Characteristics of reviewed high-intensity interval and sprint interval training studies on lipid profile

Study	**Participants**	**Intervention group baseline characteristics** **Age (y)** **BMI (kg/m^2)** **TBM (kg)** **TC (mmol/L)** **HDL (mmol/L)** **LDL (mmol/L)** **TG (mmol/L)**	**Number in intervention group**	**Intervention**	**Mode of exercise**	**Length (weeks)**	**Effects on blood lipids**
Ciolac et al. (2010)	44 F premenopausal Inactive	Age: 24 BMI: 23.5 TBM: 62 TC: 4.65 HDL: 1.57 LDL: 2.71 TG: 1.91	11 F	Protocol: 2 min walking / 1 min running for 40 min Training intensity: 50-60 % V̇O2$_{max}$ /80-90 % V̇O2$_{max}$ Sessions per week: 3 Weekly training time commitment: 180 min	Treadmill	16	←→ TC ←→ HDL ←→ LDL ←→ TG
Gunnarsson and Bangsbo (2012)	12 M 6 F Premenopausal Moderately trained	Age: 33 BMI: — TBM: 75 TC: 4.8 HDL: ~1.5 LDL: 2.3 TG: 1.4	7 M 3 F	Protocol: '10-20-30' 3-4 x 5 min intervals interspersed with 2 min recovery Training intensity: Low-, moderate-, and high-speed running (<30 %, <60 %, and >90 % of maximal intensity) Sessions per week: 3 Weekly training time commitment: ~ 90 min	Running	7	↓ 10 % TC ←→ HDL ↓ 15 % LDL ←→ TG
Hazell et al. (2014)	15 F Premenopausal Recreationally active	Age: 23 BMI: 22.6 TBM: 61 TC: 4.33 HDL: 1.34 LDL: 2.48 TG: 1.11	15 F	Protocol: 4-6 x 30 s intervals interspersed with 4 min active recovery Training intensity: maximal effort sprints Sessions per week: 3 Weekly training time commitment: ~ 60 min	Non-motorised treadmill	6	←→ TC ←→ HDL ←→ LDL ←→ TG

Keating et al. (2014)	7 M 31 F Pre and postmenopausal Overweight Inactive	Age: 42 BMI: 28.2 Body mass: 76.1 TC: 5.3 HDL: 1.4 LDL: 3.6 TG: 1.1	3 M 10 females	Protocol: 4-6 x 30-60 s intervals interspersed with 120-180 s rest Training intensity: Work: 120 % of $\dot{V}O2_{peak}$ Sessions per week: 3 Weekly training time commitment: 60-72	Cycle ergometer	12	←→ TC ←→ HDL ←→ LDL ←→ TG
Kong, Fan, et al. (2016)	26 F Premenopausal Overweight	Age: 22 BMI: 25.8 TBM: 69 TC: 4.3 HDL: 1.3 LDL: 2.4 TG: 1.0	13 F	Protocol: 60 x 8 s intervals interspersed with 12 s rest Training intensity: 'All out max effort' Sessions per week: 4 Weekly training time commitment: ~66 min	Cycle ergometer	5	←→ TC ←→ HDL ←→ LDL ←→ TG
Moreira et al. (2008)	8 M 14 F Stage of menopause not reported Sedentary	Age: 40 BMI: 28.3 TBM: 80 TC: 4.14 TG: 5.18	Not reported	Protocol: 20-60 min of 2 min intervals interspersed with 1 min rest Training intensity: 20 % above anaerobic threshold Sessions per week: 3 Weekly training time commitment 60-180 min	Cycle ergometer	12	←→ TC ←→ TG
Sandvei et al. (2012)	8 M 15 F Premenopausal Inactive	Age: 18-35 BMI: 23 TBM: 70 TC: 4.5 HDL: 1.3 LDL: 3.2 TG: 0.88	11 ratio of M:F not reported	Protocol: 5-10 x 30 s intervals interspersed with 3-6 min rest Training intensity: Near maximal sprints Sessions per week: 3 Weekly training time commitment: ~7.5-15 min	Running	8	↓ 7 % TC ←→ HDL ↓ 10 % LDL ←→ TG
Sawyer et al. (2016)	18 Ratio of M:F not reported Obese	Age: 35 BMI: 37.4 TBM: 117 TC: 4.68 HDL: 1.0 LDL: 3.18 TG: 3.83	9 ratio of M:F not reported	Protocol: 10 x 1 min intervals interspersed with 1 min recovery Training intensity: 90-95 % HR_{max} Sessions per week: 3 Weekly training time commitment: ~30 min	Cycle ergometers	8	←→ TC ←→ HDL ←→ LDL ←→ TG

Schjerve et al. (2008)	8 M 32 F Stage of menopause not reported Obese	Age: 47 BMI: 36.6 TBM: 114 TC: 6.3 HDL: 1.3 TG: 1.3	3 M 11 F	Protocol: 4 x 4 min intervals interspersed with 3 min active rest Training intensity: 85-85 % HR_{max} Sessions per week: 3 Weekly training time commitment: 48 min	Treadmill	12	←→ TC ←→ HDL ←→ LDL ←→ TG
Shepherd et al. (2015)	26 M 52 F Inactive	Age: 42 BMI: 27.7 TBM: 79 TC: 5.1 HDL: 1.36 LDL: 3.0 TG: 1.22	15 M 31 F	Protocol: repeated 15-60 s sprints interspersed with 45-120 s rest Training intensity: >90 % HR_{max} Sessions per wk:3 Weekly training time commitment: 55 min	Instructor-led group cycling class	10	↓ 6 % TC ↑ 3 % HDL ↓ 10 % LDL ←→ TG
Tjonna et al. (2008)	13 M 15 F Stage of menopause not reported MetS patients	Age: 50 BMI: 32.1 TBM: 96 TC: — HDL: 0.69 TG: 1.65	4 M 7 F	Protocol: 4 x 4 min intervals interspersed with 3 min active recovery Training intensity: 90 % of HR_{max} Sessions per week: 3 Weekly training time commitment: ~48 min	Treadmill	16	↑ 20 % HDL ←→ TG
Wallman et al. (2009)	6 M 18 F Stage of menopause not reported Overweight and obese Inactive	Age: 41 BMI: 31.4 TBM: 91 TC: 5.2 HDL: 1.4 LDL: 3.1 TG: 1.5	6 ratio of M:F not reported	Protocol: 30 min of 1 min intervals interspersed with 2 min recovery Training intensity: 90 % and 30 % of $\dot{V}O2_{peak}$ Sessions per week: 4 Weekly training time commitment: 120 min	Cycle ergometer	8	←→ TC ←→ HDL ←→ LDL ←→ TG

Abbreviations: BMI: body mass index, F: female, HDL: high density lipoprotein, LDL: low density lipoprotein, M: male, HR_{max}: maximal heart rate, $\dot{V}O_{2max}$: maximal oxygen uptake, $\dot{V}O2_{peak}$: peak oxygen uptake, TBM: total body mass, TC: total cholesterol, TG: Triglycerides.

2.4.4.5 Blood pressure

Studies on the BP response following HIIT interventions for inactive individuals have reported inconsistent results (Table 2.15). For example, no change was reported for systolic and diastolic BP for inactive adults following 12-16 wks of exercise. Training required sprint intervals ranging from of 30-60 s of cycling at 80-90 % of $\dot{V}O_{2peak}$ interspersed with 2-3 min recovery performed 3 times (Ciolac et al., 2010; Keating et al., 2014). However, baseline values for systolic and diastolic BP were 106-111 and 65-74 mmHg. In addition, no change in BP was reported following a similar 8 wk HIIT protocol for overweight/obese adults rest with baselines values of 128 and 82 mmHg for systolic and diastolic BP (Wallman et al., 2009).

Conversely, for individuals with raised baseline BP values, small reductions in MAP (2 %) and diastolic BP (7-9 %) have been reported following 2-16 wks of HIIT including 60 s sprints and 4 min high-intensity intervals for inactive overweight/obese adults carried out on a cycle ergometer, treadmill, elliptical trainer and outdoor walking (Robinson et al., 2015; Schjerve et al., 2008). In addition, following the 7 wk 10-20-30 HIIT protocol used by Gunnarsson and Bangsbo (2012), systolic BP was reduced by 4 % in moderately trained adults with no change in diastolic BP or resting HR. Baseline values for systolic and diastolic BP were 127 and 75 mmHg. To date, no study has examined the 10-20-30 protocol model in inactive women, nor has it been directly compared to traditional endurance training recommendations in a standardised manner.

It appears that for individuals with higher than normal BP at baseline, HIIT may be a useful tool to reduce systolic and diastolic BP whereas little to no change in BP has been reported for normotensives. However, very little data is available on the BP of previously inactive middle-aged premenopausal women following HIIT interventions and the literature reviewed suggests that individuals will respond differently to HIIT and SIT stimuli. Therefore, further research is required to establish whether or not HIIT and SIT can generate favourable outcomes on BP in previously inactive middle-aged premenopausal women or whether benefits are only obtained for those who are prehypertensive or higher.

Table 2.15 Characteristics of reviewed high-intensity interval and sprint interval training studies on blood pressure

Study	Participants	Intervention group baseline Age (years) BMI (kg/m^2) TBM (kg) Resting SBP (mmHg) Resting DBP (mmHg)	Number in intervention group	Intervention	Mode of exercise	Length (weeks)	Effects on BP
Ciolac et al. (2010)	44 F premenopausal Inactive	Age: 24 BMI: 23.5 TBM: 62 SBP: 106 DBP: 65	11 F	Protocol: 2 min walking / 1 min running for 40 min Training intensity: 50-60 % $\dot{V}O_{2max}$ /80-90 % $\dot{V}O_{2max}$ Sessions per week: 3 Weekly training time commitment: 180 min	Treadmill	16	←→ SBP ←→ DBP
Gunnarsson and Bangsbo (2012)	12 M 6 F Premenopausal Moderately trained	Age: 33 BMI: — TBM: 75 SBP: 127 DBP: 75	7 M 3 F	Protocol: '10-20-30' 3-4 x 5 min intervals interspersed with 2 min recovery Training intensity: Low-, moderate-, and high-speed running (<30 %, <60 %, and >90 % of maximal intensity) Sessions per week: 3 Weekly training time commitment: ~ 90 min	Running	7	↓ 4 % SBP ←→ DBP
Keating et al. (2014)	7 M 31 F Pre and postmenopausal Overweight Inactive	Age: 42 BMI: 28.2 Body mass: 76.1 SBP: 111 DBP: 74	13 3 males 10 females	Protocol: 4-6 x 30-60 s intervals interspersed with 120-180 s rest Training intensity: Work: 120 % of $\dot{V}O_{2peak}$ Sessions per week: 3 Weekly training time commitment: 60-72	Cycle ergometer	12	←→ SBP ←→ DBP

Robinson et al. (2015)	7 M 32 F Stage of menopause not reported Overweight/obese Inactive	Age: 52 BMI: 32.9 TBM: 89 SBP: 133 DBP: 83	3 M 17 F	Protocol: 4-10 x 1 min intervals interspersed with 1 min rest Training intensity: ~90 % of HR_{peak} Sessions per wk: 5 Weekly training time commitment: variable	Cycle ergometer Treadmill walking Outdoor walking Elliptical trainer	2	↓ 2 % MAP
Schjerve et al. (2008)	8 M 32 F Stage of menopause not reported Obese	Age: 47 BMI: 36.6 TBM: 114 SBP: — DBP: ~92	3 M 11 F	Protocol: 4 x 4 min intervals interspersed with 3 min active rest Training intensity: 85-85 % HR_{max} Sessions per week: 3 Weekly training time commitment: 48 min	Treadmill	12	←→ SBP ↓ 7 % DBP
Shepherd et al. (2015)	26 M 52 F Stage of menopause not reported Inactive	Age: 42 BMI: 27.7 TBM: 79 SBP: 123 DBP: 76	15 M 31 F	Protocol: repeated 15-60 s sprints interspersed with 45-120 s rest Training intensity: >90 % H_{Rmax} Sessions per wk:3 Weekly training time commitment: 55 min	Instructor-led group cycling class	10	←→ SBP ←→ DBP
Tjonna et al. (2008)	13 M 15 F Stage of menopause not reported MetS patients	Age: 50 BMI: 32.1 TBM: 96 SBP: 144 DBP: 82	4 M 7 F	Protocol: 4 x 4 min intervals interspersed with 3 min active recovery Training intensity: 90 % of HR_{max} Sessions per week: 3 Weekly training time commitment: ~48 min	Treadmill	16	↓ 7 % SBP ↓ 7 % DBP
Wallman et al. (2009)	6 M 18 F Stage of menopause not reported Overweight and obese Inactive	Age: 41 BMI: 31.4 TBM: 91 SBP: 128 DBP: 82	6 ratio of M:F not reported	Protocol: 30 min of 1 min intervals interspersed with 2 min recovery Training intensity: 90 % and 30 % of $\dot{V}O_{2peak}$ Sessions per week: 4 Weekly training time commitment: 120 min	Cycle ergometer	8	←→ SBP ←→ DBP

Abbreviations: BMI: Body mass index, BP: blood pressure, DBP: diastolic blood pressure F: female, M: male, HR_{max}: maximal heart rate, $\dot{V}O_{2max}$: maximal oxygen uptake, $\dot{V}O_{2peak}$: peak oxygen uptake, SBP: systolic BP, TBM: total body mass.

2.4.4.6 Cognitive function

It has previously been shown that cognitive function, in particular, selective attention and short-term memory have been improved following a bout of HIIT, consisting of 10 x 1 min cycling bouts at 80 % of heart rate reserve (HRR) interspersed with 1 min recovery, in middle-aged adults (Alves et al., 2014). In addition, acute HIIT comprising of 2 high-intensity runs of 3 min with 2 min recovery has been shown to improve learning performance in healthy adults with the authors attributing their findings to elevated levels of BDNF and catecholamines (i.e., dopamine, epinephrine, norepinephrine) (Winter et al., 2007). However, research on the impact and potential benefits of longer duration HIIT interventions for previously inactive women on cerebrovascular and cognitive function is notably absent. This is surprising given the importance of brain structure and function in health and disease. However, one study, which incorporated 4 months of HIIT for obese individuals, reported improvements in short-term verbal memory, attention and processing speed (Drigny et al., 2014). The 4-month programme comprised 2 sessions of HIIT, 1 session of MICT and 2 resistance training sessions per wk. The HIIT protocol consisted of 2-3 10-min sets of repeated bouts of 15-30 s at 80 % of maximal aerobic power interspersed with 15-30 s recovery.

With the lack of literature on the potential benefit of HIIT on cognitive function in different age groups, further research is clearly warranted on the effects of a prolonged HIIT intervention on cognitive function for previously inactive middle-aged premenopausal women.

2.4.4.7 Mental well-being

HIIT has many known physiological benefits, but research investigating the effect of HIIT on mental well-being is limited. Positive psychological responses to exercise, such as affect, are important for sustained exercise adherence (D. M. Williams et al., 2008) which is required to achieve long-term health benefits. However, much of the measured psychological responses to HIIT are acute in nature and assess affect in healthy adults with conflicting results reported when compared to MICT (Bartlett et al., 2011; Oliveira, Slama, Deslandes, Furtado, & Santos, 2013). For example, the recreationally active male participants in the study of Bartlett et al. (2011) perceived HIIT to be more enjoyable than MICT, whereas the male participants in the study of Oliveira et al. (2013) reported negative feelings during and following HIIT compared to MICT.

The literature regarding the psychological effects following chronic HIIT in inactive populations is much sparser. Shepherd et al. (2015) assessed the use of 10 wks low-volume HIIT in a gym setting for inactive adults. HIIT was carried out as repeated 15-60 s sprints above 90 % of HR_{max} interspersed with 45-120 s recovery three times weekly. Beneficial effects on health perceptions, positive and negative affect and subjective vitality were reported following HIIT. However, life satisfaction did not change following the intervention. Furthermore, as affective responses reflect only one dimension of well-being, randomised control trial methodology should also take into consideration other aspects of mental well-being. Further information regarding exercise enjoyment can be found below.

2.4.4.8 Conclusion on high-intensity interval training

Much of the previous HIIT literature, which has largely been based within a laboratory environment using cycle ergometers and treadmills, has shown clear improvements in cardiorespiratory fitness even when the HIIT intervention does not meet the physical activity guidelines. Beneficial changes in body composition are also apparent following HIIT but these small changes may not necessarily be clinically meaningful. However, the lack of dietary control in the majority of these studies complicates the interpretations of these observations. In addition, contradictory results have been reported for changes in [glucose], [insulin] and insulin sensitivity, blood lipids and BP, possibly due to variation in baseline values. For those individuals with higher than normal values at baseline, HIIT appears to be beneficial for the improvement of the above mentioned health profile variables, however, no further benefit typically appears for those individuals with normal values at baseline. In addition, HIIT may be useful for the improvement of cognitive function and well-being. HIIT may appeal to inactive individuals with time constraints since adherence may be increased due to the time-efficient training strategy. However, further research is required on the use of different exercise modalities to evoke the potential health benefits achievable following HIIT.

2.4.5 Exercise enjoyment during and following moderate-intensity continuous and high-intensity interval training

Exercise enjoyment and the affective response to exercise is an important aspect of any exercise training intervention, regardless of health benefits, especially for those individuals who are new to a particular exercise training protocol or individuals who were previously inactive. Affect is defined as the general valenced response of pleasure-displeasure (Ekkekakis & Petruzzello, 2000) and research in this area has led to the development of dual-mode theory to continuous exercise at varied intensities (Ekkekakis, 2005).

In examining the dose-response relationship of exercise intensities, the model suggests that moderate-intensity exercise below the anaerobic threshold should result in consistently positive responses of affective valence which are more likely to facilitate behavioural maintenance, whereas severe intensities well above the anaerobic threshold produce consistently more negative responses of affective valence (Ekkekakis, Hall, & Petruzzello, 2005). Heavy intensities slightly above the anaerobic threshold produce varied affective responses from pleasant to unpleasant due to the uncertain sustainability of the exercise and the affective response is influenced by personal self-efficacy and motivation (Martinez, Kilpatrick, Salomon, Jung, & Little, 2015). Therefore, the dual-mode model would predict that HIIT would result in negative affective responses. It is reasonable to speculate that decreases in affective valence could, in turn, reduce the motivation of individuals to adhere to HIIT programmes.

HIIT studies incorporating measures of exercise enjoyment have been summarised in Table 2.16 and, where possible, have been compared to MICT. Several studies have assessed the affective and enjoyment responses to HIIT but mainly following acute bouts of exercise. For those studies incorporating single sessions, in most instances, HIIT appears to be more enjoyable than MICT. For example, for recreationally active men, Bartlett et al. (2011) reported that ratings of perceived enjoyment were higher following HIIT (6 x 3 min 90 % $\dot{V}O_{2max}$ interspersed with 3 min recovery) compared to MICT (50 min MICT at 70 % of $\dot{V}O_{2max}$) despite higher ratings of perceived exertion with HIIT. Additionally, Jung, Bourne, and Little (2014) reported HIIT (1 min at 90 % of HR_{max} interspersed with 1 min recovery for 20 min) to be as pleasurable as MICT following a single session for inactive adults. However, for those studies incorporating longer interventions, there is less agreement as to which type of exercise is most enjoyable. For example, Saanijoki et al. (2015) compared the affective responses during and following 2 wks of 4-6 x 30 s all-out cycling efforts compared with 40-60 min MICT for sedentary men (47 y). Participants reported greater experiences of negative emotions and exertion following HIIT compared to MICT but the displeasure was reported to lessen over time suggesting similar mental adaptations to HIIT and MICT. Similarly, Smith-Ryan (2017) reported that exercise enjoyment increased over the three wk intervention for overweight/obese adults. Following 5 wks of training, Kong, Fan, et al. (2016) reported higher enjoyment scores for HIIT compared to MICT in overweight females whereas Foster et al. (2015) reported lower levels of enjoyment following HIIT compared to steady state exercise and the enjoyment of all protocols declined over the 8 wk intervention for young inactive adults (20 y).

Due to the inconsistent results regarding the enjoyment of HIIT for several populations, further research is clearly warranted to assess whether HIIT is a sustainable and enjoyable form of exercise. In particular, research is required to elucidate how HIIT compares to MICT in previously inactive premenopausal women when the training interventions surpass 8 wks and when the training modality is changed (e.g. physical activity choice, training frequency and number and duration of sprint intervals).

Table 2.16 Exercise enjoyment during and following moderate-intensity continuous and high-intensity interval training

Study	**Participants**	**Intervention group baseline** **Age (years)** **BMI (kg/m^2)** **TBM (kg)**	**Number in intervention group**	**Intervention**	**Mode of exercise**	**Length**	**Effects on enjoyment**
Bartlett et al. (2011)	18 M Recreationally active	Age: 25 BMI: 24.2 TBM: 73	18 M	HIIT: 6 x 3 min 90 % $\dot{V}O_{2max}$ interspersed with 3 min recovery MICT: 50 min at 70 % of $\dot{V}O_{2max}$	Treadmill	2 sessions 7 days apart	Ratings of perceived exertion following exercise were higher after HIIT compared with MICT despite higher ratings of perceived exertion
Foster et al. (2015)	55 M & F Inactive	Age: 20 BMI: — TBM: 69-94	19 MICT 21 Tabata 15 Meyer	MICT: 20 min at 90 % of ventilatory threshold Tabata: 8 x 20 s at 170 % of $\dot{V}O_{2max}$ with 10 s rest 13 x 30 s (20 min) at 100% $\dot{V}O_{2max}$ with 60 s rest	Cycle ergometer	8 wks	Tabata protocol was less enjoyable than the MICT and Meyer protocols and enjoyment of all three protocols declined across the duration of the study
Jung et al. (2014)	28 F 16 M Inactive	Age: 31-35 BMI: 23.3-24.9 TBM: 69-75	28 F 16 M	HIIT: 1 min at 90 % of HR_{max} interspersed with 1 min recovery for 20 min MICT: 40% W_{peak} for 40 min VICT: 80 % W_{peak} for 20 min	Cycle ergometer	3 sessions 7 days apart	Participants reported greater enjoyment of HIIT as compared to MICT and VICT, with over 50% of participants reporting a preference to engage in HIIT as opposed to either MICT or VICT.
Kong, Fan, et al. (2016)	26 F Premenopausal Overweight	Age: 22 BMI: 25.8 TBM: 69	13 HIIT 13 MICT	HIIT: 60 x 8 s “all-out” intervals interspersed with 12 s rest MICT: 40 min continuous cycling at 60-80 % $\dot{V}O_{2peak}$	Cycle ergometer	5 wks	HIIT group had significantly higher scores on physical activity enjoyment scale compared to the MICT group in any of the 5 wks during the exercise intervention
Martinez et al. (2015)	9 F 11 M Stage of menopause not reported Overweight and obese	Age: 22 BMI: 29.0 TBM: —	9 F 11 M	4 counterbalanced trials: 20 min trial of heavy continuous (10 % of the distance between anaerobic threshold and maximal capacity)	Cycle ergometer	4 sessions separated by at least 48 h	Pleasure and enjoyment were higher during shorter interval trials than during a longer interval or heavy continuous exercise

	Inactive			3 x 24 min HIIT trials that used 30, 60 and 120 s intervals (at 60 % of the difference between anaerobic threshold and maximal capacity) 1:1 work:rest ratio			
Saanijoki et al. (2015)	26 M Sedentary	Age: 47 BMI: 26.1 TBM: 83-84	13 HIIT 13 MICT	HIIT: 30 s “all-out” at 180 % of peak workload with 4-min recovery MICT: 40- to 60-min continuous cycling at 60 % of W_{peak}	Cycle ergometer	6 sessions over 2 wks	Participants reported greater experiences of negative emotions and exertion following HIIT compared to MICT but the displeasure was reported to lessen over time suggesting similar mental adaptations to HIIT and MICT
Smith-Ryan (2017)	57 M & F Overweight	Age: 40 BMI: 30.8 TBM: 93	20 M 22 F	1 MIN: 1-min bouts with 1-min passive rest periods at 90 % W_{peak} for 10 bouts 2 MIN: sets of 2-min cycling bouts with 1-min passive rest at a daily undulating intensity (80–100 % W_{peak})	Cycle ergometer	3 wks	Exercise enjoyment improved significantly over the three-week training phase
Thum, Parsons, Whittle, and Astorino (2017)	12 M & F Recreationally active	Age: 30 BMI: 23.1 TBM: 56-70	12 M & F	HIIT: 8 x 1 min bouts of cycling at 85 % W_{peak} with 1 min of active recovery MICT: 20 min of cycling at 45 % W_{peak}	Cycle ergometer	2 sessions	Results showed higher enjoyment in response to HIIT versus MICT. Eleven of 12 participants (92%) preferred HIIT to MICT. However, affect was lower for HIIT

Abbreviations: BMI: Body mass index, F: female, HIIT: High-intensity interval training, HR_{max}: maximal heart rate, M: male, $\dot{V}O_{2max}$: maximal oxygen uptake, MICT: Moderate-intensity continuous training, TBM: total body mass, VICT: vigorous-intensity continuous training, $W_{peak:}$ peak power output.

2.4.6 Moderate-intensity continuous versus high-intensity interval training

Based on the existing evidence base, it is apparent that HIIT and SIT can elicit improvements in a number of health markers in previously inactive women. Moreover, in some cases, HIIT and SIT can provide equivalent, if not greater, improvements in health markers compared to traditional MICT for a smaller time commitment. For example, improvements in cardiorespiratory fitness of 4-26 % and 4-33 % have been reported following MICT and HIIT interventions. Comparable changes in body composition have also been reported following MICT and HIIT with reductions in body fat percentage up to 13 % and 12 % following HIIT and MICT, respectively. As previously mentioned, with regards to glucose tolerance, insulin sensitivity, BP and blood lipids, a large variation in response to MICT and HIIT is evident. This may partly be due to individual variability in baseline values of the participants and interpretation is further confounded by considerable inter-study variability in intervention duration, exercise protocol and methodology including the extent of dietary control. This leads to difficulty in directly comparing between studies and gleaning a clear picture of the effects of HIIT and MICT on health markers. This challenge is compounded by gender differences in the adaptations to HIIT and SIT.

In addition, one of the main issues with assessing MICT and HIIT training studies is that the exercise intensities are tightly prescribed and controlled and are either based on a percentage of HR_{max} or maximal aerobic power and performed under close supervision which could affect compliance. In contrast, less is known about the use of HIIT and MICT within an ecologically valid or 'real world' setting. The influence of self-pacing during a HIIT programme on risk factors for NCDs appears to be undetermined. This is surprising as most exercise is unsupervised and participants have no choice but to self-select their exercise intensity (Lind, Joens-Matre, & Ekkekakis, 2005). Notably, HIIT and SIT are often termed as being a time-efficient exercise strategy, but the most commonly cited SIT protocol (4-6 repeated 30-s Wingate sprints interspersed with 4 min recovery) takes approximately 30 min per session. The resulting time commitment of approximately 90 min per wk is higher than the current recommendations for vigorous-intensity exercise of 75 min per wk (Department of Health, 2011). However, actual time exercising can be as little as 2 min which is far less than the weekly physical activity recommendations. Combined with the high RPE values reported, this form of SIT may be unsuitable as an alternative to current exercise recommendations involving MICT (Vollaard & Metcalfe, 2017). A further issue is that much of the previous literature is based on the use of cycling or treadmill exercise within a laboratory environment which may have a negative effect on attendance and enjoyment.

It is evident that the optimum dosage of HIIT needs to be established to achieve the most beneficial change in health profiles of inactive women without exposing the participant to more work than is required. Time-constrained exercisers will naturally want to know how little exercise is required to achieve beneficial changes in health. This will help remove some of the common barriers to exercise for previously inactive premenopausal women. A ‘one-size fits all’ approach to exercise recommendations may not suit all individuals, and effective alternative exercise interventions need to be identified in order to overcome this issue. In particular, when designing a HIIT or SIT protocol, the population group should be taken into consideration to optimise exercise prescription recommendations. Alternative forms of exercise which have incorporated HIIT and MICT, which may help combat enjoyment issues, will be outlined below.

2.4.7 Swimming

The majority of studies investigating the effect of MICT and HIIT on cardiovascular health have focused on exercise modalities such as walking, jogging, running and cycling. Surprisingly, very few have investigated the effects of aquatic exercise interventions (Laurent et al., 2009; Nualnim et al., 2012). Swimming may be considered a good choice of training especially for overweight individuals as it involves minimum weight-bearing stress, which may reduce the risk of injury. In addition, swimming engages the upper body musculature where the potential for metabolic adaptation can be hypothesised to be larger than in the postural musculature (Nordsborg et al., 2015).

Nualnim et al. (2012) demonstrated that 12 wks of regular 15-45 min moderate-intensity continuous swimming lowered systolic BP by 9 mmHg in older adults (>50 y) with mild hypertension. In addition, low-intensity swimming has been reported to improve insulin resistance, distance swam in 12 min, waist and hip circumferences and insulin AUC in older sedentary women (50-70 y).

Importantly, these changes were greater than achieved when walking at a matched intensity during 40 min sessions 3 times per wk for 6 months at 62 % of HRR (K. L. Cox, Burke, Beilin, & Puddey, 2010). In addition, following 12 months (6-12 months unsupervised) moderate-intensity swimming training, total body mass as well as [TC] and [LDL] cholesterol were lowered, compared to walking (K. L. Cox et al., 2010). Improvements in [TC], [HDL], [LDL], systolic BP and resting HR have also been noted in patients with T2D (54 y) following 12 wks of aquatic aerobic training performed in three weekly sessions of 45 min per session with intensity progressing from 85 % to 100 % of HR of anaerobic threshold during the intervention (Delevatti et al., 2016). Increases in carotid artery compliance (21 %) and systolic BP (7 %) have also been reported following 12 wks of continuous swim training 3-4 days per wk for 45 min at 70-75 % HR_{max} in previously sedentary (inactive) older adults (>50 y) (Nualnim et al., 2012). It should be noted that total body mass, adiposity, and plasma [glucose] and [TC] did not change following the swim training. Improvements in resting HR (12 %) and systolic BP (4 %) have also been noted following 10 wk of swim training performed three times per wk for 60 min per session at 60 % of HR_{max} in sedentary (inactive) adults (48 y) with stage 1 or 2 hypertension. In addition, insulin sensitivity was improved following 1 y of low-intensity swimming (increasing from 0-7 km) in young (22 y) hypertensive individuals (H. H. Chen et al., 2010).

However, there is a lack of literature investigating the potential of high-intensity swimming to improve the health profile of previously inactive women. Martin et al. (1987) reported improvements in $\dot{V}O_{2peak}$ (19 %) following 12 wks of swim training (30-45 min per session) including both continuous and interval swimming 6 days per wk and circuit training with weights 3 days per wk in sedentary (inactive) middle-age adults (30-48 y). In addition, Mohr, Lindenskov, et al. (2014) reported improvements in systolic BP (4 and 3 %), resting HR (7 and 6 %), total body mass (1 and 2 %), BF% (4 and 5 %) fat mass (kg) (~3 and 6 %) and lean mass (kg) (~4 and 3 %) in sedentary (inactive) premenopausal women with mild hypertension following high- or moderate-intensity swimming completed three times weekly for 15 wks. Improvements were also reported for maximal 10 min swim (13 and 22 %), intermittent swimming (23 and 8 %) and Yo-Yo Intermittent Endurance Test Level 1 (YYIE1) running performance (58 and 45 %) in HIIT and

MOD, respectively (Mohr, Lindenskov, et al., 2014). However, the metabolic health benefits following HIIT swimming for inactive premenopausal women are still unknown.

2.4.8 Team Sport

Many team sports consist of a combination of steady-state continuous exercise interspersed with short bursts of high-intensity effort where little knowledge of the sport is required to participate. In particular, as football is one of the most popular sports in the world, with over 29 million registered women players globally (Fahmy, 2011), it may serve as an appealing inexpensive exercise for inactive women. The individual may have more incentive to take part due to the development of social networks (Ottesen, Jeppesen, & Krustrup, 2010) and the experience of flow, a rewarding psychological state (Elbe, Strahler, Krustrup, Wikman, & Stelter, 2010).

Importantly, small-sided football has been successful in provoking health benefits in inactive men (20-43 y) and women (19-47 y) with no prior experience of the game. In inactive premenopausal women, Krustrup, Hansen, Randers, et al. (2010) and Andersen, Hansen, et al. (2010) found that participating in twice-weekly 1 h sessions of small-sided football for 16 wks produced a number of positive health benefits. $\dot{V}O_{2peak}$ (15 %) and lean mass (3 %) were increased and fat mass (5 %) and systolic BP (6 %) were reduced following 16 wks of football training. In addition, a decrease in diastolic BP (5 %) and LDL/HDL ratio (8 %) was evident for the football group, and the cardiac adaptations induced by the training were considered to be more consistent when compared to continuous running (Andersen, Hansen, et al., 2010). Similar health benefits have been observed after 12 wks of football, 2-3 x 1 h per wk, organised as a workplace intervention outside of working hours (Barene et al., 2014). Improvements in $\dot{V}O_{2max}$ (5 %), BF% (3 %), fat mass (4 %) and HR during a 100-W cycle test (5 %) were evident for the football group consisting of female participants (44 y) with a mean HR of 78 % of HR_{max} during training sessions. Equivalent reductions have been found in total body mass (1 %), fat mass (3 %), resting HR (10 %) and systolic (6 %) and diastolic (6 %) BP, [LDL] (15 %) and increases in $\dot{V}O_{2max}$ (13 %) and lean mass (3 %) in inactive men (20-43 y) following 12 wks of 2-3 weekly small-sided football training with a mean HR of 82 % of HR_{max} (Krustrup et al., 2009).

Nyberg et al. (2014) have successfully used floorball to improve the health profile of premenopausal women (48 y) when played for 60 min twice a wk for 12 wks. Floorball is a team sport like hockey but played indoors with plastic sticks. Each session consisted of ~30 min of technical and tactical floorball exercises and 30 min of gameplay of 4-6 min intervals (>85 % of HR_{max}) separated by 1-3 min recovery. Exercise training increased absolute $\dot{V}O_{2max}$ (4 %), LBM (2 %) and lean leg mass (3 %) with reductions in diastolic BP (4 %), sICAM-1 (27 %) and sVCAM-1 (21 %) (Nyberg et al., 2014; Seidelin et al., 2017). Although these team sport interventions produced positive health benefits, participants were required to exercise for 1 h per session, a length of time not necessarily easy to accommodate within people's daily routine.

2.4.9 Home-based physical activity

Although all of the above physical activities provide a number of health benefits, most exercise interventions have been conducted under direct supervision within a public environment or within a group or class environment, mainly to assure compliance to the training (Gossard et al., 1986). However, individual barriers due to weight status or confidence are rarely considered when designing training interventions, which could ultimately lead to increased participant dropout (Napolitano et al., 2011). Attrition rates experienced in some studies are in excess of 20 %, and sometimes as much as 50 % (White et al., 2005). Compared with men, more women have reported feeling overweight as a barrier to being physically active (Ball et al., 2000) and among 2,912 women (>40 y), 62 % of respondents rated exercise on one's own with instruction as more appealing than undertaking exercise in an instructor-led group (A. C. King et al., 2000). Although exercising on a one-to-one supervision basis is the most popular choice for inactive individuals starting out with physical activity (Daley et al., 2011), the associated cost may outweigh the health benefits. It is not clear what the effect of removing this level of supervision will have on exercise training compliance. Therefore, there is still a need to develop exercise interventions that provide a high engagement and adherence, are more cost-effective and provide greater health benefits.

Home-based exercise interventions have been successful in improving the health profile of middle-aged women. For example, improvements in cardio-respiratory fitness (15 %) have been reported following 6 months of home-based exercise in middle-aged adults (47 y) performed 5 days per wk at 69 % of HR_{peak} for 50 min per session (Juneau et al., 1987). Additionally, home-based exergaming, in particular, the use of the Nintendo Wii™ and Wii Fit™, have shown potential health benefits. For example, Nitz, Kuys, Isles, and Fu (2010) reported improvements in balance and lower limb strength in middle-aged women following a ten wk intervention. However, cardiovascular fitness, body mass and well-being were unchanged. This is not surprising as the use of the Wii Fit™ board restricts the user's movement. A review by Sween et al. (2014) reported that, when movement is not restricted, exergaming can increase energy expenditure by up to 300 % which may lead to beneficial changes in the health profile of the participant. It should be noted that of the 27 studies reported, only 5 included adult participants and none were examined over a prolonged period of time. A potential issue with exergaming is that the gaming systems can be costly, which may outweigh the benefits and the user must first learn how to use such systems which may be an obstacle for older individuals.

Internet-based health and exercise interventions are becoming an increasingly popular method to promote exercise to large populations at low cost (Nigg, 2003; Norman et al., 2007). For example, Hunter et al. (2008) have reported small but beneficial changes in total body mass and BF % following a 6-month internet-based programme with tailored feedback on exercise and nutritional regimes in overweight adults. However, it has been reported that motivation levels tend to rapidly decline and that individuals tend to selectively scan exercise information leading to incorrect movement execution compared to other forms of media (Eveland & Dunwoody, 2002). Likewise, many internet-based interventions require the user to follow written exercise guidelines and also to self-report their levels of physical activity, food intake and subsequent weight change (Dunton & Robertson, 2008). Participants are also required to be competent in using computing technology and able to interpret information from the internet-based programmes (Turner-McGrievy et al., 2009). These limitations might have

negative implications for participant compliance and the potential for these interventions to improve health outcomes.
Interestingly, the use of an exercise DVD is a popular choice of exercise modality for pre- and post-menopausal women (Daley et al., 2011) to combat the previously mentioned exercise barriers reported by women (Delextrat & Neupert, 2016). The use of audio and video may increase motivation as it can provide effective and clear visual guidance on the exercise movements and structure of the session along with music, subtitles and verbal instruction (Khalil et al., 2012). The use of exercise DVDs have resulted in higher activity levels (Gothe et al., 2015) and improvements of lower extremity flexibility and upper body strength (McAuley et al., 2013) following a 6-month intervention in older individuals (71 y) while requiring fewer professional resources (Murphy et al., 2012). However, given the independent nature of exercise DVDs, some studies have reported lower caloric expenditure when compared to exercise classes which may push participants to exercise at a higher intensity (Delextrat & Neupert, 2016; Luettgen, Foster, Doberstein, Mikat, & Porcari, 2012). For example, Delextrat and Neupert (2016) reported lower energy expenditure in fifteen women (25 y) following a Zumba® exercise DVD compared to Zumba® group classes although the energy expended during the exercise DVD still met the ACSM exercise recommendations to maintain a healthy lifestyle.

Providing a standardised exercise DVD for inactive premenopausal women might induce positive behaviour changes towards exercise in a comfortable environment that could improve adherence to the programme leading to beneficial changes in their health profile.

2.4.10 Whole-body vibration (WBV) training

WBV training is an alternative exercise modality that is becoming increasingly popular within a gym and home environment and may address time constraints and compliance issues in inactive populations due to the short duration of sessions (Hannan et al., 2004).

