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Effects of running sprint interval training versus traditional endurance exercise on
metabolic indices in sedentary, overweight and obese women

Jennifer L. Espinoza

A thesis submitted to the Graduate Faculty of

JAMES MADISON UNIVERSITY

In

Partial Fulfillment of the Requirements

for the degree of

Master of Science

Health Science

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Dedication

I dedicate this thesis to my parents, Jeannie and Rafael Espinoza. Your sense of ambition to improve and self educate has instilled me with a strong work ethic, dedication, and perseverance in everything I set out to do. You have always taught me to work hard to earn what you have in life, while never forgetting where you began. You have undoubtedly made me into the person I am today and I am eternally grateful for your undying love, encouragement, and support throughout my entire life.

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Abstract

Evidence suggests that sprint interval training (SIT) is a time efficient alternative for improving aerobic fitness or insulin sensitivity due to its reduced training volume and is of increasing interest since most sedentary individuals indicate lack of time as their number one barrier to being physically active. However, most SIT research uses cycling exercise performed with healthy active males, and limited research examines its effects on women or individuals at higher risk for inactivity related diseases, as well as different modes of exercise.

PURPOSE: To evaluate the effects of running SIT (R-SIT) versus moderate intensity endurance training (MIET) on aerobic capacity, resting HR, BP, body composition, blood lipids, and glucose in sedentary, overweight/obese women.

METHODS: Twelve sedentary, overweight/obese women ($30.7 \pm 7.4 \text{ kg/m}^2$, $33.6 \pm 5.8 \text{ y}$, $27.9 \pm 6.5 \text{ ml/kg/min}$) were randomly divided into two 12-week training protocols, each for 3 days per week. The R-SIT group ($n=5$) completed 4-10 bouts of 30s “all out” sprints on a motorized treadmill at a 3-5% incline with 4 min active recovery. The MIET group ($n=7$) completed 30-60 min of moderate intensity (45-55% HRR) walking on a treadmill at a 3-5% incline.

RESULTS: $\text{VO}_{2\text{max}}$ significantly improved 19.7% with R-SIT (mean \pm SD; 29.59 ± 7.3 to $35.57 \pm 10.4 \text{ ml/kg/min}$) and 38.6% with MIET ($26.74 \pm 35.29 \pm 6.6 \text{ ml/kg/min}$) pre to post ($p < 0.05$), with no difference between training groups. R-SIT significantly reduced body fat percent by $1.6 \pm 0.9\%$ ($p = 0.016$), but not with MIET ($p = 0.13$). Fat mass (39.5 ± 24.4 to $37.72 \pm 24.7 \text{ kg}$; $p = 0.08$) and triglycerides decreased pre to post (146.2 ± 73.7 to 93.8 ± 36.3

mg/dL; $p=0.05$). HbA1c improved mid to post (5.2 ± 0.3 to $5.1\pm 0.3\%$; $p=0.05$). There were no significant differences between training groups for any parameter ($p>0.05$).

CONCLUSION: Despite the reduced time commitment, R-SIT elicits similar improvements in aerobic fitness and was more effective at improving body composition than MIET in sedentary, overweight/obese women. Additionally, there is suggestive evidence that R-SIT may induce greater improvements in fat mass, triglycerides, and HbA1c measures. This study provides practical application for the implementation of R-SIT to reduce risk factors associated with cardiovascular disease in sedentary, overweight/obese population. More research is necessary to determine the extent of these reductions.

Introduction

The prevalence of obesity worldwide has increased drastically in the last decade, nearly doubling since 1980 (Centers for Disease Control and Prevention (CDC), 2012). Obesity is associated with a number of chronic conditions including Type 2 Diabetes, cardiovascular disease (CVD), dyslipidemia, hypertension, impaired glucose tolerance, atherosclerosis, coronary heart disease, certain types of cancers, and premature death (CDC, 2012). Currently, more than one-third (35.7%) of U.S. adults are obese (BMI \geq 30kg/m²), mainly as a result of a physically inactive lifestyle and poor diet habits (CDC, 2012).

Fortunately, there is a dose response relationship between physical activity and overall health status (Warburton, McKenzie, Haykowsky, et al., 2005). Current research suggests that physical activity has shown to improve body composition; enhance blood lipid profiles by reducing triglycerides (TG) levels, increasing high-density lipoprotein cholesterol (HDL-C), and decreasing low-density lipoprotein cholesterol (LDL-C); improve glucose regulation; lower blood pressure (BP); improve autonomic tone and coronary blood flow; and enhance endothelial function (Warburton et al., 2005). It is not surprising that measures for promoting physical activity are therefore critical for preventing chronic disease and premature death.

Traditionally, prolonged aerobic exercise has been advocated as a sufficient and effective strategy for weight loss and reducing the number of cardiovascular and metabolic health risks. The American College of Sports Medicine (ACSM) and American Heart Association (AHA) recommend the accumulation of 150 minutes to 250 minutes of moderate physical activity per week to assist in weight loss and improve health (Donnelly et al., 2009). Unfortunately, less than half (48%) of U.S. adults meet these guidelines

(CDC, 2012). Individuals list “lack of time” as the most common reason why people fail to exercise (Troost, Owen, Bauman, Sallis, & Brown 2002). As a result, metabolic related disorders are rising and have become a national health threat and notable public health challenge.

Interestingly, there has been a growing body of evidence that brief, vigorous bouts of exercise, or close to “all out” effort (i.e. $\geq 90\% \text{VO}_{2\text{max}}$), interspersed by short recovery periods of rest or lower intensity exercise, can induce similar and sometimes greater metabolic and cardiorespiratory fitness improvements as traditional endurance training elicits (Boutcher, 2011; Gibala et al., 2006; Gibala, Little, MacDonald, & Hawley 2012; Gibala, 2008). This method of training is commonly referred to as HIIT (high intensity interval training). There is great speculation that HIIT can be a time efficient alternative for high volume endurance training to improve health parameters. HIIT can be utilized during various modes of aerobic exercise, such as running, cycling, rowing, or swimming. This type of training relies more on anaerobic energy systems rather than aerobic energy systems, which is primarily utilized during regular endurance training (Gibala et al., 2006). Thus, it is surprising that HIIT can induce such an effect on oxidative energy metabolism and endurance performance. Moreover, studies support that HIIT can elicit metabolic adaptations commonly associated with high volume endurance training such as weight loss, increased fat oxidation (Tremblay, Simoneau, Bouchard, 1994; Burgomaster et al., 2008; Nybo et al., 2010; Schjerve et al., 2008), and insulin sensitivity (Little, Safdar, Wilkin, & Tarnopolsky, 2011). Low volume training such as HIIT, is speculated to result in improved health despite the minimized time commitment when compared to high volume endurance training.