Vibration is an oscillatory motion and the extent of this motion is determined by the amplitude of the vibration (in mm) and the repetition rate of the oscillation determines the frequency of the vibration (in Hz). Oscillatory motion can be produced in different forms but for the purpose of this thesis, only sinusoidal motion will be addressed. Sinusoidal motion is a smooth repetitive oscillation which repeats itself identically for a certain time interval. There are two methods of applying vibration to the human body during exercise. The first requires vibration to be applied directly to the muscle belly or to a tendon of the muscle being trained using a handheld vibration unit or fixed to an exterior support. The second method requires vibration to be applied indirectly to the muscle being trained via transmission from a vibrating source such as a vibration training plate (whole-body vibration). WBV assumes that the vibration frequency induced by a motor to the platform elicits tonic vibration reflex similar to the direct or indirect application of vibration on muscles or tendons. The amplitude and frequency applied during indirect vibration tend to be attenuated in a non-linear manner by soft tissues during transmission (Luo, McNamara, & Moran, 2005). It is the vibration amplitude and frequency which determine the gravitational load imposed on the body's neuromuscular system. Vibrating plates can deliver vibration to the whole body either through reciprocating vertical displacements on the left and right side of a fulcrum or oscillating uniformly up and down (Cardinale & Wakeling, 2005). For the purpose of this thesis, only oscillating vibration about a fulcrum will be reviewed.

It has been proposed that the mechanical action of vibration is to produce fast and short changes in the length of the muscle-tendon complex. This perturbation is detected by the sensory receptors that modulate muscle stiffness through reflex muscular activity and attempt to dampen vibratory waves (Cardinale & Bosco, 2003). The mechanisms by which this occurs may be related to tissue perfusion, fluctuations in systemic hormones, and/or occur via direct mechanical stimulation. The potential effects of WBV on several physiological systems may occur via direct or indirect mechanisms (Figure 2.4). These contractions explain the increased levels of electromyography in working muscles during WBV training (Cardinale & Bosco, 2003; Hazell, Thomas, Deguire, & Lemon, 2008) and the increased energy output that is shown to result from the addition of vibration to squat exercise (Da Silva et al., 2007). It is important to define a vibrational frequency that most effectively activates the muscle but also avoids the problems of chronic exposure to vibration stimuli. These findings have brought about research based on the usefulness of this method as a suitable exercise for special populations that cannot perform conventional exercise (Delecluse, Roelants, & Verschueren, 2003).

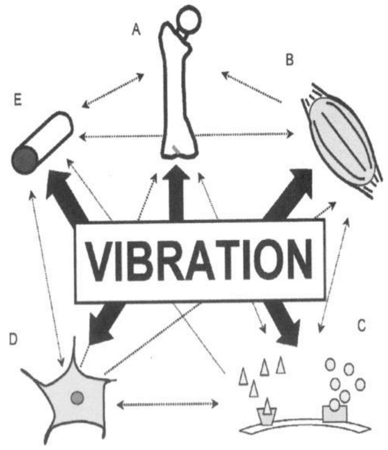


Figure 2.4 The potential effects of whole-body vibration on physiological systems and the potential interplay among systems. Whole-body vibration modulates the (A) skeletal, (B) muscular, (C) endocrine, (D) nervous, and (E) vascular systems, which may elicit secondary responses through interaction among the systems. Reproduced from Prisby, Lafage-Proust, Malaval, Belli, and Vico (2008) with permission.

Over the last decade numerous investigations have been carried out to study the effects of mechanical vibration on the physical performance of trained and untrained individuals. In the majority of cases, the vibration has been applied to the muscles of the lower extremity in a crouched position. Much of the research within this area has focused on muscle power (Marin & Rhea, 2010a) and strength (Marin & Rhea, 2010b; Osawa, Oguma, & Ishii, 2013), postural control in the elderly (Rogan, Hilfiker, Herren, Radlinger, & de Bruin, 2011) and bone mineral density (BMD) (Prisby et al., 2008; Slatkovska, Alibhai, Beyene, & Cheung, 2010) with little research on the effects of WBV training on cardiovascular fitness and body composition of premenopausal women.

Acute responses to WBV training, in combination with upper and lower body exercise, have shown that O_2 consumption increases as load, frequency and amplitude increase (Hazell & Lemon, 2012; Rittweger, Schiessl, & Felsenberg, 2001) while others have focused on the acute haemodynamics following a bout of WBV exercise. Kerschan-Schindl et al. (2001) reported increased blood flow to the popliteal artery following 9 min of continuous standing in a static semi-squat position using WBV while Lohman, Petrofsky, Maloney-Hinds, Betts-Schwab, and Thorpe (2007) reported an increase in skin blood flow while participants rested their calves on the vibration plate, which suggests that direct vibration affects inactive musculature. Increases in blood volume in the vastus lateralis have also been reported following WBV during a dynamic squat exercise (Yamada et al., 2005).

Only a small number of studies have examined the effects of WBV training as an intervention to improve lean mass, fat mass and the cardiovascular risk profile in inactive populations. Figueroa et al. (2012) reported increases in muscle mass in young (21 y) overweight/obese women following 6 wks of WBV training (3 days per wk) consisting of static and dynamic squats and calf raises with vibration intensity at 25-30 Hz and 1-2 mm amplitude. There were significant decreases in systemic arterial stiffness and aortic systolic BP through improvements in wave reflection (augmentation index). G. E. Song, Kim, Lee, and Joo (2011) reported a significant decrease in total body mass (2 %), waist circumference (2 %) and BMI (3 %) after 8 wks of WBV training, when performed for 10 min twice a wk in obese postmenopausal women (>50 y), although this was not accompanied by changes in BF%. Likewise, 18 months of WBV training in postmenopausal women (69 y) performed twice a wk (60 min per session) was associated with reductions in body BF% (2 %) and abdominal fat mass (12 %) with no change in lean mass (von Stengel, Kemmler, Engelke, & Kalender, 2012). However, these changes were not significantly different from other training modes such as aerobic dance. In addition, improvements in BF % (9 %) and fat mass (kg) (14 %) have been reported in obese middle-aged women (42 y) following 9 months of 33 min sessions 5 days per wk (Nam, Sunoo, Park, & Moon, 2016). However, it should be noted that training was in conjunction with a diet with the aim of reducing weight.

Thus, to date, it is unclear whether WBV training provides sufficient cardiovascular stimulation to improve the health profile of inactive premenopausal women after a short intervention period. The conflicting results in this area could be related to the training protocols used in terms of both vibration characteristics (method of application, frequency and amplitude) and exercise protocol (training type, intensity and volume).

2.5 Summary and experimental aims

In summary, recent evidence supports that physical inactivity plays an important role in the development of NCDs. The literature reviewed above repeatedly acknowledges that exercise is a uniquely effective prophylactic against several NCDs induced by westernised lifestyles. In particular, MICT and HIIT carried out individually or as part of a team sport elicit beneficial changes in cardiorespiratory fitness, fat and muscle mass, hypertension, insulin resistance, glucose tolerance and lipid abnormalities. Consequently, HIIT is being promoted as a more time-efficient and practical approach to optimise health. However, it is also apparent that 'one size does not fit all' and the current UK government guidelines on physical activity do not provide enough detail on preventing or treating specific risk factors for NCDs. It is apparent that the magnitude of benefits varies considerably depending on the duration, intensity and type of physical activity undertaken. It is apparent that there is a requirement for further studies to help determine the optimal dose-response for several exercise modalities for inactive premenopausal women to guide exercise prescription and to explore alternative approaches to optimise health outcomes to exercise training interventions. However, a challenge for researchers is to not only to attract more individuals to become physically active but also to keep them active. Providing data on enjoyment and adherence to certain training interventions may also help individuals make decisions about exercise that best suit their individual needs and goals.

Therefore, it is of both scientific and practical importance to further investigate the impact of other HIIT options on the health profile of previously inactive premenopausal women and how they compare to more traditional MICT protocols. This will help determine what type of exercise intensity and method of administration is better at improving the health profile of previously inactive premenopausal women and whether established NCD risk factors are improved in a training-type specific manner. It is also of importance to assess the participant's ability to comply with the training interventions.

Given the points above, the primary purpose of this thesis is to undertake a number of novel experimental studies aimed at identifying the effects of shorter-duration higher-intensity exercise interventions compared to more traditional

MICT interventions on established NCD risk factors in previously inactive middle-aged premenopausal women. The specific aims of each experimental chapter are provided below:

1. Chapter 4 investigates the effects of a 16 wk short-duration small-sided football training and WBV training intervention to improve parameters of health for previously inactive premenopausal women. In particular, their effects on body composition, aerobic fitness and muscle oxidative capacity.

2. Chapter 5 investigates the effects of a 15 wk short-duration high-intensity swim interval training programme compared to a more traditional prolonged continuous swim training intervention to improve insulin sensitivity, blood glucose control and biomarkers of vascular function in previously inactive premenopausal women with mild hypertension.

3. Chapter 6 investigates the effects of a 12 wk self-paced high-intensity interval and moderate-intensity continuous cycle training intervention on the health profile of previously inactive premenopausal women. In particular, their effects on cardiorespiratory fitness, body composition, BP, blood glucose control, blood lipid profile, cognitive function and mental well-being.

4. Finally, Chapter 7 investigates the effects of a 12 wk home-based DVD-directed moderate- to high-intensity exercise training intervention on the health profile of previously inactive premenopausal women. In particular, its effect on body composition, BP, blood glucose control, blood lipid profile and mental well-being.

Chapter 3
General Methods

3.1 Recruitment and ethical approvals

Ethical approvals for all studies were obtained from the University of Exeter Ethics Committee as well as the National Research Ethics Service (NRES) (12/SW/0045) for Chapter 4 and the Ethical Committee of the Faroe Islands for Chapter 5. The participants who volunteered to participate in the investigations related to chapters 4, 6 and 7 were recruited from Exeter University and the surrounding area via advertisement posters. Newspaper articles were also used for Chapter 4. Participants related to chapter 5 were recruited from the University of the Faroe Islands and the surrounding area via posters and radio interviews with the lead researcher.

Potential participants expressed interest via phone or email. Study procedures were explained verbally, either over the phone or in person, and participants were then given a health screening questionnaire and a written Participant Information Sheet (PIS) to read in which a detailed description of the study and experimental procedures were outlined. The potential risks and benefits of their participation were clearly explained in the PIS and participants were informed that, while their anonymity would be preserved, and their data safely stored, the group data may be published in academic peer-reviewed journals or presented at national and international conferences. It was clearly explained to participants that they had the right to withdraw from the investigation at any time with no disadvantage to themselves or others. If participants chose to participate they gave written consent. All personal information was stored securely and both participant and researcher signed and dated the written consent form.

3.2 Inclusion/exclusion criteria

All participants were aged 18 and over, had a stable weight, were premenopausal, not pregnant or attempting to become pregnant, were non-smokers, were not taking any drugs to affect bone metabolism and did not have any medical conditions that were contraindicated to an exercise intervention or that could potentially hinder the effects of the exercise intervention. In addition, participants were inactive prior to the initiation of the exercise intervention and were not participating in more than 150 min of moderate-intensity exercise per wk. All participants also reported having a regular menstrual cycle.

Variations in inclusion/exclusion criteria for Chapter 5 were that participants had a BMI > 25 kg/m^2, mild to moderate hypertension (MAP 96 - 110 mmHg) and lived an inactive lifestyle for the last 2 years (not taking part in regular training or physical activity).

3.3 Health and safety

All testing procedures adhered to the health and safety guidelines established by the School of Sport and Health Sciences at the University of Exeter; the Faculty of Sport and Health Sciences at the University of St Mark and St John, Plymouth; the Faculty of Natural and Health Sciences at the University of the Faroe Islands; and the Department of Nutrition, Exercise and Sports, Copenhagen Centre for Team Sport and Health at the University of Copenhagen. Great care was taken to ensure the laboratories provided a clean and safe environment that was appropriate for exercise testing of human participants. Ergometers, vibration training machines, trolleys and work surfaces were cleaned using dilute Virkon™ disinfectant, Clinell® Universal Wipes and Azowipe™ alcohol disinfectant and all respiratory apparatus were similarly disinfected according to manufacturer's recommendations. Researchers involved with the experiments wore disposable latex gloves and laboratory coats during blood sampling and all sharps and biohazard materials were disposed of appropriately. A thorough 'cool-down' was provided upon completion of all exercise tests and training sessions and participants were allowed and encouraged to drink water *ad libitum* upon completion of testing as well as during training sessions. Prior to initiation of the treadmill 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.

3.4 Standardisation of testing conditions

For performance related tests, participants were instructed to report to the laboratory at least 2 h postprandial, having completed no strenuous exercise within the previous 24-48 h. Participants were also instructed to avoid alcohol and caffeine for 24 and 12 h preceding each exercise test, respectively. Each participant underwent testing at the same time of day (± 2 h) and all participants were familiarised with the mode(s) of exercise and experimental procedures prior to the initiation of the experimental testing. For fasted visits, participants were asked to refrain from eating after 20:00, and replicate the same evening meal for the post-intervention visit. Time was taken during the initial visit to the laboratory to ensure that each participant understood the importance of these requests. Food diaries were also collected for the three days leading up to pre- and post-intervention testing. Completed food diaries were viewed by the primary investigator during the pre-intervention laboratory visit and discussed with the participants in order to promote compliance and ensure a satisfactory level of detail. No participants were allowed to make a conscious change in their eating habits. To minimise the burden of completing food diaries, participants were instructed to indicate unit size (e.g. one spoonful, one small glass) rather than weigh all food and drink consumed. Food diaries were assessed for total energy and macronutrient intake (Nutritics v4.267 Academic Edition, Dublin, Ireland) upon completion of the study. Testing periods were not timed in relation to the menstrual cycle.

3.5 Study sites

For Chapters 4, 6 and 7, exercise outcome measures were assessed and blood samples were collected within the School of Sport and Health Sciences at the University of Exeter with the addition of the Faculty of Sport and Health Sciences at the University of St Mark and St John, Plymouth for Chapter 6. For Chapter 5, exercise outcome measures were assessed and blood samples were collected within the Faculty of Natural and Health Sciences at the University of the Faroe Islands. Other than the assessment of glucose, venous blood samples collected for Chapter 6 and 7 were then assessed at the Royal Devon and Exeter NHS Foundation Trust whereas venous blood samples from Chapter 4 and 5 were assessed at the Department of Nutrition, Exercise and Sports, Copenhagen Centre for Team Sport and Health at the University of Copenhagen.

3.6 Study design

As the main outcome of the thesis was to test the effectiveness of several short duration, high-intensity intermittent exercise training interventions (experimental group) against more traditional prolonged continuous training (conventional group) or no training at all (control group), RCTs were implemented. RCTs were used as they are the most rigorous method of determining a cause-effect relationship (Sibbald & Roland, 1998). The methodological advantages of using RCTs include that participants are randomised to either the experimental or control group which eliminates selection bias and minimises confounding variables and in some cases participants and researchers can be blinded to which group an individual is assigned. However, blinding was not possible in the current thesis due to the nature of the interventions. Another advantage of using RCTs is that both groups are treated identically with regards to pre- and post-intervention testing and the analysis is focused on estimating the size of the difference in predefined outcomes between intervention groups (Kendall, 2003). Notably, the RCT needs to be adequately powered to avoid both Type 1 and Type 2 errors.

3.7 Measurement procedures

3.7.1 Anthropometry and physical characteristics

3.6.1.1 Height and body mass

Standard procedures were used for the measurement of basic anthropometry. Height was measured to the nearest 0.1 cm using a stadiometer (Seca 225, Seca, Hamburg, Germany) and body mass was measured to the nearest 0.1 kg in the fasted state using digital scales (Seca 703, Seca, Hamburg, Germany). Participants were weighed in bare feet with light clothing.

3.7.1.2 Body mass index (BMI)

BMI was calculated from measured height and body mass using the standard formula (BMI = body mass (kg)/height (m^2)) (Keys, Fidanza, Karvonen, Kimura, & Taylor, 2014).

3.7.1.3 Waist and hip circumference

Waist and hip circumference were measured in Chapter 7 over light clothing and after exhalation; participants stood with their feet together and arms at their side for the measurement. Waist measurements were taken at the midpoint between the lower rib margin and the iliac crest in the horizontal plane. Hip measurements were taken at the maximum circumference around the buttocks, below the iliac crest. Measurements were taken to the nearest cm and waist to hip ratio was calculated by dividing waist measurement by hip measurement (World Health Organization, 2008a).

3.7.1.4 Air displacement plethysmography

Air Displacement Plethysmography was used to assess body composition in Chapter 6. This procedure was carried out in the laboratory using the BodPod® apparatus (Life Measurement Inc., Concord, CA USA) (Figure 3.1). This method is based on a two-compartment model of body composition, which assumes that the body mass is made up of two types of tissue, fat mass and fat-free mass (including protein, water, mineral and glycogen). This method determines body volume from pressure measurements via Poisson's Law:

$$P1/P2 = (V2/V1)\lambda \qquad \text{(Equation. 3.1)}$$

Where P = pressure, V = volume and λ = the ratio of the specific heat of the gas at constant pressure compared to that of constant volume. The letters 1 and 2 denote pressure and volume of the two chambers within the BodPod® with a diaphragm system that produces small volume and pressure perturbations of equal and opposite magnitude in order to obtain body volume

Bone density is then calculated using the following equation:

$$D = M / (Vbraw + 0.40\ Vtg - SAA) \qquad \text{(Equation 3.2)}$$

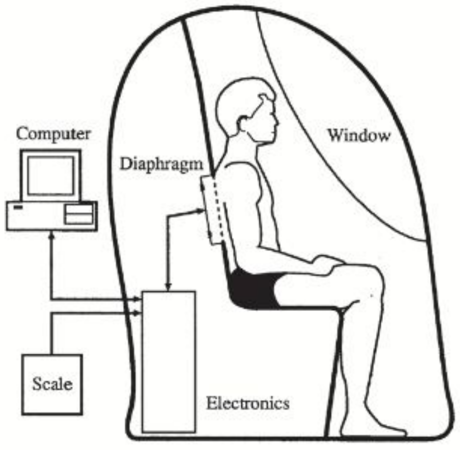
Where M = body mass (kg), Vbraw = raw body volume (L), Vtg = thoracic gas volume (L), and SAA is the surface area artefact (L); this variable is automatically computed by the software of the device, and accounts for the presence of isothermic air in the chamber which can affect accuracy of the measurement.

Since it is known that lean mass (1.06 kg/L) is denser than fat mass (0.9196 kg/L) (Lukaski, 1987), the following equation (Siri, 1993) is used to calculate body fat percentage from body density:

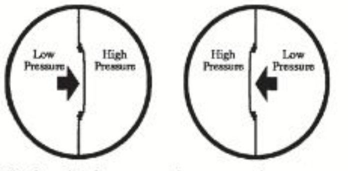
$$\% \text{ fat} = (495\text{-Density}) - 450 \qquad \text{(Equation 3.3)}$$

As this method is based on a two-compartment model the remaining proportion is assumed to be entirely fat-free mass and this can be calculated by subtracting the value obtained for fat mass from total body mass.

Prior to each measurement, the BodPod® was calibrated empty and then against a 49.998 L cylinder. Participants were assessed in the fasted state. Participants were required to wear a swimming costume and cap, reducing the likelihood of air pockets underneath loose clothing affecting accuracy of the measurement. Age, sex, and height of the participant were entered before beginning the test. Body mass was measured directly, to the nearest 0.01 kg, using the integrated scales. Participants were instructed to sit quietly with their hands on their lap, avoid touching the sides of the pod and breathe normally during measurement. The investigator running the test demonstrated to the participant on how to exit the pod if they felt uncomfortable at any point during the test. Two measurements were made and averaged in order to obtain accurate values. If values obtained from the first two measurements were not within 5 % agreement a third measurement was automatically carried out to ensure accuracy of results.



General arrangement of chambers, subject, and diaphragm.



Moving diaphragm produces complementary pressure changes in the chambers.

Figure 3.1 Schematic of the BodPod® apparatus. Source: http://hitcenterhuntington.com/testing/bod-pod/

3.7.1.5 Dual X-ray absorptiometry (DXA)

In Chapter 1, body composition was assessed by whole-body dual X-Ray absorptiometry (DXA) scans. In this method, a constant potential energy source of 76 kV and a dose efficient K-edge filter were used to create a congruent beam of dual energy radiation. These energies were attenuated to different degrees by bone mineral content and fat and lean mass content. The differences in attenuation of the dual energy radiation allowed determination of body composition. Fat and lean tissue were compartmentalised using standard regions of interest. All scans were conducted at the University of Exeter, Exeter, UK, by a trained and qualified operator using a GE Lunar Prodigy scanner (GE Healthcare, Bedford, UK). Whole-body scans were acquired with the participant in the supine position and aligned with scanner table as recommended by the manufacturer. The amount of radiation exposure received from a DXA scan is about 0.002 rem (a unit of radiation). This amount of radiation is a small part (0.3 rem) of the average whole body radiation exposure that each member of the public receives per year from radiation exposure that is recognised as being totally free of the risk of causing genetic defects (cellular abnormalities) or cancer. The risk associated with the amount of radiation exposure received from this procedure is considered to be low and comparable to other everyday risks. Qualified staff regularly monitored machine maintenance and repair as well as any software upgrades.

Scan results included total body mass, body fat percentage and mass, lean mass (excluding bone mass) and information regarding central fat distribution which included fat mass of the android and gynoid region. Android fat describes the extent of abdominal adiposity whereas gynoid describes fat deposited around the pelvic region, as illustrated in Figure 3.2. To interpret the BMD data, t-scores and z-scores provided young and age-matched SD respectively for identifying osteoporosis (-2.5 SD or lower). The participants removed outer clothing and positioned themselves in a supine position on the scanner. A member of the research team assisted participants to align themselves correctly and instructed them to lie as still as possible for the duration of the scan to optimise image quality.

Figure 3.2 Fat distribution of the android and gynoid region in DXA body composition analysis. Source: GE Medical systems lunar densitometry.

3.7.1.6 Magnetic resonance imaging (MRI)

For Chapter 7, quantification of visceral and abdominal adipose fat was undertaken via MRI scans (1.5T Intera scanner, Philips, The Netherlands). A series of 8 mm slices (2mm x 2 mm in-plane resolution), with 2 mm gap, were acquired centred around L3 (Demerath et al., 2007). A fast gradient echo sequence was utilised with water suppression via a frequency selective binomial excitation in order to obtain fat selective images. Fat quantification for each slice was undertaken using software present within the scanner package based on intensity windowing such that only voxels containing fat were included. Measurements were carried out to determine a cross-sectional area of separate subcutaneous and visceral fat components within a single slice at L3 and volumes over five slices centred around L3.

3.8 Cycle ergometry

For Chapter 6, participants completed a ramp test to exhaustion to establish peak oxygen uptake using an electronically braked cycle ergometer (Lode Excalibur Sport, Groningen, the Netherlands). The ergometer functions that were used included the step and proportional work rate forcing functions. The step function allowed work rate to be increased or decreased rapidly (1000W·s^{-1}) from one constant work rate to another in a stepwise manner for a predetermined duration. The step function was employed for warm-ups prior to the incremental tests to exhaustion. The proportional work rate forcing function was employed during all ramp incremental exercise tests to exhaustion as this allowed work rate to be increased or decreased linearly as a function of time. Both the step and proportional work rate functions administered the external power independent of pedal cadence by instantaneously adjusting the resistance via electrical braking.

3.9 Pulmonary gas exchange

Pulmonary gas exchange and ventilation were measured breath-by-breath during the ramp incremental tests to exhaustion and 6-min submaximal treadmill walking tests related to Chapter 6. This analysis was performed using a metabolic cart system that consisted of a bidirectional “Triple V” volume transducer that measured inspired and expired airflow an electrochemical cell to analyse expired O_2 concentrations and a nondispersive infrared analyser to measure expired carbon dioxide (CO_2) concentrations, respectively (Metalyzer 3B, CORTEX Biophysik GmbH, Leipzig, Germany). The gas analyser was calibrated before each visit with gases of known concentration and the volume sensor was calibrated using a 3-litre syringe (Hans Rudolph, Kansas City, MO). During all tests, participants wore a Hans Rudolph Oro-Nasal 7450 V2 mask with headgear and custom mask adapter (Hans Rudolph, Kansas City, MO) that was connected securely to the transducer. Gas was sampled continuously via a capillary line and $\dot{V}O_2$, carbon dioxide output ($\dot{V}CO_2$) and minute ventilation ($\dot{V}E$) were displayed breath-by-breath on-line. Following the completion of each test, raw breath-by-breath gas exchange and ventilation data were exported for subsequent analysis.

3.10 Determination of $\dot{V}O_{2peak}$

For the experimental chapter that measured $\dot{V}O_{2peak}$ (Chapter 6), testing involved the performance of a ‘ramp’ incremental cycling test to volitional exhaustion. The incremental test consisted of a three min period of baseline pedalling at 20 W, followed by a continuous linear (ramp) increase in work rate of 15 $W{\cdot}min^{-1}$ until the participants were unable to sustain the prescribed cadence (60-80 rpm). The ramp test was terminated when a drop of > 10 $rev{\cdot}min^{-1}$ below the prescribed cadence was observed. Strong verbal encouragement was provided throughout the test. Saddle and handlebar heights and reach were recorded following the baseline ramp test and the settings were replicated on post-intervention testing. No talking was allowed during the test unless to communicate feelings of severe discomfort or fatigue. Pulmonary gas exchange and HR were measured through all incremental tests. From the ramp incremental cycling tests breath-by-breath $\dot{V}O_2$ data were averaged into 10-s measurements and $\dot{V}O_{2peak}$ was defined as the highest 30-s rolling value. Volitional exhaustion was confirmed by incidence of a plateau in $\dot{V}O_2$ as well as a maximum respiratory exchange ratio (RER) > 1.15, and an RPE > 18.

3.11 Heart rate (short-range telemetry)

During exercise tests related to Chapter 4, with the exception of those conducted within the magnetic resonance scanner, HR was measured using Polar T34 transmitters and FT1 watches (Polar Electro Oy, Kempele, Finland) during WBV training whereas Polar T34 transmitters in conjunction with a portable 15-Hz global positioning system (GPS; SPI Pro X, GPSports, Canberra, Australia) were used during the football training. This allowed HR data to be recorded to the GPS unit for subsequent analysis using Team AMS v.1.5 (GPSports, Canberra, Australia). For the swimming training sessions related to Chapter 5, HR was recorded using a Polar Vantage NV transmitter and watch (Polar Electro Oy, Kempele, Finland). Five-second average values for HR were recorded for all experimental Chapters. HR recorded for the investigations related to Chapter 6 and 7 required a Polar WearLink Coded transmitter which allowed raw data to be recorded to a Polar RS400 watch (Polar Electro Oy, Kempele, Finland). Raw data were subsequently downloaded to Polar ProTrainer 5 (Polar Electro Oy, Kempele, Finland) and exported to Microsoft Excel for further analysis.

3.12 Blood pressure

For experimental Chapters 4, 6 and 7, BP of the brachial artery was measured with participants in a fasted state and in a rested, seated position following 10 min of sitting quietly. BP was measured five times using a semi−automated device (M7, OMRON, Lake Forest, IL in Chapter 4 and Dinamap Pro 100V2, GE Medical Systems Information Technologies 2002, Tampa, FL, USA in Chapter 6 and 7). The mean of the final three measurements was used to determine resting systolic and diastolic BP. BP was measured in Chapter 5 in a fasted state and in a rested supine position using an automatic device (HEM-709; OMRON, IL, USA) with BP measured once every 30 min for 2 h. The average of the four measurements was used as the test result. In Chapter 6, mean arterial pressure (MAP) was calculated as 1/3 × systolic pressure + 2/3 x diastolic pressure.

3.13 Blood sampling

In Chapters 6 and 7, fingertip capillary blood samples were collected to determine whole blood glucose concentration ([glucose]) prior to and during the oral glucose tolerance test (OGTT). Prior to obtaining the sample, the tip of the finger was cleaned thoroughly with alcohol (Steret) and a disposable safety lancet (Safety Lancet Normal 21G, Sarstedt Ltd, Leicester, UK) was used to puncture the skin. The first drop of blood was wiped away in order to prevent contamination of the sample and ~20-25 μL of free-flowing blood was collected into a microvette coated with fluoride (Microvette CB300, Sarstedt Ltd, Leicester, UK) and analysed using an automated blood lactate and glucose analyser (YSI 2300, Yellow Springs Instruments, Kent, UK). The analyser was calibrated hourly or every ten samples and daily maintenance was undertaken in accordance with the manufacturer's recommendations.

In addition, in Chapter 6 and 7, blood samples were drawn from an antecubital vein using venipuncture technique (BD Vacutainer® Safety-Lok™, Becton-Dickinson, Oxford, UK) into 5-ml serum separator tubes (BD Vacutainer® SST™, Becton-Dickinson, Oxford, UK) and left to clot for 45 min at room temperature. Subsequently, samples were centrifuged at room temperature at 1300 RCF for 10 min and serum supernatants were removed and stored at -80˚C for later analysis. Samples were analysed using an automatic analyser (Roche Modular P-module, Roche Diagnostics, Indianapolis, IN) for [HDL] (coefficient of variation (CV) 2.1 %), [TC] (CV 2.3 %) and [TG] (CV 2.4 %).

In Chapter 5, blood samples were drawn from an antecubital vein using venipuncture technique (BD Vacutainer® Safety-Lok™, Becton-Dickinson, Oxford, UK) into 5-ml serum separator tubes (BD Vacutainer® SST™, Becton-Dickinson, Oxford, UK). The blood was rapidly centrifuged for 30 s and the plasma was collected and analysed by an automatic analyser (Cobas Fara, Roche, France) for plasma [glucose] and [insulin] using enzymatic kits (Roche Diagnostics, Germany). Furthermore, 100 µl of plasma was used to determine concentrations of sICAM-1 and sVCAM-1 by immunoassays (Elisa, R&D Systems, Minneapolis, MN) using an Emax precision microplate reader (Molecular Devices, Sunnyvale, CA, USA). The intra-assay CV values for sICAM-

1 and sVCAM-1 are 4.9 ± 3.5 and 5.1 ± 5.9 %, respectively. All plasma and serum samples were kept at -80˚C and defrosted immediately prior to testing. Each sample was measured in duplicate within the same assay, and any samples that did not give a value, or returned an anomalous value, were reanalysed where possible. All assays were performed by the same experienced individual.

3.14 ^{31}Phosphorus magnetic resonance spectroscopy during one-legged knee-extension exercise

In Chapter 4, intramuscular metabolic responses to exercise were measured *in vivo* by calibrated ^{31}Phosphorous Magnetic Resonance Spectroscopy (^{31}P-MRS). The exercise test described required the participant to be lying in the prone position within the bore of a 1.5-T superconducting MR scanner with their body secured to the ergometer bed using Velcro straps at the thigh, buttocks, lower and middle back to minimise extraneous movement. The custom designed ergometer consisted of one-legged knee-extension exercise over a distance of ~0.22 m. Participants lifted the weight via a pulley system in accordance with a visual cue at a frequency of 40·min^{-1}.

To examine PCr recovery kinetics, two 24-s bouts of exercise were performed, separated by a recovery period of 4 min. In order to obtain a significant PCr depletion (~40 %), thereby maximising the accuracy of the recovery data fitting, exercise was undertaken with weights of mass 1 kg less than the maximum weight each subject achieved during the previous familiarity session. As the rate of PCr recovery has previously been shown to be pH dependent (Jubrias, Crowther, Shankland, Gronka, & Conley, 2003; van den Broek, De Feyter, de Graaf, Nicolay, & Prompers, 2007), exercise bouts were limited to 24 s as it has previously been determined that exercise for that period does not lead to a measurable decrease in pH (Vanhatalo et al., 2011).

The ramp protocol was carried out with a weight of 1 kg mass. This was then increased by 0.5 kg every 30 s until exhaustion, the time of which was recorded. The termination criterion was the inability to maintain the prescribed cadence.

Prior to the commencement of the exercise protocol, absolute baseline concentrations of metabolites were established via a technique similar to that described by Kemp, Meyerspeer, and Moser (2007) using a 6-cm ^{31}P transmit/receive surface coil. Firstly, spatially localised spectroscopy was undertaken to determine the relative signal intensities obtained from a phosphoric acid source within the scanner bed and inorganic phosphate (P_i) from the participant's right quadriceps muscle which was centred over the coil. A further scan was obtained comparing the signals obtained from the phosphoric acid standard and an external P_i solution, where the localised voxel sampled within the external solution were of the same dimensions and distance from the coil as the muscle, allowing the calculation of muscle Pi concentration following corrections for relative coil loading. Absolute values of PCr and ATP concentrations were subsequently calculated via the ratio of P_i:PCr and P_i:ATP.

For the exercise protocol, the knee-extension rate was set in unison with the magnetic pulse sequence to ensure the quadriceps muscles were positioned in approximately the same phase of contractions during each MR pulse acquisition. Initially, fast field echo images were acquired to determine whether the muscle was positioned correctly relative to the coil. This was aided by placing cod liver oil capsules, which yield high-intensity signal points within the image, adjacent to the coil, allowing its orientation relative to the muscle volume under examination to be assessed. A number of pre-acquisition steps were carried out to optimise the signal from the muscle under investigation. Matching and tuning of the coil was performed and an automatic shimming protocol was then undertaken within a volume that defined the quadriceps muscle. Before and during exercise, data were acquired every 1.5 s, with a spectral width of 1,500 Hz and 1K data points. Phase cycling with four phase cycles was employed, leading to a spectrum being acquired every 6 s. These spectra were analysed via peak fitting at a later date. Participants were familiarised to this set-up and performed a step incremental test during the familiarisation visit using a purpose-built mock MRI unit to replicate testing conditions.

3.15 Cognitive function tests

In chapter 6, participants completed a battery of cognitive function tests using the Cogstate® computerised cognitive testing system (Cogstate Ltd., Melbourne, VIC, Australia) to assess visual, verbal and attention/working learning & memory. Specifically, the tests employed included the International Shopping List Task

(ISLT) including delayed recall (ISLTR), One Card Learning Task (OCL), One Back Task (ONB) and Two Back Task (TWOB).

Continuous visual learning was assessed using OCL which used a pattern separation paradigm to measure visual memory. Participants were presented with a single playing card (without joker cards) presented in the middle of the laptop computer screen and were required to established whether they had seen the card before by clicking ‘Yes’ or ‘No’ using the left and right click of the trackpad on the laptop before a new card was presented on screen. The ‘Yes’ button was always related to the right click using the right hand and the ‘No’ button always related to the left click using the left hand. Six cards were chosen at random from the deck and repeated throughout the task. These six cards were interspersed with distractor cards (non-repeating cards). At the beginning of the task, task rules were presented on screen and also provided verbally to the participant by the researcher. Participants were encouraged to work as quickly and accurately as possible. Subsequently, participants were able to complete the practice trials before beginning the task. The task ended after 80 trials. The primary performance measure for OCL task was the proportion of correct answers (accuracy) which was normalised using an arcsine square-root transformation. A higher score equated to a better performance.

To assess working memory and attention, participants completed the ONB and TWOB in two separate tests. Again, the participants were presented with a single playing card in the middle of the laptop screen and had to respond to the question of whether the card was the same as one (ONB) or two cards before (TWOB) by clicking ‘Yes’ or ‘No’ before a new card was presented on screen. Participants were encouraged to work as quickly and accurately as possible. The primary performance measure for ONB and TWOB task was the proportion of correct answers (accuracy) which was normalised using an arcsine square-root transformation. A higher score equated to a better performance.

To assess verbal learning, the primary investigator read a 12-item shopping list to the participant at a rate of one word every 2 s. Following this, participants had to recall as many items as possible. When the participant could not recall any more items, the list was read out again and the participant attempted to recall all items. Three attempts were presented to the participant. The primary outcome measure for ISLT was the total number of correct responses to remembering the shopping list following three attempts. A higher score equated to a better performance.

Memory was also assessed using ISLTR having completed all previous tests. The aim was to remember as many shopping list items as possible from the original list. The primary performance measure for ISLTR was the total number of correct responses to remembering the original shopping list. A higher score equated to an improved performance.

The cognitive function battery took around 20 min to complete.

3.16 Global positioning system (GPS)

During all football training sessions related to Chapter 1, GPS data were recorded using a portable 15-Hz GPS unit (SPI Pro X, GPSports, Canberra, Australia) which is coupled with a 100 Hz accelerometer. The GPS device was attached to the participant’s upper back via a neoprene vest. The device was switched on and attached to the participant immediately prior to the training session and switched off immediately following the training session. Although distance and speed data were captured, the GPS unit was primarily used to collect HR data. The observations were subsequently downloaded using the dock provided and analysed using Team AMS v.1.5 (GPSports, Canberra, Australia) where average and peak HR was automatically generated following a user-defined time split for the session duration. Distance covered during the submaximal YYIE1 were checked using the Team AMS software.

3.17 Warwick-Edinburgh mental well-being scale (WEMWBS)

For Chapters 6 and 7, the WEMWBS was used to assess the mental well-being of participants prior to and following the intervention period (Appendix 1). This 14-item scale with 5 response categories was developed as an intervention outcome measure to monitor mental well-being in the general population and provides a single score ranging from 14-70. The 14 items are positively worded and cover feeling and functioning aspects of well-being. The WEMWBS includes items on positive affect, satisfying interpersonal relationships, and positive psychological functioning. Higher scores indicated higher positive mental well-being. The WEMWBS is supported by evidence of individual and group-level responsiveness as well as test-retest reliability and external validation in a representative general population sample of British adults (Tennant et al., 2007).

3.18 International physical activity questionnaire (IPAQ)

In order to assess participant's normal physical activity habits prior to acceptance on to the experiments related to Chapters 4, 5 6 and 7, the short-format IPAQ was used (Appendix 2). This seven-item questionnaire required participants to think about their physical activity over the previous seven days in terms of sitting, walking, moderate-intensity and vigorous-intensity activities lasting 10 min or more.

3.19 Groningen enjoyment questionnaire (GEQ)

For Chapter 6, enjoyment of participating continuous and high-intensity interval cycling was measured using an adapted version of the GEQ (Appendix 3). The GEQ was originally developed for sedentary older adults and reports satisfactory reliability and validity (M. Stevens, Moget, de Greef, Lemmink, & Rispens, 2000). The GEQ consists of 10 statements with which participants are asked to rate their agreement on a 7-point scale (1 = "absolutely disagree" to 7 = "absolutely agree").

3.20 Oral glucose tolerance test (OGTT*)*

For Chapters 5, 6 and 7, participants consumed 75 g glucose in 300 mL of water with capillary blood sampled at 30, 60, 90 and 120 min for assessment of plasma [glucose]. A 90 min sample was not collected for Chapter 2. Throughout the 2 hr OGTT participants remained in the laboratory completing only sedentary activities.

3.21 Submaximal Yo-Yo intermittent endurance test level 1 (YYIE1)

The submaximal YYIE1 was employed in Chapter 4 and 7 (DVD) as a measure of exercise economy using HR. For Chapter 4 each training session was preceded by a submaximal YYIE1 and acted as a warm-up for subsequent football training. The test requires participants to complete repeated 2 x 20 m shuttle runs interspersed with a 5 s period of active recovery, at increasing speeds controlled by audio signals from an audio player. Only the first six 2 x 20 m shuttle runs are completed as part of the submaximal YYIE1.

3.22 Ratings of perceived exertion (RPE)

During the ramp test to exhaustion in Chapter 6, RPE was measured using the 6-20 Borg scale (G. Borg, 1970) with '6 ' representing no exertion at all and '20' representing maximal exertion. In Chapters 6 and 7, following each training session, participants were asked to rate their perceived exertion using the 11-point CR-10 scale (G. A. Borg, 1982) with '0' representing rest and '10' representing maximal exertion. When providing their RPE scores, participants were asked to consider the whole training session.

3.23 Submaximal exercise treadmill test

In Chapter 6, participants completed a 6-min submaximal exercise walking test on a treadmill (Woodway Desmo, Waukesha, WI) at a speed of 4 $\text{km}\cdot\text{h}^{-1}$ with a 1% incline (Jones & Doust, 1996). Pulmonary gas exchange (Cortex Metalyzer 3B, Germany) and HR were measured during the final 3 min of this test. No talking was allowed during the test unless to communicate feelings of severe discomfort or fatigue.

3.24 Data analysis procedures

3.24.1 Peak fitting of ^{31}phosphorous magnetic resonance spectra

In Chapter 4, the spectra acquired via ^{31}P-MRS were quantified by peak fitting, with assumption of prior knowledge, using Java-based magnetic resonance spectroscopy (jMRUI) (version 3) software and the AMARES fitting algorithm (Vanhamme, van den Boogaart, & Van Huffel, 1997). Spectra were fitted according to the assumption that P_i, PCr, α-ATP (two peaks, amplitude ratio 1:1), γ-ATP (two peaks, amplitude ratio 1:1), β-ATP (three peaks, amplitude ratio 1:2:1) and phosphodiester peaks were present.

For the ramp protocol, for each participant the PCr depletion at the end of exercise was determined. In addition, the PCr depletion at the same time point from both visits was determined, with the time selected corresponding to the shorter exercise finish time from the two visits.

3.24.2 Mathematical modelling of phosphocreatine concentration data

The PCr data in recovery following the 24-s exercise period was modelled according to the following equation:

$$PCr_{(t)} = PCr_{end} + PCr_{(0)}(1-e^{(-t/\tau)}) \quad \text{(Equation 3.4)}$$

where PCr_{end} is the value at the end of exercise, $PCr_{(0)}$ is the difference between the PCr at end exercise and fully recovered, *t* is the time from exercise cessation and τ is the time constant for the exponential recovery of PCr. Each 24-s recovery period was fitted individually and the time constants determined for each before being averaged to give the value quoted for the trial.

3.24.3 Calculation of intramuscular metabolites

The chemical shift of the P_i spectral peak relative to the PCr peak was used to calculate intracellular pH (Taylor, Bore, Styles, Gadian, & Radda, 1983).

3.24.4 Insulin sensitivity

For Chapter 5, insulin sensitivity was performed using the HOMA-IR (Yokoyama et al., 2003). The relationship between glucose and insulin in the basal, fasted state reflects the balance between hepatic glucose output and insulin secretion, which is maintained by the homeostatic feedback loop between the liver and β-cells (T. M. Wallace, Levy, & Matthews, 2004)

3.24.5 Total area under the curve (tAUC)

For Chapter 5, the magnitude of response and change over time for plasma [glucose] and [insulin] during the OGTT's were quantified using tAUC analyses employing the trapezium rule (GraphPad Prism, San Diego, CA).

3.25 Training interventions

3.25.1 Small-sided football training

In Chapter 4, those participants randomised to the football group completed 32 football training sessions organised as small sided games comprising two teams with no goalkeepers. The football training sessions took place on various playing surfaces which included outdoor natural and artificial turf and an indoor court. Playing areas measured 15-25 m wide and 20-40 m long. Each participant was supplied with correct footwear and shin guards. All sessions were fully supervised by an instructor who had previous experience of playing football and could act as an extra participant when teams were unequal. Each training session lasted for 13.5 min.

3.25.2 Whole-body vibration training

In chapter 4, those participants randomised to the WBV group completed 32 sessions and were exposed to oscillating WBV using a Galileo Sport Plate (Novotec Medical GmbH, Pforzheim, Germany). The oscillating movement of the vibration plate produces an alternating force induction in the legs which is transferred to the pelvis. With shoes removed, the participants stood on the platform with heels touching the plate and knees slightly bent with body weight over the forefoot while grasping the handles in front of them. The protocol consisted of a 3 min warm-up at a frequency of 6 Hz with an amplitude of 2 mm. After the warm-up, the participants completed 1 min bouts of 1) static squats (at 30˚ knee flexion), 2) dynamic squats (between 30˚ and 90˚ knee flexion), 3) pelvic floor muscle loading, 4) alternating “hump back, swallow back”, 5) static squats (at 30˚ knee flexion), 6) dynamic squats (between 30˚ and 90˚ knee flexion), and 7) pelvic floor muscle loading (Figure 3.3). Each 1 min bout was followed by 1 min of recovery. For the duration of the study, the first four exercises were completed at a frequency of 12 Hz. For the first 4 wks, the final three exercises were also completed at 12 Hz and increased to 18 Hz for wks 5-7 and 27 Hz for the remaining 9 wks. Vibrational amplitude increased from 1mm in the first wk to 1.5 mm in wks 2-3, 2 mm in wks 4-5, 2.5 mm in wk 6, 3 mm in wks 7-9, 3.5 mm in wk 10, and 4 mm in wks 11-16. A load of 4, 6, and 8 kg was also applied in wks 14, 15, and 16 for exercises 1, 2, 5, and 6. All WBV sessions were organised on a one-to-one basis and were fully supervised by a trained investigator.

Figure 3.3 Positions adopted by the participants on the vibration plate during the protocol. From left to right: Squat, two legged; Pelvis tilt forward, backward; Hump back, swallow back. (Source: http://www.galileo-training.com/us-english/products/galileo-training-devices/background/exercises.html

3.25.3 Swimming training

In Chapter 5, participants completed 45 swimming training sessions in an indoor swimming pool. All sessions were supervised by five trained swimming coaches who provided technical supervision and guidance and a safe exercise environment. HR was measured during training sessions performed in the first and 15th wk of training. Swimming distance was noted in every session. Drinking water facilities were provided.

3.25.3.1 Moderate-intensity continuous swimming

The moderate-intensity swimming group required participants to swim (front-crawl) continuously for 1 h with as few stops as possible.

3.25.3.2 High-intensity interval swimming

The high-intensity swimming group required participants to swim (front-crawl) ‘all-out’ for 6-10 30 s bouts interspersed by 2 min of passive recovery. Training sessions lasted ~15-25 min correlating to 3-5 min of effective swimming.

3.25.4 Cycling training

In Chapter 6, participants completed 36 cycling training sessions using a Monark 894E cycle ergometer (Monark, Sweden) interfaced with Wingate Anaerobic Test software (Monark, Sweden) to record power output (W) and work done (kJ). Each training session included a 5 min warm up and a 5 min cooldown at ~50 W completed using the cycle ergometer. Participants were encouraged to increase their own work rate throughout the 12-wk intervention by increasing the pedal cadence or applying more resistance to the flywheel. HR data and RPE, 10-point scale were recorded during every training session. All training sessions were fully supervised by members of the Sport and Health Sciences department at the University of Exeter who were able to provide technical advice and guidance within a safe exercise environment. Participants were encouraged to cycle as far as possible. Audio/visual entertainment were provided for all sessions as well as drinking water facilities.

3.25.4.1 Continuous cycling

The continuous cycling training required the participants to continuously cycle at a self-paced intensity (~60 % of maximum effort) for 50 min (Figure 3.4).

3.25.4.2 High-intensity interval cycling

The high-intensity interval cycling training was based on the “10-20-30” running training intervention by Gunnarsson and Bangsbo (2012) which consisted of 5 min bouts of 1 min micro cycles of self-paced cycling comprising 30 s low-intensity (~30 % of maximum effort), 20 s moderate-intensity (50~60 % of maximum effort) and 10 s high-intensity (>90 % maximum effort) cycling. Participants completed 5 x 5 min bouts interspersed with 2 min recovery (Figure 3.4).

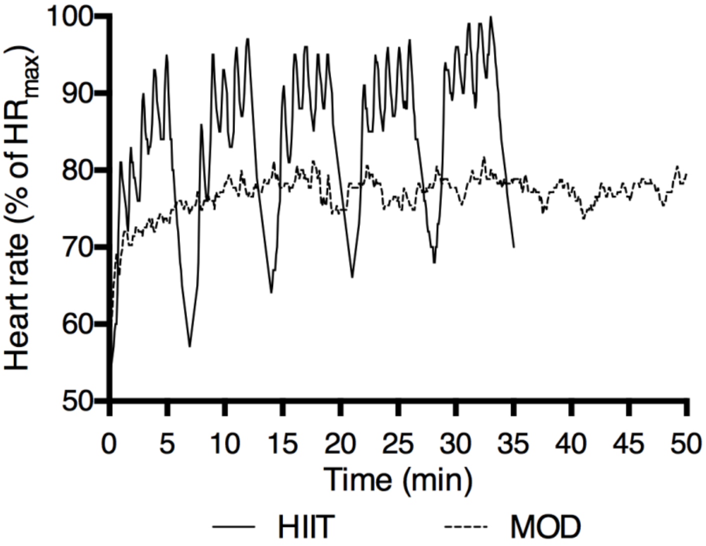


Figure 3.4 Typical cycling training session displaying the high-intensity and moderate-intensity HR trace.

3.25.5 Home-based exercise training

In Chapter 7, participants completed 36 home-based exercise sessions within a pre-determined 3 x 1.5 m square referred to as the ‘Grid’ (Figure 3.5). Within the Grid, participants completed 14.5 min exercise bouts consisting of low-, moderate-, and high-intensity exercise patterns 3 times weekly, similar to the 10-20-30 programme from Gunnarsson and Bangsbo (2012). The pre-choreographed movements within the grid required 30 and 60 s intervals followed by 5 s transitions. Each 60 s interval required the action to be completed at low-intensity for 30 s, moderate-intensity for 20 s and high-intensity for 10 s and each interval was interspersed with intervals of active rest. This pre-choreographed movement training (Scott, 2014) incorporated slow-speed-, moderate-speed- and high-speed-running, backwards-running, backwards and sideways walking, side-cutting as well as 90° and 180° turns, jumps and stops interspersed with spinal and lower limb mobility and balance and coordination challenges (full protocol available in Chapter 7). The movement protocol remained consistent for 6 wks (Level 1) before participants were asked to return to the laboratory for mid-intervention testing. At this stage, participants were then familiarised to a new protocol (Level 2) which required more challenging movements which they performed for wks 6-12. Participants were familiarised with level 1 and 2 DVDs under the supervision of a member of the research team. A member of the research team also made weekly contact with the participants to provide encouragement, receive feedback and answer any queries the participant may have had. YouTube links to the exercises were also available in addition to the DVD. Participants were asked to record RPE and HR at least once a wk using the attendance sheet and HR monitors provided.

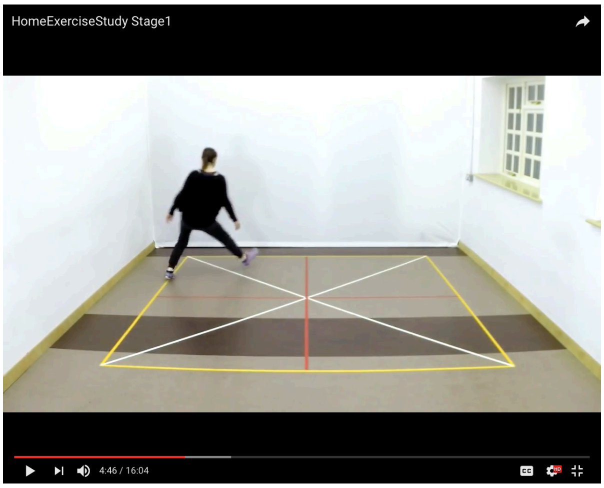


Figure 3.5 Video available through YouTube outlining the grid in which to perform the exercise movements

3.26 Ethical issues

Recruitment: As outlined at the start of this chapter, inactive women showing an interest in the training studies could contact the researcher by phone or meet in person. However, there was the possible issue that potential female participants would not feel conformable talking to a male researcher. Therefore, it was clearly explained to the individual that they were able to speak to a female who had a clear understanding of the study design but was not part of the research team. The potential participants were also given adequate time and the ability to freely consider whether or not they wished to take part in the study. While no monetary incentives were offered for the completion of the intervention periods, it cannot be discounted that the participation in 'free' exercise training and testing of health markers may have been viewed as an incentive to take part in the study. However, it was ensured that information presented to the individual regarding the study was provided accurately, clearly presented and information was balanced and free of misleading emphasis that made the studies excessively attractive.

Allocation to groups: Expectedly, many of the participants wanted to participate in the exercise training rather than the control group but it was clearly outlined to the individuals that, as these studies required randomised allocation to the groups, participants did not have a choice as to which group they would be allocated to. However, the participants in the control groups were offered access to training materials (e.g. exercise DVD) and training sessions to familiarise them to the exercise protocols which they could then perform competently outside of the study environment. Training materials were made available once the participants had completed the study.

Experimental procedures: It was apparent that some tests required the participants to wear minimal clothing (i.e. swimming costume for use with the BodPod). Where this was the case, it was clearly communicated to the participant that participation was completely voluntary and that a female researcher could perform the test if preferred. To note, this was not required and all participants were comfortable with a male performing the tests.

Data management: As briefly mentioned at the start of this chapter, participant's data was anonymised for presentation of results. Additionally, hard copies of the participant's sensitive information was filed and locked in the research data storage facility at the University of Exeter. Electronic copies of sensitive information were password protected and only accessible by the principal investigator of the research team. All participants were given access to their own data as well as anonymised group data once all data had been collected and analysed.

3.27 Statistical methods

All statistical analyses in relation to the experimental chapters of this thesis were conducted with the Statistical Package for the Social Science (SPSS, version 20 and 21, SPSS Inc., Chicago, IL, USA) apart from the calculation of tAUC analyses which was performed using GraphPad (Prism, GraphPad Software, San Diego, California, USA). Specific information regarding the particular statistical tests that were employed for the four investigations is provided within each of the experimental chapters. Before any statistical tests were carried out, the data were checked for normality using standard procedures. Statistical significance was accepted at the level of $P < 0.05$. All data are presented as means ± SD unless otherwise stated in the individual experimental chapters.

Chapter 4

Effects of small-volume soccer and vibration training on body composition, aerobic fitness, and muscular PCr kinetics for inactive women aged 20—45

Contribution: Investigation, project administration, formal analysis, writing – original draft preparation, review and editing.

The overarching aim of this thesis is to investigate a number of potential time-efficient exercise interventions to increase participation in physical exercise and improve the health profile of previously inactive premenopausal women. Chapter 4 contributes to this aim by building upon previous literature of small-sided football training interventions. Previous studies have reported significant improvements in a number of key health markers in premenopausal women following 16 wks of training with no previous experience of playing football (Krustrup et al., 2010). However, due to a significant training time commitment (2 x 1 h per week), Chapter 4 utilises a time-efficient regimen which may be more favourable for the population in question and directly compares the results to a control group as well as an alternative exercise training intervention known as WBV training. WBV training has shown some potential for improving body composition in premenopausal women with a low training time commitment (Roelants et al., 2004).

A priori power analysis was performed for the primary outcome, body fat percentage, using G*Power (Faul et al., 2007). Power was set at 0.8 with a significance level of 0.05. Based on previous small-sided football studies aiming to reduce body fat percentage using comparable physical exercise interventions (Krustrup et al., 2010), an average reduction of 5 % with a standard deviation of 2 from baseline values was expected. Based on these assumptions, 20 participants were required for comparison between each respective intervention group and the control group. Assuming participant attrition such as drop out, 22 females were recruited for each group (66 participants in total) for this study.

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Journal of Sport and Health Science 3 (2014) 284–292

www.jshs.org.cn

Original article

Effects of small-volume soccer and vibration training on body composition, aerobic fitness, and muscular PCr kinetics for inactive women aged 20–45

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Received 21 February 2014; revised 19 May 2014; accepted 3 July 2014
Available online 7 August 2014

Abstract

Purpose: The present study investigated the effects of 16 weeks of small-volume, small-sided soccer training soccer group (SG, $n = 13$) and oscillating whole-body vibration training vibration group (VG, $n = 17$) on body composition, aerobic fitness, and muscle PCr kinetics in healthy inactive premenopausal women in comparison with an inactive control group (CO, $n = 14$).

Methods: Training for SG and VG consisted of twice-weekly 15-min sessions with average heart rates (HRs) of $\sim$155 and 90 bpm respectively. Pre- and post-measurements of body composition (DXA), phosphocreatine (PCr) on- and off-kinetics, and HR measurements during standardised submaximal exercise were performed.

Results: After 16 weeks of training in SG, fat percentage was lowered ($p = 0.03$) by 1.7% ± 2.4% from 37.5% ± 6.9% to 35.8% ± 6.2% and the PCr decrease in the quadriceps during knee-extension ramp exercise was attenuated (4% ± 8%, $p = 0.04$), with no changes in VG or CO (time-group effect: $p = 0.03$ and $p = 0.03$). Submaximal exercise HR was also reduced in SG after 16 weeks of training (6% ± 5% of HR_{max}, $p = 0.01$).

Conclusion: Short duration soccer training for 16 weeks appears to be sufficient to induce favourable changes in body composition and indicators of aerobic fitness and muscle oxidative capacity in untrained premenopausal women.

Keywords: Fat percentage; Heart rate; MRS; PCr kinetics; Small-sided soccer

1. Introduction

It is well documented that physical activity (PA) can improve the cardiorespiratory fitness and health profile and may lower the risk for several cardiovascular and metabolic diseases.[1] However, inactive behavior has continued to

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Peer review under responsibility of Shanghai University of Sport.

http://dx.doi.org/10.1016/j.jshs.2014.07.003

increase over the past few decades,[2,3] with lack of time commonly cited as an issue preventing women from meeting PA recommendations.[4] Focus should therefore be placed on developing PA interventions for inactive women for which high compliance rates can be achieved while obtaining the positive health benefits of exercising.

As soccer is one of the most popular sports in the world, with over 29 million registered women players globally,[5] it may serve as an appealing, inexpensive PA for inactive women. Soccer is a motivational and social activity[6,7] and, most importantly, participation in small-sided recreational soccer games has been shown to be an effective health-promoting activity for both untrained men[8−11] and women.[12−18] In untrained premenopausal women, Krustrup et al.[17] and Andersen et al.[18] found that participating in twice-weekly 1-h sessions of small-sided recreational soccer or outdoor continuous running for 16 weeks produced a number of positive health benefits. Maximal oxygen uptake, lean mass, and heart function were increased and fat mass and systolic blood pressure (BP) were reduced for both groups. In addition, a decrease in diastolic BP and low-density/high density lipoprotein cholesterol ratio was evident for the soccer group only, and the cardiac adaptations induced by the training were considered to be more consistent when compared to continuous running.[18] Similar health benefits have been observed after 12 weeks of soccer, 2−3 × 1 h per week, organised as a workplace intervention outside working hours.[14] Although these interventions produced positive health benefits, they required participants to exercise for 1 h per session, a length of time not necessarily easy to accommodate within peoples' daily routine. However, it is not known whether the same health benefits can be achieved with a reduction in training session duration.

Whole-body vibration (WBV) training is an alternative exercise modality that is becoming increasingly popular in gyms and may address time constraints and compliance issues in inactive populations[19] due to the short duration of sessions. However, rather than a cardiovascular focus, much of the research within this area has examined muscle strength[20] and power,[21,22] postural control in the elderly[23] and bone mineral density in postmenopausal women.[24] Acute responses to WBV training (vertical and oscillating), in combination with upper- and lower-body exercises, have shown that oxygen consumption increases linearly as load, frequency (f), and amplitude (A) rise.[25,26] However, only a small number of studies have examined the effects of WBV training as an intervention to improve the cardiovascular risk profile in inactive populations. Song et al.[27] revealed a significant decrease in weight, waist circumference and BMI after 8 weeks of oscillating WBV training, 10 min twice a week, in obese postmenopausal women, although this was not accompanied by changes in body fat percentage. Likewise, 18 months of WBV training in postmenopausal women performed twice a week (60 min/session) was associated with reductions in body fat percentage and abdominal fat mass and an increase in lean body mass.[28] However, these changes were not significantly different from other training modes (e.g., aerobic dance). Thus, to date it is unclear whether oscillating WBV training provides sufficient cardiovascular stimulation to improve the health profile of inactive premenopausal women after a short intervention period.

As such we aimed to investigate some of the potential differences in health benefits that may arise between two very different exercise modalities, thereby possibly informing the decision process of individuals when selecting an exercise regime to fit into the limited time available to them. Hence, the goal of the present study was to undertake a pilot study to examine the feasibility of measuring cardiovascular and metabolic adaptations in inactive middle-aged premenopausal women in response to participation in 16 weeks of small-sided soccer training and WBV training. The main focus was to assess whether measureable changes could still be detected with short exercise durations, when examining similar group sizes to those that have shown beneficial health effects with longer duration exercise intervention[9−11,16] and to assess the differences in responses between exercise modalities. We hypothesised that low-volume small-sided soccer training would reduce fat mass, resting heart rate (HR) and HR during submaximal tasks, and would improve muscle PCr kinetics. In contrast, it was hypothesised that WBV training would not provide a sufficient cardiovascular and metabolic challenge to induce equivalent adaptations.

2. Methods

2.1. Participants

Participants were recruited through advertisements in the local newspaper, community venues, and local radio stations. No financial or other inducements were offered to participants. All participants completed a questionnaire prior to the training intervention to confirm that they were premenopausal and that none of them were smokers, pregnant, or on medication. Participants also confirmed there were no known medical conditions that would exclude them from undertaking in an exercise program. None of the participants had been taking part in regular PA for at least 2 years. This was established via questionnaire at baseline requiring participants to detail time spent weekly undertaking activities likely to cause significant increases in cardiovascular output. Activities listed included jogging, cycling, swimming, gym sessions, fitness classes, and sporting events. In addition, the participants had no previous experience of participating in competitive or professional level sport and had little or no experience of playing soccer or using WBV equipment. Although not directly monitored, the participants were encouraged not to change their dietary intake for the duration of the study and, apart from the intervention, were requested to maintain their normal lifestyle. All the participants gave their written informed consent after they were fully informed of the potential benefits, possible risks, and discomforts associated with the study. The study was approved by the National Research Ethics Service (NRES) (12/SW/0045) and the institutional research ethics committee (NHS 2012/329).

The participants were randomly assigned to a soccer group (SG, $n = 21$), a WBV group (VG, $n = 21$), or a control group who performed no physical training (CO, $n = 24$). Switching between groups was generally not possible. However, two participants who had initially been assigned to SG were reassigned to VG prior to any training sessions taking place, as it was impossible for them to attend any of the soccer training sessions due to work commitments at those times. Eight, four, and 10 participants in SG, VG, and CG, respectively withdrew from the study due to pregnancy, personal problems, minor injuries, or low compliance with the training.

2.2. Study design

Of the 44 participants of Caucasian ($n = 42$) and Southeast Asian ($n = 2$) origin who completed the study; i.e., SG ($n = 13$), VG ($n = 17$), and CO ($n = 14$), those in SG and VG trained for 16 weeks, while CO continued their normal daily lives. The participants were assessed before and after the intervention period with continuous recordings of HR throughout the training sessions.

2.3. Training intervention

The soccer training was organised as small-sided games made up of two teams with no goalkeepers and the aim of the game was to score in the opposition's goal. The sessions took place twice a week for 13.5 min on various playing surfaces, including outdoor natural grass, artificial turf and, during bad weather, an indoor court. All surfaces were 15−25 m wide and 20−40 m long. Each participant was supplied with relevant soccer footwear for indoor and outdoor facilities. Three to four morning and evening training sessions were organised every week in order to ensure that each participant could attend two of them, with a recommended gap of at least 48 h between sessions and a minimum gap of at least 24 h between sessions. All sessions were fully supervised by an instructor who had previous experience of playing soccer and could act as an extra participant when teams were unequal. Due to the variation in session participants, the small-sided games were played as 2 v 2, 3 v 3 or 4 v 4. Each training session was preceded by a standardised 2-min warm-up consisting of the first six 20-m shuttle runs of the Yo-Yo intermittent endurance level 1 test (YYIE1).[29] After each 40-m run, the participants had a 5-s active recovery period during which they walked 2×2.5 m.

The 13.5-min WBV training was also administered twice a week on a WBV plate (Galileo Sport, Novotec Medical GmbH, Pforzheim, Germany) with at least a 24-h gap between sessions. The participants were instructed to remove their shoes, stand on the plate with slightly bent knees and heels touching the board and bring their weight over the forefoot. The protocol consisted of a 3-min warm-up at a frequency of 6 Hz with amplitude of 2 mm. After the warm-up, the participants completed 1-min bouts of 1) static squats (at 30° knee flexion), 2) dynamic squats (between 30° and 90° knee flexion), 3) pelvic floor muscle loading, 4) alternating "hump back, swallow back", 5) static squats (at 30° knee flexion), 6) dynamic squats (between 30° and 90° knee flexion), and 7) pelvic floor muscle loading. Each 1-min bout was followed by 1 min of recovery. For the duration of the study, the first four exercises were completed at a frequency of 12 Hz. For the first 4 weeks, the final three exercises were also completed at 12 Hz and increased to 18 Hz for weeks 5−7 and 27 Hz for the remaining 9 weeks. Vibrational amplitude increased from 1 mm in the first week to 1.5 mm in weeks 2−3, 2 mm in weeks 4−5, 2.5 mm in week 6, 3 mm in weeks 7−9, 3.5 mm in week 10, and 4 mm in weeks 11−16. A load of 4, 6, and 8 kg was also applied in weeks 14, 15, and 16 for exercises 1, 2, 5, and 6. All WBV sessions were organised on a one-to-one basis with a trained supervisor to ensure safety and guidance in the required exercises.

Compliance for both training groups was monitored, with attendance records controlled by the supervisors.

2.4. Pre- and post-exercise intervention testing procedures

The subjects were familiarised with all testing procedures on at least one occasion before baseline testing and no PA was performed 2 days prior to testing. All measures were performed at baseline and were subsequently repeated within 1 week of the completion of the 16-week training intervention.

Height (Seca stadiometer SEC-225; Seca, Hamburg, Germany), resting HR and BP were obtained after at least 10 min of rest with the participant in a seated position. A minimum of five measurements were performed using an automatic upper-arm BP monitor (M7; OMRON, Lake Forest, IL, USA) with an average value calculated.

In order to examine body composition, a total body DXA scan was performed (GE Lunar Prodigy, GE Healthcare, Bedford, UK), and fat and lean tissue were compartmentalised using standard regions of interest.

To examine muscle phosphorus metabolite concentrations at rest and during two different exercise protocols, the participants were positioned in the bore of a 1.5 T superconducting magnet (Intera; Philips, Amsterdam, the Netherlands) at the University of Exeter Magnetic Resonance Research Centre. Prior to the exercise bouts, baseline measurements were taken. On completion, two different exercise regimes were carried out to examine different facets of muscle function. In the first, PCr recovery kinetics was examined by undertaking short bouts of continuous exercise. Subsequently, after a recovery period, a ramp exercise protocol was undertaken in which the workload was continually increased until the point of participant failure.

The participants were positioned in the scanner head first in a prone position such that the subject's right quadriceps muscle was centred directly over a 6-cm ^{31}P transmit/receive surface coil. They were subsequently secured to the scanner bed using Velcro straps at the thigh, buttocks, lower back, and middle back to minimise extraneous movement. In order to undertake exercise testing, a custom-designed nylon ergometer frame fitted onto the bed in alignment with the subject's feet and a base unit was positioned behind the bed. Cuffs with

Velcro straps were secured to the subject's foot and attached to a rope which passed around pulleys housed within the frame to the base unit, where they were attached to non-magnetic weights.

Prior to the beginning of exercise, images were acquired to confirm that the quadriceps muscle was positioned directly above the ^{31}P coil. Subsequently, a pre-exercise baseline spectrum was acquired with long repetition time (TR = 20 s) in which the relative unsaturated peak amplitudes could be determined. Molar concentrations of PCr and ATP were subsequently calculated via the ratio of Pi:PCr and Pi:ATP, assuming a resting concentration of ATP of 8.2 mmol/L.

The exercise protocol consisted of one-legged knee extensions, which resulted in the lifting of weights via the pulley system. The extensions took place at a frequency of 0.67 Hz with the foot moving over a distance of ~0.22 m, with both visual and audio cues being given to ensure that the rate of contraction was maintained at the desired value. To examine PCr recovery kinetics, two 24-s bouts of exercise were performed, separated by a recovery period of 4 min. In order to obtain a significant PCr depletion (~40%), thereby maximising the accuracy of the recovery data fitting, exercise was undertaken with weights of mass 1 kg less than the maximum weight each subject achieved during the previous familiarity session. As the rate of PCr recovery has previously been shown to be pH dependent,[30,31] exercise bouts were limited to 24 s as we have previously determined that exercise for that period does not lead to a measurable decrease in pH. The ramp protocol involved the participants continually exercising to volitional fatigue. Initially, exercise was carried out with a weight of 1 kg mass. This was then increased by 0.5 kg every 30 s until exhaustion, the time of which was recorded. During exercise and recovery, ^{31}P data were acquired every 1.5 s and phase cycling with four phase cycles was employed, leading to spectra being acquired every 6.0 s.

2.5. *Measurements during training*

HR was recorded during WBV training for 10 participants, using Polar T34 belts (Polar Electro Oy, Kempele, Finland) and noted each minute during the 13.5-min protocol. The remaining seven participants in VG opted not to have HR recorded during WBV training. HR was recorded during soccer warm-ups and training sessions using Polar T34 belts and a portable 15-Hz global positioning system (GPS; SPI Pro X, GPSports, Canberra, Australia). Data were subsequently downloaded using Team AMS v.1.5 (GPSports) where average and peak HR was automatically generated following a user-defined time split for the session duration. Individual HR_{peak} was determined as the highest HR reached within a single soccer session across the length of the study. HR was also analysed for the last 15 s of each YYIE1 warm-up to determine any change in HR over time for the same given work rate. Using GPS measurements, only those who covered a distance of $\geq$150 m for the YYIE1 in the given time were included in the analyses.

2.6. *Data analysis*

The acquired spectra were quantified via peak fitting, assuming prior knowledge, using the jMRUI (version 3) software package employing the AMARES fitting algorithm.[32] Spectra were fitted assuming the presence of the following peaks: P_i, phosphodiester, PCr, α-ATP (2 peaks, amplitude ratio 1:1), γ-ATP (2 peaks, amplitude ratio 1:1), and β-ATP (3 peaks, amplitude ratio 1:2:1). Intracellular pH was calculated using the chemical shift of the P_i spectral peak relative to the PCr peak.[33]

For the PCr values following the 24-s exercise period, PCr recovery was fitted with Prism 5 software (GraphPad Software Inc., La Jolla, CA, USA) by a single exponential of the form:

$$\text{PCr}_{(t)} = \text{PCr}_{\text{end}} + \text{PCr}_{(0)}\left(1 - e^{(-t/\tau)}\right)$$

where PCr_{end} is the value at the end of exercise, $\text{PCr}_{(0)}$ is the difference between the PCr at end exercise and fully recovered, t is the time from exercise cessation and τ is the time constant for the exponential recovery of PCr. Each 24-s recovery period was fitted individually and the time constants determined for each before being averaged to give the value quoted for the trial.

For the ramp protocol, for each participant the PCr depletion at the end of exercise was determined. In addition, the PCr depletion at the same time point from both visits was determined, with the time selected corresponding to the shorter exercise finish time from the two visits.

2.7. *Statistics*

Statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS, v.20, SPSS Inc., Chicago, IL, USA). Before analysis, data were checked for normality using a Shapiro–Wilk test. Non-normally distributed data were assessed using the Kruskal–Wallis test. Homogeneity of variance was determined using Levene's *F*-test. Repeated measures analysis of variance (ANOVA) were used to evaluate data for 0, 8 (YYIE1 warm-up only), and 16 weeks of the intervention with group as between-subjects factor and time as the repeated factor. Effect sizes (partial η^2) were also reported for interpretative purposes with 0.01, 0.06, and 0.14 regarded as a small, moderate, and large effect.[34] Due to the mean age (40 ± 5 years) and age range (29–46 years) of the participants, repeated measures analysis of covariance (ANCOVA) with age as a covariate were also used. However, as the covariate did not have a significant ($p > 0.05$) relationship to any of the outcome variables, only ANOVA data are reported. When a significant *F*-value was detected, data were subsequently analysed using *post hoc t* tests with a Bonferroni correction. Between-group differences in baseline characteristics as well as intervention-induced changes were evaluated by a one-way ANOVA. Significance was selected at the level of $p < 0.05$. All statistical analyses were presented as mean ± SD unless otherwise stated.

Table 1
Baseline characteristics and (absolute change) in fat mass and lean mass following 16 weeks of training for the soccer (SG), vibration (VG), and control (CO) group (mean ± SD).

Baseline characteristics	SG ($n = 13$)	VG ($n = 17$)	CO ($n = 14$)	ANOVA interaction (p value)	Partial η^2
Age (year)	39 ± 6	40 ± 4	40 ± 5		
Height (m)	1.65 ± 0.05	1.69 ± 0.05	1.66 ± 0.06		
Weight (kg)	67.1 ± 9.8 (−0.67 ± 2.78)	74.0 ± 14.4 (0.26 ± 2.14)	68.8 ± 14.4 (0.04 ± 2.19)		
BMI (kg/m^2)	24.5 ± 3.6	25.9 ± 4.9	25.0 ± 4.9		
Fat					
Arms (kg)	2.22 ± 0.64 (−0.10 ± 0.16)	2.71 ± 1.00 (0.03 ± 0.30)	2.31 ± 0.94 (−0.06 ± 0.53)	0.60	0.02
Legs (kg)	9.79 ± 2.81 (−0.25 ± 1.15)	10.89 ± 3.28 (0.01 ± 1.26)	8.85 ± 3.50 (0.03 ± 0.86)	0.80	0.01
Trunk (kg)	12.65 ± 4.64 (−1.02 ± 1.40)^{a,b}	14.50 ± 6.16 (0.33 ± 1.17)	12.96 ± 5.79 (−0.08 ± 1.51)	0.03	0.16
Android (kg)	2.05 ± 0.85 (−0.17 ± 0.27)^{a,b}	2.37 ± 1.15 (0.08 ± 0.28)	2.19 ± 1.06 (−0.02 ± 0.20)	0.04	0.15
Gynoid (kg)	5.28 ± 1.31 (−0.18 ± 0.47)	5.76 ± 1.41 (0.03 ± 0.44)	4.84 ± 1.70 (−0.03 ± 0.42)	0.46	0.04
Total (kg)	25.43 ± 7.69 (−1.41 ± 2.59)	28.92 ± 9.99 (0.37 ± 1.92)	24.90 ± 9.90 (−0.17 ± 1.98)	0.09	0.11
Total (%)	37.46 ± 6.94 (−1.69 ± 2.38)^{a,b}	38.97 ± 6.93 (0.36 ± 1.81)	35.49 ± 8.28 (−0.23 ± 2.04)	0.03	0.15
Lean					
Arms (kg)	4.02 ± 0.64 (−0.03 ± 0.19)	4.39 ± 0.80 (−0.07 ± 0.19)	4.17 ± 0.67 (−0.19 ± 0.73)	0.62	0.02
Legs (kg)	13.03 ± 1.96 (0.37 ± 0.49)	13.55 ± 2.23 (−0.04 ± 0.60)	12.97 ± 1.95 (0.07 ± 0.83)	0.24	0.07
Trunk (kg)	18.66 ± 2.35 (0.41 ± 0.85)	19.86 ± 3.42 (0.03 ± 1.21)	19.74 ± 1.98 (0.29 ± 2.25)	0.78	0.01
Android (kg)	2.69 ± 0.39 (0.05 ± 0.16)	2.85 ± 0.50 (0.01 ± 0.16)	2.82 ± 0.31 (0.02 ± 0.19)	0.81	0.01
Gynoid (kg)	5.82 ± 0.92 (0.13 ± 0.25)	6.07 ± 0.85 (0.01 ± 0.27)	5.74 ± 0.81 (0.05 ± 0.25)	0.40	0.04
Total (kg)	38.66 ± 4.64 (0.77 ± 1.02)	40.84 ± 6.15 (−0.12 ± 1.37)	40.04 ± 4.43 (0.21 ± 1.17)	0.15	0.09

Abbreviations: ANOVA = analysis of variance; BMI = body mass index.

[a] Significant difference between 0 and 16 weeks ($p < 0.05$).

[b] Delta value significantly different from VG ($p < 0.05$).

3. Results

For the participants who completed the study (SG, $n = 13$; VG, $n = 17$; CO, $n = 14$), no group differences were present for the pre-intervention baseline values (Table 1).

3.1. Fat mass and lean body mass

A significant group × time interaction was found for total fat percentage ($p = 0.03$; partial $\eta^2 = 0.15$). *Post hoc* analysis revealed that in SG, fat percentage significantly decreased by 1.69% ± 2.38% ($p = 0.03$) during the 16-week intervention period, with no changes for VG or CO (Fig. 1). A significant group × time interaction was also evident for fat mass of the trunk ($p = 0.03$; partial $\eta^2 = 0.16$) and android ($p = 0.04$; partial $\eta^2 = 0.15$). *Post hoc* analysis revealed that fat mass of the trunk and android (central fat predictive of body shape) significantly decreased by 1.02 ± 1.40 kg ($p = 0.02$) and 0.17 ± 0.27 kg ($p = 0.04$) respectively in SG over 16 weeks of training, with no changes for VG or CO (Table 1). The changes in fat percentage ($p = 0.03$) for SG was significantly greater than for VG, as was the changes in fat mass of the trunk ($p = 0.03$) and android ($p = 0.03$). Lean mass was not significantly altered in any of the three groups following the 16-week intervention (Table 1).

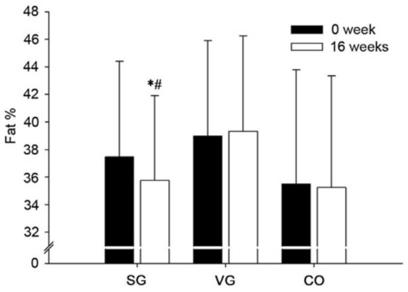

Fig. 1. Fat percentage for inactive premenopausal women after 16 weeks of soccer training (SG), whole-body vibration training (VG), or continuation of a sedentary lifestyle (CO) (mean ± SD). *Significant difference from baseline. #Significant delta value difference from VG following 16 weeks of training.