The most common type of HIIT cited in the literature is the Wingate test; an “all out” 30 second sprint against a high braking force on a specialized cycle ergometer. This type of training is commonly known as sprint interval training (SIT) (Gibala et al., 2012). Research utilizing this SIT model has mainly examined cardiorespiratory fitness and muscle oxidative capacity (Burgomaster, Hughes, Heigenhauser, Bradwell, & Gibala, 2005; Burgomaster et al., 2008; Bayati, Babak, Reza, & Agha-Alinejad, 2011; Whyte, Gill, & Cathcart, 2010; Astorino, Allen, Roberson, & Jurancich, 2012), although few have additionally examined body composition (Trilk, Singhal, Bigelman, & Cureton, 2011; Whyte et al., 2010; Astorino et al., 2012), insulin sensitivity and blood glucose (BG) concentrations (Whyte et al., 2010; Whyte, Ferguson, Wilson, Scott, & Gill, 2013; Richards et al., 2010; Babraj et al., 2009; Burgomaster et al., 2007; Harmer et al., 2008; Whyte et al., 2010; Freese, Levine, Chapman, Hausman, & Cureton, 2011), blood markers relating to metabolic disease (Whyte et al., 2013; Harmer et al., 2008), and resting heart rate and blood pressure (Whyte et al., 2010; Astorino et al., 2012), and only a few of these directly compare physiological and metabolic adaptations to subjects performing high volume, endurance training.

The growing body of evidence supporting SIT as an effective, time efficient alternative for improving health related parameters has mainly been conducted on healthy, active (Burgomaster et al., 2007) or recreationally active individuals (Astorino et al., 2012; Gibala et al., 2006; Freese et al., 2011; Babraj et al., 2009; Burgomaster, Hughes, Heigenhauser, Bradwell, & Gibala, 2005; Burgomaster et al., 2008; MacDougall et al., 1998; Bayati, Farzad, Gharakhanlou, & Agha-Alinejad, 2011; Richards et al., 2010; Rakobowchuk et al., 2008; Hazell, Hamilton, Oliver, & Lemon, 2014). Fewer studies

have examined its effects on sedentary individuals (Trilk et al., 2011; Astorino, Schubert, Palumbo, Stirling, & McMillan, 2013; Sandvei et al., 2012), overweight and obese individuals (Heydari, Freund, & Boutcher, 2012; Whyte et al., 2010, 2013; Tjonna et al., 2008, 2009; Trilk et al., 2011), or diabetic patients (Harmer et al., 2008). Moreover, the majority of these researchers utilized male subjects and only one that utilized exclusively women subjects (Trilk et al., 2011).

Running is perceived as a more universal and practical method of aerobic exercise compared with cycling used in previous studies (Macpherson, Hazell, Olver, Paterson, & Lemon, 2011). Minimal HIIT studies have been conducted using other modalities, such as treadmills, so it unknown whether the benefits seen in Wingate type SIT studies utilizing a specialized cycle ergometer can translate to running sprint interval training performed on treadmills. To the researcher's knowledge, only three studies have examined the effects of running sprint interval training on enhancing health (Macpherson et al., 2011; Sandvei et al., 2012; Hazell et al., 2014). Moreover, no study has examined the SIT model in overweight or obese, sedentary women. Therefore, the purpose of this study is to examine the effects of low volume, running sprint interval training (R-SIT) on factors linked to a woman's risk for chronic disease, including resting heart rate and blood pressure, maximal oxygen consumption (VO_{2max}), body composition, cholesterol levels, TG levels, BG, and hemoglobin A1c (HbA1c), in overweight and obese, sedentary adult women. Additionally, this study will compare the magnitude of effects of R-SIT with traditional moderate intensity endurance running (MIET) on the aforementioned health parameters.

Null Hypothesis

It is hypothesized that running sprint interval exercise will not have a significantly greater improvement in metabolic and physiological risk factors (i.e. resting heart rate and blood pressure, VO_{2max} , body composition, cholesterol levels, TG levels, BG, and HbA1c) than moderate intensity endurance running exercise.

Assumptions

The assumptions of the study are:

1. Subjects exerted maximal effort for each 30 second sprint during SIT running sessions.
2. Subjects followed pre-fitness and pre-clinical testing instructions.
3. Habitual lifestyle, regarding diet and physical activity, was to remain the same throughout the study (excluding training sessions).
4. Subjects were honest and accurate on three-day dietary records.

Limitations

The limitations of the study are:

1. Subjects are sedentary individuals, thus may find it difficult to perform and adhere to such training protocols.
2. Dizziness, light-headedness, or nausea has been reported by subjects after Wingate based training.
3. It is possible that training may elicit overuse injuries or musculoskeletal complications in older or less fit individuals.

4. SIT-type training requires a great deal of motivation, therefore may not be applicable to the general public.
5. Diet was self-reported which could result in an underreporting of food intake.
6. Absence of a control group that performs no exercise.

Delimitations

The delimitations of the study were:

1. Subjects included women from the Harrisonburg community.
2. Subjects were all sedentary adult women, with a BMI of 25.0 - 34.9kg/m², thus cannot be generalized to other populations.
3. SIT running will be performed on a treadmill under a controlled setting to ensure they execute their exercise training and perform the appropriate intensity.

Significance of the Study

This is the first study to examine the effects of sprint interval training, performed as walking/running, on the selected health markers: resting heart rate and blood pressure, VO_{2max}, body composition, cholesterol levels, triglyceride levels, blood glucose and HbA1c in overweight and obese, sedentary adult women. Additionally, previous studies that examined high intensity interval training lack information on the physiological and metabolic responses in women. No known study has examined all aforementioned parameters while comparing the outcomes of traditional endurance training in this population. An evaluation of the effects of R-SIT on cardiovascular and metabolic risk factors in a wide range of populations, especially sedentary and overweight individuals,

will provide evidence based physical activity recommendations for an effective alternative for individuals pressed for time.

Definitions

High Intensity Interval Training (HIIT): HIIT is comprised of brief periods of high-intensity exercise interposed with recovery periods of lower intensity aerobic exercise or rest.

Running Sprint Interval Running (R-SIT): R-SIT is comprised of 4-12 brief bouts of "all out" 30 second sprints (Wingate test) on a motorized treadmill, interspersed with 4 minutes of active recovery.

Moderate intensity endurance training (MIET): Continuous, prolonged running at an intensity level of 40-60% HRR.

Rationale for the Study

The rationales for conducting this study are:

1. Current studies have not explored other modes of training utilizing the HIT or SIT principle in overweight/obese women. Studies have primarily used a specialized cycle ergometer and examined healthy, young adult males.
2. This study will investigate whether the training regimen can elicit improvements in body composition and other metabolic risk factors, in addition to an increase in aerobic fitness similar to that of traditional endurance exercise training.
3. This is the first study to examine the effects of sprint interval running on the selected health markers: resting heart rate and blood pressure, VO_{2max} , body

composition, cholesterol levels, triglyceride levels, blood glucose, and hemoglobin A1C, in overweight and obese sedentary adult women.

Objectives

The objectives of the study are:

1. To determine if R-SIT is as effective as the traditional recommended MIET regimen on metabolic health risks, despite the lower amount of time commitment involved.
2. To determine whether the benefits seen in Wingate type SIT studies utilizing a specialized cycle ergometer can translate to sprint interval training utilizing a treadmill.
3. To determine if sprinting on a treadmill can be used as a safe, effective, and efficient alternative of training in previously sedentary, overweight and obese women.

Review of Literature

Metabolic Indices Related to Chronic Disease

The prevalence of obesity worldwide has increased drastically in the last decades of the 20th century, nearly doubling since 1980 (Centers for Disease Control and Prevention (CDC), 2012). Currently, more than one-third of U.S. adults (35.7%) are obese. Behaviors such as a inactivity and poor dietary habits, play a key role in obesity and can result in a number of unfavorable physiological and metabolic risk factors including low cardiorespiratory fitness, high plasma total cholesterol levels, high levels of LDL-C, low levels of HDL-C, high BG levels, and high BP (CDC, 2012). These risk factors substantially raise one's risk of morbidity from hypertension, dyslipidemia, coronary heart disease, stroke, and some cancers. Given the health consequences of obesity, physical activity and diet are two critical areas for prevention and treatment strategies for U.S adults.

The association between cholesterol, particularly LDL-C and cardiovascular risk is substantial (Schenck-Gustafsson, 2009). A meta-analysis of 26 randomized clinical trials showed that a reduction of 1.0 mmol/L in LDL-C can decrease your risk of cardiovascular disease (CVD) by more than 19% (Baigent, Keech, Kearney et al., 2005). Likewise, low levels of HDL-C level lower than 40 mg/dL for women is an independent, inverse predictor for CVD (Schenck-Gustafsson, 2009). An increase in HDL-C by 1% reduces cardiovascular risk by 3-5% for women (Schenck-Gustafsson, 2009). Evidently, improving cholesterol levels can help lower a woman's risk for cardiovascular events and premature death.

Hypertensive women are 3.5 times more likely to develop cardiovascular heart disease than normotensive (Schenck-Gustafsson, 2009). A meta-analysis (Lewington et

al., 2002) consisting of 61 prospective studies, including a total of 1 million people, showed that the risk of cardiovascular mortality is significantly reduced for individuals who have lower blood pressure (BP). There is substantial evidence supporting the ability for aerobic exercise of various durations and intensities to significantly reduce blood pressure.

Benefits of Exercise - “Exercise as Medicine”

It is well established that exercise can be used to prevent or treat chronic disease, thereby improving the health status and quality of life of individuals (Pederson & Saltin, 2006). The total amount and intensity level of exercise for optimal health improvements is of recent debate.

Physical Activity Recommendations

It is recommended by both the American College of Sports Medicine (ACSM) and American Heart Association (AHA) that 150 – 250 minutes per week, or 30 minutes per day, of moderate intensity physical activity is sufficient for weight loss, preventing weight gain, and reducing inactivity associated risk factors for developing chronic disease (Donnelly et al., 2009). For overweight and obese individuals ACSM guidelines encourage progressing from 150minutes to 300 minutes per week. For the present study, the moderate intensity endurance training (MIET) group corresponded to these guidelines.

Traditional Endurance Exercise

ACSM suggests that exercise benefits can occur even when exercise is accumulated throughout the day (i.e. 10 minutes, 3x per day), which evidence has suggested shows greater adherence from individuals who claim they have no time to exercise (Jakicic, 1995). A study by Snyder et al. (1997), examined the effects of intermittent moderate intensity exercise in overweight females (age 43 ± 11 , BMI 32.5 ± 8.0). He reported that 10 minutes per day for 32 weeks at a brisk walk (corresponding to 50-65% HRR) resulted in a significant increase in treadmill time to exhaustion ($+2.7 \pm 2.4$ min $p < 0.05$), and although not significant, exercise increased aerobic capacity by 0.5 ± 3.0 and decreased resting heart by 4.6 ± 12.3 bpm, all of which indicate improvements in general health. Moreover, blood lipids, glucose, and insulin were not significantly different after 32 weeks, though, baseline values for glucose and insulin were inversely correlated with their changes after the intervention ($r = -0.58$, $p < 0.58$ and $r = -0.72$, $p < 0.05$). This may suggest that individuals with poor baseline values tend to experience superior improvements post-intervention than those of healthy baseline values (Snyder et al., 1997). Another study by Murphy and investigators (2002) of twenty-one normolipidemic sedentary adults (women $n=14$, men $n=7$) aged 44.5 ± 6.1 yr (mean \pm SD) consisted of two different programs of brisk walking in a cross over design, including a two week washout period. One program consisted of subjects exercising 30 continuous minutes and the other program performed three 10 min walks per day. Each was performed 5 days per week at 70-80% HRR for 6 weeks. Results indicated that after both walking programs subjects experienced a significant decrease in the sum of the

skinfolds, waist and hip circumference, DBP, TC, and plasma TG concentrations. Both programs had a significant increase in VO_{2max} (3.6% and 12.4%) and fasting plasma concentrations of HDL-C (Murphy, Nevill, Neville, Biddle, & Hardman, 2002). Moreover, months of exercise training that progressed to 40 min per session, 5 days per week, prevented weight gain and induced weight loss in men and women subjects. For men, body weight, BMI, and total fat mass were significantly decreased compared to non-exercising controls (5.2 ± 4.7 kg; 1.6 ± 1.4 kg; 4.9 ± 4.4 kg, respectively). The women remained at a stable weight throughout the study, with a small decrease in fat mass. Alternatively, women who didn't exercise gained a significant amount of weight (2.9 ± 5.5 kg) and fat mass (2.1 ± 4.8 kg) (Donnelly et al., 2003). In addition, a meta-analysis consisting of studies that included 1-7 sessions per week of exercise lasting between 30-60 minutes for durations ranging from 4 to 52 weeks (average intensity of 30-90% VO_{2max} R), all concluded reduced BP post-intervention. This evidence suggests that endurance aerobic exercise can have favorable outcomes on BP (Pescatello et al., 2004). After a review of the literature, 30 minutes of moderate intensity exercise is sufficient to improve cardiorespiratory and metabolic health by improved plasma lipid profiles and induced weight loss.