3.2. Magnetic resonance spectroscopy measurements

During one-legged knee-extensor ramp exercise, a significant group × time interaction was evident ($p = 0.03$; partial $\eta^2 = 0.18$) for PCr depletion at the same time for the pre- and post-tests. In SG, after 16 weeks of training the degree of PCr depletion was less ($p = 0.04$) (PCr content relative to baseline: 54.7% ± 12.5% *vs.* 59.1% ± 12.6% for pre- *vs.* post-training) with no change for VG or CO (Table 2). Data for a representative participant is illustrated in Fig. 2. At the same time-point a significant main effect with time was seen for muscle pH but no significant interaction effects with group (SG: 6.95 ± 0.09 *vs.* 6.98 ± 0.07; VG: 6.95 ± 0.05 *vs.* 6.98 ± 0.06). Following 16 weeks of training, the rate of PCr recovery was not significantly altered after bouts of 24 s constant load exercise (SG; τ: 35.1 ± 8.7 *vs.* 30.7 ± 7.7 s; VG; τ: 32.8 ± 9.3 *vs.* 34.6 ± 9.6 s; CO; τ: 35.5 ± 8.8 *vs.* 32.7 ± 5.9 s, for pre- *vs.* post-training, respectively) in any of the groups.

Table 2
Summary of magnetic resonance spectroscopy measurements prior to and at the end of the ramp exercise test performed before and after the 16-week intervention period in the soccer group (SG), the vibration training group (VG), and the inactive control group (CO) (mean ± SD).

	SG		VG		CO		ANOVA interaction (p value)	Partial η^2
	Week 0	Week 16	Week 0	Week 16	Week 0	Week 16		
Baseline PCr (mmol/L)	32.2 ± 3.5	32.0 ± 3.0	31.3 ± 4.6	31.3 ± 3.3	29.8 ± 4.0	32.6 ± 5.2	0.35	0.06
Baseline PCr:P_i	8.5 ± 1.4	8.5 ± 1.4	9.3 ± 1.7	9.0 ± 1.5	9.2 ± 1.0	8.2 ± 1.4	0.32	0.07
End exercise time (s)	250.8 ± 103.9	282.8 ± 92.8	312.8 ± 46.0	320.0 ± 55.1	293.2 ± 56.2	285.2 ± 59.7	0.50	0.04
End exercise PCr (%)	53.8 ± 57.2	57.2 ± 11.6	51.1 ± 8.2	52.2 ± 9.3	61.8 ± 7.0	59.0 ± 8.0	0.33	0.06
PCr%	54.7 ± 12.5	59.1 ± 12.6[a,b]	52.3 ± 7.8	55.5 ± 8.2	65.1 ± 7.5	60.4 ± 7.8	0.03	0.18

Abbreviations: ANOVA = analysis of variance; PCr% = PCr percentage at the point of volitional exhaustion at 0 week and the equivalent time point at 16 weeks.

[a] Significant difference between 0 and 16 weeks ($p < 0.05$).

[b] Delta value significantly different from CO ($p < 0.05$).

3.3. HR and BP

After 16 weeks, resting HR was not significantly lowered in SG (77 ± 8 *vs*. 73 ± 8 bpm), VG (74 ± 11 *vs*. 72 ± 11 bpm), or CO (77 ± 9 *vs*. 74 ± 6 bpm), respectively. Resting systolic and diastolic BP was also unaltered in all groups following the 16-week intervention (SG: 117 ± 15/75 ± 11 *vs*. 119 ± 13/76 ± 10 mmHg; VG: 121 ± 13/78 ± 9 *vs*. 118 ± 17/77 ± 11 mmHg; CO: 112 ± 16/74 ± 11 *vs*. 113 ± 17/74 ± 10 mmHg, respectively).

The average HR during WBV training conducted in the first and last week of training were 92 ± 14 and 92 ± 17 bpm, respectively. The average and peak HR during the soccer training ($n = 13$) was 159 ± 8 and 178 ± 6 bpm and 155 ± 7 and 175 ± 6 bpm during the first and last week of training, respectively, which corresponded to 85% ± 5% and 96% ± 4%, and 83% ± 3% and 93% ± 2%, respectively, of peak HR (HR_{peak}).

3.4. Physiological response to the submaximal YYIE1 test

There was a significant time effect on HR ($p < 0.01$; partial $\eta^2 = 0.54$) during the last 15 s of the YYIE1 warm-up for SG. HR during the last 15 s of the YYIE1 warm-up was 160 ± 7, 157 ± 6, and 148 ± 9 bpm after 0, 8, and 16 weeks of the study respectively, corresponding to 85% ± 6%, 84% ± 5%, and 79% ± 5% of HR_{max}. A significant decrease of 6% ± 5% and 5% ± 5% of HR_{max} was evident when comparing 0–16 weeks ($p = 0.01$) and 8–16 weeks ($p = 0.04$), respectively.

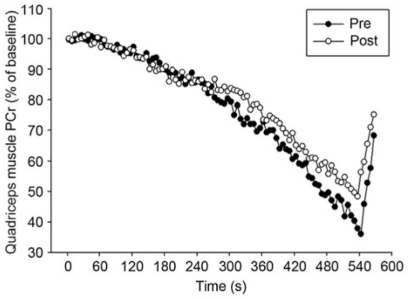

Fig. 2. PCr depletion during a ramp exercise test, pre- and post- the 16-week soccer training intervention for a representative participant.

4. Discussion

The main findings of the present study were that small-volume recreational soccer training resulted in several benefits in body composition and aerobic fitness of inactive premenopausal women relative to either WBV or control participants. Specifically, fat percentage decreased along with reductions in HR during a submaximal running task and positive adaptations in muscle oxidative capacity, as determined by measurements of PCr kinetics.

4.1. Energy expenditure and fat mass

The mean HR for the SG during training sessions was 155 bpm, corresponding to ~85% of HR_{max}, which is markedly higher than the 90 bpm observed for the WBV training group. The HR during the soccer training was found to be similar to values for 1-h small-sided training sessions for untrained premenopausal females[35] and slightly higher than that observed in untrained and habitually active 25–65-year-old female hospital employees.[14] The high HRs in the soccer group during training illustrates the energy demanding nature of small-sided games, with multiple intense actions such as accelerations, decelerations, rapid changes of direction, and unorthodox movements having been observed to occur as often as every ~4 s on average.[12,13,35]

A significant finding of the present study is that the fat percentage was reduced markedly (1.7%) in the SG over the 16-week intervention despite the short duration of the twice-weekly training sessions, whereas no changes were observed for the VG and the CO. The decrease in fat percentage was very consistent for the SG participants with as many as 92% of them having a lowered fat percentage after 16 weeks, i.e., all except one, whereas this was only the case for 41% of the VG participants and 43% of the control subjects. Interestingly, the decrease in fat mass for the SG was 1.4 kg which is similar to values reported in previous studies with 12–16 weeks of 1-h twice-weekly recreational soccer training for untrained women[13−17] even though the training volume was only a quarter of that in the other studies (30 *vs*. 120 min/week). The potential clinical significance of reducing abdominal fat has been highlighted by studies such as Rexrode et al.[36] who have reported a higher abdominal adiposity being associated with an increased risk of coronary heart disease in a cohort of 44,702 female registered nurses aged 40−65. The estimated energy consumption over 8 h of soccer training (30 min/week over 16 weeks) at an average HR of 155 bpm for untrained women would be in the area of 4000 kcal, corresponding to about 0.5 kg of fat.[9] It may therefore be speculated that fat oxidation was elevated outside the soccer training, as was found in other studies[17] which demonstrated a positive effect on cardiovascular and metabolic fitness after 12−16 weeks of recreational soccer training, where an increase in the fat oxidation capacity at low to moderate exercise intensities, corresponding to the intensity during everyday life activity, was observed. That no equivalent overall group fat losses were seen following WBV training may well be due to the absence of an equivalent raising of the HR as observed during the soccer training. Other studies using oscillating[27,28] and vertical[37] WBV training have similarly reported no alterations in fat mass. Although WBV training has been reported to stimulate muscular work and to elevate metabolic rate to some extent,[38] the stimulus is probably insufficient to cause any change in fat mass for inactive premenopausal women.

4.2. Aerobic fitness

After 16-week of soccer training, the HR was on average 10 bpm lower in the last phase of a standardised submaximal YYIE1 test. A drop in HR loading during submaximal exercise indicates an increase in aerobic fitness and is in accordance with findings from previous studies using recreational soccer training for premenopausal women. HR was found to decrease by 10−20 bpm during walking and jogging at 6−11 km/h after 16 weeks of twice-weekly 1-h soccer sessions for 20−45-year-old untrained women in conjunction with an increase in maximal oxygen uptake of 15%,[13,17] and HR decreased by 7 bpm during submaximal cycling exercise after 12 weeks of training for twice-weekly 1-h soccer sessions for 25−65-year-old women, who had an increase in maximal oxygen uptake of 5% over the course of training.[14]

The present study also indicated positive effects on muscular aerobic fitness for the SG in comparison to the VG and the CO. The suggestion of an improvement in oxidative metabolism for the SG is reinforced by the recorded decrease in PCr depletion at the end of the ramp test at an equivalent time point, after the training intervention compared with the pre-training value. The changes observed for this parameter indicate that the training was of sufficient intensity to induce adaptive responses within the muscle, either at a mitochondrial level via biogenesis or at a vascular level such that O_2 availability was improved. The fact that the relative PCr sparing is not the result of an increased contribution from glycolytic energy metabolism is confirmed by no differences being recorded for end-exercise muscle pH. Thus, the inference is that a higher proportion of the energy demands during the ramp test were being met by oxidative mechanisms for the participants in the soccer group post-intervention, and hence that a greater oxidative capacity had been developed as a direct result of the training. However, given the inactive nature of the population investigated, vascular changes cannot be ruled out as a potentially contributory factor.

4.3. BP

No changes in BP were observed in any of the groups in the present study. However, decreases in systolic (7−8 mmHg) and diastolic (4−5 mmHg) BP have been previously observed for normotensive premenopausal women and young normotensive men after 12−16 weeks of small-sided soccer played twice weekly for 1 h.[8,17] The lack of change in BP for any of the groups could therefore have been due to the small volume of training, which suggests that a minimum duration and intensity is required to induce a reduction in BP.[18] However, it should also be noted that the SG had baseline systolic pressures of 117 mmHg and diastolic pressures of 75 mmHg, and many participants had values below 115/75 mmHg, where further reductions following exercise interventions have been shown to limit health effects.[39] Further studies are required to elucidate whether small-volume soccer can be used to lower BP for participants with mild to moderate hypertension. In line with some[27] but not all[40] previous studies, no changes were observed in BP after 16 weeks of WBV training. The low HRs and implied lack of cardiovascular challenge may explain why BP did not change in the present intervention. Mechanisms behind the change in BP found in previous studies[40] have not been elucidated and further studies are needed to evaluate whether it was the dynamic nature of the exercises or the heavy load placed on the lower limbs which was associated with the positive impact on BP.

4.4. Limitations

The study has a number of limitations which may impact upon the conclusions subsequently drawn. One aspect was that the net time actually spent exercising was potentially not equal for the SG and VG as soccer is an unpredictable, start-stop exercise modality, in contrast to the carefully regulated vibration protocol. However, one of the central aims of the study was to compare health benefits of different training regimes, which took equivalent times to undertake, and so the time duration was kept constant between modalities rather than trying to ensure equivalent workloads. An additional concern was that the age range of the participants was also quite wide. However, when age was included as a covariate within the analysis it did not affect the results found. A potentially more significant problem were changes in lifestyle that may have occurred over the relatively long intervention period. Although participants were asked to maintain their normal diet and PA, we were not able to directly control it. In particular, for the exercise groups it is not known whether the soccer or vibration training resulted in a reduction in the time spent undertaking other PAs relative to before the beginning of the study, i.e., soccer or vibration training became a replacement activity, rather than an additional one on top of their pre-existing activities.

5. Conclusion

In summary, 16 weeks of small-volume recreational soccer improved body composition, muscle PCr kinetics, and HR during submaximal exercise in inactive premenopausal women with no prior experience of soccer. Specifically, twice-weekly 15-min sessions of soccer were sufficient to reduce fat percentage and fat mass of the trunk and android region. None of the above measures were altered after the WBV training. As such it provides evidence that more aerobically challenging exercise regimes such as small-volume, small-sided soccer training may be a more favourable choice for a training intervention for individuals with time constraints where weight loss and improvements in muscle oxidative capacity are of primary concern.

Acknowledgments

The authors would like to thank the participants for their great efforts. We would also like to thank Rebecca Lear, Don Kim, and Jamie Blackwell for excellent technical support. FIFA-Medical Assessments and Research Centre (F-MARC) and Nordea-fonden supported the study (No. 1-ST-P-$$$-$$$-036-JZ-F1-05858).

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Chapter 5

Low-volume high-intensity swim training is superior to high-volume low-intensity training in relation to insulin sensitivity and glucose control in inactive middle-aged women

Contribution: Conceptualisation, formal analysis, writing – original draft preparation, review and editing.

Evidently, Chapter 4 required a number of participants to perform each football training session which can cause difficulty for such a time-constrained population. Additionally, in the first instance, some participants felt anxious of playing football in front of others due to their inexperience of this weight-bearing physical activity. Chapter 5 builds upon Chapter 4 and contributes to the overarching aim of this thesis by investigating an alternative time-efficient, easily accessible water-based HIIT intervention for inactive premenopausal women which incorporates non-weight-bearing exercise and can be undertaken independently or with others. The participants of Chapter 5 presented with mild hypertension and this was the first time that high-intensity interval swimming had been studied for its potential use to treat hypertension as well as investigating its effects on several other key health markers. Results were also directly compared to prolonged continuous swim training and a control group.

A priori power analysis was performed for the primary outcome, systolic BP, using G*Power (Faul et al., 2007). The primary outcome differed to Chapter 4 as Chapter 5 was part of a larger project investigating the effect of high-intensity interval swim training on the cardiovascular health status of the same participants (Mohr et al., 2014). Power was set at 0.8 with a significance level of 0.05. Based on previous exercise training studies aiming to improve systolic BP using comparable physical exercise interventions (Nualnim et al., 2012), an average reduction of 9 mmHg with a standard deviation of 5 from baseline values was expected. Based on these assumptions, 18 participants were required for comparison between each respective intervention group and the control group. Assuming participant attrition such as drop out, 21 females were recruited for each training group and 20 for the control group (62 participants in total) for this study.

Eur J Appl Physiol
DOI 10.1007/s00421-016-3441-8

ORIGINAL ARTICLE

Low-volume high-intensity swim training is superior to high-volume low-intensity training in relation to insulin sensitivity and glucose control in inactive middle-aged women

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Received: 10 May 2016 / Accepted: 20 July 2016

Abstract

Purpose We tested the hypothesis that low-volume high-intensity swimming has a larger impact on insulin sensitivity and glucose control than high-volume low-intensity swimming in inactive premenopausal women with mild hypertension.

Methods Sixty-two untrained premenopausal women were randomised to an inactive control ($n = 20$; CON), a high-intensity low-volume ($n = 21$; HIT) or a low-intensity high-volume ($n = 21$; LIT) training group. During the 15-week intervention period, HIT performed 3 weekly 6–10 × 30-s all-out swimming intervals (average heart rate (HR) = 86 ± 3 % HR_{max}) interspersed by 2-min recovery periods and LIT swam continuously for 1 h at low intensity (average HR = 73 ± 3 % HR_{max}). Fasting blood samples were taken and an oral glucose tolerance test (OGTT) was conducted pre- and post-intervention.

Results After HIT, resting plasma [insulin] was lowered (17 ± 34 %; $P < 0.05$) but remained similar after LIT and CON. Following HIT, 60-min OGTT plasma [insulin] and [glucose] was lowered (24 ± 30 % and 10 ± 16 %; $P < 0.05$) but remained similar after LIT and CON. Total area under the curve for plasma [glucose] was lower ($P < 0.05$) after HIT than LIT (660 ± 141 vs. 860 ± 325 mmol min L^{-1}). Insulin sensitivity (HOMA-IR) had increased ($P < 0.05$) by 22 ± 34 % after HIT, with no significant change after LIT or CON, respectively. Plasma soluble intracellular cell adhesion molecule 1 was lowered ($P < 0.05$) by 4 ± 8 and 3 ± 9 % after HIT and CON, respectively, while plasma soluble vascular cell adhesion molecule 1 had decreased ($P < 0.05$) by 8 ± 23 % after HIT only.

Conclusions These findings suggest that low-volume high-intensity intermittent swimming is an effective and time-efficient training strategy for improving insulin sensitivity, glucose control and biomarkers of vascular function in inactive, middle-aged mildly hypertensive women.

Keywords Blood glucose · Type 2 diabetes · Body composition · Upper body exercise · Metabolic health

Abbreviations

ANOVA	Analysis of variance
CON	Control
HIT	High-intensity training
HOMA-IR	Homeostatic model assessment of insulin resistance
HR	Heart rate
OGTT	Oral glucose tolerance test
LIT	Low-intensity training
SEM	Standard error of the mean
sICAM-1	Soluble intracellular cell adhesion molecule 1

Communicated by Michael Lindinger.

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sVCAM-1	Soluble vascular cell adhesion molecule 1
T2DM	Type 2 diabetes mellitus
tAUC	Total area under the curve

Introduction

Lack of physical activity is considered a global pandemic and one of the most serious public health problems of the 21st century (Kohl et al. 2012). Physical inactivity is an independent risk factor for major chronic diseases and the annual global mortality attributable to physical inactivity is estimated at approximately 3.2 million (World Health Organization 2016). Type 2 diabetes mellitus (T2DM), an example of a pathological condition associated with an inactive lifestyle, shows an increasing growth rate, imposing a significant health and economic burden on the health care system. In the US alone, the incidence of T2DM increased 117 % from 1980 to 2011 (Al Tunaiji et al. 2014). The population attributable fraction of T2DM related to physical inactivity is reported to be higher in women than in men (Al Tunaiji et al. 2014).

Women experience a decline in health status in the years following the menopause (Appelman et al. 2015), including a higher prevalence of insulin resistance, which plays a major role in the pathophysiology of T2DM (Rizzoli et al. 2014; Shufelt et al. 2015). In addition, there is evidence that a relationship exists between insulin resistance and markers of endothelial dysfunction which also contributes to cardiovascular disease (Chen et al. 2000; Kim et al. 2006). Two markers of endothelial dysfunction that have been shown to predict cardiovascular disease include soluble intracellular cell adhesion molecule 1 (sICAM-1] and soluble vascular cell adhesion molecule 1 [sVCAM-1] (Weyer et al. 2002), which are mediators of platelet rolling and cell attachment (Marsh and Coombes 2005). It is well known that exercise training has a preventive effect on the development of lifestyle-related deficiencies (Chedraui and Perez-Lopez 2013); thus, exercise-interventions targeting an improvement in glucose control, insulin sensitivity and endothelial function are clearly warranted for inactive middle-aged women approaching the menopause period.

High-intensity interval training protocols have garnered attention in recent years as a time-efficient exercise option for improving metabolic health, and they may be particularly effective for improving blood glucose homeostasis in individuals with, or at risk of, T2DM (Little and Francois 2014). In a recent study by Little and Francois (2014), high-intensity interval cycling induced greater and longer-lasting effects on postprandial blood glucose control than continuous moderate-intensity exercise in obese middle-aged adults. Moreover, 10 × 1 min of high-intensity intermittent cycling caused a reduction in insulin resistance measured using the homeostatic model assessment of insulin resistance (HOMA-IR) in inactive women (Durrer et al. 2015), which is supported by studies on patients with T2DM (Shaban et al. 2014) and non-diabetic subjects (Adams 2013). These studies, and the vast majority of studies on the health effects of high-intensity training regimes have deployed running or cycling exercise, while a limited number of studies have deployed exercise modalities such as swimming, which involves a significant taxation of the upper body.

Swimming is a popular physical leisure activity among the female population and may be considered a good choice of exercise training for obese, middle-aged and elderly individuals due to the minimal weight-bearing stress involved. In addition, swimming highly engages the upper-body muscles, where the adaptive capacity of the skeletal muscle has shown to be higher than the lower limbs due to the bipendular nature of humans (Nordsborg et al. 2015). For example, low-intensity swimming has been shown to be more efficient for improving insulin resistance than walking at a matched intensity in 50- to 70-year-old sedentary women (Cox et al. 2010). In addition, in obese mice (Motta et al. 2015) and rats (Song et al. 2014) swimming has been demonstrated to facilitate glucose control and insulin sensitivity. Moreover, 1 year of participation in low-intensity swimming has been demonstrated to increase insulin sensitivity in young hypertensive patients (Chen et al. 2010). However, limited information exists on the impact of high-intensity intermittent swimming, and, as far as we know, no studies have compared the effects of different swimming protocols on insulin resistance and blood glucose control in middle-aged, inactive women.

Thus, the objective of the present study was to investigate the effects of low-volume high-intensity swimming compared to high-volume low-intensity swimming, on insulin sensitivity and blood glucose control in middle-aged, inactive women with mild hypertension. It was hypothesised that short-term high-intensity interval swimming is a more efficient training method than prolonged, continuous low-intensity swimming for improving metabolic fitness in untrained middle-aged mildly hypertensive women.

Materials and methods

Participants

Sixty-two inactive premenopausal women with mild to moderate arterial hypertension were recruited for the study. The subjects were selected from 262 volunteers based on training history, medication, blood pressure and body mass index. A total of 83 participants were recruited in the original sample. Sixty-two took part in the present study, for which the cardiovascular data are presented in Mohr et al. (2014b) and 21 were randomly assigned to a football group as part of another study (Mohr et al. 2014a). Data for the adaptive capacity of skeletal muscle for the above-mentioned participants were also presented in Nordsborg et al. (2015). In addition, the control group (20 participants) in the present study was also the controls in the above-mentioned studies (Mohr et al. 2014a, b; Nordsborg et al. 2015) The study was approved by the ethical committee of the Faroe Islands as well as the Sport and Health Sciences Research Ethics Committee at the University of Exeter, Exeter, United Kingdom, and conducted in accordance with the Declaration of Helsinki (1964). After being informed verbally and in writing of the experimental procedures and associated risks, all participants gave their written consent to take part in the study.

Experiment design

The study was designed as a randomised controlled trial. After initial screening of the 262 volunteers, 62 participants were enrolled in the present study based on the selection criteria: an inactive lifestyle for the last 2 years; mild to moderate hypertension (mean arterial pressure 96–110 mmHg); and body mass index >25. Participants undergoing treatment with adrenergic beta-antagonists were excluded. Participants using diuretics and ACE inhibitors ($n = 4$) were not excluded from the study, but none of the four subjects changed their medication during the intervention period. The participants were randomised into a high-intensity intermittent swim-training group (HIT: age; 44 ± 5 (±SD) (range 36–49) years, height; 164 ± 6 cm, weight; 76.5 ± 8.8 kg; $n = 21$), a low-intensity continuous swimming group (LIT: age; 46 ± 4 (38–48) years, height; 165 ± 5 cm, weight; 83.8 ± 18.8 kg; $n = 21$) and a control group (CON: age; 45 ± 4 (35–48) years, height; 166 ± 6 cm, weight; 77.3 ± 10.4 kg; $n = 20$). The randomization process first separated the participants in groups and thereafter determined the type of intervention. Both steps were carried out in random and blinded conditions. The training groups took part in two types of swim training involving three training sessions per week for 15 weeks, while CON had no training or lifestyle changes in the same period. There were no drop-outs from the study, but one subject in the LIT group suffered aquatic phobia and was therefore moved to CON after the randomization process. The participants also performed an oral glucose tolerance test (OGTT) and had a resting blood sample taken. Dietary intake was not controlled during the training period and the testing periods were not timed in relation to the menstrual cycle.

Training intervention

The HIT participants completed a total of 44 ± 1 (39–50) training sessions over the 15-week intervention period, corresponding to 2.9 ± 0.1 (2.6–3.3) sessions per week. Each session lasted ~15–25 min (3–5 min of effective swimming) and consisted of 6–10 30-s all-out free-style swimming (front crawl) intervals interspersed by 2 min of passive recovery according to training principles previously described (Iaia et al. 2009; Mohr et al. 2007). In the first 6 weeks of training each comprised 6 intervals, the following 6 weeks comprised 8 intervals and the final 3 weeks comprised 10 intervals. The LIT group completed a total of 43 ± 1 (37–49) training sessions over 15 weeks, corresponding to 2.9 ± 0.1 (2.5–3.3) training sessions per week. All LIT training sessions lasted 1 h and consisted of continuous front-crawl swimming, with the participants encouraged to swim as far as possible in every session. Five trained swimming coaches were present during all training sessions to give technical advice, control the intensity and duration of the training, and secure a safe training environment. There were no injuries from the swim-training during the 15 wks. Heart rate was measured during one training session in week 1 and one session in week 15 of the training intervention, and the swimming distance was noted in every session. Average mean and peak HR during HIT training in the first and last weeks of the intervention was 158 ± 5 and 176 ± 2 bpm, respectively, corresponding to 86 ± 3 and 96 ± 1 % $\mathrm{HR_{max}}$, respectively, which was higher ($P < 0.05$) than average values in LIT (132 ± 4 and 144 ± 3 bpm equivalent to 73 ± 3 and 79 ± 1 % $\mathrm{HR_{max}}$).

Resting blood sampling and OGTT testing

On the day of testing, the participants reported to the laboratory after transport by car or bus. No training was performed 48-72 h prior to the testing and participants were instructed to avoid physical activity the day prior to the OGTT tests. A resting blood sample was collected under standardised conditions from an antecubital vein between 7 and 8 a.m. after an overnight fast using venipuncture technique. The blood was rapidly centrifuged for 30 s and the plasma was collected and analysed by an automatic analyzer (Cobas Fara, Roche, France) using enzymatic kits (Roche Diagnostics, Germany) to determine the relevant variables. Furthermore, 100 µl of plasma was used to determine concentrations of sICAM-1 and sVCAM-1 by immunoassays (Elisa, R&D Systems, Minneapolis, MN) using an Emax precision microplate reader (Molecular Devices, Sunnyvale, CA, USA). The intra-assay coefficient of variations for sICAM-1 and sVCAM-1 are 4.9 ± 3.5 and 5.1 ± 5.9 %, respectively.

Also, an OGTT test was performed as previously described (Durrer et al. 2015), with blood samples taken after 0, 30, 60 and 120 min and analysed for plasma [glucose] using enzymatic kits (Roche Diagnostics, Germany) and [insulin]. Insulin sensitivity was evaluated for all subjects using the homeostatic model assessment method (HOMA-IR); (Yokoyama et al. 2003). Changes in plasma [glucose] and [insulin] during the OGTT were quantified using total area under the curve (tAUC) analyses employing the trapezium rule (GraphPad Prism, San Diego, CA, USA). The intra-assay coefficient of variations for glucose and insulin are 3.0 ± 3.5 and 4.8 ± 3.6 %, respectively.

Statistical analysis

Data are presented as mean ± SD. Statistical analyses were performed using SPSS v.22. A two-factor mixed ANOVA design with the between factor 'group' (HIT versus LIT versus CON) and repeated factor 'condition' (pre-training versus post-training) was used to analyse all data apart from the 2-h OGTT. Responses to the OGTT were analysed using a three-factor mixed ANOVA design, with the factors 'group' (HIT versus LIT versus CON), 'condition' (pre-training versus post-training) and 'time' (0, 30, 60 and 120 min). When significant interactions or main effects were detected, data were subsequently analysed using Bonferroni post hoc *t* tests. The significance level was $P < 0.05$.

Results

Plasma [glucose] and [insulin]

Pre-intervention fasting plasma [glucose] was 4.9 ± 0.3, 5.8 ± 2.3, and 4.9 ± 0.5 mmol L^{-1} in HIT, LIT and CON, respectively, with a tendency for higher ($P = 0.07$) values in LIT than HIT. Fasting plasma [glucose] was unaltered after the intervention period (Fig. 1). Plasma [glucose] increased (main effect for time, $P < 0.05$) in all three groups after 30 and 60 min during the OGTT, but was normalised after 120 min pre- and post-training. In HIT, plasma [glucose] was 10 ± 16 % lower after 60 min post- compared to pre-intervention, with the concentration being lower (condition x time x group interaction, $P < 0.05$) than the corresponding concentration in LIT and tending ($P = 0.054$) to be lower than in CON (Fig. 1). For plasma [glucose] tAUC, there were no significant differences between groups prior to the training intervention (HIT: 700 ± 155, LIT: 833 ± 324 and CON: 764 ± 186 mmol min L^{-1}), respectively. However, following the training intervention HIT tAUC (660 ± 141 mmol min L^{-1}) was significantly lower than LIT tAUC (860 ± 325 mmol min L^{-1}, group–condition interaction, $P < 0.05$).

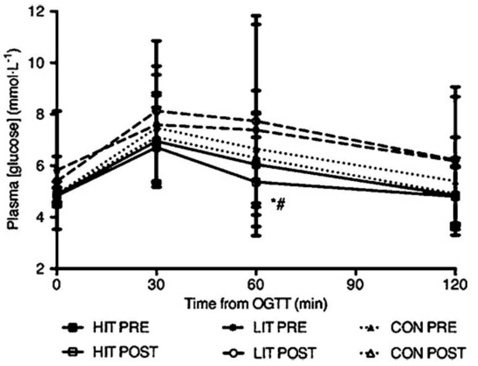

Fig. 1 Plasma [glucose] response following the OGTT displayed over time in HIT, LIT and CON before and after the 15-wk intervention. Data are mean ± SD. *Asterisk* denotes significant difference from pre intervention. *Hash* denotes significant difference from LIT. $P < 0.05$

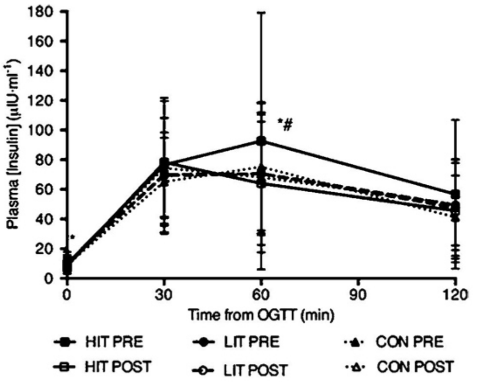

Fig. 2 Plasma [insulin] response following the OGTT displayed over time in HIT, LIT and CON before and after the 15-week intervention. Data are mean ± SD. *Asterisk* denotes significant difference from pre intervention. *Hash* denotes significant difference from LIT. $P < 0.05$

Pre intervention fasting plasma [insulin] was 9.6 ± 4.2, 10.2 ± 7.3 and 9.9 ± 4.6 μIU·ml^{-1} in HIT, LIT and CON, respectively, with no significant differences between groups (Fig. 2). A training-induced decrease of 17 ± 34 % in baseline plasma [insulin] occurred following HIT (group–condition interaction, $P < 0.05$), while levels remained constant after LIT and CON. Plasma [insulin] increased in all three groups during the OGTT, being higher than at baseline at 30-, 60- and 120-min pre- and post-intervention (main effect for time, $P < 0.05$, Fig. 2). However, plasma [insulin] was only lower (24 ± 30 %) at 60 min into the

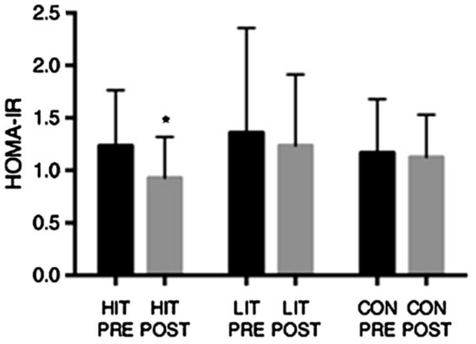

Fig. 3 Insulin sensitivity (HOMA-IR) in HIT, LIT and CON before and after the 15-week intervention. Data are mean ± SD. *Asterisk* denotes significant difference from pre intervention. $P < 0.05$

OGTT following HIT which was lower than the corresponding value for LIT (condition x time x group interaction, $P < 0.05$). There was also a tendency ($P = 0.09$) for a lower concentration following HIT at the 120 min time point (Fig. 2). There were no differences between pre- and post-plasma [insulin] during the OGTT in LIT and CON (Fig. 2). For plasma [insulin] tAUC, there were no significant differences between groups prior to (HIT: 9121 ± 7606, LIT: 6879 ± 3621, and CON: 6947 ± 3116 μIU ml min^{-1}, respectively) and following (HIT: 6634 ± 3449, LIT: 6809 ± 2973, and CON: 6712 ± 2999 μIU ml min^{-1}, respectively) the training intervention. However, there was a tendency ($P = 0.09$) for plasma [insulin] tAUC to be lower after HIT.

Insulin sensitivity: HOMA-IR

Insulin sensitivity data are shown in Fig. 3. There were no significant differences in insulin sensitivity between HIT, LIT and CON pre intervention (HIT: 1.3 ± 0.5, LIT: 1.4 ± 1.0, and CON: 1.2 ± 0.5). Following the training-intervention, there was a 22 ± 34 % improvement in insulin sensitivity after HIT (group–condition interaction, $P < 0.05$), with no change in LIT and CON.

Plasma [sICAM-1] and [sVCAM-1]

There were no significant differences in plasma [sICAM-1] between HIT, LIT and CON groups pre intervention (146 ± 68, 142 ± 56 and 134 ± 67 ng ml^{-1}), but it was lowered (group–condition interaction, $P < 0.05$) by 4 ± 8 and 3 ± 9 % post-intervention after HIT and CON only, respectively (Fig. 4a). There were no significant differences in plasma [sVCAM-1] between groups pre intervention (624 ± 154, 667 ± 106 and 553 ± 198 ng ml^{-1} in HIT, LIT and CON, respectively; Fig. 4b). However, plasma [sVCAM-1] was lower (group–condition interaction, $P < 0.05$) by 8 ± 23 % after HIT (Fig. 4b), with no change after LIT and CON.

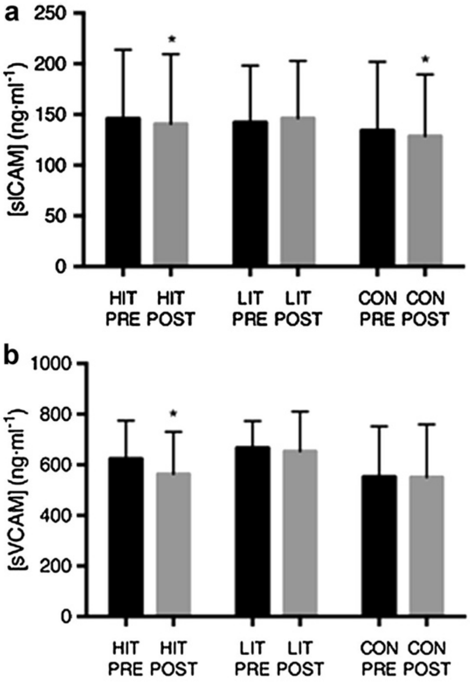

Fig. 4 Fasting plasma [sICAM-1] (**a**) and [sVCAM-1] (**b**) in HIT, LIT and CON before and after the 15-week intervention. Data are mean ± SD. *Asterisk* denotes significant difference from pre-intervention. $P < 0.05$

Discussion

For the first time, the effects of low-volume high-intensity versus high-volume low-intensity swim training on insulin sensitivity and blood glucose control have been studied in middle-aged, inactive women. The major findings were that short-term high-intensity intermittent swim training lowered the fasting plasma [insulin], as well as plasma [glucose] and [insulin] during an oral glucose tolerance test, demonstrating an improvement in insulin sensitivity. In contrast, no changes occurred in those parameters after prolonged low-intensity swimming despite a ~12-fold longer efficient swimming time and ~fivefold longer swimming distance covered during training.

Although previous literature on high-intensity swim training is lacking, Chen et al. (2010), Nualnim et al. (2012), and Cox et al. (2010) have implemented 3-12 months of moderate-intensity swim training for a combination of hypertensive and normotensive young (21 years), and older adults (>50 years) in which there were no significant improvements in insulin sensitivity, fasting [glucose], [insulin] or [glucose] AUC. In contrast the present study displayed a 22 % improvement in insulin sensitivity after HIT. However, it should be noted that fasting values for Nualnim et al. (2012) and the present study were already within the normal range. Interestingly, HIT in the present study decreased [glucose] values by 10 % at 60 min during the OGTT. Thus, HIT swimming may represent an attractive alternative to moderate-intensity swimming.

In the present study, 17 % decrease in fasting [insulin] was also reported for HIT along with a 24 % improvement at 60 min of the OGTT. The present findings are comparable with effects on metabolic health from other forms of high-intensity exercise interventions. For example, Little et al. (2011) demonstrated that 10 × 60 s of high intensity cycling over only 2 weaks reduced hyperglycemia and improved muscle mitochondrial capacity in patients with type 2 diabetes. Ciolac et al. (2010) found that 16 wks of high-intensity aerobic interval running 3 times per week (1 min running interspersed with 2 min walking for 40 min) for young females (20–30 years) at risk of hypertension resulted in a 35 % improvement in fasting [insulin]. In addition, Trapp et al. (2008) conducted 15 wks of high-intensity intermittent cycling 3 times per week (8-s all-out interspersed with 12 s of slow cycling for 60 repetitions) for inactive women (18–30 years) which resulted in a 31 % and 33 % improvement in fasting [insulin] and HOMA-IR score whereas the steady-state exercise group only resulted in a 9 % and 11 % improvement. The slightly lower improvement in fasting [insulin] in the present study compared to Ciolac et al. (2010) and Trapp et al. (2008) may be due to the exercise modality given that swimming differs in medium, position, breathing pattern and muscle groups used, providing a different training stimulus to cardiovascular parameters due to differences in ventricular volumes (Lazar et al. 2013; Sundstedt et al. 2003). It may also be speculated that the less pronounced systemic adaptation may be due to the smaller muscle mass activated during swimming compared to other forms of exercise (Nordsborg et al. 2015). Although the positive effect of high-intensity training on insulin sensitivity has been confirmed in numerous studies, the additional knowledge provided by this study is that high-intensity swimming provides a useful alterative for inactive middle-aged women compared to other modes of exercise.

On the other hand, not all high-intensity training interventions have reported insulin improvements. For example, Arad et al. (2015), Gillen et al. (2013) and Keating et al. (2015) found no change in fasting [insulin] and [glucose] and insulin sensitivity following 8–16 weeks of cycling interval training in overweight females (27–40 years). One reason for the discrepancy between these studies and the present study may be due to this study applying front-crawl training primarily taxing the upper-body muscles, which have a lower baseline training status than the legs and, hence, a higher improvement potential (Nordsborg et al. 2015).

Studies of swim training in rats have reported increased upregulation of molecules related to insulin signalling transduction in the skeletal muscle. For example, Fujimoto et al. (2010) previously reported that 5 days of non-exhaustive high-intensity intermittent swimming in male Sprague–Dawley rats provided an excellent stimulus for improving GLUT4 expression in skeletal muscle. In addition, in a study by Terada et al. (2001), male Sprague–Dawley rats performed short-term bouts of extremely high, relatively high and low intensity swimming over an 8-day period. GLUT4 content in the three training groups was increased following the exercise period, with no differences between groups. In support of these changes, Burgomaster et al. (2007) found increased muscle GLUT4 content after 1 week of sprint interval training, which remained higher during detraining of young (22 years) active men, which is supported by findings by Little et al. (2011). GLUT4 has been shown to be responsible for insulin-stimulated and contraction-induced glucose uptake (Daugaard and Richter 2001). As shown by Nordsborg et al. (2015), muscle glycogen in the deltoideus muscle of the study's participants increased by 63 % following HIT, which could strengthen the notion that muscular uptake of glucose increased via GLUT4 transporters.