High Intensity versus Low Intensity Exercise

The following evidence examines the effects of various intensity levels on health outcomes. Evidence strongly supports that aerobic training reduces resting BP in young and older normotensive and hypertensive people (Pescatello et al., 2004). There seems to be an even more pronounced reduction in BP in hypertensive compared to normotensive individuals (Pescatello et al., 2004). Aerobic exercise consisting of moderate intensity

exercise (40-70% $\text{VO}_{2\text{max}}$) reduced BP to a similar extent, and aerobic exercise performed at an intensity $\leq 70\% \text{VO}_{2\text{max}}$ demonstrated an even pronounced reduction when compared to higher intensity training in hypertensive individuals. Though, it should be noted that there is limited data on the effects of training at intensities $\geq 85\%$ on BP (Pescatello et al., 2004). Therefore, further research would be needed on the effects of high intensity training on BP to determine whether low intensity exercise would be more favorable

A review by Swain and Franklin (2006) consisted of epidemiological studies that evaluated the benefits of physical activity of varying intensity levels (described in MET levels) and clinical trials that trained individuals at different intensities of exercise while controlling for energy expenditure (EE). These studies consistently found that vigorous activity (≥ 6 METs) elicited a greater reduction in CVD risk and more favorable health outcomes associated with heart disease - aerobic fitness, BP, blood lipids, waist circumference – than with moderate intensity activity (3-6 METs). These findings are bolstered by the clinical trials which report greater improvements in aerobic capacity, DBP, and glucose control after higher intensity exercise ($\geq 60\% \text{VO}_{2\text{max}}$) compared to moderate intensity (40-65% $\text{VO}_{2\text{max}}$). Of the 11 studies that found an increase in aerobic capacity, six found that higher intensity exercise elicited greater increases compared to lower intensity exercise. The other five studies found comparable increases in aerobic capacity between both intensities, and no study found a greater increase after lower intensity training compared to higher intensity (Swain & Franklin, 2006). Likewise, increases in insulin sensitivity were found after higher exercise intensities than with moderate intensity exercise. Though, regardless of intensity level, HDL-C and body fat

were improved.

The following study reports that higher intensity exercise is more effective than moderate intensity exercise for improving aerobic capacity in patients with coronary artery disease (CAD) (Rognmo, Hetland, Helgerud, Hoff, & Slordahl, 2004). Twenty-one angiographically documented CAD patients participated in a 10 week study comparing the effects of high intensity versus moderate intensity aerobic exercise performed on a treadmill. The high intensity group (HIT) (6 men, 2 women, aged 62.9 ± 11.2 yr) completed 4 bouts of 4 minutes at 85-95% VO_{2peak} separated by 3 minutes of walking at 50-60% VO_{2peak} . The moderate intensity group (8 men, 1 woman, aged 62.2 ± 7.3 yr) exercised for 41 continuous minutes at 50-60% VO_{2peak} . The author alluded that he chose this particular range for high intensity because it was previously proven to yield great improvements in healthy individuals and the range for low intensity range has typically been used in previous training studies involving CAD patients. Both groups were matched for total work load, resulting in the HIT group only exercising for 33 minutes, whereas the moderate intensity group exercised for 41 minutes. Both groups trained 3 days per week and were instructed not to participate in any other leisurely activity outside of training. Heart rate monitors were worn by the subjects in order to ensure the proper intensities were elicited throughout the exercise sessions. The results demonstrated that the HIT group elicited a significantly greater ($p = 0.011$) improvement compared to the moderate intensity group (17.9%, $p = 0.012$, versus 7.9%, $p = 0.038$, respectively). During each session, the high intensity group showed an improvement of 0.63%, which was higher compared to the 0.29% improvement in the moderate intensity group ($p = 0.006$). However, there was no reported change in resting BP, resting HR, or

body mass with either training program. These findings concluded that high intensity aerobic exercise can elicit superior improvements in aerobic capacity compared to moderate intensity exercise beyond a healthy population, but also to individuals with stable CAD as well.

Moreover, Hansen et al. (2009) reported no significant differences between intensity levels on improving HbA1c (average BG concentration over the past three months) and whole body and skeletal muscle oxidative capacity in recently diagnosed type 2 diabetics. Subjects (n=50) were assessed before, after 2 months, and 6 months of intervention. Subjects were obese (BMI of $32 \pm 4 \text{ kg/m}^2$), average age 59 ± 8 years, and currently using oral glucose lowering medication. Training groups consisted of a low to moderate intensity group (LI) ($50\% \text{ VO}_{2\text{peak}}$) and a high intensity group (HI) ($75\% \text{ VO}_{2\text{peak}}$) and were matched for energy expenditure. Therefore, the LI group exercised for 55 min and the HI group exercised for 40 minutes, both exercising 3 days per week. Thirty-seven subjects completed the entire 6 month program. Diet and physical activity outside of training did not significantly change throughout the intervention and did not differ between groups, therefore the significant improvements in HbA1c content, body composition, and whole body and skeletal muscle oxidative capacity seen in these subjects can be rationalized as a direct result of the exercise intervention. HbA1c was reduced to a similar extent in both HI and LI. LI reported a decrease from 7.4 ± 0.3 to $7.2 \pm 0.3 \%$ ($p < 0.05$) and the HI group reported a decrease from 7.2 ± 0.2 to $6.9 \pm 0.2 \%$ ($p < 0.05$), which clinically, would correspond with a 6% reduction in premature death. Furthermore, resting glucose and insulin levels were assessed three days after discontinuation of oral blood glucose lowering medication and reported no changes when

measured after two and six months of the intervention. Both groups however, showed similar reductions in LDL-C following training ($p < 0.01$). The HI group showed a greater improvement in whole body aerobic capacity ($16 \pm 2\%$ versus $9 \pm 2\%$, respectively; $p < 0.05$) and trunk fat mass (2.0 ± 0.4 kg versus 1.0 ± 0.4 kg, respectively; $p < 0.05$) than after LI training. Increases in skeletal muscle oxidative enzyme capacity were reported for both training intensities, suggested by the significant increase in citrate synthase and cytochrome c oxidase from baseline to 6 months ($p < 0.01$). These findings are significant since low oxidative capacity of skeletal muscle has been associated with a reduced capacity for fat oxidation and a greater risk of developing obesity, insulin resistance and/or type 2 diabetes (Hansen et al., 2009).