While little research is available on [sICAM-1] and [sVCAM-1] following high-intensity swimming in middle-aged women, the improvement in vascular function as indicated by the 4 and 8 % reductions in [sICAM-1] and [sVCAM-1] following HIT is of interest as endothelial dysfunction is known to initiate not only the process of atherosclerosis, but also the development of insulin resistance (Glowinska et al. 2005). The present findings are not as notable as the improvements presented by Nyberg et al. (2014) following a 12-week floorball training intervention for premenopausal women ([sVCAM-1] pre: 674 and post: 535 ng ml^{-1}; [sICAM-1] pre: 166 and post: 122 ng ml^{-1}, however, this may be due to the exercise modality. On the other hand, the swimming data of the present study appears to be more promising than those of cycling based training, for example, Sabatier et al. (2008) failed to show a significant improvement in [sICAM-1] following a 14 week cycling exercise intervention in healthy premenopausal women with a baseline [sICAM-1] of 169 ng ml^{-1}. In addition, although not significantly correlated (data not shown), the reductions in [sICAM-1] and [sVCAM-1] after HIT were also accompanied by improvements in glucose handling which was not the case following LIT, which is in agreement with previous studies incorporating continuous aerobic training (Padilla et al. 2008). As shear stress on endothelial cells lining conduit blood vessels increases in direct proportion to intensity (Padilla et al. 2008), it may be speculated that HIT has greater potential for improving endothelial function compared to LIT (Wisloff et al. 2009). The improvement in glucose handling following HIT may have been enhanced by vascular actions of insulin in endothelium leading to an increased stimulation of the production of nitric oxide (NO). It has previously been reported that the NO-dependent increase in vasodilatation and skeletal muscle blood flow accounts for 25–40 % of the increase in glucose uptake in response to insulin stimulation (Kim et al. 2006). It may therefore be postulated that to induce changes in [sVCAM-1] and [sICAM-1] improvements are likely to occur quicker when exercising at high intensity and quite possibly without the need to change the individual's diet.

Despite HIT only exercising for one-third of the time of LIT, similar changes in whole-body fat and lean body mass occurred, although leg lean mass increased by 6 % after HIT with no changes after LIT (data not shown). As the speed of swimming increases, drag forces increase exponentially, reducing the mechanical efficiency of front crawl by 5–9.5 % (Lazar et al. 2013). This may have increased the energy requirements of the lower limbs in HIT and, in turn, increased leg lean mass. It is also possible that the number of muscles recruited during HIT and LIT swimming differ, possibly causing a faster depletion of glycogen during HIT, and, together with increased circulating catecholamines, this may contribute to an increase in glucose utilisation and an improved insulin response (Vollestad and Blom 1985). The favourable change in body composition may also have been brought about by an increased capacity for fat oxidation. Previous research has shown that endurance exercise (Holloszy and Booth 1976) and high-intensity exercise (Talanian et al. 2007) enhance the capacity for fat oxidation and mitochondrial enzyme activity. This has been shown to improve the potential for muscle to utilise lipids as a substrate for energy and is also associated with improved insulin sensitivity (Goodpaster et al. 2003). It is interesting to note that, in this study, HIT participants of this study increased mitochondrial enzyme activity more than LIT (data published in Nordsborg et al. (2015)). If the training had continued for a longer period (6 months to 1 year), it is possible that the decrease in [insulin] would have led to higher fat oxidation and fat loss in the long term (Ferrannini et al. 1997). However, it cannot be ruled out that changes in body composition could have been due to unreported changes in diet, as diet was not directly controlled. As stated by Chen et al. (2010), interventions that enhance insulin sensitivity can alleviate hypertension, and the findings of the present study, together with those of Nordsborg et al. (2015), may help explain the reduction in blood pressure in the present participants shown by Mohr et al. (2014b).

Conclusions

In conclusion, 15 weeks of low-volume high-intensity intermittent, but not prolonged low intensity high-volume, swim training improves insulin sensitivity and reduces biomarkers of endothelial activation in inactive premenopausal women with mild hypertension. Consequently, high-intensity intermittent swim training appears to be an appealing non-weight bearing training regime with a very low risk of injury.

Acknowledgments The authors would like to express their appreciation for the outstanding efforts and positive attitude of the participants. In addition, they are extremely grateful for the professional assistance given by swimming coaches Remi Lamhauge, Brynhild Klein, Pauli Øssursson Mohr, Heini Rasmussen, Oluffa Høvdanum, and the late J kup Mohr, and for the technical support provided by Ivy Hansen, Gunnrið J annesarson, Guðrið And rsd ttir, Hergerð Joensen, Ann Østerø, Ebba Andreassen, Maud av Fløtum, Liljan av Fløtum Petersen, Marjun Thomsen, Annika Lindenskov, Jann Mortensen, David Childs, Sarah R. Jackman and Jens Jung Nielsen. The study was supported by a Grant from the Faroese Research Council, as well as by The Faroese Confederation of Sports and Olympic Committee (tr ttarsamband Føroya), and the Danish Sports Confederation (Danmarks Idrætsforbund). In addition, financial support was obtained from Eik Bank.

Compliance with ethical standards

Conflict of interest The authors declare that there is no conflict of interests

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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Chapter 6

Effects of self-paced interval and continuous training on health markers in women

Contribution: Conceptualisation, investigation, project administration, formal analysis, writing – original draft preparation, review and editing.

Chapter 6 builds upon the findings from Chapter 4 and 5 and adds to the overarching aim of this thesis by investigating an additional time-efficient, land-based HIIT alternative on the health profile off inactive premenopausal women. The protocol adapts the “10-20-30” running regimen used by Gunnarsson and Bangsbo (2012) which has previously reported improvements in several health markers of trained runners, to offer non-weight-bearing self-paced cycling which may be more tolerable for novice exercisers. The effects of the HIIT protocol on the health profile of the participants was also compared to a more traditional self-paced prolonged continuous cycling training protocol and control group which has not been directly compared before. This study utilised stationary cycle ergometers but the exercise intervention could also be performed on an outdoor bicycle independently or with others which may increase accessibility.

A priori power analysis was performed for the primary outcome, $\dot{V}O_{2peak}$, using G*Power (Faul et al., 2007). The primary outcome differed to Chapter 4 and 5 as cardiorespiratory fitness, as assessed by an incremental cycling test to exhaustion, has been proposed to be an independent and strong, if not stronger, predictor of mortality relative to other established risk factors (Arena & Cahalin, 2014; Myers et al., 2002; Ross et al., 2016). This type of test was not available for Chapters 4 and 5. Power was set at 0.8 with a significance level of 0.05. Based on previous HIIT studies aiming to increase $\dot{V}O_{2peak}$ using comparable physical exercise interventions (Kong et al., 2016, Trapp et al., 2008), an average increase of 15 % with a standard deviation of 5 from baseline values was expected. Based on these assumptions, 14 participants were required for comparison between each respective intervention group and the control group. Assuming participant attrition such as drop out, 16 participants were recruited for each group (48 participants in total) for this study.

Eur J Appl Physiol
DOI 10.1007/s00421-017-3715-9

ORIGINAL ARTICLE

Effects of self-paced interval and continuous training on health markers in women

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Received: 12 July 2017 / Accepted: 28 August 2017

Abstract

Purpose To compare the effects of self-paced high-intensity interval and continuous cycle training on health markers in premenopausal women.

Methods Forty-five inactive females were randomised to a high-intensity interval training (HIIT; $n = 15$), continuous training (CT; $n = 15$) or an inactive control (CON; $n = 15$) group. HIIT performed 5 × 5 min sets comprising repetitions of 30-s low-, 20-s moderate- and 10-s high-intensity cycling with 2 min rest between sets. CT completed 50 min of continuous cycling. Training was completed self-paced, 3 times weekly for 12 weeks.

Results Peak oxygen uptake (16 ± 8 and 21 ± 12%), resting heart rate (HR) (−5 ± 9 and −4 ± 7 bpm) and visual and verbal learning improved following HIIT and CT compared to CON ($P < 0.05$). Total body mass (−0.7 ± 1.4 kg), submaximal walking HR (−3 ± 4 bpm) and verbal memory were enhanced following HIIT ($P < 0.05$), whereas mental well-being, systolic (−5 ± 6 mmHg) and mean arterial (−3 ± 5 mmHg) blood pressures were improved following CT ($P < 0.05$). Participants reported similar levels of enjoyment following HIIT and CT, and there were no changes in fasting serum lipids, fasting blood [glucose] or [glucose] during an oral glucose tolerance test following either HIIT or CT ($P > 0.05$). No outcome variable changed in the CON group ($P > 0.05$).

Conclusions Twelve weeks of self-paced HIIT and CT were similarly effective at improving cardiorespiratory fitness, resting HR and cognitive function in inactive premenopausal women, whereas blood pressure, submaximal HR, well-being and body mass adaptations were training-type-specific. Both training methods improved established health markers, but the adaptations to HIIT were evoked for a lower time commitment.

Keywords Cardiovascular health · Self-paced exercise training · Inactive · Cycling training · Cognitive function · Time commitment

Abbreviations

ANOVA	Analysis of variance
BMI	Body mass index
BP	Blood pressure
bpm	Beats per minute
cm	Centimetre
CON	Control
CT	Continuous training
CV	Coefficient of variation
GEQ	Groningen Enjoyment Questionnaire
HDL	High-density lipoprotein
HIIT	High-intensity interval training
HR	Heart rate

Communicated by Michael Lindinger.

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HR_{peak}	Peak heart rate
ISLT	International shopping list task
ISLTR	International shopping list task delayed recall
kj	Work done
kg	Kilogram
MAP	Mean arterial pressure
min	Minute
ml	Millilitres
$ml \cdot kg^{-1} \cdot min^{-1}$	Millilitres per kilogram body mass per minute
mmHg	Millimetres mercury
LDL	Low-density lipoprotein
NCD	Non-communicable disease
OCL	One card learning task
OGTT	Oral glucose tolerance test
ONB	One back task
RPE	Ratings of perceived exertion
RPP	Rate pressure product
SD	Standard deviation
tAUC	Total area under the curve
TWOB	Two back task
$\dot{V}O_{2peak}$	Maximal oxygen uptake
W	Watt
WEMWBS	Warwick-Edinburgh mental well-being scale

Introduction

It is well documented that physical inactivity and age are associated with increased morbidity from non-communicable diseases (NCDs) and are accompanied by declining cardiorespiratory fitness, cognitive and metabolic dysfunction, and hypertension (Booth et al. 2012). Middle-aged women are particularly susceptible to develop NCDs and associated co-morbidities, but regular physical activity is known to mitigate the development of NCD risk factors (Garber et al. 2011). Consequently, there are clear physical activity guidelines of 150 min of moderate aerobic activity or 75 min of vigorous aerobic activity per week to improve public health (Garber et al. 2011). Nonetheless, there is evidence that 34–39% of women aged 25–54 years in Western societies such as the United Kingdom are failing to meet physical activity recommendations (Townsend et al. 2015). Therefore, the development of physical activity interventions with high compliance rates are required to improve the health status of inactive middle-aged women.

Regular (2–4 sessions weekly), instructor-directed, continuous (40–60 min), moderate-to-vigorous intensity [55–80% of peak heart rate (%HR_{peak})] exercise has been shown to improve established NCD risk factors in women. Clinically relevant improvements have been reported for peak oxygen uptake ($\dot{V}O_{2peak}$, +10–19%) (Kong et al. 2016; Trapp et al. 2008), fat mass (−1.1 to −1.4 kg) (Mohr et al. 2014; Kong et al. 2016), systolic blood pressure (BP) (−4 to −6 mmHg) (Mohr et al. 2014), resting heart rate (HR) (−5 bpm) (Mohr et al. 2014), fasting blood glucose (−5%), [insulin] (−28%) and insulin sensitivity (+27%) (Ciolac et al. 2010; Robinson et al. 2015) and plasma [low-density lipoprotein] (LDL) (−5%) and [high-density lipoprotein] (HDL) (+3%) (Kelley et al. 2004). While regular regimented CT training can attenuate the development of NCDs, this fixed intensity training regimen requires a significant weekly time commitment. Since time constraints and enjoyment are commonly cited as two of the main barriers preventing middle-aged women from meeting physical activity guidelines (Booth et al. 2012), the time commitment of CT training might contribute to the large percentage of middle-aged women who fail to meet physical activity guidelines (Townsend et al. 2015).

In contrast, high-intensity interval training (HIIT) may provide an alternative, more time-efficient strategy for improving the health profile of inactive premenopausal women. Indeed, instructor-directed HIIT has been shown to improve cardiorespiratory fitness (Trapp et al. 2008; Trilk et al. 2011; Weston et al. 2014), body composition (Mohr et al. 2014; Trapp et al. 2008), resting systolic BP and HR (Mohr et al. 2014), and fasting blood [glucose], [insulin] and insulin sensitivity (Connolly et al. 2016; Trapp et al. 2008) to the same or greater extent compared to CT. However, some of these training-induced responses to HIIT, in particular, those related to insulin sensitivity, have been reported to be blunted in women compared to men (Gibala et al. 2014) and some HIIT regimens comprise repeated 'all-out' sprints, which may be unsuitable for inactive middle-aged women. It is therefore unsurprising that HIIT data on middle-aged women and women in general is limited (Weston et al. 2014). In addition, the majority of studies investigating the effects of HIIT on health outcomes have imposed longer intervals or strict work rates allowing minimal variation in session intensity which may adversely impact participant enjoyment and HIIT adherence (Kong et al. 2016; Trapp et al. 2008). Unfortunately, studies related to HIIT for women have not reported data regarding enjoyment (Mohr et al. 2014; Connolly et al. 2016; Trapp et al. 2008; Trilk et al. 2011). As a result, it is unclear whether HIIT is more or less enjoyable compared to CT (Bartlett et al. 2011; Foster et al. 2015).

It has been reported that interventions aimed at increasing physical activity tend to be more effective when the intensity of physical activity is lower rather than higher (Dishman and Buckworth 1996). However, evidence suggests that novice exercisers are generally inaccurate in self-monitoring and self-regulating the intensity of their efforts when the intensity is prescribed (Duncan et al. 2001). For example, it has been reported that women exceed their target heart rates when participating in aerobics, resulting in exercise intensities much higher than expected (Laukkanen et al. 2001). However, despite this, very little is presently known about how the exercise intensity chosen by previously inactive middle-aged premenopausal women may change over the course of a prolonged HIIT and CT intervention.

Cognitive function has been shown to decline in middle-aged adults (45–49 years) (Singh-Manoux et al. 2012) and it is known that participation in exercise can alleviate this decline in older individuals (Angevaren et al. 2007). There is some evidence to suggest that the acute improvement in cognitive function after an exercise bout is more pronounced following short-duration HIIT exercise compared to CT with this effect attributed to enhanced cerebral blood flow in the former compared to the latter (Angevaren et al. 2007). However, at present, it is not clear if chronic HIIT and CT would have different effects on cognitive function in inactive middle-aged women. Consequently, further research is required to assess how self-paced HIIT and CT influence enjoyment, training progression (increases in work rate during training sessions), adherence, and established health markers in inactive middle-aged premenopausal women.

The aim of the present study was therefore to investigate the effects of 12 weeks of self-paced HIIT and CT training on cardiorespiratory fitness, BP, parameters of cognitive function, blood glucose tolerance, serum lipid profile, body composition, and enjoyment of and adherence to exercise in inactive premenopausal women. It was hypothesised that both self-paced training methods would evoke beneficial changes in the health profile parameters outlined above, but that self-paced HIIT would elicit equivalent physiological and greater cognitive adaptations for a lower time commitment compared to self-paced CT training.

Methods

Subjects

Participants were recruited through advertisements in local community venues and the University of Exeter news bulletin. All participants gave their written informed consent after being informed verbally and in writing of the experimental procedures, potential benefits, and the possible risks and discomforts associated with the study. Individuals expressing an interest in participating completed a questionnaire to confirm that they met the inclusion criteria of being premenopausal, non-smokers, not pregnant or on medication, and without known metabolic or cardiovascular diseases. It was also confirmed that none of the participants had ever been an athlete or participated in vigorous exercise and were currently inactive, having not participated in regular physical activity for at least 2 years. The participants completed the International Physical Activity Questionnaire. Participants self-reported their dietary intake during the first, sixth and last week of the intervention period which was subsequently analysed by a member of the research team using nutritional software (Nutritics v4.267 Academic Edition, Dublin, Ireland). Food records were analysed to assess the type and amount of food consumption. Participants were also encouraged to avoid deviation from their normal dietary practices for the duration of the study and to maintain their normal lifestyle. The study was approved by the Sport and Health Sciences Research Ethics Committee at the University of Exeter, Exeter, UK.

Experimental design

The study was designed as a randomised controlled trial. Fifty-five women were initially recruited; however, seven failed to meet the inclusion criteria and were, therefore, excluded from the study. Once inclusion criteria were met, participants were randomly assigned to a high-intensity interval training cycling group (HIIT: age, 44 ± 7 (mean ± SD) years; height, 1.63 ± 0.04 m; body mass, 67.3 ± 13.5 kg; $n = 16$), a continuous cycling group (CT: age, 43 ± 7 years; height, 1.64 ± 0.07 m; body mass, 72.6 ± 17.5 kg; $n = 16$), or a control group (CON: age, 45 ± 7 years; height 1.63 ± 0.09 m; body mass, 72.0 ± 17 kg; $n = 16$). One participant from HIIT and CT withdrew from the study due to non-study related injuries (lower back and knee pain) and one participant from CON withdrew due a substantial increase in physical activity. Of the 45 participants who completed the study, those in HIIT and CT completed a 12-week training programme as described below, while CON continued their normal daily lives. Before and after the 12-week intervention period, participants completed a series of tests in the laboratory consisting of two separate visits both pre and post intervention.

Training

The exercise training interventions consisted of an indoor cycling program with exercise sessions completed 3 times per week for 12 weeks. All sessions were preceded by a 5 min warm up at 50 W and a 5 min cool down at 50 W, and were supervised by members of the Sport and Health Sciences department at the University of Exeter for safety reasons. The training sessions were organised around the availability of each individual participant and ranged from 1 to 5 participants cycling at any one time. As the cycle ergometers were moveable, participants had the choice to cycle as a group or independently. Audio and visual entertainment were provided. The training sessions were completed on a cycle ergometer (Monark 894E, Monark Exercise AB, Sweden) which was interfaced with Wingate Anaerobic Test software (Monark Exercise AB, Sweden) to record power output (W) and work done (kJ). HR (Polar RS400, Polar Electro Oy, Kempele, Finland) and ratings of perceived exertion (RPE, 10-point scale) were recorded during every training session. HR data were subsequently downloaded using Polar ProTrainer 5 (Polar Electro Oy, Kempele, Finland) and mean session HR was calculated. %HR$_{peak}$ was calculated from values recorded during an incremental cycling test to exhaustion.

The HIIT cycling protocol was a modification of the "10-20-30" running training program of Gunnarsson and Bangsbo (2012). Briefly, each participant completed repeated 1 min self-paced exercise bouts comprising 30 s low-intensity (~30% of maximum effort), 20 s moderate-intensity (~50–60% of maximum effort) and 10 s high-intensity (>90% maximum effort) cycling. This 1-min cycle was repeated for 5 min with each 5 min block separated by 2 min passive recovery. During the first week of training (familiarisation), participants were asked to perform 3–4 × 5 min bouts. In subsequent weeks participants completed 5 × 5 min bouts interspersed with 2 min recovery (Fig. 1). Effective training time equated to 25 min per session.

The CT protocol consisted of cycling continuously at a self-paced intensity which they could sustain for 50 min. During the first week of training (familiarisation), participants were asked to cycle continuously for 30–40 min. In subsequent weeks, participants cycled continuously for 50 min each session (Fig. 1). Effective training time equated to 50 min per session.

During the first training session, participants were given guidance on the requirements of each protocol but the intensities during all training sessions were self-selected by the individual and self-adjusted throughout the intervention period. A higher work rate could be attained by an individual self-selecting to increase pedal cadence and/or the resistance applied to the flywheel. The HIIT group were supplied with a timer to remind participants when to switch exercise intensity. Participants were able to visualise in real-time their revolutions per min trace on the cycle ergometer's electronic display which may have helped maintain the specific exercise intensities.

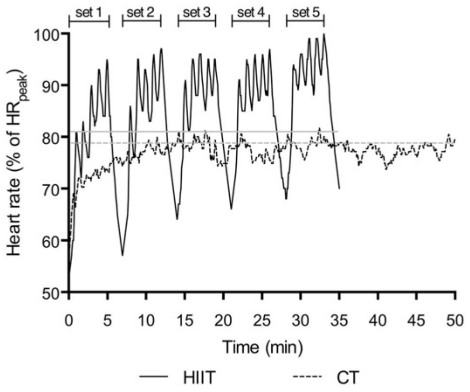

Fig. 1 Actual heart rate during a single training session for a single participant from the high-intensity interval training (HIIT) group and the continuous training (CT) group represented by black lines. Grey lines represent mean session HR for HIIT and CT

Cognitive testing

During cognitive testing participants completed verbal and attention/working learning and memory tasks using the Cogstate computerised cognitive testing system (Cogstate Ltd., Melbourne, VIC, Australia). These parameters were chosen as they have been connected with age-related cognitive decline, mobility and the ability to perform daily activities but have also been reported to improve following exercise (Cox et al. 2015). The specific tests employed consisted of the One Card Learning Task (OCL, 6 min), One Back (ONB, 4 min) and Two Back Task (TWOB, 4 min), and the International Shopping List Task (ISLT, 5 min) including delayed recall (ISLTR, 2 min). The primary performance measure for OCL, ONB and TWOB task was the proportion of correct answers (accuracy) which was normalised using an arcsine square-root transformation. A higher score equated to a better performance. The primary outcome measure for ISLT was the total number of correct responses when remembering a shopping list over three repetitions while ISLTR assessed the shopping list recall following a delay. A higher score equated to a better performance. The order of cognitive function tests was standardised and the total time to complete all tests was around 21 min.

Experimental testing

Participants were required to refrain from alcohol and exercise for 48 h preceding all visits and instructed to report to the laboratory at least 2 h postprandial in a rested state. On arrival at the laboratory for the first visit pre intervention, participants were familiarised to the cognitive function tests that would occur during the second visit pre and post intervention (see below). Height (Seca stadiometer SEC-225; Seca, Hamburg, Germany), body mass (Seca digital column scale SEC-170, Seca, Hamburg, Germany), body mass index (BMI) and waist-to-hip ratio were obtained prior to testing. Thereafter, pulmonary gas exchange (Cortex Metalyzer 3B, Leipzig, Germany) and HR were measured during the final 3 min of a standardized treadmill test (Woodway Desmo, Waukesha, WI, USA), consisting of 6 min walking at 4 km h^{-1} with 1% incline, and throughout a standardised incremental cycle test to exhaustion (Lode Excalibur Sport V2 electrically-braked cycle ergometer, Lode BV, Groningen, The Netherlands). The ramp incremental test commenced with 3 min cycling at 20 W followed by a continuous linear increase in work rate of 15 W min^{-1}. The ramp test ceased when cadence dropped >10 rev min^{-1} below the prescribed cadence of 70 rpm. Along with vocal encouragement to continue to exhaustion, the criteria used to determine $\dot{V}O_{2\text{peak}}$ included a plateau in $\dot{V}O_2$ toward the end of the test despite an increase in workload, a respiratory exchange ratio value ≥1.10 and a HR_{peak} within five beats of a participant's age-related estimated HR_{peak}. Participants gave a symptom-limited maximal effort on all occasions. $\dot{V}O_{2\text{peak}}$ and HR_{peak} were determined as the peak value reached in a 30-s period during the incremental test.

The second visit pre and post intervention was undertaken no less than 48 h following the first visit pre or post intervention and ultimately no less than 96 h following the final exercise training session. Following an overnight fast and under standardised conditions at ~08:00, resting HR and BP were measured following the participant sitting quietly for 10 min. BP was measured five times using a semi-automated device (Dinamap Pro 100V2, GE Medical Systems Information Technologies 2002, Tampa, Florida, USA) and the mean of the final three measurements was used to determine resting systolic and diastolic BP. Rate pressure product (RPP) was calculated as HR × systolic BP and mean arterial pressure (MAP) was calculated as 1/3 × systolic pressure + 2/3 × diastolic pressure. Subsequently a 4 ml blood sample was drawn from an antecubital vein into serum separator tubes (Vacutainer, Becton–Dickinson, NJ, USA) and left to clot for 45 min at room temperature. Samples were then centrifuged at room temperature at 1300 relative centrifugal force for 10 min and serum supernatants were removed and stored at −80 °C for later analysis. Samples were analysed using an automatic analyser (Roche Modular P-module, Roche Diagnostics, Indianapolis, IN) for [HDL] (coefficient of variation (CV) 2.1%), total [cholesterol] (CV 2.3%) and [triglycerides] (CV 2.4%). [LDL] was derived using the Friedewald formula (Friedewald et al. 1972).

Following HR, BP and blood measurements, the cognitive battery was undertaken. Thereafter, body composition (body fat percentage, total fat mass and total lean mass) was measured using air displacement plethysmography (The BodPod Body Composition System, Life Measurement Instruments, Concord, CA, USA). Participants then provided a capillary blood sample for assessment of fasting blood [glucose] (YSI 2300 glucose/lactate analyser, Yellow Springs Instruments, Kent, UK) and [haemoglobin] (HemoCue HB 201, Angelholm, Sweden). After consuming 75 g glucose in 300 ml of water, capillary blood samples were collected at 30, 60, 90 and 120 min for the assessment of blood [glucose] and total area under the curve (tAUC) (GraphPad Prism, San Diego, CA). Following the OGTT, subjective mental well-being was measured using the 14-item Warwick-Edinburgh Mental Well-being Scale (WEMWBS) (Tennant et al. 2007). For the post intervention visit, enjoyment of the exercise intervention was also assessed using a modified version of the Groningen Enjoyment Questionnaire (GEQ) (Stevens et al. 2000).

Statistical analysis

Statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS v21, SPSS Inc., Chicago, IL, USA). A two-factor mixed analysis of variance (ANOVA) design with the between factor 'group' (HIIT versus CT versus CON) and the repeated factor 'time' (pre-intervention versus post-intervention) was used to analyse all data. Data recorded during training sessions were clustered into 4-week periods and a two-factor mixed ANOVA with the between factor 'group' (HIIT versus CT) and repeated factor 'time' (1–4, 5–8 and 9–12 weeks) used to analyse training session variables (i.e. HR, RPE, power output and total work done). Effect size was calculated using partial Eta squared (η^2_{partial}) which ranged from very small (<0.01) to small (0.01–0.05) to medium (0.06–0.13) to large (≥0.14) (Cohen 1988). Where the effect of the intervention was shown to be statistically significant, all post hoc comparisons were Bonferroni adjusted. The significance level was $P < 0.05$. Data are reported as mean ± standard deviation (SD).

Results

Training data

Diet was stable for HIIT, CT and CON when analysed at baseline, 6 weeks and 12 weeks of the intervention (Table 1). Both HIIT and CT groups completed a total of 35 ± 1 training sessions over the 12-week period, corresponding to 2.9 ± 0.1 sessions per week. Weekly training time spent performing HIIT (75 min/week) was half that of the time spent performing CT (150 min/week). Mean power output during the training sessions increased from 1–4 to 5–8 to 9–12 weeks in both groups ($P < 0.01$) with no difference between groups ($P > 0.05$), but CT completed more work than HIIT at all time points ($P < 0.01$, Table 2). Mean HR was not different between training groups during the intervention ($P > 0.05$, Table 2). For the HIIT group, the $\%HR_{\text{peak}}$ achieved in the 10 s high-intensity periods during weeks 1–4, 5–8 and 9–12 was 94 ± 2, 94 ± 1 and 95 ± 3%. RPE was

Table 1 Dietary intake during weeks 1, 6 and 12

	HIIT ($n = 15$)			CT ($n = 15$)			CON ($n = 15$)			Interaction effect	
	Week 1	Week 6	Week 12	Week 1	Week 6	Week 12	Week 1	Week 6	Week 12	*P*	Partial η^2
Energy intake (kcal)	2009 ± 315	2020 ± 314	2033 ± 307	2043 ± 308	2058 ± 304	2042 ± 296	2136 ± 362	2147 ± 279	2018 ± 306	0.087	0.091
Energy from CHO (%)	53 ± 9	51 ± 9	54 ± 7	50 ± 8	52 ± 7	52 ± 6	53 ± 7	56 ± 8	53 ± 5	0.489	0.039
Energy from fat (%)	30 ± 5	31 ± 6	31 ± 5	33 ± 5	33 ± 5	32 ± 4	32 ± 4	30 ± 5	32 ± 4	0.596	0.032
Energy from protein (%)	17 ± 6	17 ± 6	16 ± 4	18 ± 5	15 ± 5	16 ± 4	16 ± 5	14 ± 6	15 ± 3	0.703	0.025

Values are expressed as means ± SD

Partial η^2 value for effect sizes

P values for interaction (group × time) effect

CHO carbohydrate, *CT* continuous training group, *CON* control group, *HIIT* high-intensity interval training group

higher in weeks 1–4 and 5–8 ($P < 0.05$), but not weeks 9–12 ($P > 0.05$) in HIIT compared to CT (Table 2).

Body composition

Body composition was not significantly different between groups at baseline. Body mass index, body fat percentage, lean mass, fat mass, and waist-to-hip ratio were not different when comparing post- to pre- intervention following HIIT, CT or CON ($P > 0.05$); however, total body mass was lower following HIIT (−0.7 ± 1.4 kg, $P < 0.05$, Table 3).

Exercise variables

HR during the submaximal treadmill walking test was lower when comparing post intervention to pre- after HIIT ($P < 0.05$) but not CT or CON ($P > 0.05$, Table 3). Submaximal $\dot{V}O_2$ (absolute and relative to body mass) was not different following HIIT, CT or CON ($P > 0.05$). There was a significant group × time interaction for $\dot{V}O_{2peak}$ (absolute and relative to body mass, $P < 0.01$) during the ramp incremental cycling test to exhaustion, with post hoc tests revealing a 16 ± 8% ($P < 0.01$) and 21 ± 12% ($P < 0.01$) improvement following HIIT and CT (Fig. 2) but not CON, respectively. There was also a group × time interaction for peak power output (PPO) during the ramp incremental test to exhaustion ($P < 0.05$). PPO was higher post training compared to pre training for HIIT and CT ($P < 0.05$) with no pre-post difference in the CON group ($P > 0.05$). There were no differences between training groups for any of the exercise variables ($P > 0.05$).

Resting BP and HR

Resting BP and HR were not significantly different between groups at baseline. There was a group × time interaction for systolic BP ($P < 0.05$). Post hoc tests revealed a reduction in systolic BP was apparent following CT ($P < 0.05$) but not HIIT or CON ($P > 0.05$, Table 3). Diastolic BP was not different following CT, HIIT or CON ($P > 0.05$); however, MAP was lower after CT (P = 0.02), but not HIIT or CON ($P > 0.05$). Resting HR and RPP were lowered following HIIT and CT but not CON ($P > 0.05$).

Serum lipids, haemoglobin and blood glucose

Serum total cholesterol-HDL ratio, total [cholesterol], [HDL], [LDL], [triglycerides], [haemoglobin], and fasting and OGTT [glucose] were unchanged when comparing post intervention to pre- for HIIT, CT or CON ($P > 0.05$, Table 3; Fig. 3).

Table 2 Mean training data during intervention

	HIIT ($n = 15$)			CT ($n = 15$)			Interaction effect	
	1–4 weeks	5–8 weeks	9–12 weeks	1–4 weeks	5–8 weeks	9–12 weeks	P	Partial η^2
Power output (W)	95 ± 20	$105 \pm 17^{\dagger}$	$109 \pm 18^{\dagger\$}$	81 ± 16	$94 \pm 18^{\dagger}$	$100 \pm 20^{\dagger\$}$	0.203	0.057
Heart rate (%HR$_{\text{peak}}$)	81 ± 4	81 ± 5	81 ± 3	78 ± 5	79 ± 5	79 ± 6	0.587	0.019
RPE (0–10 scale)	6.1 ± 1.2	5.8 ± 1.3	5.2 ± 1.2	4.5 ± 1.5*	4.6 ± 1.7*	4.7 ± 1.7	0.003	0.212
Total work done (kJ)	146 ± 25	149 ± 49	153 ± 28	247 ± 46*	$278 \pm 55^{\dagger}$*	$286 \pm 55^{\dagger}$*	0.031	0.117
Weekly training time commitment	~75 min (~129 min including warm up, rest and cool down)			~150 min (~180 min including warm up and cool down)				

Values are expressed as means ± SD

Partial η^2 value for effect sizes

P values for interaction (group × time) effect

CT continuous training group, *HIIT* high-intensity interval training group, HR_{peak} heart rate peak (includes recovery periods for HIIT group), *RPE* rating of perceived exertion

*Significantly different from HIIT at same time point ($P < 0.01$)

†Significantly different from 1 to 4 weeks

$^{\$}$Significantly different from 5 to 8 weeks

Mental well-being and enjoyment

WEMWBS scores increased following CT ($P < 0.05$, Table 3) but not HIIT or CON. There was no difference in WEMWBS between training groups. GEQ was not different between the two training groups following the intervention ($P > 0.05$, Table 3).

Cognitive function tests

Performance was enhanced in the OCL, ISLT and ISLTR tests following HIIT ($P < 0.05$, Table 4) representing an improvement in visual learning and memory, and verbal learning and memory, respectively. Performance was improved in the OCL and ISLT tests after CT ($P < 0.05$, Table 4) representing an improvement in visual learning and memory and verbal learning, respectively. No changes were observed for CON. There were no significant differences between training groups for any cognitive function tests.

Discussion

The main original findings of the present study were that self-paced HIIT and CT were both effective at improving $\dot{V}O_{2peak}$, resting HR, RPP and cognitive function of previously inactive middle-aged premenopausal women. A novel feature of our study was the self-paced nature of the training which might be considered to have better ecological validity than instructor-directed exercise in laboratory studies. Interestingly, as reflected by training HR, the CT group sustained a vigorous intensity for 50 min which would exceed physical activity recommendations (Garber et al. 2011). The similar mean HR during training may also help explain the similar adaptations between HIIT and CT.

The training interventions also resulted in comparable levels of adherence and enjoyment, but the adaptations to HIIT were achieved despite completing 49, 62 and 61% less work (kJ) in weeks 1–4, 5–8 and 9–12 and committing less time compared to CT training. However, while HIIT and CT training resulted in some common improvements in NCD risk factors, a reduction in BP and an increase in well-being were only apparent following CT training whereas improvements in verbal, memory and reductions in sub-maximal exercise HR and total body mass were only found following HIIT. Therefore, while self-paced HIIT and CT can equally improve several parameters related to the health profile of previously inactive middle-aged premenopausal women, HIIT was a more time efficient strategy to induce such changes. These findings suggest that self-paced exercise has the potential to improve the health profile of inactive middle-aged premenopausal women which might have important implications for future exercise prescription.

The present study demonstrated that 3 weekly HIIT and CT cycling training sessions over 12 weeks resulted in a 16% and 21% improvement in $\dot{V}O_{2peak}$, respectively, with no difference between the training groups. Importantly, the reported improvements in $\dot{V}O_{2peak}$ (+4.1 ml·kg^{-1}·min^{-1} following HIIT and +4.9 ml·kg^{-1}·min^{-1} following CT training) are clinically relevant as a 3.5 ml·kg^{-1}·min^{-1} increase in exercise capacity relates to a 17% reduction in all-cause mortality (Gulati et al. 2003). The increase in $\dot{V}O_{2peak}$ following HIIT and CT training in the present study is in accord with findings from a previous study employing HIIT (+24%)

Table 3 Outcome measures pre and post 12-week intervention

	HIIT ($n = 15$)		CT ($n = 15$)		CON ($n = 15$)		Interaction effect	
	Pre	Post	Pre	Post	Pre	Post	*P*	Partial η^2
TBM (kg)	67.3 ± 13.5	66.6 ± 13.7†	72.6 ± 17.5	72.1 ± 17.8	76.1 ± 19.4	76.5 ± 19.0	0.066	0.122
BMI (kg/m^2)	25.3 ± 4.9	25.0 ± 5.1	26.9 ± 6.3	26.8 ± 6.4	28.4 ± 6.9	28.5 ± 6.6	0.130	0.093
LM (kg)	42.5 ± 4.2	42.3 ± 4.1	42.9 ± 6.2	42.6 ± 6.2	44.1 ± 6.8	44.1 ± 6.6	0.899	0.005
FM (kg)	24.3 ± 11.6	24.0 ± 13.2	29.2 ± 14.6	29.3 ± 15.2	31.3 ± 15.9	31.0 ± 15.7	0.892	0.005
BF (%)	35.0 ± 9.1	33.9 ± 10.0	37.9 ± 9.7	37.7 ± 9.6	37.3 ± 10.4	37.1 ± 10.1	0.431	0.039
Waist-to-hip ratio	0.84 ± 0.06	0.82 ± 0.04	0.81 ± 0.06	0.82 ± 0.04	0.85 ± 0.06	0.86 ± 0.05	0.290	0.057
$\dot{V}O_{2peak}$								
l·min^{-1}	1.71 ± 0.26	1.92 ± 0.27†	1.76 ± 0.35	2.09 ± 0.32$^{\dagger *}$	1.71 ± 0.27	1.77 ± 0.29	<0.001	0.411
ml·kg^{-1}·min^{-1}	26.1 ± 5.9	30.2 ± 6.5†	24.8 ± 4.8	29.7 ± 5.0†	25.3 ± 4.6	25.7 ± 4.5	<0.001	0.523
Resting systolic BP (mmHg)	111 ± 15	109 ± 14	112 ± 6	107 ± 7†	116 ± 17	116 ± 16	0.026	0.160
Resting diastolic BP (mmHg)	69 ± 9	69 ± 9	70 ± 5	68 ± 8	71 ± 9	72 ± 7	0.593	0.025
MAP (mmHg)	83 ± 10	83 ± 10	84 ± 5	81 ± 7†	86 ± 12	86 ± 11	0.249	0.064
Resting HR (bpm)	70 ± 6	65 ± 8†	67 ± 6	63 ± 7†	68 ± 8	69 ± 7	0.115	0.098
RPP	7754 ± 1110	7184 ± 1393†	7555 ± 730	6760 ± 775$^{\dagger *}$	7982 ± 1745	7989 ± 1691	0.025	0.161
Fasting blood glucose (mmol/L)	4.17 ± 0.53	4.26 ± 0.48	4.14 ± 0.37	4.07 ± 0.53	3.58 ± 0.84	3.84 ± 0.56	0.283	0.058
tAUC (mmol/L*120 min)	704 ± 88	732 ± 126	695 ± 108	700 ± 105	662 ± 187	666 ± 175	0.682	0.018
Hb (g/L)	134 ± 7	131 ± 13	133 ± 11	133 ± 12	135 ± 7	134 ± 6	0.474	0.035
TC (mmol/L)	4.50 ± 0.70	4.65 ± 0.83	4.85 ± 0.67	4.71 ± 0.57	5.13 ± 1.06	5.18 ± 1.02	0.292	0.580
HDL (mmol/L)	1.77 ± 0.36	1.73 ± 0.39	1.87 ± 0.42	1.80 ± 0.40	1.34 ± 0.53	1.34 ± 0.50	0.540	0.029
LDL (mmol/L)	2.40 ± 0.77	2.52 ± 0.84	2.68 ± 0.50	2.60 ± 0.44	3.13 ± 1.19	3.19 ± 1.15	0.303	0.055
TCl-HDL ratio	2.65 ± 0.60	2.73 ± 0.59	2.69 ± 0.54	2.75 ± 0.58	3.11 ± 1.44	3.20 ± 1.41	0.917	0.004
Triglycerides (mmol/L)	0.82 ± 0.31	0.87 ± 0.44	0.68 ± 0.26	0.73 ± 0.28	0.91 ± 0.32	0.90 ± 0.30	0.886	0.006
Submaximal $\dot{V}O_2$								
ml·kg^{-1}·min^{-1}	11.4 ± 1.5	10.6 ± 1.2	10.9 ± 2.3	10.7 ± 2.3	11.2 ± 2.1	11.2 ± 1.9	0.089	0.111
l·min^{-1}	0.75 ± 0.18	0.71 ± 0.19	0.77 ± 0.24	0.76 ± 0.22	0.81 ± 0.19	0.82 ± 0.18	0.180	0.080
Submaximal HR (%HR$_{max}$)	55 ± 7	52 ± 6†	55 ± 6	54 ± 8	55 ± 10	57 ± 11	0.063	0.123
WEMWBS	52 ± 9	54 ± 7	49 ± 9	52 ± 7†	42 ± 8	42 ± 6	0.198	0.074
GEQ		56 ± 8		53 ± 10				

Vales are expressed a means ± SD. *P* values for interaction (group × time) effect

Partial η^2 value for effect sizes

BF body fat, *BMI* body mass index, *BP* blood pressure, *CON* control group, *CT* continuous training group, *FM* fat mass, *GEQ* Groningen Enjoyment Questionnaire, *Hb* haemoglobin, *HDL* high density lipoprotein cholesterol, *HIIT* high-intensity interval training group, *HR* heart rate, *LDL* low density lipoprotein cholesterol, *LM* lean mass, *MAP* mean arterial pressure, *RPP* rate pressure product, *tAUC* total area under the curve, *TBM* total body mass, *TC* total cholesterol, $\dot{V}O_{2peak}$ peak oxygen uptake, *WEMWBS* Warwick-Edinburgh Mental well-being scale

*Significantly different from CON ($P < 0.05$)

†Significantly different versus pre-training ($P < 0.05$)

and CT training (+19%) (Trapp et al. 2008). Taken together, these findings are in line with a report that increasing exercise intensity during short-duration exercise and ensuring that lower-intensity exercise duration exceeds 35 min are important factors for improving cardiorespiratory fitness (Wenger and Bell 1986).