Fortunately, these data demonstrates positive evidence that exercise is an effective method for weight management and health promotion. Unfortunately, more than half (52%) of American adults are not physically active (CDC, 2012) mainly due to lack of time (Troost, Owen, Bauman, Sallis, & Brown, 2002). As a result, an increase of interest is directed towards determining the most time efficient method of exercise capable of achieving optimal health.

High Intensity Interval Training

Recent studies have demonstrated that high intense interval-type training is more effective than traditional endurance-type training for health outcomes. For this reason, there is a growing amount of research utilizing various types of high intensity interval training (HIIT) and its effects on health variables. HIIT consists of brief bouts of very high intensity (either “all out effort” or $\geq 90\%$ VO_{2max}) interspersed by brief recovery periods at a lower intensity or rest (Boutcher, 2011; Gibala & McGee, 2008; Gibala,

Little, MacDonald, & Hawley, 2009). Although there is no standard lower intensity level, in most studies that employed cycling type HIIT, recovery periods were completed by decreasing the speed (revolutions per minute), or rest. The length of exercise and recovery periods in HIIT normally vary from six seconds to four minutes (Boutcher, 2011), thus this type of exercise results in very low volumes of training and has been suggested to be a more time-efficient approach to exercise (Coyle, 2005). HIIT can be utilized while performing various modalities of aerobic exercise, including, running, cycling, rowing, or swimming. The majority of research in the literature utilizes cycling and interventions typically last two to eight weeks. Only a few studies have employed longer intervention periods that range from 12 to 24 weeks (Tjønnå et al., 2008, 2009; Tremblay, Simoneau, & Bouchard, 1994; Warburton et al., 2005). Additionally, these studies have primarily focused on aerobic capacity and aerobic performance in young, healthy individuals and only a few examine the effects on certain metabolic indices for risk of chronic disease, which is a primary concern for individuals who don't find time to exercise.

Effects of HIIT on Physiological and Metabolic Indices

It is recognized that HIIT can result in superior health improvements compared to low intensity exercise. The following evidence reviews the effects of HIIT-type exercise on physiological and metabolic health indices. Talanian, Galloway, Heigenhauser, Bonen, and Spriet, (2007) examined two weeks of cycling HIIT which consisted of ten, four-minute bouts at 90% VO_{2peak} , interspersed with a two-minute rest period on eight recreationally active, young women (age 22.1 ± 0.2 yr, body weight 65.0 ± 2.2 kg). All training sessions were supervised. These subjects experienced a significant increase

(13%) in $\text{VO}_{2\text{peak}}$ (2.36 ± 0.24 l/min versus 2.66 ± 0.21 l/min), 36% increase in whole body fat oxidation during submaximal exercise ($\sim 60\% \text{VO}_{2\text{max}}$), and a reciprocal 23% decrease in carbohydrate oxidation. Moreover, this study supported that two weeks of HIIT can elicit significant adaptations in mitochondrial activity enzymes, including citrate synthase (CS) by 20% and β -HAD (3-hydroxyacyl CoA dehydrogenase) by 32% which play key roles in the rate limiting steps in fat oxidation (Burgomaster et al., 2008). Similarly, Little, Safdar, Wilkin, Tarnopolsky, & Gibala (2010) found an approximate 16% increase in CS activity and 20% increase of CS protein content after two weeks of cycling HIIT on seven young, recreationally active men (age 21 ± 1 yrs, body weight 83 ± 4 kg, $\text{VO}_{2\text{peak}}$ 46 ± 2 ml/kg/min). However, this protocol utilized a shorter exercise and rest periods than the previous study (60 second interval, interspersed with a 75 second active recovery period). Further, GLUT4 protein content increased by 119% ($p = 0.04$) and muscle glycogen by 17% ($p = 0.05$). GLUT4 protein is a key glucose transporter protein that enhances glucose transport capacity, thereby increasing insulin sensitivity (Goodyear & Kahn, 1998). Likewise, an increase in resting muscle glycogen is associated with enhanced insulin sensitivity (Goodyear & Kahn, 1998). Another study utilized the same HIIT protocol as Talanian et al. (2007) and further showed that cycling HIIT induced an increase in aerobic capacity and enhanced exercise performance (Perry, Heigenhauser, Bonen, Spriet, 2008). In this study, $\text{VO}_{2\text{peak}}$ significantly increased by 9% ($p < 0.05$) and an exercise time to fatigue test increased by 111% ($p < 0.001$) in young, recreationally active males ($n=5$) and females ($n=3$) aged 24 ± 1 yr (body weight 72.7 ± 4.0 kg). Likewise, resting GLUT4 and muscle glycogen content increased by 21% ($p < 0.01$) and 59% ($p < 0.001$), respectively. Additionally, subjects experienced a significant