The improved $\dot{V}O_{2peak}$ following HIIT and CT training in the present study was accompanied by improvements in aspects of cardiovascular function. Indeed, HIIT and CT training lowered resting HR by 5 bpm and 4 bpm, respectively. This is important as resting HR has been recognised as an independent risk factor for cardiovascular disease in women and is recommended to form part of the cardiovascular risk assessment (Perk et al. 2012). Moreover, HR was lower during submaximal walking after HIIT. This lowering of HR post training is likely linked to an increased cardiac stroke volume (Blomqvist and Saltin 1983). The lower resting systolic BP (by 5 mmHg) and MAP following CT training, is similar to a meta-analysis which reported a significant reduction in systolic BP (~3 mmHg) in normotensive

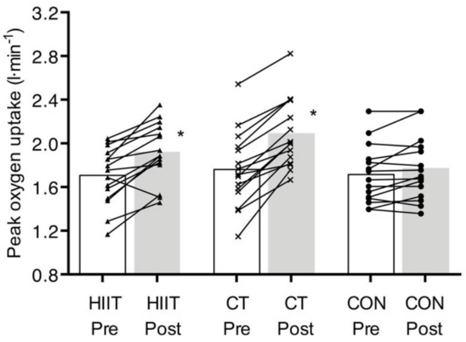

Fig. 2 Peak oxygen uptake (l·min^{-1}) before and after 12 weeks of high intensity interval training (HIIT), continuous training (CT) and continuation of an inactive lifestyle (CON). Data are mean ± SD. Asterisks denotes significant difference from pre intervention. $P < 0.05$

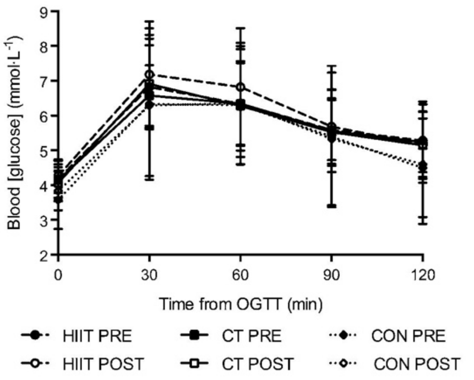

Fig. 3 Blood [glucose] response during the oral glucose tolerance test (OGTT) displayed over time for the high-intensity interval training (HIIT) group, continuous training (CT) group and the control (CON) group before and after the 12-week intervention. Data are mean ± SD

individuals following aerobic exercise performed three to five times per week for 30–60 min (Cornelissen and Fagard 2005). It could be speculated that a reduction in BP may be more sensitive to exercise volume rather than intensity. This is of interest as a reduction of 5 mmHg in systolic BP has been estimated to reduce stroke, coronary heart disease and all-cause mortality by 14, 9 and 7%, respectively across the general population (Whelton et al. 2002). The reduction in systolic BP might be a function of a lower sympathetic and increased parasympathetic outflow, consistent with a lower resting HR, and/or increased muscular capillarisation and vascular remodeling with a resulting reduction in systemic vascular resistance (Andersen et al. 2010). These collective changes in cardiovascular function might have the potential to increase muscle oxygen (O_2) delivery following HIIT and CT training which, along with potential improvements in mitochondrial biogenesis and function (Nordsborg et al. 2015), and muscle O_2 extraction (Daussin et al. 2007), might account for the improved $\dot{V}O_{2\text{peak}}$ following HIIT and CT training in the present study.

Serum total [cholesterol], [HDL], total cholesterol/HDL ratio, [LDL], [triglycerides], fasting [glucose] and responses to the OGTT were unchanged in both training groups, which is consistent with some (Connolly et al. 2016; Trapp et al. 2008) but not all (Robinson et al. 2015) previous observations. Since the participants in the present study exhibited normal baseline values for these variables, this might account for the lack of training-induced changes. However, as explained by Gibala et al. (2014), the lack of change in blood [glucose] following HIIT in the present study may also be due to the reduced breakdown of muscle glycogen in type I fibers following HIIT in women compared to men. Indeed, the increased rate of glycogen breakdown and resynthesis following HIIT has reported to be important for improvements in insulin sensitivity (Gibala et al. 2014). In contrast, there was a small but significant decrement (−0.7 kg) in body mass following HIIT with no change in CT or CON groups. Although statistically significant, the 1% reduction in body mass is lower than the 5–10% reduction recommended for overweight and obese individuals to reduce their cardiovascular risk profile (Wilson et al. 1999). Therefore, the clinical relevance of this change in body mass after HIIT is likely to be small. The lack of change in fat mass of the present participants is in agreement with some (Keating et al. 2014) but not all (Trapp et al. 2008) previous studies on overweight adults following 12–14 weeks of HIIT.

To our knowledge, this is the first study to report similar improvements in visual learning and memory and verbal learning following self-paced HIIT and CT training, and improved verbal memory following self-paced HIIT but not CT, in premenopausal, inactive females. These improvements are in line with findings from a recent systematic review by Cox et al. (2015). Participation in high-intensity exercise has been associated with the upregulation of brain-derived neurotrophic factor (BDNF) which has been linked to the stimulation of the hippocampus and pre-frontal cortex leading to chronic improvements in cognitive function via neurovascular remodeling including neuro/synaptogenesis and angiogenesis (Hillman et al. 2008). In line with the similarities in mean training HR, this may help explain the similar improvements in cognitive function following HIIT and CT in the present study. An improvement in verbal memory was also found for the HIIT group following completion of the ISLTR (delayed recall) test. It should be acknowledged

Table 4 Cognitive function test scores pre and post 12-week intervention

	HIIT ($n=15$)		CT ($n=15$)		CON ($n=15$)		Interaction effect	
	Pre	Post	Pre	Post	Pre	Post	P	Partial η^2
OCL (acc)	0.98±0.18	1.09±0.10*†	1.03±0.10	1.09±0.08*†	1.02±0.13	1.00±0.13	0.007	0.211
ONB (acc)	1.35±0.19	1.39±0.14	1.32±0.17	1.44±0.12	1.34±0.22	1.33±0.21	0.138	0.090
TWOB (acc)	1.26±0.21	1.33±0.14	1.30±0.17	1.33±0.15	1.19±0.27	1.20±0.29	0.407	0.042
ISLT (cor)	28.5±3.4	30.3±3.2*†	30.3±2.8	32.1±1.9*†	28.8±3.4	27.9±2.9	0.001	0.283
ISLTR (cor)	9.9±2.3	10.7±1.3†	10.9±1.0	11.3±1.0*	10.0±1.9	10.0±1.8	0.053	0.130

Vales are expressed a means ± SD

P values for interaction (group × time) effect. Partial η^2 value for effect sizes

Acc proportion of correct answers (accuracy) normalised using an arcsine square-root transformation, *CON* control group, *cor* total number of correct responses to remembering a shopping list, *CT* continuous training group, *HIIT* high-intensity interval training group, *ISLT* international shopping list task, *ISLTR* International shopping list recall, *OCL* one card learning, *ONB* one back memory, TWOB: two back memory

*Significantly different from CON ($P<0.05$)

†Significantly different versus pre-training ($P<0.05$) as determined by post-hoc analyses following a group × time interaction

however that the ISLTR test is based on a possible score out of 12 which was attained by a number of individuals on their baseline visit and thus a ceiling effect was present. Despite this limit to sensitivity, the HIIT group still displayed a within-group improvement. However, the lack of equivalent effect in the CT group may partially result from the limited scope for improvement. Interestingly, baseline results of all cognitive tests employed in the present study were similar to, or better than, normative data provided by Cogstate of 341 healthy individuals aged 35–49, which could account for the lack of improvement in some of the tests. Therefore, while both CT and HIIT enhanced cognitive function, improvements were attained with a smaller time commitment following HIIT suggesting that this exercise modality might provide a more time-efficient exercise modality to enhance cognitive function compared to CT training, at least in inactive, premenopausal women.

Following training, well-being scores were only improved in CT. This corroborates previous studies reporting that mental well-being improves more with CT training compared to HIIT (Moses et al. 1989). However, although not significantly different, baseline scores were slightly higher for HIIT (52) compared to CT (49) and remained higher following the training intervention (HIIT = 54; CT = 52). In addition, post-intervention enjoyment (GEQ) was not different between training groups in this study. The similar levels of enjoyment in CT training and HIIT are in line with some previous studies (Heinrich et al. 2014), but conflict with other studies reporting greater enjoyment following HIIT (Kong et al. 2016) or CT training (Foster et al. 2015). These contrasting results could be due to discrepancies in the HIIT and CT exercise training protocols and the stage of the training intervention at which enjoyment levels were assessed. Indeed, as RPE was significantly higher for HIIT during the first 8 weeks of exercise, this may have affected enjoyment. Therefore, it is possible that if enjoyment was assessed during earlier time points in the intervention, between-training group differences may have occurred based on the differences in RPE. However, it is likely that the participants became accustomed to the higher intensity of exercise at the later stages of the intervention (+8 weeks) as no difference in RPE existed between training groups in the final 4 weeks, even though both groups significantly increased their power output. These findings suggest that, if inactive individuals are able to tolerate the initial higher perceived exertion during HIIT (8 weeks), they are likely to report similar levels of enjoyment to CT. This is important as enjoyment of exercise can predict adherence (Parfitt and Hughes 2009). Nonetheless, it should also be noted that, even though RPE was higher in the first 8 weeks of HIIT, no participants dropped out of this group due to the intensity with a single participant dropping out of the HIIT and CT training groups over the course of the intervention. This may partly be attributable to the fact that the participants were able to self-pace their workout during every training session.

Although the American College of Sports Medicine recommends 150 min of moderate or 75 min of vigorous physical activity per week to improve health (Garber et al. 2011), and while self-paced HIIT and CT training were similarly effective at improving some health markers, HIIT and CT training differed in their ability to improve other health-related variables in the current study. It should also be noted that, based on previous research which classified responders and non-responders using two times the typical error for results obtained from repeated $\dot{V}O_{2\text{peak}}$ tests separated by a week in recreationally active adults (20 years) (Bonafiglia et al. 2016), four participants from the HIIT group could be classed as non-responders or at least having a low sensitivity to HIIT. There were no non-responders following CT. Therefore, further research is required to assess whether combining these two training methods, or switching training methods (Bonafiglia et al. 2016), can produce greater health benefits compared to either training method completed independently. Additionally, it should be noted that testing periods were not timed in relation to the menstrual cycle and the social aspect of training was not controlled in relation to the number and interaction of participants during training which could increase variance in the reported results (Gibala et al. 2014). It is noteworthy that the 10–20–30 training concept, which was employed as the HIIT method in the current study, resulted in clinically-relevant improvements in established health markers despite the completion of only ~12 min cycling at a ≥90% self-perceived intensity per week. This is striking as the completion of high-intensity work was considerably lower than the recommended 75 min of vigorous activity per week to improve health (Garber et al. 2011). Moreover, the adaptations to HIIT were achieved from the completion of less total work done and for a lower time commitment. Collectively, our results indicate that both self-paced HIIT and CT training are effective interventions to improve established health markers in inactive middle-aged premenopausal women, but that self-paced HIIT is a more time efficient strategy to elicit many of the adaptations that can be achieved through conventional self-paced CT training. Ultimately, given that enjoyment was similar between groups, previously inactive middle-aged premenopausal women should be informed that both self-paced HIIT and CT are beneficial to health as long as the intervention-specific time commitments are adhered to.

In conclusion, 12 weeks of self-paced HIIT and CT cycle training were similarly effective at improving cardiorespiratory fitness, resting HR and RPP and cognitive function in inactive middle-aged premenopausal women which may be due, in part, to the similar mean HR between groups, with both groups training at a vigorous intensity. However, BP was lowered and well-being was only improved following CT training and submaximal exercise HR and total body mass were only lowered by HIIT, indicating that some health markers are more likely to be improved in a training-type-specific manner. Although participants reported similar levels of enjoyment and showed similar levels of adherence to both training methods, the adaptations to HIIT were achieved for the completion of less work and the commitment of less time compared to CT training. These findings support the use of self-paced exercise training methods (HIIT or CT) to improve the health profile of inactive middle-aged premenopausal women, as long as the intervention-specific time commitments are adhered to. These findings might have implications for exercise prescription for the improvement of clinically-relevant health markers in inactive middle-aged premenopausal women. While beneficial adaptations on health markers are clearly apparent, individuals unaccustomed to vigorous exercise, in particular older adults, should consult their doctor before starting an exercise program.

Acknowledgements Firstly, we thank the participants for their commitment during the testing and intervention period. Secondly, we thank Sean Kilroe, Paul Morgan, Chris Thompson, Sam Bailey, Nadine Sammy and Adam Linoby for supervising many of the cycling training sessions. Finally, we thank the Royal Devon and Exeter NHS Foundation Trust for assistance with analyzing the blood samples and Dr. Brad Metcalf for advice on statistics. The study was supported by FIFA-Medical Assessment and Research Centre (F-MARC).

Compliance with ethical standards

Conflict of interest There were no conflicts of interest for any of the authors.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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Chapter 7

Influence of a novel DVD-directed home-based exercise intervention on health indicators in inactive premenopausal women

Contribution: Conceptualisation, investigation, project administration, formal analysis, writing – original draft preparation.

Chapters 4 and 6 contributed to the design of Chapter 7 by combining movements commonly found in small-sided football and adapting them into a “10-20-30” style exercise protocol. Additionally, Chapter 7 contributes to the overarching aim of this thesis by investigating the effects of an additional, easily accessible, time-efficient HIIT intervention on several important health markers for inactive premenopausal women. The home-based nature of the exercise intervention may be more appealing for individuals who may wish to exercise within the comfort of their own home or do not have access to transport or gym memberships.

A priori power analysis was performed for the primary outcome, systolic BP, using G*Power (Faul et al., 2007). Power was set at 0.8 with a significance level of 0.05. Based on previous varied-intensity intermittent exercise studies aiming to reduce systolic BP using comparable physical exercise interventions (Krustrup et al., 2010), an average reduction of 5 mmHg with a standard deviation of 2 from baseline values was expected. Based on these assumptions, 14 participants were required for comparison between the intervention group and the control group. Assuming participant attrition such as drop out, we recruited 16 for each group (32 participants in total) for this study.

Abstract

Purpose: This study tested the hypothesis that a novel, DVD-directed, home-based exercise training intervention would be effective at improving health indicators in inactive premenopausal women. **Methods:** Twenty-four inactive premenopausal women (39 ± 10 y) were randomly assigned to a DVD-directed exercise training group (DVD; *n* = 12) or control group (CON; *n* = 12). During the 12-week intervention period, the DVD group performed 3-weekly training sessions of 15 min. Training sessions comprised varying-intensity movements involving multiplanar whole-body accelerations and decelerations (average heart rate (HR) = 76 ± 3 % HR_{max}). CON continued their habitual lifestyle with no physical exercise. A series of health markers were assessed prior to and following the intervention periods. **Results:** Following the DVD intervention, [HDL cholesterol] (Pre: 1.83 ± 0.45, Post: 1.94 ± 0.46 mmol/L) and mental well-being (Warwick Edinburgh Mental Well-Being Scale) were improved ($P<0.05$). Conversely, [LDL cholesterol], [triglycerides], fasting [glucose], body composition and resting blood pressure and HR were unchanged following the DVD intervention (P>0.05). There were no pre-post intervention changes in any of the outcome variables in the CON group ($P>0.05$). **Conclusion:** The present study suggests that a novel, DVD-directed exercise training intervention, which consisted of varied-intensity movements interspersed with spinal and lower limb mobility and balance tasks, can improve HDL cholesterol and mental well-being in premenopausal women. Home-based, DVD-directed exercise training may be a useful tool to initiate exercise and improve aspects of health in previously inactive premenopausal women.

Keywords: Exercise DVD, high-intensity interval training, health profile, premenopausal women

Introduction

Participation in regular physical activity is associated with decreased morbidity of non-communicable diseases (NCDs) such as cardiovascular disease, obesity and type II diabetes mellitus (I. M. Lee et al., 2012). However, in spite of the well-established health benefits of regular physical activity, and despite clear physical activity guidelines for health (at least 150 min of moderate-intensity activity or 75 min of vigorous-intensity activity per wk (Department of Health, 2011), it has been reported that over 45 % of women are not meeting physical activity recommendations. This is higher than the 33 % of men who are not meeting these guidelines (Townsend, Wickramasinghe, et al., 2015). During the ages of 25-54, only 61-66 % of women in England are meeting physical activity recommendations whereas 70-76 % of their male counterparts are achieving the same recommendations (Townsend, Wickramasinghe, et al., 2015). Importantly, physical inactivity is associated with increased use of healthcare services (Scarborough et al., 2011) and was estimated to have cost the NHS over £900 million in 2009/10 (British Heart Foundation, 2013). These observations underscore the requirement to develop interventions to increase exercise participation in inactive premenopausal women.

One of the most commonly cited barriers preventing women from meeting physical activity recommendations is a lack of time (Welch et al., 2009). This arises due to work, child-care commitments, travel and financial restrictions (Napolitano et al., 2011). In addition, women have been reported to prefer training on their own with instruction (A. C. King et al., 2000) or with a family member or friend (Im, Chee, Lim, Liu, & Kim, 2008). Consequently, several home-based exercise interventions have been developed in an attempt to provide a convenient, cost-effective method to increase exercise adherence in women. Home-based exercise interventions delivered through exercise booklets and information sheets have been successful in improving the health profile of middle-aged women (Gossard et al., 1986; Juneau et al., 1987; A. C. King, Haskell, Young, Oka, & Stefanick, 1995). However, it has been reported that individuals tend to selectively scan printed exercise information leading to incorrect movement execution compared to other forms of media (Eveland & Dunwoody, 2002). This limitation might have a negative impact on the potential health benefits achievable through such interventions.

The use of DVD-directed exercise has emerged as a popular choice of physical activity for pre- and post-menopausal women (Daley et al., 2011). The complementary use of audio and video may increase motivation and correct exercise execution through clear visual guidance on the exercise movements and session structure combined with music, subtitles and verbal instruction (Khalil et al., 2012). The use of exercise DVDs has resulted in higher activity levels (Gothe et al., 2015) and improvements of lower extremity flexibility and upper body strength following a 6-month intervention in older individuals (McAuley et al., 2013). However, while many exercise DVDs are commercially available, the exercise regimens tend to be generalised for a wide audience which might limit their potential to promote participant compliance and health benefits in premenopausal women. Recently, a dance movement protocol (Dance Grid) has been developed to mimic some of the movements commonly found in recreational football since recreational football has been reported to positively impact the cardiovascular disease risk profile of premenopausal women (Krustrup, Hansen, Randers, et al., 2010). This dance movement exercise DVD has been associated with an average heart rate (HR) of ~80 % of age-predicted HR maximum (HR_{max}), repeated accelerations and decelerations, and 99.5 % training compliance in inactive perimenopausal women (Scott, 2014). Therefore, this method of exercise training might hold promise as a DVD-based exercise intervention to evoke beneficial changes to the health profile of premenopausal women. However, it has yet to be determined whether this home-based, DVD-instructed exercise training programme can improve risk factors for NCDs in previously inactive premenopausal women.

The purpose of this study was to investigate adherence to, and the potential health benefits of, a novel, DVD-directed exercise training intervention in premenopausal women. It was hypothesised that a DVD-directed exercise training intervention completed in the participant's own home would be associated with a high participation rate and improvements in mental well-being and risk factors for NCDs in inactive premenopausal women.

Materials and Methods

Participants. Participants were recruited through advertisements in local community venues and the University of Exeter news bulletin. No financial or other inducements were offered to participants apart from them being allowed to keep the exercise DVD following completion of the intervention. Potential participants were given the opportunity to contact the research team by phone or in person to confirm that they were premenopausal, non-smokers, not pregnant or on medication and without diagnosed metabolic or cardiovascular diseases. It was also confirmed that none of the participants had been taking part in regular physical activity for at least 2 years in addition to completing the International Physical Activity Questionnaire (IPAQ). Although diet was only monitored in the first and last wk of the intervention period, participants were encouraged not to change their normal dietary practices for the duration of the study and, apart from the intervention, were requested to maintain their normal lifestyle. All participants gave their written informed consent having being informed verbally and in writing of the experimental procedures and potential benefits risks and discomforts associated with the study. The study was approved by the Sport and Health Sciences Research Ethics Committee at the University of Exeter, Exeter, UK.

Design. The study was designed as a randomised control trial. Thirty-two women were initially recruited to the study. However, eight participants withdrew from the study due to relocation, loss of contact or illness or surgery unrelated to the interventions. The remaining twenty-four participants were randomly assigned to a DVD-directed exercise training group (DVD: age; 41 ± 8 (mean ± SD) (range: 24 - 52) y, height; 1.70 ± 0.07 m, body mass; 66.1 ± 14.5 kg; *n* = 12) or a control group (CON: age; 38 ± 11 (20 - 49) y, height; 1.63 ± 0.05 m, body mass; 74.8 ± 19.3 kg; *n* = 12). Those participants in the DVD group completed a 12-wk training programme, as described below, while CON continued their normal daily lives. Before and after the 12-wk intervention period, a series of health markers were assessed (see below).

DVD-directed exercise training intervention. Within a 3 m x 1.5 m grid, participants completed 15 min exercise bouts consisting of low-, moderate-, and high-intensity exercise patterns 3 times weekly. This involved multiplanar whole-body accelerations and decelerations (30 and 60 s intervals followed by 5 s transitions). Each 60 s interval required the action to be completed at low-intensity for 30 s, moderate-intensity for 20 s and high-intensity for 10 s and each interval was interspersed with intervals of active rest (Table 1). This pre-choreographed movement training (Scott, 2014) incorporated slow-speed running, moderate-speed running, high-speed running and backwards running, walking sideways and backwards, and side-cutting as well as 90° and 180° turns, jumps and stops interspersed with spinal and lower limb mobility and balance and coordination challenges. A member of the research team made weekly contact with each participant to provide encouragement, receive feedback and answer any queries the participant may have had. Prior to the intervention (prior to the second visit to the laboratory; see below), participants were provided with a DVD and sent a link to a YouTube video which consisted of each section being verbally explained and visually demonstrated at a slow speed and then at actual speed on the training DVD. In addition, all participants were familiarised with the movement sequences in person and instructed on how to set up the exercise space in their own homes (see visit 2 below). In the sixth wk of training, participants were asked to revisit the laboratory where they were familiarised to, and provided the DVD for, a second dance-based exercise routine. This second exercise regime incorporated more challenging movements and also allowed for variation in exercise due to the long duration of the exercise intervention (Table 2).

Table 1. Home exercise DVD description level 1

Section title	Description
1. 60 s Walk, Jog, Run	30 s walk fast- 20 s jog -10 s run
2. 60 s Ankle, Hip Mobility	30 s ankle plantar-dorsiflexion; 30 s rear lunge in plantarflexion
3. 60 s Walk, Jog, Run	60 s repetition of section 1 at faster speed all actions
4. 60 s Spinal Mobility	60 s spinal side bending, side bending with flexion and extension
5. 60 s Skater	30 s side step jump turn- 20 s increase speed- 10 s lateral hop
6. 60 s Side Mobility	30 s lateral lunge spinal side bend- 30 s single leg balance task
7. 60 s Diagonal Skip & Turn	20 s diagonal step with 180° turn- 10 s faster 180°jump turn- L & R side
8. 60 s Brushes	30 s single leg balance task- 30 s repeat balance task with increased hip range of movement
9. 60 s ¼ Turn with Fast Feet	20 s step & ¼ turn- 10 s fast footwork side ladder with jump; repeat 20 s ¼ turn section faster- 10 s repeat side ladder footwork faster
10. 60 s Quadruped Mobility	60 s quadruped kneeling spinal mobility, with modified press up
11. 60 s Folk Step	30 s skip forwards and back- 20 s bound forwards and back- 10 s bilateral jump forward fast jog back
12. 30 s Arrow Balance	15 s rear lunge in narrow base of support arms above head- repeat L & R side
13. 60 s Side Cut	30 s side shuffle- 20 s side cut fast- 10 s lateral bound L to R foot
14. 30 s Hip Mobility	15 s rear lunge with spinal side bend & lateral hip shift- L & R side
15. 60 s Walk, Jog, Run	60 s repetition of section 1 at faster speed all actions
16. 30 s Spine mobility	30 s spinal flexion & extension; ankle plantarflexion

Table 2. Home exercise DVD description level 2

Section title	Description
1. 60 s Fast Walk, Jog, Run	30 s walk fast- 20 s jog -10 s run
2. 60 s Ankle, Hip Mobility	30 s ankle plantar-dorsiflexion; 30 s rear lunge in plantarflexion
3. 60 s Walk, Jog, Run	60 s repetition of section 1 at increased speed all actions
4. 60 s Spinal Mobility	60 s spinal side bending, side bending with flexion and extension
5. 60 s Skater	30 s side step jump turn- 20 s increase speed- 10 s lateral hop
6. 60 s Side Mobility	30 s lateral lunge spinal side bend- 30 s single leg balance task
7. 60 s Diagonal Skip & Turn	20 s diagonal step with 180° turn- 10 s faster 180°jump turn- L & R side
8. 60 s Brushes	30 s single leg balance task- 30 s repeat balance task with increased hip range of movement
9. 60 s ¼ Turn with Fast Feet	20 s step & ¼ turn- 10 s fast footwork side ladder with jump; repeat 20 sec. ¼ turn section faster- 10 s repeat side ladder footwork faster
10. 60 s Elevated Quadruped	60 s elevated quadruped- modified push up- push up & spinal rotation
11. 60 s Folk Step with Jumps	30 s fast skip forwards and back- 20 s bound forwards and back- 10 s continuous bilateral jumping forward & backwards
12. 30 s Arrow Balance	15 s rear lunge in narrow base of support arms above head- repeat L & R side
13. 60 s Dynamic Side Cut	30 s dynamic lateral shuffle- 20 s dynamic lateral cutting- 10 s dynamic lateral bound L to R foot
14. 40 s Giant Steps	40 s alternating single leg balance with plantar flexion & increased hip range of movement gesture leg- L-R; L-R
15. 60 s Jog, Run, Sprint	60 s repetition of section 1 at increased speed all actions
16. 60 s Spine Mobility	60 s spinal flexion, extension, rotation; ankle plantarflexion whole body elevation

Measurement and test procedures.

On the first visit to the laboratory, blood samples were obtained and blood pressure (BP), body anthropometry and composition, oral glucose tolerance and mental well-being were assessed. Participants were required to refrain from alcohol and exercise for 48 h preceding the first test day and to report to the laboratory after an overnight fast at ~08:00.

Blood sampling and blood pressure assessment. After arriving at the laboratory, resting seated HR and BP were measured following the participant sitting quietly for ten min. BP was measured five times using a semi−automated device (Dinamap Pro 100V2, GE Medical Systems Information Technologies 2002, Tampa, Florida, USA) with the mean of the final three measurements used to determine resting systolic and diastolic BP. Mean arterial pressure (MAP) was subsequently calculated as (1/3 x systolic pressure) + (2/3 x diastolic pressure). Thereafter, 4 mL of whole blood was drawn from an antecubital vein into serum separator tubes (Vacutainer, Becton-Dickinson, NJ, USA) and left to clot for 45 min at room temperature. Samples were then centrifuged at 1300 RCF for 10 min and serum supernatants were removed and stored at -80˚C for later analysis.

Samples were analysed using an automated analyser (Roche Modular P-module, Roche Diagnostics, Indianapolis, IN) for [High-density lipoprotein cholesterol] (HDL) (CV 2.1%), total [cholesterol] (TC) (CV 2.3%) and [triglycerides] (CV 2.4%). [Low-density lipoprotein cholesterol] (LDL) was derived using the Friedewald formula (Friedewald, Levy, & Fredrickson, 1972).

Body anthropometry. Height (Seca stadiometer SEC-225; Seca, Hamburg, Germany), body mass (Seca digital column scale SEC-170, Seca, Hamburg, Germany), body mass index (BMI, in kg/m^2) and waist-to-hip ratio were obtained prior to testing.

Body composition. Quantification of visceral and abdominal adipose fat was undertaken via magnetic resonance imaging (MRI) scans (1.5T Intera scanner, Philips (The Netherlands)). A series of 8 mm slices (2mm x 2 mm in-plane resolution), with 2 mm gap, were acquired centred around L3 (Demerath et al., 2007). A fast gradient echo sequence was utilised with water suppression via a frequency selective binomial excitation in order to obtain fat selective images. Fat quantification for each slice was undertaken using software present within the scanner package based on intensity windowing such that only voxels containing fat were included. Measurements were carried out to determine a cross-sectional area of separate subcutaneous and visceral fat components within a single slice at L3 and volumes over five slices centred around L3.

Oral glucose tolerance test (OGTT). Following the assessment of body composition, participants provided a capillary blood sample for fasting plasma [glucose] and [haemoglobin]. Participants then consumed 75 g of glucose in 300 mL of water with capillary blood samples collected at 30, 60, 90 and 120 min for assessment of plasma [glucose] using a YSI 2300 glucose and lactate analyser (Yellow Springs Instruments, Kent, UK). Throughout the 2 hr OGTT, participants remained in the laboratory completing only sedentary activities. Changes in plasma [glucose] during the OGTT were quantified using total area under the curve (tAUC) analyses employing the trapezium rule (GraphPad Prism, San Diego, CA, USA).

Warwick-Edinburgh Mental Wellbeing Scale. During the OGTT, participants' subjective mental well-being was measured using the 14-item Warwick-Edinburgh Mental Well-being Scale (WEMWBS) (Tennant et al., 2007). WEMWBS was scored by summing responses (i.e. 1 = none of the time to 5 = all of the time) to each of the 14 items. Permission to use WEMWBS was granted by the University of Warwick. Higher scores were related to increased well-being.

During visit 2, participants were asked to wear a HR monitor (Polar RS400, Polar Electro Oy, Kempele, Finland) and were familiarised to the training intervention so they could exercise safely and correctly at home. Prior to familiarisation, participants completed a submaximal version of the Yo-Yo Intermittent Endurance Level 1 test (YYIE1). This required participants to complete the first six 20-m shuttle runs of the YYIE1. After each 40-m run, the participants had a 5-s active recovery period during which they walked 2 x 2.5 m. The YYIE1 was used as a warm up but also to determine whether sub-maximal exercising HR was impacted by the 12-wk intervention on completion of this session, participants were provided with a training diary, exercise DVD and a recordable HR monitor (Polar RS400, Polar Electro Oy, Kempele, Finland) which they were asked to wear during all training sessions. A typical HR trace of a single training session from wks 0-6 (A) and 7-12 (B) can be seen in Figure 1. Participants were also asked to record ratings of perceived exertion (RPE, 10-point scale) after every session.

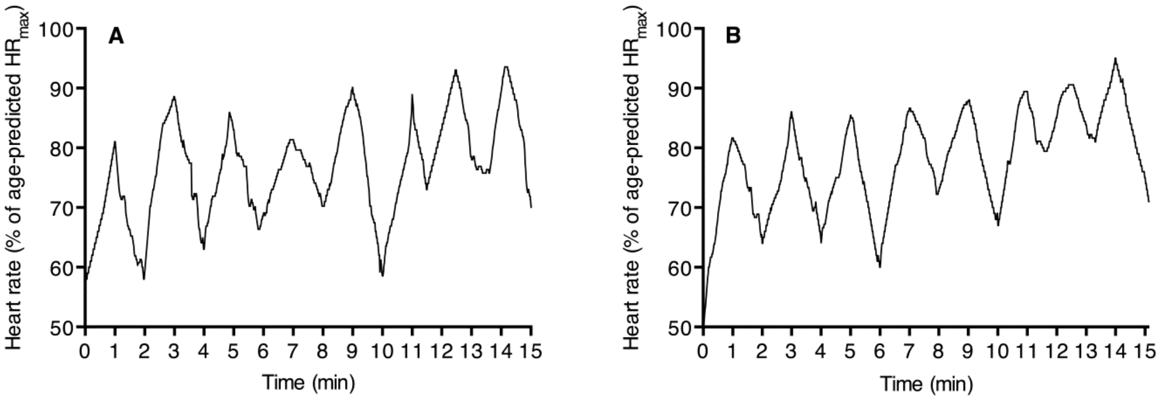

Figure 1. Actual heart rate during a single level 1 (A) and level 2 (B) training session for a single participant from the home-based DVD-directed exercise group

Statistics

Data were analysed using the Statistical Package for the Social Sciences (SPSS v23. SPSS Inc., Chicago, IL, USA). Mean differences between groups at baseline were tested using a one-way analysis of variance (ANOVA). A two-factor mixed-model ANOVA design was used to test for group (DVD *versus* CON) and time (pre-intervention *versus* post-intervention) main effects and group × time interaction effects for all variables apart from the 2-h OGTT. Responses to the OGTT data were analysed using a three-factor mixed-model ANOVA design, with the factors 'group' (DVD *versus* CON), 'time' (pre-intervention *versus* post-intervention) and 'duration' (0, 30, 60, 90 and 120 min). Effect size was calculated using partial η^2 with 0.01, 0.06 and 0.14 regarded as small, moderate and large effects (Cohen, 1988). Where ANOVAs revealed significant differences, post hoc comparisons were undertaken with the α-level adjusted using a Bonferroni correction. The significance level was set at $P<0.05$. Data are reported as mean ± SD.

Results

Training Data. The DVD group completed a total of 36 ± 1 training sessions over the 12-wk period, corresponding to 2.9 ± 0.4 sessions per wk equivalent to 45 min per wk. Home-based mean session HR during 0-6 wks (74 ± 4 % HR_{max}) was significantly lower ($P<0.01$) compared to 7-12 wks (77 ± 3 % HR_{max}). The mean HR during the baseline supervised laboratory-based session was not significantly different to the home-based sessions during wks 0-6 (78 ± 8 vs 74 ± 4 % HR_{max}, $P>0.05$), however, mean HR during the 12th wk supervised laboratory-based session was significantly higher ($P<0.01$) than the home-based sessions during wks 0-6 (83 ± 5 vs 74 ± 4 HR_{max}) and 7-12 (83 ± 5 vs 77 ± 3 %) (Table 3). In addition, the mean HR during the 6th wk laboratory-based follow-up session was significantly higher than the home-based sessions during wks 7-12 (81 ± 4 vs 77 ± 4 % HR_{max}, $P<0.01$). HR_{max} achieved during the supervised laboratory-based sessions at 0, 6 and 12 wks was 94 ± 6, 97 ± 2 and 95 ± 4 % HR_{max}. HR_{max} achieved during the home-based training sessions was not significantly different when comparing 0-6 and 7-12 wks (92 ± 2 and 93 ± 2 % HR_{max}, $P>0.05$). RPE during the first 6 wks (Level 1 DVD, RPE: 7 ± 2) was not different ($P>0.05$) to the following 6 wks (Level 2 DVD, RPE 7 ± 1). HR during the last 15 s of the submaximal YYIE1 was not significantly different after 6 and 12 wks of training (*P*>0.05) compared to baseline (Table 3).

Table 3. Heart rate and RPE data during DVD-directed exercise training intervention

	DVD (*n* = 12)
Mean single supervised session HR (%HR$_{max}$)	
- Baseline	78 ± 8
- 6 wk follow up	81 ± 4
- 12 wk follow up	83 ± 5
Mean home-based training HR (%HR$_{max}$)	
- 0-6 wks	74 ± 4*
- 7-12 wks	77 ± 4$^{\$†}$
Submaximal Yo-Yo IE1 HR (%HR$_{max}$) (final 15 s)	
- Baseline	83 ± 7
- 6 wk follow up	81 ± 7
- 12 wk follow up	80 ± 4
Mean training RPE	
- 0-6 wks	7 ± 2
- 7-12 wks	7 ± 1

Values are expressed as mean ± SD. HR: heart rate, RPE: rating of perceived exertion, IE1: Intermittent Endurance level 1. * denotes significant difference between mean heart rate during first 6 wks of home-based training compared to supervised follow up session at 6 wks. $^{\$}$ denotes significant difference between mean heart rate during final 6 wks of home-based training compared to supervised follow up session at 12 wks. † denotes significant difference between home-based mean HR during 0-6 and 7-12 wks

Body anthropometry. There were no interaction effects for body mass, BMI or waist-to-hip ratio (*P*>0.05, Table 4). Subcutaneous and visceral fat were not different following the intervention period in either the DVD or CON groups (*P*>0.05, Table 4).

Resting blood pressure and heart rate. Resting BP, MAP and HR were not different following the intervention period in the DVD or CON groups (*P*>0.05, Table 4).

Fasting blood [glucose] and oral glucose tolerance test. Fasting blood [glucose] was unchanged in the DVD and CON groups after the 12 wk intervention period (*P*>0.05, Table 4). A main effect of duration was apparent for all three groups during the OGTT (*P*<0.01), however, there were no time × group, duration × group, time × duration or time × duration × group interactions with regards to the blood [glucose] during the OGTT (Figure 2) and the blood [glucose] tAUC (*P*>0.05, Table 4).

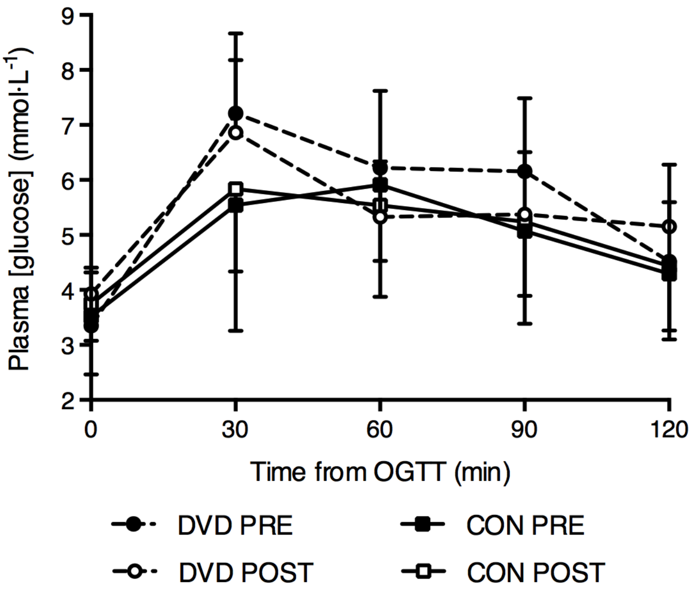

Figure 2. Plasma [glucose] response following the oral glucose tolerance test (OGTT) displayed over time for the DVD-directed exercise (DVD) and control (CON) group before and after the 12-wk intervention. Data are mean ± SD.

Serum lipids and haemoglobin. [Haemoglobin], T[C], TC/HDL ratio, [LDL] and [triglycerides] were unchanged following the 12 wk intervention (P>0.05, Table 4). However, there was a main effect for group (P<0.05) and a tendency for a time × group interaction for HDL (P=0.06, Table 4). Post hoc analyses revealed that, following the DVD intervention, HDL was higher than CON (P<0.05). Post hoc analyses also revealed a significant improvement in HDL/LDL ratio following the DVD intervention compared to CON (P<0.05).

Warwick-Edinburgh Mental Wellbeing Scale. There was a tendency for a time × group interaction (P=0.06) with post hoc analysis revealing that mental well-being was higher in the DVD group compared to the CON group following the intervention period (P<0.01, Table 4).

Table 4. Outcome measures pre and post 12-week intervention.

	DVD (*n*=12)		**CON (*n* = 12)**		**Interaction effect**	
	Pre	**Post**	**Pre**	**Post**	***P***	**Partial η^2**
Body mass (kg)	66.1 ± 14.5	66.9 ± 15.3	72.9 ± 19.5	73.1 ± 19.5	0.485	0.022
BMI (kg/m^2)	23.7 ± 5.0	24.0 ± 5.1	28.2 ± 6.2	27.4 ± 6.8	0.074	0.138
Waist-to-hip ratio	0.26 ± 0.07	0.82 ± 0.04	0.86 ± 0.09	0.87 ± 0.04	0.646	0.012
Subcutaneous fat			*n = 9*	*n = 9*		
Single (cm^2)	179 ± 121	180 ± 122	324 ± 170	313.7 ± 164	0.263	0.066
Volume (cm^3)	905 ± 610	902 ± 602	1649 ± 832	1572 ± 829	0.188	0.089
Visceral fat			*n* = 9	*n* = 9		
Single (cm^2)	54 ± 53	58 ± 58	93 ± 63	99 ± 70	0.745	0.006
Volume (cm^3)	288 ± 297	274 ± 281	461 ± 308	479 ± 330	0.353	0.046
Resting systolic BP (mmHg)	113 ± 16	112 ± 17	114 ± 16	117 ± 22	0.453	0.029
Resting diastolic BP (mmHg)	70 ± 10	70 ± 11	70 ± 10	70 ± 11	0.864	0.001
MAP (mmHg)	85 ± 11	84 ± 12	86 ± 10	88 ± 14	0.569	0.016
Resting HR (bpm)	71 ± 12	67 ± 8	72 ± 15	69 ± 11	0.865	0.001
Fasting [glucose] (mmol/L)	3.7 ± 0.8	3.9 ± 0.5	3.7 ± 1.0	3.7 ± 0.7	0.659	0.009
tAUC (mmol/L*120 min)	700 ± 110	663 ± 90	613 ± 198	621 ± 99	0.375	0.036
Hb (g/L)	132 ± 13	133 ± 13	134 ± 7	131 ± 8	0.462	0.027
TC (mmol/L)	4.67 ± 1.61	5.04 ± 0.68	4.44 ± 0.70	4.71 ± 0.52	0.849	0.002
HDL-C (mmol/L)	1.83 ± 0.45	1.94 ± 0.46	1.54 ± 0.43	1.49 ± 0.35	0.064	0.147
LDL-C (mmol/L)	3.07 ± 0.76	2.84 ± 0.74	2.70 ± 0.65	3.01 ± 0.57	0.095	0.127
TC/HDL ratio	2.80 ± 0.59	2.57 ± 0.58	2.63 ± 1.07	2.88 ± 1.22	0.108	0.118
HDL/LDL ratio	0.7 ± 0.4	0.8 ± 0.3	0.6 ± 0.3	0.5 ± 0.2	0.131	0.105
TG (mmol/L)	0.73 ± 0.27	0.75 ± 0.30	0.98 ± 0.57	1.02 ± 0.59	0.938	0.000
WEMWBS	55 ± 4	58 ± 6	52 ± 4	51 ± 6	0.056	0.156

Vales are expressed as mean ± SD. P values for interaction (group × time) effect. Partial η^2 value for effect sizes. BMI: body mass index, BP: blood pressure, Hb: [haemoglobin], HDL-C: [high density lipoprotein cholesterol], HR: heart rate, LDL-C: [low density lipoprotein cholesterol], MAP: mean arterial pressure, tAUC: total area under the curve, TC: [total cholesterol], TG: [triglycerides], WEMWBS: Warwick-Edinburgh Mental Well-being Scale.

Discussion

The main original findings from the present study were that a home-based, DVD-directed exercise training intervention, which involved bouts of multiplanar whole-body accelerations and decelerations, improved [HDL cholesterol], HDL/LDL ratio and mental well-being in inactive premenopausal women. However, [LDL cholesterol], [triglycerides], fasting [glucose], body composition and resting BP and HR were unchanged following the DVD training intervention. These findings suggest that small-volume, unsupervised, home-based training instructed via a DVD has the potential to initiate positive exercise changes in previously inactive women and might represent a time-efficient strategy to improve aspects of health.

In the present study, 12 wks of home-based, DVD-directed exercise, comprising 3 weekly sessions of 15 min, increased [HDL cholesterol] by 0.11 mmol/L and improved HDL/LDL ratio with no change in the CON group. This is in line with reports suggesting that HDL cholesterol is the constituent of the lipid profile which is most likely to improve following physical activity (Mann et al., 2014). This is important as increased [HDL cholesterol] affords protection from CHD (T. Gordon, Castelli, Hjortland, Kannel, & Dawber, 1977). Moreover, the magnitude of the [HDL cholesterol] improvement in the DVD group is likely to be of clinical significance as every 0.026 mmol/L increase in [HDL cholesterol] corresponds to a 2-3% reduction in CHD prevalence (D. J. Gordon et al., 1989). The improvement in HDL following 3 weekly sessions of 15 min conflicts with previous studies reporting no improvement in [HDL cholesterol], as well as [TC], TC-HDL ratio, [LDL cholesterol] and [triglycerides], following intermittent exercise of a similar intensity but longer duration (Barene et al., 2014; Cugusi et al., 2016; Krishnan et al., 2015). However, our finding of improved serum [HDL cholesterol] after the home-based exercise training intervention in the current study is consistent with studies reporting improvements in the blood lipid profile of previously inactive women after completing a small-sided football training intervention (Krustrup, Hansen, Randers, et al., 2010). A common feature of our training intervention and the football training (Krustrup et al., 2010) is the incorporation of numerous accelerations and decelerations. These exercise patterns might provide a potent stimulus for upregulating anti-inflammatory and antioxidant pathways leading to a reduction in [HDL cholesterol] oxidation to LDL cholesterol (Dekleva, Lazic, Arandjelovic, & Mazic, 2017; Kannan et al., 2014).

Although not measured in the present study, mechanisms for increased [HDL cholesterol] may be related to increases in lipoprotein lipase activity (LPL) and lecithin-cholesterol acyltransferase (LCAT) which is activated by apolipoprotein A-I (Kwiterovich, 1998; Mann et al., 2014). Therefore, the present results suggest that exercising for ~ 48 min per wk, which is lower than the recommended guidelines (Department of Health, 2011), has the potential to improve serum [HDL cholesterol]. However, while participants completed food diaries in the first and final wk of the intervention and these were consistent, diet was not directly controlled for the entire intervention so it cannot be excluded that a portion of the improvement in [HDL cholesterol] might be linked to changes in diet.

Mental well-being, as assessed by the WEMWBS, was improved following the 12-wk home-based exercise training intervention with no change apparent for the CON group. This is of interest as improved mental well-being through physical activity has been linked to an improved quality of life (Gillison, Skevington, Sato, Standage, & Evangelidou, 2009), with individuals less likely to suffer clinical depression, anxiety and psychological distress (Fox, 1999). There is also evidence that dance and/or intermittent-based exercise interventions can improve quality of life (Cugusi et al., 2016; Donath, Roth, Hohn, Zahner, & Faude, 2014). However, since these interventions have been administered within a group setting, it is difficult to establish whether the exercise itself or the enhanced social environment led to improvements in quality of life. Notwithstanding the positive effects of exercising in a group setting in certain population groups, persuading inactive individuals to participate in group activities may present some challenges. Indeed, when 2,912 women aged ≥ 40 years were questioned on their preferred exercise setting, 62 % of respondents rated exercising alone with instruction as more appealing than undertaking exercise in an instructor-led group (King et al., 2000). Although exercising on a one-to-one basis is the most popular choice for inactive individuals starting out with exercise (Daley et al., 2011), one-to-one sessions with a personal trainer are costly. The present study suggests that limited face-to-face consultations in combination with telephone communication may be a cost-effective approach to maintain participation in exercise and improve mental well-being. It should be acknowledged, however, that the request for participants to wear a HR monitor during all training sessions may have also influenced training adherence as participants were aware that this would indicate to the researchers whether a given training session had been completed or not

In the present study, DVD-directed exercise training did not impact body mass, BMI, waist-to-hip ratio or subcutaneous or visceral fat. Similarly, Juneau et al. (1987) reported no change in body mass following a 6-month, self-monitored, home-based exercise intervention for middle-aged women (47 y) who completed moderate-intensity exercise (65-77 % of HR_{max}) 5 times weekly for ~ 54 min per session. Conversely, modest reductions in waist and hip circumferences, as well as reductions in total fat mass, have been reported following 12-16 wks of dance-related exercise conducted 2-3 times per wk in overweight women (39-51 y) (Barene et al., 2014; Cugusi et al., 2016; Krishnan et al., 2015). The lack of change in body mass in the present study compared to previous studies reporting improvements in body mass following home-based exercise interventions (Barene et al., 2014; Cugusi et al., 2016; Krishnan et al., 2015) may be due to a larger body mass (71-94 vs 66 kg) prior to the intervention, longer session durations (60 vs 15 mins) or longer training programmes (40 vs 12 wks) compared to the current study. However, it is also possible that completing the exercise intervention at home influenced the level of effort and energy expenditure in a given session compared to exercise completed under supervision and/or in a class setting. For example, the mean HR during wks 7-12 (level 2) of home-based training was 7 % lower compared to the supervised 12th wk follow-up session (level 1) even though the exercise regimen of level 2 was intended to be more challenging as reflected by the significantly higher mean HR during wks 7-12 compared to wks 0-6. As resting HR did not change following the training intervention, an increase in stroke volume is unlikely to be responsible for this effect. In addition, mean HR was higher for the 6th wk follow up session (level 2) compared to the home-based sessions during wks 7-12 (level 2). Consistent with this, it has been reported that energy expenditure (6.8 ± 0.9 vs 5.6 ± 0.9 $kcal \cdot min^{-1}$) and time spent about 85 % of HR reserve (14.7 vs 1.7 %) were higher during Zumba classes compared to a Zumba DVD performed at home. Therefore, it is possible that the energy expenditure, and the potential for body composition changes, may have been increased in the present study if the intervention had been administered under supervision or in a group environment.

There were no changes in resting HR, systolic and diastolic BP, and MAP following the DVD and CON interventions in the current study. This lack of an effect of the DVD-directed exercise training intervention on these cardiovascular health markers might be linked to the normal values observed at baseline. Indeed, baseline values for systolic and diastolic BP were 113/70 for DVD training group and it has been reported that resting BP and HR are not impacted following 12 wks of home-based dance/intermittent exercise interventions when BP values are normal at baseline (Barene et al., 2014; Connolly et al., 2014). Similarly, no changes in fasting blood [glucose] and blood [glucose] responses during the OGTT were evident following the 12-wk intervention for the DVD and CON groups. Again, this might be a function of fasting [glucose] values being within the normal range. Similarly, no change in fasting [glucose] was reported by Krishnan et al. (2015) following dance based exercise in participants with baseline values of 6.5 mmol/L. However, while the home-based, DVD-directed exercise training intervention administered in the current study did not improve body composition, cardiovascular health markers and blood [glucose] regulation in the relatively healthy premenopausal women who participated in the current study, further research is required to assess whether this method of exercise training has potential therapeutic value in individuals with obesity, hypertension, insulin resistance and other NCDs. It is also unclear whether greater benefits can be achieved if the duration of the individual sessions and/or the intervention period is extended or if training under direct supervision can provide additional health benefits due to the higher training HR compared to independent home-based training. Moreover, further research is required to establish the mechanisms for the improvements in blood [HDL cholesterol] and mental well-being following this novel, home-based exercise intervention and how the monitoring of HR during all training sessions and frequent correspondence with participants may have impacted adherence to the training intervention and the amount of effort the participants were willing to expend in each session. Notably, the participants willingly volunteered to take part in the present study but a key challenge is to engage ‘harder-to-reach’ groups in physical activity.

In conclusion, the present study demonstrated that a novel, home-based, DVD-directed exercise training programme can improve blood [HDL cholesterol] and mental well-being in previously inactive premenopausal women. Furthermore, the high adherence to the 12-wk intervention suggests that this type of training is an acceptable exercise modality for previously inactive premenopausal women. However, it was not effective at improving resting BP and HR, blood glucose regulation or body composition. Therefore, our results suggest that a DVD-directed, home-based exercise training intervention, which was associated with high levels of adherence, can improve some aspects of health in premenopausal women but may be less effective than supervised training interventions within a gym/laboratory environment or recreational football training. These data might have implications for improving the health profile of previously inactive premenopausal women.

Acknowledgements: The authors would like to thank the participants for their outstanding efforts and perseverance throughout the testing and intervention period. The authors would also like to thank the Royal Devon and Exeter NHS Foundation Trust for their analytical help. The study was supported by FIFA-Medical Assessments and Research Centre (F-Marc) and Nordea-fonden.

Chapter 8

General Discussion

8.1 Overview

From a public health perspective, it is well known that participation in regular exercise is a beneficial behaviour. Although there is a wealth of descriptive literature demonstrating that various chronic exercise interventions can reduce the risk for a number of NCDs (Garber et al., 2011), levels of exercise participation remains poor (Townsend, Wickramasinghe, et al., 2015). Since physical inactivity increases NCD risk factors, and there is abundant epidemiological evidence of a relationship between sedentary and inactive behaviours and NCD risk, there is a clear benefit to regular participation in exercise. Consequently, there is a requirement not solely to establish the impact of exercise upon risk factors for health, but also to examine exercise regimes and modalities which may help to promote motivation to exercise and exercise adherence. In particular, many researchers have focussed on overcoming the commonly reported 'time limitation to undertake exercise' barrier by the general population.

The primary aim of this thesis was to implement and assess the efficacy of a series of novel short duration high-intensity exercise investigations to improve a range of health markers in previously inactive premenopausal women. In addition, several HIIT programmes were compared to more conventional continuous exercise training. Collectively, the experimental chapters in this thesis provide a significant contribution to understanding in this field and offer important novel information regarding the potential prevention of several NCD risk factors in inactive premenopausal women. This general discussion chapter will briefly summarise the key findings from the four experimental chapters, place these findings into context within the existing literature in this field and highlight the practical implications of this work as well as avenues for future research.

8.2 Summary of experimental chapters

8.2.1 Chapter 4

The purpose of this experimental chapter was to investigate the effects of 16 wks of small-volume, small-sided football training and WBV training on the body composition of previously inactive premenopausal women between the ages of 20-45 y. The study also investigated the effects of small-sided football on aerobic fitness while muscle PCr kinetics was assessed following both training interventions. At the time of the investigation, no study had implemented such a short duration of football training (twice-weekly 13.5 min sessions) for inactive premenopausal women and compared these adaptations with WBV training. It was found that, following 16 wks of football training, body fat percentage was lowered and PCr depletion was attenuated at a given isotime during one-legged knee extensor incremental exercise which is consistent with the reduction of HR during standardised submaximal exercise. No such benefits were reported following 16 wks of WBV training. This study is the first to report data comparing two popular training interventions easily accessible by premenopausal women and suggest that small-volume, small-sided football training, but not WBV training, may have important health implications for previously inactive premenopausal women.

8.2.2 Chapter 5

Chapter 5 examined the effect of low volume high-intensity interval swim training on glucose control and insulin sensitivity in inactive middle-aged premenopausal women with mild hypertension and compared these responses to a high volume continuous swim training group. At the time of investigation, no study had directly compared high-intensity swim training and prolonged continuous swim training in premenopausal women with mild hypertension. The strengths of this study include the use of a unique population, who manifest heightened risk factors for future compromised health and incorporating an exercise modality easily accessible for premenopausal women without weight-bearing activity. The number of participants and high adherence rate is also a strength of this study and the adoption of the similar land-based HIIT protocols such as Burgomaster, Heigenhauser, and Gibala (2006) and Gibala et al. (2006) also helped to facilitate between-study comparisons. The data from this study indicate that high-intensity interval swim training may be more effective than continuous lower-intensity swim training. Superior results following HIIT were apparent for reducing resting plasma [insulin], [glucose] and [insulin] during an OGTT, tAUC for plasma [glucose] and there was an improvement in insulin sensitivity. Considering similar adherence rates between the two training groups, high-intensity swim training may be an attractive and feasible alternative to traditional continuous swim training to improve the health profile of middle-aged premenopausal women with mild hypertension. These observations built on the previous chapter by providing evidence of an alternative short-duration HIIT programme which was beneficial for several aspects of health for previously inactive, mildly hypertensive premenopausal women. Chapter 5 also demonstrates that HIIT is not only beneficial in the form of land-based exercise but can also be successfully implemented using non weight-bearing water-based exercise.

8.2.3 Chapter 6

The purpose of this study was to examine the effects of 12 wks of self-paced high-intensity interval cycling training in comparison to continuous cycling training on a number of health markers in previously inactive premenopausal women. The HIIT protocol was based on the 10-20-30 running intervention devised by Gunnarsson and Bangsbo (2012). Findings from the present study revealed that, in an inactive group of premenopausal women, 12 wks of HIIT or continuous training improved $\dot{V}O_{2peak}$, resting HR and visual and verbal learning with these adaptations achieved for a lower time commitment with HIIT. However, some adaptations were training-type-specific with total body mass, submaximal walking HR and verbal memory improvements observed following HIIT whereas systolic BP, MAP and mental well-being improvements were improved following continuous training. Interestingly, the self-selected exercise intensity by the participants in the continuous training group was similar to that of the HIIT group which suggests some individuals may be misinterpreting physical activity guidelines. Given the similarities in enjoyment and adherence, it could be suggested that premenopausal women participate in either self-selected HIIT or CT to improve several aspects important health markers. The findings built upon the previous chapter by demonstrating that non weight-bearing HIIT can also be successfully implemented through the use of cycle ergometers for previously inactive premenopausal women who are able to self-select their exercise intensity. Additionally, the health benefits were achieved even though the total duration of 'all-out' exercise was 50 % lower compared to Chapter 5.

8.2.4 Chapter 7

The purpose of this study was to extend the work performed in Chapter 6 and provide insight into how the 10-20-30 training concept devised by Gunnarsson and Bangsbo (2012) could be modified and used in a DVD-directed home-based setting to improve the health profile of previously inactive premenopausal women. The exercise DVD, as produced and used by Scott (2014), incorporated bouts of varying-intensity multi-planar whole-body accelerations and decelerations as seen in the football training in Chapter 4 and in previous studies of football training for inactive women (Krustrup, Hansen, Andersen, et al., 2010; M. T. Pedersen et al., 2009). Movements selected for the choreography included 90˚, 180˚, 270˚ and 360˚ turns, jumps, and stops. Also included were episodic movements evaluated in four different football match analysis systems (Randers, Nybo, et al., 2010) slow-, intermediate-, high-speed and backwards- running, walking sideways and backwards, and side-cutting. This investigation was the first to use this novel exercise training concept as a 12-wk intervention for previously inactive premenopausal women. Findings from this study showed that this training method was able to improve [HDL cholesterol] and mental well-being of the individuals compared to a control group who continued their normal daily lives. As training adherence was high, these findings suggest that the use of a population-specific home-based exercise DVD may be a useful exercise modality to improve exercise adherence and some aspects of health in inactive premenopausal women.

8.3 Summary of key outcome variables

This section collates the outcomes from the experimental chapters and places these observations into context within the existing literature.

Plasma [glucose], [insulin] and insulin sensitivity

Experimental chapters 5, 6 and 7 included the measurement of plasma [glucose] with the additional measure of [insulin] and insulin sensitivity in Chapter 5 (Table 8.1). Fasting plasma [glucose] did not significantly change for any group in Chapters 5, 6 and 7 following the various training interventions. However, this is not unexpected due to the normal values at baseline (mean group range: 3.48-4.90 mmol/l) which is in agreement with a number of similar exercise training studies for premenopausal women outlined in Tables 2.8 and 2.14 of a similar session duration with normal baseline plasma [glucose] following a MICT (Ciolac et al., 2010; Kong, Sun, et al., 2016; Ross et al., 2004) or HIIT (Ciolac et al., 2010; Kong, Sun, et al., 2016) intervention.

Experimental Chapters 5, 6 and 7 also included an OGTT. Chapter 5 reported a 10 % reduction in [glucose] for the HIIT group after 60 min of the OGTT compared to pre-intervention, however, no such change was apparent for any other training group within those 3 chapters. Surprisingly, the 60 min baseline value was only 6.1 mmol/l which was the lowest of all training groups at this time point. Accordingly, only the HIIT swim training group had a reduction in glucose tAUC following the training period whereas no significant changes in glucose tAUC were apparent for any other training group. It could be speculated that the longer duration 'all-out' bouts incorporated into the swimming intervention (30 s) induced further metabolic benefits compared to the 10 s 'all-out' efforts incorporated in Chapters 6 and 7. Similarly, Metcalfe et al. (2016) reported suppressed benefits during an OGTT following reduced-exertion HIIT when sprint resistance was reduced from 7.5 % to 5 % of body mass. It could be speculated that the longer duration 30 s 'all-out' swimming bouts in Chapter 5 could induce higher rates of glycogen breakdown and subsequent resynthesis compared to the shorter duration 10 s 'all-out' efforts in Chapter 6 and 7 leading to improvements in glucose tolerance in the former compared to the latter (Metcalfe et al., 2012). The improvements in glucose tolerance following high-intensity interval swim training may be improved by increased skeletal muscle glucose transport capacity, mediated in part by the glucose transporter protein, GLUT4 (Brozinick, J, Yaspelkis, & Ivy, 1994; Gibala et al., 2012; Hansen et al., 1995). Following 2 wks of HIIT, GLUT4 has been shown to increase around 2-fold and average 24 h blood glucose concentration and postprandial glucose excursions are reduced in support of a key role of GLUT4 on glucose disposal (Little et al., 2011).

Although no changes in fasting plasma [glucose] were reported, Chapter 5 did report a 17 % reduction in fasting plasma [insulin] post-training in the high-intensity swim group. In addition, similar to the [glucose] response during the OGTT's, only the high-intensity interval swimming group from Chapter 5 reported a reduction (24 %) in [insulin] after 60 min of the OGTT, whereas no significant changes were apparent for any other training group. In turn, insulin sensitivity, as measured using HOMA-IR, was improved by 22 % following the exercise intervention. This is important as an increase in insulin sensitivity following exercise may reduce the incidence of age-related chronic conditions including hypertension, CHD, stroke and cancer (Facchini et al., 2001) and with each 500 kcal/wk increase in physical activity, the risk of T2D is reduced by ~9 % (Helmrich et al., 1991). This improvement is similar to previous land-based HIIT interventions in premenopausal women (Ciolac et al., 2010; Trapp et al., 2008). Although previous MICT interventions have also resulted in improvements in insulin sensitivity in premenopausal women (Ciolac et al., 2010; Trapp et al., 2008; Wiklund et al., 2014), this was not the case in Chapter 5 of the current thesis. Previous studies have shown that women break down up to 42 % less glycogen in type 1 muscle fibres during a typical "all-out" 30 s sprint (Esbjornsson-Liljedahl et al., 2002; Esbjornsson-Liljedahl et al., 1999), a finding which is supported both by the smaller excursion in blood lactate (Esbjornsson-Liljedahl et al., 2002; Gratas-Delamarche et al., 1994), and a greater contribution of aerobic metabolism to ATP demand (D. W. Hill & Smith, 1993) in women during sprint exercise. However, it could be speculated that the improvement in insulin sensitivity reported in Chapter 5 could be due to the exercise modality. As mentioned in Chapter 5, front-crawl swimming primarily taxes the upper body muscles (as well as working the lower limb muscles), which have a lower baseline training status compared to the legs which may lead to a higher training adaptation potential (Nordsborg et al., 2015).

Several mechanisms induced by exercise may contribute to increased insulin sensitivity, including increases in GLUT4, which has been shown to be responsible for insulin-stimulated and contraction-induced glucose uptake (Daugaard & Richter, 2001), as well as reductions in fatty acid mobilization (Santomauro et al., 1999; Schenk, Harber, Shrivastava, Burant, & Horowitz, 2009), and counteraction of lipid-induced insulin resistance (Little et al., 2011; Schenk et al., 2009). Increased GLUT4 expression has been reported following just one wk of SIT (Burgomaster et al., 2007). In addition, the same participants from chapter 5 (as shown by Nordsborg et al. (2015)) reported a 63 % increase in muscle glycogen of the deltoideus muscle following the high-intensity swim training intervention. This is suggestive of a greater drive for glycogen synthesis (Burgomaster et al., 2005; Gibala et al., 2006) which might play an important regulatory role in increasing insulin sensitivity.

Table 8.1 Percentage change in fasting [glucose] and [insulin] following the intervention periods related to Chapters 5, 6 and 7.

		Fasting [glucose]	**Fasting [insulin]**
Chapter 5	HIIT	↓ 1 ± 5 %	↓ 17 ± 34 %*
	CT	↓ 3 ± 13 %	↑ 3 ± 28.4 %
	CON	↑ 1 ± 10 %	↑ 4 ± 44 %
Chapter 6	HIIT	↑ 4 ± 16 %	X
	CT	↓ 1 ± 13 %	X
	CON	↑ 11 ± 22 %	X
Chapter 7	DVD	↑ 11 ± 28 %	X
	CON	↑ 10 ± 29 %	X

Abbreviations: CT: continuous training group, CON: control group, DVD: DVD-directed training group, HIIT: high-intensity interval training group. * Significant difference between pre and post intervention

Fasted serum lipids

Fasted serum lipids were assessed in Chapters 6 and 7 (Table 8.2). The fasted serum lipid profile of the participants in Chapter 6 did not change following the training interventions. This is in agreement with a number of similar HIIT and MICT studies for premenopausal women which are outlined in Tables 2.9 and 2.15 (Ciolac et al., 2010; Kong, Fan, et al., 2016; Krustrup, Hansen, Randers, et al., 2010; Wiklund et al., 2014). This may be due to the normal lipid profile levels at baseline. However, this was not the case for Chapter 7 where an increase in [HDL cholesterol] was apparent following the training intervention despite the normal level at baseline. As highlighted in Chapters 2 and 7, [HDL cholesterol] is the component of the lipid profile which is most likely to improve following physical activity (Mann et al., 2014).

Improvements in LDL/HDL ratio have been reported in previously inactive women following small-sided football training (Krustrup, Hansen, Randers, et al., 2010). The results presented in this thesis are unable to explain why improvements in [HDL cholesterol] were evident following a home-based DVD-directed exercise intervention (Chapter 7) but not a self-paced cycling training intervention (Chapter 2). However, it could be speculated that a common feature of the training programme of Chapter 7 and small-sided football are the numerous repetitions of high-intensity accelerations and decelerations (M. T. Pedersen et al., 2009). As highlighted in chapter 7, high-intensity accelerations and decelerations might stimulate the upregulation of anti-inflammatory and antioxidant pathways leading to a reduction in HDL cholesterol oxidation. In addition, mechanisms for increased [HDL cholesterol] may be related to increases in lipoprotein lipase activity (LPL) and lecithin-cholesterol acyltransferase (LCAT) which is activated by apolipoprotein A-I (Kwiterovich, 1998; Mann et al., 2014). It could also be speculated that due to the lack of control of diet during the 12 wks, improvements in [HDL cholesterol] in Chapter 7 may be due to variations in diet. Although HDL cholesterol was the only constituent of the lipid profile to improve following exercise, this is still of importance as every 0.026 mmol/L increase in [HDL cholesterol] corresponds to a 2-3 % reduction in CHD prevalence (D. J. Gordon et al., 1989).

Table 8.2 Percentage change in fasting serum lipid profile following the intervention periods related to Chapters 6 and 7.

		Total cholesterol	**HDL**	**LDL**	**Triglycerides**
Chapter 6	HIIT	↑ 3 ± 12 %	↓ 2 ± 9 %	↑ 7 ± 17 %	↑ 5 ± 31 %
	CT	↓ 2 ± 10 %	↓ 4 ± 10 %	↑ 10 ± 22 %	↓ 2 ± 13 %
	CON	↑ 2 ± 6 %	↑ 2 ± 12 %	↑ 4 ± 9 %	↑ 4 ± 16 %
Chapter 7	DVD	↓ 2 ± 13 %	↑ 7± 15 %*	↓ 4 ± 24 %	↑ 7 ± 41 %
	CON	↑ 8 ± 23 %	↓ 2 ± 11 %	↑ 21 ± 59 %	↑ 13 ± 49 %

Abbreviations: CT: continuous training group, CON: control group, DVD: DVD-directed training group, HDL: high-density lipoprotein, HIIT: high-intensity interval training group, LDL: Low-density lipoprotein. * Significant difference between pre and post intervention

Blood pressure and heart rate

The assessment of resting BP and HR was present in Chapters 4, 6 and 7 (Table 8.3). It should also be noted that resting HR and BP were assessed for the participants of Chapter 5 and were published by Mohr, Nordsborg, et al. (2014). The MICT group of Chapter 6 and Mohr, Nordsborg, et al. (2014) reported a decrease in systolic BP by 4 and 3 % with baseline values of 112 and 142 mmHg. In addition Mohr, Nordsborg, et al. (2014) highlighted a 4 % decrease in systolic BP from a baseline value of 138 mmHg following high-intensity interval swimming while no other changes in BP were reported across the studies in the current thesis. A decrease in resting HR was also evident in Chapter 5 following HIIT and MICT (-5 bpm) swimming (Mohr, Nordsborg, et al., 2014) and Chapter 6 following HIIT (-5 bpm) and MICT (-4 bpm) cycling. However, resting HR did not significantly change following training in Chapters 4 and 7. It could be argued that the reduction in systolic BP reported by Mohr, Nordsborg, et al. (2014) is a function of the higher than normal (prehypertension/stage 1 hypertension) baseline values for systolic BP which is in line with a previous HIIT intervention for previously inactive men and premenopausal women with diagnosed MetS (Tjonna et al., 2008). However, it is surprising that a reduction in systolic BP of a similar magnitude was evident in Chapter 6 following continuous cycling training as baseline systolic BP values were normal. This reduction in systolic BP is rarely evident following HIIT interventions for inactive men and premenopausal women with normal baseline BP values (Table 2.17). However, reductions in BP have been reported following MICT interventions for inactive premenopausal women with normal BP at baseline (Dalleck et al., 2008; Krustrup, Hansen, Randers, et al., 2010) as well as those with elevated baseline systolic BP (Shepherd et al., 2015; Tjonna et al., 2008) (Table 2.11). These results are of importance as it has been estimated that a 5 mmHg reduction in systolic BP could lead to 14, 9 and 7 % reduction in stroke, CHD and all-cause mortality (P. K. Whelton et al., 2002).

The reduction in systolic BP following MICT may be a function of a lower sympathetic and increased parasympathetic outflow, consistent with a lower resting HR (Andersen, Randers, et al., 2010). The reduction in systolic BP may also be due to an increased muscular capillarisation and vascular remodelling with a resulting reduction in systemic vascular resistance (Andersen, Randers, et al., 2010). It could also be speculated that the improvement in systolic BP following high-intensity interval swimming is due to the rapid acceleration of HR and stroke volume during square-wave transitions from low- to high-intensity exercise supported by studies on the cardiovascular effects of recreational football training for sedentary (inactive) men (Krustrup, Aagaard, et al., 2010; Krustrup, Hansen, Andersen, et al., 2010; Krustrup et al., 2013) and women (Andersen, Hansen, et al., 2010; Barene et al., 2014).

The lack of improvement following football training in Chapter 4, and following similar movements found in football training in Chapter 7, may well be due an insufficient training duration compared to previous football training studies and because of the normal BP at baseline. In some review articles, it is suggested that low-to-moderate-intensity exercise training interventions are more effective than protocols encompassing high-intensity exercise to reduce systolic and diastolic BP (J. P. Wallace, 2003).

Table 8.3 Percentage change in resting heart rate and systolic and diastolic blood pressure following the intervention periods related to Chapters 6 and 7.

		Systolic BP	**Diastolic BP**	**Resting HR**
Chapter 4	FB	↑ 2 ± 7 %	↑ 2 ± 11 %	↓ 5 ± 5 %
	WBV	↓ 1 ± 10 %	↓ 1 ± 10 %	↓ 1 ± 14 %
	CON	↑ 1 ± 7 %	↓ 1 ± 14 %	↓ 3 ± 4 %
Chapter 6	HIIT	↓ 2 ± 8 %	↓ 2 ± 7 %	↓ 6 ± 7 %*
	CT	↓ 5 ± 5 %*	0 ± 9 %	↓ 6 ± 12 %*
	CON	↑ 1 ± 1 %	↑ 1 ± 5 %	↑ 1 ± 4 %
Chapter 7	DVD	↓ 1 ± 10 %	0 ± 9 %	↓ 4 ± 14 %
	CON	↑ 2 ± 10 %	↑ 2 ± 18 %	↓ 1 ± 22 %

Abbreviations: BP: blood pressure, CT: continuous training group, CON: control group, DVD: DVD-directed training group, FB: football training group, HIIT: high-intensity interval training group, HR: heart rate. * Significant difference between pre and post intervention

Body Composition

Body composition was assessed in Chapters 4, 6 and 7 using DXA scans, BodPod and MRI scans (Table 8.4). Body composition of the participants of Chapter 5 was also assessed and published by Mohr, Nordsborg, et al. (2014) using DXA scans. The studies in this thesis have focused on inactive premenopausal women who in many cases were not overweight or obese. This decision was taken as inactivity, independent of body fatness, is an independent risk factor for both T2D and cardiovascular disease (Li et al., 2006; Rana et al., 2007). In addition, low cardiorespiratory fitness is the strongest predictor of morbidity and mortality (C. D. Lee et al., 1999) and an inactive lifestyle predisposes the individual to low levels of aerobic fitness (Krogh-Madsen et al., 2010). Nevertheless, in the context of a culture where overweight and obesity are ever increasing, and exert major strains on public health care systems, the question as to whether HIIT would be beneficial for the body composition of previously inactive premenopausal women is a pertinent one. In particular, one of the motivations (both personally and clinically) of increasing physical activity in such populations is to aid in the loss of body fat (Bendixen et al., 2002; Teixeira et al., 2010).

A reduction in BF%, android fat mass and fat mass of the trunk was reported following small-sided football training in Chapter 4. In addition, Mohr, Nordsborg, et al. (2014) reported reductions in total body mass, BF% and fat mass (kg) and an increase in lean mass of the participants in Chapter 5 following HIIT and MICT swimming. A small reduction in total body mass was also evident following high-intensity interval cycling whereas body composition did not change following the training period in Chapter 7. Due to variations in equipment used and baseline body composition values of the participants, it is difficult to evaluate across studies. However, it is interesting to note that reductions in BF% were evident for the football group in Chapter 4 following a short duration of exercise where, in most cases, baseline BMI values were classed as normal (Table 2.2). Similarly, reductions in BF% have also been reported following short duration HIIT even though baseline body composition values were reported as normal (Table 2.12). Part of the inclusion criteria for Chapter 5 was a BMI of >25 which would understandably lead to an increased possibility for body composition improvements following both HIIT and MICT swimming.