29% increase ($p < 0.05$) in β -HAD maximal activity after six weeks, which was of a similar magnitude previously demonstrated with only two weeks of SIT (Talanian et al., 2007). In another study, fat oxidation during exercise improved significantly (26%, $p = 0.02$) in sedentary young women (age 24.2 ± 6.2 yr) after 12 weeks of cycling HIIT, three days per week (Astorino, Schubert, Palumbo, Stirling, & McMillan, 2013). Subjects ($n=16$) performed 6-10 one minute bouts (ranging between 75-100% HR_{max}) interspersed by 60-75 seconds of recovery. Fat oxidation measured during exercise improved in the initial three to six weeks of training, although no change in body weight, percent body fat, or abdominal circumference was reported ($p > 0.05$) (even though workload progressively increased throughout the study). Contrarily, two studies that employed similar protocols for 12 and 15 weeks showed significant reductions in total fat mass (Trapp, Chisholm, Freund, & Boutcher, 2008; Heydari, Freund, & Boutcher, 2012). Trapp et al. (2008) examined the effects of HIIT on 11 inactive, young adult women (age 22.4 ± 0.7 years, BMI of 24.4 ± 1.5 kg/m^2), whereas Heydari et al. (2012) examined the effects on 20 inactive, young, overweight men (age 24.7 ± 4.8 yrs, BMI 28.4 ± 0.5 kg/m^2 , percent body fat 34.8 ± 1.1 %). Both protocols required subjects to exercise three days per week. Similar to previous short term studies, these subjects experienced a significant increase in VO_{2peak} by 15% in men and 23.8% in women (Heydari et al., 2012; Trapp et al., 2008). Women lost a significant amount of fat mass 2.5 ± 0.83 kg ($p < 0.05$) (Trapp et al., 2008) which was expected since a prior study by Trapp, Chisholm, & Boutcher (2007), demonstrated gradual increases in blood glycerol levels (indicator of lipid release) and elevated catecholamine levels over 20 minutes of high intensity interval exercise. Likewise, Heydari et al. (2012) reported that male subjects lost 2 kg (6.7%, $p <$

0.005) of total fat mass and demonstrated a 13% greater increase in fat oxidation ($p < 0.001$) when compared to controls. Additionally, it appears that males experienced a greater increase in fat free mass (FFM) than women did after training (1.2 kg versus no significant change in women). Interestingly, the majority of improvements in body composition occurred during the first 6 weeks with attenuated reductions thereafter (Heydari et al. 2012). Contrary to this study, no weight change was induced after a six week HIIT intervention which consisted of a total of 10 minutes of exercise, three days per week (including warm-up and cool down), in sedentary young men ($n=7$, age 26 ± 3 yrs, body weight 73.7 ± 6.0 kg) and women ($n=8$, age 24 ± 3 yrs, body weight 59.7 ± 2.7 kg) (Metcalf, Babraj, Fawcner, & Vollaard, 2012). In this study, subjects performed one or two bouts of 10-20 seconds of “all out” sprints separated by low intensity cycling. Even though total exercise time was minimal, men and women subjects showed improvements in VO_{2peak} , 15% and 12% respectively, which concurs with the previous alluded short term studies. There are limited long term studies that have examined the response in fat oxidation to HIIT, so it remains unknown whether this type of training is capable of sustaining the short term increases in fat oxidation as seen in previous studies. This is significant considering fat oxidation can significantly influence improvements in body composition.

Current evidence also proposes HIIT as an effective method in improving insulin and glucose levels which has been recognized as an important adaptation following traditional endurance exercise. For example, Little et al. (2010) determined a 119% ($p = 0.04$) increase in GLUT4 proteins and 17% ($p = 0.05$) increase in resting muscle glycogen in seven young (21 ± 0.4 yr), healthy, recreationally active men after a 2 week

HIIT intervention. Similarly, Perry et al. (2008) found a 21% increase in resting GLUT4 ($p < 0.01$) and 59% increase in muscle glycogen ($p < 0.001$) after 6 weeks of HIIT on young (21 ± 1 yr) subjects (5 males, 3 females), and both substrates are associated with enhanced insulin sensitivity (Goodyear & Kahn, 1998). Moreover, Metcalfe et al. (2012) noted a 28% improvement in insulin sensitivity after six weeks of HIIT in male subjects ($n=13$), but not females ($n=16$). Shorter studies lasting only 2 weeks generated an increase in IS of similar magnitude seen in these men (Babraj et al., 2009; Richards et al., 2010; Whyte, Gill, & Cathcart, 2010). Both men and women were sedentary, young subjects (25 ± 1 yr). It should be noted that post testing was measured three days after their last training session, thus there is a possibility subject could have experienced an increase in insulin sensitivity immediately after training. Conversely, Trapp et al. (2008) reported a 31% decrease ($p < 0.05$) in fasting insulin levels in eleven women (age 22.4 ± 0.7 yrs, BMI 24.4 ± 1.5 kg/m²) after 15 weeks of HIIT, indicating improved insulin sensitivity. No changes were found in fasting glucose from baseline to 15 weeks.

HIIT versus Prolonged Endurance Training on Health Outcomes

The following studies have compared the physiological and metabolic adaptations after HIIT compared to prolonged endurance training (ET). Tremblay et al. (1994) examined 27 healthy males ($n=13$) and females ($n= 14$) aged 18-32 years, who were not previously engaged in sports or other physical activities. Seventeen subjects (body weight = 60.6 ± 13.4 kg) completed a 20 week ET program while the other 10 subjects (body weight = 63.9 ± 11 kg) completed a 15 week cycling HIIT protocol. The ET group progressed from 30 minutes to 45 minutes of continuous cycling (progressing from 60 to 85% HRR) five days a week. The HIIT group progressed from 15, 30 second

bouts to 4 to 5, 90 second bouts, five days a week, resulting in a total of 19 short intervals and 16 long interval sessions. The intensity levels for the short and long interval durations were initially 60% HRR_{max} and 70% HRR_{max} , respectively, and increased five percent every three weeks. Energy costs of the two programs were very different (HIIT: 57.9 MJ versus ET: 120.4 MJ, $p < 0.01$). Despite the lower energy cost in the HIIT group, they experienced a greater reduction of the sum of six skinfolds than ET. Furthermore, skeletal muscle enzymes related to fat oxidation (β -HAD enzyme) resulted in a greater increase after HIIT than ET, which may propose greater fat utilization after HIIT than ET. Both training groups significantly improved VO_{2max} . The HIIT group increased from 38.7 ± 8.8 to 48.6 ± 7.0 ml/kg/min ($p < 0.01$) and the ET group increased from 36.6 ± 7.9 ml/kg/min to 48.2 ± 7.7 ml/kg/min ($p < 0.01$). HIIT, therefore leads to more favorable outcomes in fat loss and aerobic capacity compared to less intense exercise despite the lower energy cost during training.