Although not directly assessed in the current thesis, it has been suggested that the fat loss associated with HIIT may be due to the oscillations in work and rest periods, preventing skeletal muscle metabolism from adapting to the stereotypical high-intensity exercise with glucose being the predominant substrate utilised. It has also been proposed that the work and rest model of HIIT induces substrate partitioning, where glycogen is utilised during the high-intensity work periods, and fat sources contribute to energy production during the passive rest periods (Gillen et al., 2012; Little et al., 2011). Trapp, Chisholm, and Boutcher (2007) proposed that shifts in fat metabolism during HIIT were evident as plasma glycerol and epinephrine concentrations were increased post-exercise where plasma glycerol is reflective of lipolysis while epinephrine is known to stimulate lipolysis. Nevertheless, the use of indirect methods of fat loss and the absence of plasma, muscle and urine metabolic data do not provide a comprehensive metabolic view of substrate utilisation of HIIT compared to continuous exercise. In addition, the amount of total and/or fat-specific calories used during and after HIIT is often greater than that of lower intensity exercise which, following exercise, may result in fat metabolism and resting metabolic rate (RMR) being elevated for up to 24 h (Treuth, Hunter, & Williams, 1996). This acute increase in fat metabolism and RMR will serve to facilitate weight loss (via increased total daily energy expenditure).

The weight loss brought about by exercise alone may not lead to clinically significant improvements. Exercise alone has proven to be a relatively unsuccessful method of achieving a significant body mass reduction compared to other methods. It has been shown that regular exercise participation was associated with maintenance of intentional body mass loss, but exercise on its own produced the smallest body mass changes compared to dietary restriction interventions (Wing & Hill, 2001). This finding has been echoed in several meta-analyses (Franz et al., 2007; Garrow & Summerbell, 1995; Miller et al., 2002) which have all reported that exercise as the sole means of inducing body mass reduction is relatively unsuccessful compared to dietary interventions and pharmaceutical methods aimed at reducing appetite or reducing the amount of fat absorbed by the body. Many medium-term interventions produce a statistically significant, but often not clinically meaningful, body mass reduction, and a dose-response relationship between exercise and body mass change is well documented (Ohkawara, Tanaka, Miyachi, Ishikawa-Takata, & Tabata, 2007; Ross & Janssen, 2001). Indeed, it could be argued that the %BF reduction and weight loss brought about by the football training in Chapter 4 and high-intensity interval cycling in Chapter 6 is not of clinical significance.

It is well established that the extent of weight or fat loss in response to exercise training varies between individuals (Barwell et al., 2009). The extent of compliance to the exercise intervention clearly contributes to this variation (McTiernan et al., 2007). However, even when exercise compliance is accounted for, inter-individual differences in weight and fat loss are observed (N. A. King, Hopkins, Caudwell, Stubbs, & Blundell, 2008). Furthermore, compensatory decreases in non-intervention energy expenditure have been shown to lead to smaller than expected increases in total energy expenditure in response to exercise interventions (Goran & Poehlman, 1992). Potential mechanisms driving these changes, such as exercise-induced alterations in appetite-regulating hormones, have been hypothesised (Hazell, Islam, Townsend, Schmale, & Copeland, 2016). Changes in perceived appetite and desire for food have been identified in overweight and obese individuals who do not achieve predicted body mass reduction during a supervised 12-wk exercise intervention (Finlayson et al., 2011).

Emerging evidence indicates that even a single session of exercise may increase liking, wanting, and perceived reward value of food in some individuals (Finlayson, Bryant, Blundell, & King, 2009; N. A. King et al., 2007). Although the participants in the current thesis were asked to maintain their normal diets, record sheets were only collected periodically throughout the interventions. In addition, increased feelings of fatigue from participation in vigorous activity may result in increased sedentary behaviour outside of exercise sessions (Manthou, Gill, Wright, & Malkova, 2010). Physical activity was not assessed outside of the training sessions for the current participants so it is possible sedentary behaviour could have increased preventing significant improvements in body composition in Chapters 6 and 7. It should also not be discounted that continuous exercise may still be useful for the improvement or stabilisation of body mass in previously inactive premenopausal women evident in Chapter 6 and reported by Mohr, Nordsborg, et al. (2014) for the participants of Chapter 5.

Table 8.4 Percentage change in body composition following the intervention periods related to Chapters 4, 6 and 7.

		Total body mass	**Fat mass**	**Lean mass**	**Body fat %**
Chapter 4	FB	↓ 1 ± 4 %	↓ 5 ± 10 %	↑ 2 ± 3 %	↓ 2 ± 2 %*
	WBV	0 ± 3 %	↑ 2 ± 7 %	0 ± 3 %	0 ± 2 %
	CON	0 ± 3 %	0 ± 8 %	↑ 1 ± 3 %	0 ± 2 %
Chapter 6	HIIT	↓ 1 ± 2 %*	↓ 3 ± 9 %	0 ± 4 %	↓ 1 ± 2 %
	CT	↓ 1 ± 2 %	0 ± 10 %	1 ± 5 %	0 ± 3 %
	CON	↑ 1 ± 1 %	↓ 1 ± 4 %	0 ± 1 %	0 ± 1 %
Chapter 7	DVD	↑ 1 ± 2 %	x	x	x
	CON	↑ 1 ± 2 %	x	x	x

Abbreviations: CT: continuous training group, CON: control group, DVD: DVD-directed training group, FB: football training group, HIIT: high-intensity interval training group. * Significant difference between pre and post intervention

Cardiorespiratory fitness and functional testing

Submaximal HR was assessed in Chapter 4 and 7 using a standardised YYIE1 as well as an assessment of muscle PCr depletion in Chapter 4 through the use of a one-legged knee extensor ramp exercise test using magnetic resonance spectroscopy. Participants of Chapter 5 completed performance testing and this was published by Mohr, Nordsborg, et al. (2014) which included two front crawl swimming tests including a repeated swimming sprint test (4 x 25 m) and a 10 min continuous swimming performance as well as completion of the YYIE1 test. $\dot{V}O_{2peak}$ was assessed in Chapter 6 through the completion of a ramp incremental cycling test to exhaustion as well as a submaximal treadmill walking test (Table 8.5).

The improved performance following the ramp incremental cycling test to exhaustion in Chapter 6 and one legged-knee extensor test to exhaustion in Chapter 4 is indicative of improved functional capacity. This was linked to an improvement in $\dot{V}O_{2peak}$ after HIIT and CT in Chapter 6 and a decrease in PCr depletion for a given work rate during exercise after the football training in Chapter 4. As highlighted in Chapter 4, it is possible that beneficial changes in oxidative capacity might be linked, at least in part, to mitochondrial biogenesis and enhanced muscle perfusion (Delp, 1998). The improved performance after high-intensity swimming intervals as well as moderate-intensity swimming in Chapter 5 conducted in Mohr, Nordsborg, et al. (2014) may also be linked to improved oxidative metabolism. However, it cannot be discounted that the improvements reported in Mohr, Nordsborg, et al. (2014) may also be related to an improvement in swimming technique. Nevertheless, with the additional large improvement in the land-based YYIE1 test, it could be speculated that physiological adaptations are a major contributor to the increased exercise capacity observed during both shuttle runs and swim tests. Improvements in aerobic fitness are also reflected by the ~4-5 % HR reduction observed for the participants following 10 x 20 m runs in Chapters 4 and 5 (Mohr, Nordsborg, et al., 2014) and submaximal walking test in Chapter 6. Conversely, no reduction in submaximal HR was evident following the DVD-directed training in Chapter 7. As similar improvements in $\dot{V}O_{2max}$ and performance tests were also evident for the CT groups in Chapter 5 and 6, it is difficult to conclude whether HIIT is more beneficial than CT. The results from Chapter 6 agree with previous research that suggests that the magnitude of improvement in absolute $\dot{V}O_{2max}$ following 2-6 wks of HIIT is in the region of ~10 %, and appears to be comparable to changes observed following CT at 60-70 % of $\dot{V}O_{2max}$ (Burgomaster et al., 2008; Cocks et al., 2016). The improvement in aerobic capacity arguably has greater clinical/preventative utility compared to weight loss given that aerobic fitness consistently manifests as the strongest predictor of future morbidity and mortality (Blair et al., 1989; C. D. Lee et al., 1999; D. C. Lee et al., 2011; Myers et al., 2002). An average increase of ~3-4 ml/kg/min in $\dot{V}O_{2max}$ would be expected to reduce the risk of all-cause mortality by 15 % and cardiovascular mortality by 19 %, respectively (D. C. Lee et al., 2011). This is of interest as the HIIT and CT participants of Chapter 6 had a 4-5 ml/kg/min increase in $\dot{V}O_{2max.}$

Table 8.5 Percentage change in functional capacity following the intervention periods related to Chapters 4, 6 and 7

		$\dot{V}O_{2peak}$	**Submaximal $\dot{V}O_2$**	**Submaximal heart rate**
Chapter 4	FB	X	X	↓ 6 ± 5 %*
	WBV	X	X	X
	CON	X	X	X
Chapter 6	HIIT	↑ 16 ± 8 %*	↓ 6 ± 8 %	↓ 3 ± 7 %*
	CT	↑ 21 ± 12 %*	↓ 1 ± 8 %	↓ 2 ± 9 %
	CON	↓ 2 ± 5 %	↑ 1 ± 8 %	↑ 2 ± 2 %
Chapter 7	DVD	X	X	↓ 2 ± 7 %
	CON	X	X	X

Abbreviations: CT: continuous training group, CON: control group, DVD: DVD-directed training group, FB: football training group, HIIT: high-intensity interval training group, $\dot{V}O_2$: oxygen uptake, $\dot{V}O_{2peak}$: peak oxygen uptake * Significant difference between pre and post intervention

Cell adhesion molecules

Cell adhesion molecules were assessed in Chapter 5. Plasma sICAM-1 was reduced by 4 and 3 % following high-intensity interval swim training and also for those individuals in the control group. In addition, plasma sVCAM-1 was reduced following high-intensity interval swimming. This is of interest as the early phase of atherosclerosis involves the recruitment of inflammatory cells from the circulation and their transendothelial migration and endothelial dysfunction is linked with the development of insulin resistance (Glowinska et al., 2005). However, the reduction in plasma sICAM-1 following high-intensity interval swimming must be interpreted with caution as a comparable reduction was also evident in the control group and it remains unclear whether these concentrations represent a useful cardiovascular risk indicator.

Regulation of cell adhesion molecules is thought to be under the influence of oxidative stress (Ceriello et al., 1996), nitric oxide availability (Marfella et al., 2000), the renin-angiotensin system (Ferri et al., 1998) and insulin sensitivity (N. G. Chen, Holmes, & Reaven, 1999). Therefore, it could be speculated that the reduction in sICAM-1 and sVCAM-1 following high-intensity interval swimming is related to the fact that exercise training has anti-inflammatory and anti-oxidative effects and increases shear stress and nitric oxide availability, all of which lead to reduced peripheral vasoconstriction, improved endothelial function and enhanced endothelial repair (Aksoy, Findikoglu, Ardic, Rota, & Dursunoglu, 2015). As highlighted in Chapter 5, since shear stress on endothelial cells lining conduit blood vessels increases in direct proportion to intensity (Padilla et al., 2008), it could be speculated that HIIT has a greater potential for improving endothelial function compared to lower intensity continuous exercise (Wisloff et al., 2009). It could also be speculated that the reduction of cell adhesion molecules following HIIT is related to improvements in insulin sensitivity (as seen in Chapter 5) and body composition (Mohr, Nordsborg, et al., 2014) as adipose tissue is an important site for secretion of inflammatory markers and cytokines (Zoppini et al., 2006).

Cognitive function

A number of parameters of cognitive function were assessed following HIIT and CT for previously inactive middle-aged premenopausal women in Chapter 6. Visual and verbal learning were improved following high-intensity interval and continuous cycling training while verbal memory was only improved following HIIT. This is of interest as there is evidence that cognitive function starts to decline from the age of 45 y (Singh-Manoux et al., 2012). It has been reported that in older aged individuals, the brain can become mildly hypoxic with reduced cerebral oxygenation possibly affecting brain function which may partly be brought about by a physically inactive lifestyle (Waldstein, 2000). Therefore, the maintenance or improvement of cognitive function is of importance. Interestingly, mean group scores at baseline for each cognitive function test in Chapter 6 were higher than the normative data provided by Cogstate of 341 healthy individuals aged 35-49. However, it must be reiterated that as cognitive function was only assessed following high-intensity interval and continuous cycling, this cannot be confidently extrapolated to a wider range of exercise interventions at present.

There is some evidence that aerobic fitness spares the loss of brain tissue during ageing, and enhances functional aspects of higher order regions involved in the control of cognition. It has been speculated that physical activity exerts its effects on cognition by affecting molecular events related to the management of energy metabolism and synaptic plasticity (Gomez-Pinilla & Hillman, 2013). For example, following a randomised control study of 120 older adults, those in the exercise group reported a 2 % increase in hippocampal volume as well as increases in serum BDNF which was associated with improvements in spatial memory (Erickson et al., 2011). Although not directly assessed in this thesis, the improvement in cognitive function following high-intensity interval and continuous cycling in Chapter 6 could be a function of an upregulation of BDNF. Indeed, BDNF has previously been linked to acute and chronic improvements in cognitive function via neurovascular remodelling including neuro/synaptogenesis and angiogenesis (Hillman et al., 2008). Additionally, the improvements in cognitive performance may also be related to a selective upregulation of cerebral blood volume in the denate gyrus, which is the only region of the hippocampus that has been observed to support adult neurogenesis (Pereira et al., 2007). Increases in blood volume in the denate gyrus have also been observed following 12 wks of aerobic exercise in adults which correlated with changes in aerobic fitness and was associated with improvements in cognitive function (Pereira et al., 2007). There is some evidence that the blood flow and BDNF-induced stimulation of the hippocampus and pre-frontal cortex are increased more following HIIT (Hillman et al., 2008). However, as highlighted in Chapter 6, the similarities in mean HR of the two training groups may help explain the similar improvements in visual and verbal learning tasks

Recent studies in the imaging of the hippocampus of older individuals have shown that those individuals who had higher physical fitness assessed through a maximal graded exercise test were associated with larger bilateral hippocampal volume and greater physical fitness and hippocampal volume were associated with better spatial memory performance (Erickson & Kramer, 2009). Given that the hippocampus demonstrates disproportionately larger degradation during ageing, it could be suggested that aerobic fitness may be an effective means for preventing age-related cortical decay and cognitive impairment. Therefore, keeping individuals mobile through the use of high-intensity interval and continuous cycling in middle-age may offset the detrimental effects of physical inactivity on cognitive function in later life as it has been repeatedly shown that those who have participated in physical activity throughout their lifetime report higher cognitive function scores compared to those who have lived an inactive lifestyle (Angevaren et al., 2007; Lista & Sorrentino, 2010). However, while lifelong participation in physical exercise may be preferable, the adoption of exercise at any age to delay or reverse cognitive decline is worthwhile given the prevalence of physical inactivity and the increasing proportion of older adults in the population.

Mental well-being

Mental well-being was only reported in Chapters 6 and 7 using the WEMWBS (Table 8.5). Mental well-being was improved following moderate-intensity cycling in Chapter 6 and home-based intermittent exercise in Chapter 7. It should be noted that, although not significantly different, baseline scores were higher for HIIT compared to continuous training and no between-training group differences were apparent following training in Chapter 6.

The mechanisms underlying the potential improvements in mental well-being following exercise are not fully understood, however, there are several candidates. From a biochemical perspective, endogenous opioid peptides in the blood during and after exercise may result in improved mental well-being. Plasma β-endorphin is thought to produce a feeling of euphoria, while norepinephrine is thought to trigger reductions in anxiety and depression (Fox, 1999). There have also been reports of an interaction between physical activity and central serotonin (5-hydroxytryptamine) as a mood enhancer (Chaouloff, 1997) with increases in synthesis and metabolism following acute exercise. However, less is known about the extent to which this is a trigger for improved well-being following chronic exercise.

With regard to mental well-being on a mean level, scores were at least maintained, or in some cases improved following HIIT and CT. This is of importance as maintaining positive well-being is considered a crucial aspect of healthy ageing which has been associated with a reduced risk of premature mortality (Chida & Steptoe, 2008) and CHD (Boehm et al., 2011). However, of the 40 individuals in the training groups across Chapters 6 and 7, 14 individuals reported impaired WEMWBS scores. Body image is also closely related to self-esteem, particularly for females (Davis, 1997; Fox, 1997) and physical activity offers a means of improving body image through fat loss and improved muscle fitness. However, exercise may raise body awareness and expectations and it can be counterproductive to satisfaction and self-esteem if expectations are not met (Davis, 1997). As over half of the participants in the training groups across Chapters 6 and 7 reported increases in total body mass, this may have affected WEMWBS scores.

As highlighted, the mechanisms underpinning improved mental well-being are difficult to isolate and establish. It is likely that multiple mechanisms are effective and the dominance of any one mechanism will be determined by exercise characteristics (type, intensity and duration), characteristics of the individual and environmental factors surrounding the exercise. Due to the intervention lasting 12 wks, mental well-being may have been affected by issues outside of the training environment which may have affected mental well-being in a positive and/or negative way. Therefore, results are difficult to interpret and can only be associated with indoor cycling or home-based intermittent exercise.

Table 8.5 Percentage change in mental well-being following the intervention periods related to Chapters 6 and 7

		WEMWBS
Chapter 6	HIIT	↑ 5 ± 11 %
	CT	↑ 8 ± 17 %*
	CON	0 ± 3 %
Chapter 7	DVD	↑ 4 ± 7 %
	CON	↓ 3 ± 11 %

Abbreviations: CT: continuous training group, CON: control group, DVD: DVD-directed training group, FB: football training group, HIIT: high-intensity interval training group, WEMWBS: Warwick-Edinburgh mental well-being scale. * Significant difference between pre and post intervention

Exercise enjoyment and adherence

Adherence to training was recorded for all experimental chapters of this thesis whereas exercise enjoyment was only assessed in Chapter 6. Although not directly comparable, the fact that only one participant withdrew from the studies described in Chapters 4, 5, 6 and 7 due to poor adherence levels or feelings of displeasure is encouraging. However, it cannot be ruled out that, although completely voluntary with no disadvantage to themselves, participants may have felt obliged to fulfil their requirements through the exercise intervention or only continued the intervention as there was no cost associated with the training. Similarly, individuals may have continued their exercise programme due to the known beneficial physiological effects but may not have enjoyed the experience. With regard to Chapter 6, there was no significant difference between enjoyment levels following the exercise intervention (HIIT: 56, continuous training: 53), however; scores ranged from 33 to 69 out of a possible score of 70 with 70 reflecting the greatest enjoyment. It is clear that, regardless of the physiological benefits of exercise, it is important to find an exercise modality that is enjoyed by the individual to maintain adherence and the accompanying health benefits.

There is some evidence that participants find HIIT a more enjoyable mode of exercise training (Bartlett et al., 2011). However, the notion that HIIT would stimulate greater exercise adherence based on these findings currently lacks empirical evidence. Foremost, the optimal structure and modality of HIIT and CT interventions, both from the perspective of promoting healthy adaptations and in terms of suitability for the general population need to be established. Specifically, the HIIT models that have been studied to date, whilst generally effective at improving physiological functioning, require very high levels of participant motivation, are very fatiguing, and can be associated with feelings of nausea. Such protocols include the traditional 'Wingate' protocol including 4-6 30 s sprints with 4 min rest and 'Tabata' protocol using 8 x 20 s high-intensity intervals with 10 s rest. As such, it seems unlikely that these protocols would be suitable for recommendation to previously inactive premenopausal women whereas those protocols used as part of this thesis may be more appealing.

8.4 Practical implications

Given that 34-39 % of British women aged 25-54 y do not achieve the recommended minimum of 150 min of moderate-intensity or 75 min of vigorous intensity physical activity per wk (Townsend, Bhatnagar, et al., 2015), it is essential to identify how smaller volumes of exercise can be utilised for the prevention and treatment of NCDs.

This thesis demonstrates that, for a group of inactive premenopausal women, DVD-directed home-based interval exercise may be a useful exercise modality to initiate exercise participation for those individuals who would prefer to exercise alone or may have difficulty in exercising away from home due to a lack of time, or work, transport or child care issues. Interestingly, the lipid profile and mental well-being of the participants was improved following just 3-weekly training sessions of 15 min, which is below the recommended weekly physical activity guidelines (Department of Health, 2011). This thesis also demonstrated that short-duration, small-sided football training may also be a useful exercise modality to help increase physical activity levels for inactive premenopausal women who struggle to find the time to exercise but would prefer to exercise as part of a group for increased social interaction. Health benefits were achieved for body fat percentage and aerobic fitness even though weekly training time was less than the recommended government guidelines for physical activity (twice-weekly training sessions consisting of 13.5 min). No such health benefits were evident for the inactive premenopausal women who participated in duration-matched WBV which may be reflected by the lower mean training HR (92 bpm) compared to the small-sided football training (157 bpm). However, WBV may still be useful for improving health markers not measured in Chapter 4 such as neurological, musculoskeletal and metabolic conditions, especially for individuals with mobility issues.

Although small-sided football and DVD-directed home-based exercise provided numerous health benefits following training, previously inactive premenopausal women may be hesitant to participate in exercise which consists of repetitive weight-bearing activity. Chapters 5 and 6 demonstrated that participating in non-weight bearing high-intensity interval cycling or swimming was similar, if not superior to, prolonged continuous cycling and swimming training for improving metabolic and cardiovascular health for inactive premenopausal women, some of whom presented with mild hypertension. Although the total time per training session was similar to the government guidelines, the effective time spent actually exercising at a high intensity was far below the government guidelines which may be of interest for those previously inactive premenopausal women who would like to exercise for the minimal amount of time and exertion while still improving their health.

Of interest, following the completion of exercise training, several of the health benefits achieved by the premenopausal women throughout this thesis may be of clinical interest. For example, the increase in $\dot{V}O_{2peak}$ following both the self-selected high-intensity interval and prolonged continuous cycling training and the reduction in submaximal heart rate following small-sided football training has been associated with a reduction in all-cause mortality (Gulati et al., 2003). In addition, the decrease in abdominal adiposity evident following small-sided football has been associated with a reduced risk of coronary heart disease

(Rexrode et al., 1998). Furthermore, the improvement in [HDL cholesterol] following home-based DVD-directed exercise has been associated with a reduction in CHD while the improvements in insulin sensitivity following high-intensity interval swimming may aid in reducing the risk of T2D (Helmrich et al., 1991).

It is also of great importance that shorter-duration higher-intensity interval exercise is considered to be equal to or more enjoyable than prolonged CT, which is an important factor to the success of exercise interventions for previously inactive premenopausal women (Jekauc, 2015). Indeed, Chapter 6 adds to a growing body of literature which demonstrates that HIIT is as enjoyable as prolonged CT. In addition, the high adherence to training in Chapters 4, 5 and 7 demonstrate that high-intensity exercise interventions are feasible. However, this thesis also highlights the importance of educating this population on how to interpret exercise intensities as reflected by the misinterpretation of moderate-intensity continuous exercise in Chapter 6.

To date, evidence from a cardiac rehabilitation setting suggests that there is a low risk for acute adverse cardiovascular events during HIIT (P. A. Ribeiro, Boidin, Juneau, Nigam, & Gayda, 2017). However, it should be noted that the likelihood of an event occurring is around 5 times higher than that observed during MICT (1 event per 23,182 h of HIIT versus 1 event per 129,456 h of MICT (Rognmo et al., 2012). In addition, a meta-analysis of HIIT for clinical populations (coronary artery disease, heart failure, hypertension, MetS, and obesity) reported no adverse events related to the exercise training (K. S. Weston et al., 2014). Further studies are certainly warranted over the safety of HIIT programmes for inactive and clinical populations but studies reporting no elevated risk of cardiovascular events during HIIT compared with MICT are promising (Rognmo et al., 2004).

Collectively, this thesis has demonstrated that shorter duration, higher intensity exercise can produce similar, if not superior, improvements to established risk factors important to current and future health in previously inactive premenopausal women. The findings from Chapters 4-7 may add to the growing body of literature which could help strengthen physical activity recommendations for this population. With the high adherence and low injury risk reported in this thesis, several forms of HIIT could be considered as a time-efficient alternative to more "traditional" MICT, at least for exercise interventions lasting up to 16 wks for inactive premenopausal women with little or no experience of exercise. It is also possible that the findings of this thesis could be transferable to other populations. Thus, it is plausible that the data presented in this thesis may have significant implications for health promotion in other population groups and/or that health markers not measured as part of Chapters 4-7 might have been improved by the interventions administered in the current thesis.

8.5 Methodological considerations and areas for future investigation

Collectively, the experimental chapters demonstrate that performing HIIT is important for a number of health outcomes. However, the optimal training protocol remains unclear and, in some cases, disparate health benefits were observed following more traditional prolonged continuous exercise training and the HIIT training equivalent. Therefore, to directly build on the experimental chapters of this thesis, immediate directions for future research should focus on investigating a common set of health markers across the various exercise modalities within this thesis using the same methodological approaches to facilitate comparison of results across studies and inform researchers of exercise interventions worthy of larger studies. Additionally, the use of similar time-efficient HIIT exercise training interventions and its effect on important health markers should be assessed on postmenopausal women as well as those individuals already presenting with a heightened risk for non-communicable disease and compared to traditional prolonged MICT. Further details on areas for future investigation can be found later on in this section.

As the literature has largely focused on acute, laboratory-based exercise responses, mixed training modes and assessment of adherence and training effect after less than three months of training, subsequent research is needed to evaluate the longer-term implications of HIIT as an alternative to prolonged continuous exercise programmes. Evidently, this thesis did not focus on resistance training which is also an important aspect for health and forms part of the recommended physical activity guidelines set out by the government (Department of Health, 2011). The interaction between the adaptations to strength and endurance exercise is a complex issue (Baar, 2014). Therefore, to maximise the health benefits achievable following MICT, HIIT and resistance training we need to more effectively establish the underlying mechanisms for the adaptations to these training methods, including factors that dictate responders and non-responders, and ascertain the importance of each training variable (intensity, frequency, mode, and duration) in optimising health and well-being. This knowledge will inform exercise prescription guidelines to optimise the health benefits achieved following a period of exercise training and is, therefore, of economic and societal importance.

The findings of the four exercise training studies in this thesis must be considered within the context of several limitations which are implicit to all long-term intervention studies. Firstly, although we performed a supervised intervention in three of the four studies, meaning incomplete training adaptations can be discounted, they were otherwise free-living studies, meaning that other chronic changes in lifestyle may have contributed to individual alterations in outcomes. Whilst we asked each participant not to make any conscious changes to their current diet and physical activity levels, other than periodical diet records, we have no objective measures to confirm that this was adhered to. This may have affected the standardisation procedure prior to the 48-72 h before each OGTT in Chapters 5, 6 and 7 and aerobic capacity assessment in Chapter 6. In future studies, to better isolate the effects of the training interventions, it would be beneficial (but costly) to provide each participant with their meals over these three day periods. It would also be useful to obtain an objective measure of physical activity prior to each OGTT.

Notably, an important limitation of the present thesis is that the studies could potentially be underpowered. As the sample size for each experimental chapter was calculated for the primary outcome measure, this may have led to low or insufficient statistical power for between-group comparisons of secondary outcome markers. In turn, the probability of making a type II error may have been inflated for secondary outcome measures. Therefore, in future investigations it may be beneficial to perform power calculations for several important health markers rather than one.

Another limitation of the present thesis is that the menstrual cycle was not directly controlled in relation to between-participants and pre- and post-intervention testing. For example, in Chapter 4, if participants missed a training session, they were asked to make this up at the end of the original 16 wks. In addition, the participants in Chapter 5 completed a total of 39-50 training sessions due to block testing days ensuring no more than 48-72 h had elapsed with regards to the OGTT. Similar to Chapter 4, Chapters 6 and 7 ensured participants completed all training sessions which, for some individuals, required training sessions to be added on to the original 12 wk training intervention. Future investigations should look to control timing of menstrual cycle when undertaking training interventions for premenopausal women as it has been shown that physiological responses to exercise, such as thermoregulation, ventilation and cardiovascular strain, are influenced by hormonal fluctuations across the cycle (Hooper, Bryan, & Eaton, 2011; Oosthuyse & Bosch, 2010).

Additionally, exclusion criteria varied across experimental chapters. It is not unlikely that the recruitment process for the studies in this thesis resulted in a biased sample, i.e. one where BMI, aerobic fitness and habitual physical activity are not representative of the wider adult population. In future studies, it would be useful to maintain consistent inclusion/exclusion criteria across studies when comparing the health benefits of different training interventions for premenopausal women.

The timing of the post-training OGTT should also be considered a limitation in Chapters 5, 6 and 7. A 48-72 h post-exercise time point was chosen as we were specifically interested in isolating training adaptations. However, some training adaptations may be relatively transient and, as such, clinically important changes in [glucose], [insulin] and insulin sensitivity in response to feedings may have been missed on the immediate days after completion of the training intervention. Indeed, previous HIIT studies in obese individuals have demonstrated no effect of a single bout of HIIT on insulin sensitivity (Whyte, Ferguson, Wilson, Scott, & Gill, 2013), yet improvements after a 2 wk training intervention were evident at 1 day, but not at 3 days, after the final exercise session (Whyte et al., 2010). It is also important to note that the OGTTs were performed in a fasted state. After an overnight fast, liver glycogen levels will be depleted and, as the liver has precedence over any glucose taken up from the gut, the liver will be a major determinant of the glucose and insulin response to an oral glucose load in the fasted state. As such, the impact of changes in skeletal muscle insulin sensitivity (which are most likely to be altered with exercise) may therefore be underestimated using a fasting-based OGTT. It would be worthwhile investigating the impact of the approaches taken in Chapters 5, 6 and 7 on insulin sensitivity using the intravenous glucose tolerance test or the gold standard insulin clamp method.

In addition, as highlighted in Chapter 4, the number of participants per team per training session ranged from 2 v 2 to 4 v 4. This could have affected the exercise intensity for a given individual which, following 12 wks of training, may have resulted in significantly different adaptations between two individuals predominantly participating in 2 v 2 and 4 v 4 training sessions. Although football is a sporadic intermittent sport, future studies would benefit from a study design where the number of participants per team is fixed to remove unnecessary variability in exercise intensity.

The data presented in this thesis raise several potential areas for future research, including further characterisation of the training effects of the approaches taken in the experimental chapters in healthy and clinical populations as well as further examination of the acute effect of small-sided football and high-intensity interval swimming on the health profile of premenopausal women. As demonstrated in Chapter 5, this thesis has provided some evidence to suggest that 15 wks of high-intensity interval swimming may improve insulin sensitivity in previously inactive premenopausal women with mild hypertension. As such, it is logical to suggest that future research should aim to further examine the effects of HIIT swimming on insulin sensitivity (and other biomarkers), in other clinical populations such as those with impaired glucose tolerance and T2D. In addition, the assessment of the wider issues relating to long-term adherence to training interventions and clinical benefit in a free-living setting is clearly warranted.

Interestingly, as has been done with acute small-sided football (Bowtell et al., 2016), it will be of importance to assess the potential changes in bone mineral content and BMD following the exercise training interventions employed in the present thesis as BMD decreases with age particularly amongst women, with a sharp decline following the menopause. For this reason, it would also be of interest to compare the exercise intervention effects between pre- and postmenopausal women. Although WBV did not prove to be more effective compared to other training methods on the chosen health markers, it has previously been shown to be a less fatiguing and less time-consuming method to enhance physical capabilities in older individuals. Therefore, future research should focus on the effectiveness of WBV for premenopausal women who are unable to participate in high-intensity interval or lower-intensity prolonged continuous exercise.

Whether benefits and adherence to exercise persist beyond 12-16 wks, and if additional health benefits can be obtained by combining HIIT and continuous training, is presently unknown, and thereby warrants further investigation. In addition, more research is necessary in order to identify whether a prolonged exposure to HIIT is safe for previously inactive premenopausal women and those individuals with a heightened risk.

8.6 Conclusion

There is irrefutable evidence of the effectiveness of regular exercise in the primary and secondary prevention of several chronic diseases. The work contained within this thesis adds to the body of literature by investigating the effects of WBV as well as higher intensity small-sided football, swimming, cycling and home-based exercise training on a number of health profile markers and, in some cases, is compared to more traditional continuous exercise in previously inactive premenopausal women.

Results in the current thesis demonstrate that the interventions were well adhered to and the magnitude of improvements in several health markers following intermittent exercise in the form of small-sided football, swimming, cycling and a home-based exercise DVD were potentially clinically relevant. Additionally, the magnitude of improvements in several health markers following HIIT in the form of cycling and swimming appear to be similar, if not greater, than those following continuous exercise training despite requiring a significantly lower time commitment. The occurrence of similar gains in a number of health markers with a smaller training volume is highly relevant since a lack of time is the principal reported reason for individuals being inactive. These protocols are easily implemented and do not require specific, expensive equipment. However, premenopausal women should not be discouraged from participating in continuous exercise as the experimental chapters in this thesis have shown that, as long as premenopausal women are engaged in exercise which raises their heart rate, at least some aspects of health are likely to be improved. In addition, allowing premenopausal women to have more control over the protocol may increase adherence to the intervention but exercise guidelines may be misinterpreted and exercise intensity may also be reduced when exercise is performed unsupervised.

Although the findings of the current thesis suggest that participation in a variety of exercise protocols of differing intensities, durations and modalities is beneficial to aspects of overall health, it appears that HIIT is at least as effective as MICT at eliciting most of these benefits. Moreover, since HIIT is a more time-efficient strategy to achieve such beneficial health effects, the findings of this thesis advocate its promotion as a viable and effective method of exercise for premenopausal women.

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Appendix

Appendix 1

The Warwick-Edinburgh Mental Well-being Scale (WEMWBS)

Below are some statements about feelings and thoughts.
Please tick the box that best describes your experience of each over the last 2 weeks

STATEMENTS	None of the time	Rarely	Some of the time	Often	All of the time
I've been feeling optimistic about the future	1	2	3	4	5
I've been feeling useful	1	2	3	4	5
I've been feeling relaxed	1	2	3	4	5
I've been feeling interested in other people	1	2	3	4	5
I've had energy to spare	1	2	3	4	5
I've been dealing with problems well	1	2	3	4	5
I've been thinking clearly	1	2	3	4	5
I've been feeling good about myself	1	2	3	4	5
I've been feeling close to other people	1	2	3	4	5
I've been feeling confident	1	2	3	4	5
I've been able to make up my own mind about things	1	2	3	4	5
I've been feeling loved	1	2	3	4	5
I've been interested in new things	1	2	3	4	5
I've been feeling cheerful	1	2	3	4	5

Warwick-Edinburgh Mental Well-Being Scale (WEMWBS)

Appendix 2

INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE

We are interested in finding out about the kinds of physical activities that people do as part of their everyday lives. The questions will ask you about the time you spent being physically active in the **last 7 days**. Please answer each question even if you do not consider yourself to be an active person. Please think about the activities you do at work, as part of your house and yard work, to get from place to place, and in your spare time for recreation, exercise or sport.

Think about all the **vigorous** activities that you did in the **last 7 days**. **Vigorous** physical activities refer to activities that take hard physical effort and make you breathe much harder than normal. Think *only* about those physical activities that you did for at least 10 minutes at a time.

1. During the **last 7 days**, on how many days did you do **vigorous** physical activities like heavy lifting, digging, aerobics, or fast bicycling?

   _____ **days per week**

   ☐ No vigorous physical activities → ***Skip to question 3***

2. How much time did you usually spend doing **vigorous** physical activities on one of those days?

   _____ **hours per day**

   _____ **minutes per day**

   ☐ Don't know/Not sure

Think about all the **moderate** activities that you did in the **last 7 days**. **Moderate** activities refer to activities that take moderate physical effort and make you breathe somewhat harder than normal. Think only about those physical activities that you did for at least 10 minutes at a time.

3. During the **last 7 days**, on how many days did you do **moderate** physical activities like carrying light loads, bicycling at a regular pace, or doubles tennis? Do not include walking.

   _____ **days per week**

   ☐ No moderate physical activities → ***Skip to question 5***

SHORT LAST 7 DAYS SELF-ADMINISTERED version of the IPAQ. Revised August 2002.

4. How much time did you usually spend doing **moderate** physical activities on one of those days?

_____ **hours per day**

_____ **minutes per day**

☐ Don't know/Not sure

Think about the time you spent **walking** in the **last 7 days**. This includes at work and at home, walking to travel from place to place, and any other walking that you might do solely for recreation, sport, exercise, or leisure.

5. During the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time?

_____ **days per week**

☐ No walking ➡ ***Skip to question 7***

6. How much time did you usually spend **walking** on one of those days?

_____ **hours per day**

_____ **minutes per day**

☐ Don't know/Not sure

The last question is about the time you spent **sitting** on weekdays during the **last 7 days**. Include time spent at work, at home, while doing course work and during leisure time. This may include time spent sitting at a desk, visiting friends, reading, or sitting or lying down to watch television.

7. During the **last 7 days**, how much time did you spend **sitting** on a **week day**?

_____ **hours per day**

_____ **minutes per day**

☐ Don't know/Not sure

This is the end of the questionnaire, thank you for participating.

SHORT LAST 7 DAYS SELF-ADMINISTERED version of the IPAQ. Revised August 2002.

Appendix 3

Adapted HIIT Groningen Enjoyment Questionnaire (GEQ)

INSTRUCTIONS:
Please circle a number to show how much you agree or disagree with each statement

KEY: 1 = Absolutely disagree
2 = Disagree
3 = Slightly disagree
4 = Undecided
5 = Slightly agree
6 = Agree
7 = Absolutely agree

1. Doing high-intensity interval training makes me feel good 1 2 3 4 5 6 7
2. I like being physically active 1 2 3 4 5 6 7
3. Doing high-intensity interval trainings makes me feel energetic and alive 1 2 3 4 5 6 7
4. Doing high-intensity interval training cheers me up 1 2 3 4 5 6 7
5. I think each class is really interesting 1 2 3 4 5 6 7
6. Doing high-intensity interval training gives me satisfaction 1 2 3 4 5 6 7
7. I often give it all I have in high-intensity interval training sessions 1 2 3 4 5 6 7
8. I forget the time when I’m doing high-intensity interval training 1 2 3 4 5 6 7
9. I feel relaxed when I’m doing high-intensity interval training 1 2 3 4 5 6 7
10. During high-intensity interval training, I feel I can be myself 1 2 3 4 5 6 7

Adapted MICT Groningen Enjoyment Questionnaire (GEQ)

INSTRUCTIONS:
Please circle a number to show how much you agree or disagree with each statement

KEY: 1 = Absolutely disagree
2 = Disagree
3 = Slightly disagree
4 = Undecided
5 = Slightly agree
6 = Agree
7 = Absolutely agree

11. Doing moderate-intensity continuous training makes me feel good 1 2 3 4 5 6 7

12. I like being physically active 1 2 3 4 5 6 7

13. Doing moderate-intensity continuous training makes me feel energetic and alive

1 2 3 4 5 6 7

14. Doing moderate-intensity continuous training cheers me up 1 2 3 4 5 6 7

15. I think each class is really interesting 1 2 3 4 5 6 7

16. Doing moderate-intensity continuous training gives me satisfaction 1 2 3 4 5 6 7

17. I often give it all I have in moderate-intensity continuous training sessions

1 2 3 4 5 6 7

18. I forget the time when I’m moderate-intensity continuous training 1 2 3 4 5 6 7

19. I feel relaxed when I’m doing moderate-intensity continuous training 1 2 3 4 5 6 7

20. During moderate-intensity continuous training, I feel I can be myself 1 2 3 4 5 6 7