There is growing appreciation for the capability of HIIT to stimulate beneficial adaptations in various populations, including patients with heart disease (Rognmo et al., 2004; Guiraud et al., 2013). Recently, Guiraud et al., (2013) compared a single session of two diverse training protocols on 18 individuals with stable coronary heart failure (CHF). This study included subjects aged 53 ± 2.0 yrs with an average BMI of 26.9 ± 7.1 and subjects were taking medications, including betablockers (n=18) and ACE inhibitors (n=14). The high intensity interval exercise (HIIE) group completed two 8 minute bouts, comprised of 30 second cycling sprints at 100% peak power output (PPO) interspersed with 30 seconds passive recovery. Four minutes passive recovery was completed between sets. The moderate intensity continuous exercise (MICE) group completed 22 minutes of

continuous cycling at 60% PPO. Energy expenditure was similar in both training groups. Guiraud et al. (2013) demonstrated that a single session of HIIE induced an earlier and larger improvement in of the parasympathetic nervous system for at least 24 hours, in comparison to MICE. Average HR was significantly lower compared to baseline with HIIE (-2.1bpm, $p < 0.01$) and MICE (-1 bpm, $p < 0.01$). HIIE also significantly reduced the occurrence of premature ventricular contractions compared to baseline assessment and MICE ($p < 0.01$). These findings support that high intensity interval training could potentially lower the risk of arrhythmias and other cardiovascular risks of CHF patients.

Health Outcomes of HIIT Performed on Treadmills versus Prolonged Endurance

Training

Few studies have employed HIIT using treadmills rather than cycle ergometers (Nybo et al., 2010; Corte de Araujo et al., 2012; Tjonna et al., 2008; Schjerve et al., 2008). Nybo et al. (2010) examined the effectiveness of short term HIIT on cardiorespiratory fitness, resting heart rate and blood pressure, glucose tolerance, and plasma lipids compared to prolonged endurance training on untrained men. One group performed intense interval running (INT) and another group performed prolonged moderate intense continuous running (MOD). Subjects ($n=36$) were free from metabolic or cardiovascular diseases, and did not participate in any type of regular physical training for at least two years prior to recruitment (INT: age 37 ± 3 yrs, body weight 96.3 ± 3.8 kg MOD: age 31 ± 2 yrs, body weight 85.8 ± 5.5 kg) (Nybo et al, 2010). Both groups completed a pre- and post-testing session following 12 weeks, which consisted of an exercise test, oral glucose tolerance test (OGTT), resting HR and BP measurements, and a plasma lipoprotein profile. Participants were instructed to continue their habitual

physical activity and dietary lifestyle throughout the intervention. The INT group performed five intervals of two minutes of near maximal running ($>95\%$ HR_{max}), totaling exercise time (including warm-up) to 20 minutes. The MOD group performed one hour of continuous running at 80% HR_{max} (65% VO_{2max}). Both groups were instructed to train three times a week, however due to overuse injuries or absence of other sessions, the INT group completed on average, 2 ± 0.1 sessions per week, totaling 480 minutes of training time (including warm-up). The MOD group completed on average, 2.5 ± 0.2 sessions per week, totaling 1800 min of training time. INT protocol induced a twofold increase in VO_{2max} than MOD training ($p < 0.05$). Both groups reported a reduction of 8 mmHg in SBP after training ($p < 0.05$), although greater reductions in resting HR and DBP were reported with MOD. The INT group experienced a nonsignificant decrease in resting HR by 3 bpm, whereas the MOD group experienced a significant decrease by 6 bpm ($p < 0.05$). DBP after MOD training was significantly reduced from 81 ± 3 mmHg pre-training, to 76 ± 2 mmHg post-training ($p < 0.05$). Both fasting BG and BG concentration measured 2 hrs after OGTT were reduced to a similar extent in both training groups and were significantly different than pre-training values ($p < 0.05$). In regards to plasma lipids, fasting HDL-C, LDL-C, TC, and TC: HDL-C ratio, the INT group reported no changes, whereas the MOD group demonstrated a reduction in fasting TC:HDL-C ratio. In result, INT may not be a sufficient training stimulus to improve plasma lipoprotein-lipid profiles, but enough to improve cardiorespiratory fitness in untrained subjects.

Recently, Araujo et al. (2012) compared high intensity training (HIT) with endurance training (ET) on health related parameters in obese children aged 8 to 12 years. HIT protocol consisted of three to six bouts of 60 seconds sprints at 100% VO_{2max}

interspersed with three minutes active recovery, and ET consisted of continuous exercise at 80% HR_{peak} progressed from 30 to 60 minutes, all performed on a treadmill. Araujo et al. (2012) reported that after 12 weeks of training, both protocols were equally effective at improving BMI, insulin sensitivity, and aerobic fitness in obese children (Araujo et al., 2012). Unfortunately, only a few studies have simultaneously examined the effects of these two diverse protocols in a population in great need of exercise-induced benefits, such as overweight or obese adults.

For example, only two studies compared the effects of high intensity training to moderate intensity aerobic training on variables relating to a high cardiovascular risk profile in obese adults (Tjonna et al., 2008; Schjerve et al., 2008). Tjonna et al. (2008) evaluated thirty-two subjects with metabolic syndrome as defined by the World Health Organization. Subjects were, on average, 52.3 ± 3.7 yrs, BMI of 29.6 ± 5.2 kg/m^2 , and had a VO_{2max} of 34 ml/kg/min. Subjects were randomized into either moderate continuous exercise (CME) or aerobic interval training (AIT), conducted three times a week for 16 weeks. The CME group performed 47 minutes of endurance training walking/running “uphill” on a treadmill at 70% of maximal heart frequency (Hf_{max}). AIT subjects performed 40 minutes per session, consisting of a 10 minute warm-up, four 4-minute intervals at 90% Hf_{max} interspersed with 3 minute recovery periods at 70% Hf_{max} , and a five minute cool down. Energy expenditure per session was matched between groups. Twenty-eight of the 32 subjects completed all scheduled training sessions. Withdrawals were due to personal reasons or minor injury. Both training groups exhibited a similar reduction in body weight (AIT: 3% $p < 0.05$ and CME: 4% $p < 0.05$), BMI ($p < 0.05$), and waist circumference (AIT: 5 cm and CME: 6 cm). AIT had a

significantly greater increase in insulin sensitivity than CME ($p < 0.05$) at 16 weeks. AIT and CME both noted a decrease in SBP by ~ 10 mmHg and DBP by ~ 6 mmHg, but only AIT reported significance (AIT, $p < 0.05$; CME, $p = 0.24$). AIT and CME both increased $VO_{2\max}$ significantly by 35% and 16% ($p < 0.01$) respectively, however AIT showed a significantly greater increase than CME ($p < 0.01$). Moreover, AIT caused a significantly greater improvement in fasting BG, insulin sensitivity, and B-cell function ($p < 0.05$) compared to CME. HDL-C increased by $\sim 25\%$ ($p < 0.05$) with AIT but remained unchanged with CME. No training group reported changes in TG, TC, or LDL-C after training. Overall, 46% of subjects in the AIT group and 37% in the CME group were no longer diagnosed with metabolic syndrome by the end of the training intervention.

Another study by Schjerve et al. (2008) reported improvements in blood pressure, aerobic capacity, body weight, in both moderate and high intensity training groups consisting of obese male and female adults (age 44 ± 2 yrs, BMI 35 kg/m^2 , $VO_{2\max} \sim 24 \text{ ml/kg/min}$). The high intensity training protocol consisted of a 10 minute warm-up, four sets of four minute intervals at 85-95% HR_{\max} interspersed with three min active recovery and a five minute cool down. The moderate intensity group walked continuously for 47 minutes at 60-70% HR_{\max} . All sessions were either walking or running on a treadmill, with the exception of one session per week completed in a free living setting (outdoor uphill walking). Protocols were matched for energy expenditure and subjects were instructed to complete three sessions/week for 12 weeks. Fasting blood lipids were measured after an 8 hour fast and no changes were reported in TG, HDL-C, TC, HbA1c, glucose & insulin C-peptide after both training protocols and only the moderate intensity group experienced a significant reduction in LDL-C ($p < 0.04$). SBP remained unchanged after both training

interventions but both groups experienced a significant reduction in DBP (high intensity by 7%, $p < 0.002$; moderate intensity by 9%, $p < 0.02$). The high intensity group reported a greater increase in VO_{2max} compared to moderate intensity, 33% versus 16%, respectively (both $p < 0.01$). Further, both training groups experienced significant improvements in body composition. These studies suggest that high intensity interval training can elicit similar, if not greater, improvements in the cardiovascular risk profile in obese subjects than moderate endurance training.

Another study by Trapp et al. (2008) examined the effects of a less demanding 20 minute bout of high intensity intermittent exercise (HIIE) program on body composition and insulin resistance compared to longer, steady state exercise (SSE). In contrast to the aforementioned studies, subjects only consisted of women. Thirty-four inactive, healthy subjects (aged 18-30 years) were randomly allocated into one of the exercise groups. HIIE group progressed to 20 minutes, consisting of 60 bouts of 8 second sprints “as hard as they could”, interspersed with 12 seconds recovery performed at a lower cadence on a cycle ergometer. At baseline, subjects were aged 22.4 ± 0.7 yrs with a BMI of 24.4 ± 1.5 kg/m^2 . The SSE group progressed to 40 minutes of continuous cycling at 60% VO_{2peak} . At baseline SSE subjects were aged 21.0 ± 0.8 yrs with a BMI of 22.4 ± 1.0 kg/m^2 . Training sessions were performed three days/week over a 15 week period and subjects were instructed to keep dietary intake the same throughout the intervention period. Both training groups showed increases in VO_{2peak} from baseline (HIIE by 23.8% and SSE by 19.3%, $p < 0.0001$). However, only HIIE group showed significant reductions in total body mass (pre, 63.6 ± 3.8 kg to post, 61.8 ± 3.6 kg), fat mass (pre, 22.2 ± 3.0 kg to post, 19.7 ± 2.6 kg), central abdominal fat (-9.5%, -0.15 ± 0.07 kg), and percent body fat ($p <$

0.05). In contrast, SSE resulted in gained FM and a non-significant 10% increase in central abdominal fat ($+0.1 \pm 0.08$ kg). Only HIIE resulted in a significant decrease in fasting insulin (HIIE 31% $p < 0.05$ versus SSE 9% $p > 0.05$) and neither group experienced changes in fasting glucose after training. Despite the significantly lower time commitment of 36 minutes per week with HIIE compared to 120 minutes per week with SSE, HIIE still induced significantly greater improvements on fasting insulin levels and body composition, and a similar improvement in $VO_{2\max}$ than the latter.

Sprint Interval Training (SIT)

The most common HIIT protocol researched in the literature is an "all out" 30 second sprint on a cycle ergometer referred to as a Wingate test. This type of training is commonly known as sprint interval training (SIT) and typically consists of four to six Wingate tests, interspersed with four or four and half minutes of active recovery (Gibala et al., 2006; Coyle, 2005). Total time of very intense exercise amounts to two to three minutes and total time commitment per session is typically between 25-30 minutes (Coyle, 2005). The power generated in SIT protocols is mostly derived via anaerobic energy systems, rather than aerobic energy systems (Gibala et al., 2006). SIT especially places great stress on recruitment and adaptation of type II, fast twitch muscle fibers which are equally and remarkably responsive in their ability to increase mitochondrial enzyme activity as demonstrated in Type I muscle fibers (Coyle, 2005). Type I, or slow twitch muscle fibers are predominantly used during ET, which is why traditionally, prolonged submaximal aerobic training has been recommended for maintaining good health. Therefore, there is suggestive evidence that prolonged endurance training is not the most effective method for optimizing aerobic adaptations in skeletal muscle, and a

growing amount of research on SIT and its effects on other health parameters has prevailed.

Similar to the extensive review on the effects of HIIT on aerobic capacity, the majority of studies utilizing SIT have primarily focused on its effects on aerobic capacity (Astorino, Allen, Roberson, & Jurancich, 2012; Burgomaster, Hughes, Heigenhauser, Bradwell, & Gibala, 2005; Whyte et al., 2010; Trilk, Singhal, Bigelman, & Cureton, 2011; MacDougall et al., 1998). Moreover, investigators have examined insulin sensitivity, changes in substrate utilization and skeletal muscle oxidative enzymes after SIT training (Whyte et al, 2010, 2013; Chan & Burns, 2013; Harmer et al., 2008; MacDougall et al., 1998; Burgomaster et al., 2005; Vincent et al., 2004). Despite the number of studies that evaluated changes in substrate utilization following SIT, only a few measured changes in body composition (Whyte et al., 2010, Astorino et al., 2012, Trilk et al., 2011). In addition, there is still a lack of information on whether SIT can induce favorable outcomes on blood lipid profiles and blood pressure. After further review of the literature, the majority of studies investigating the effects of SIT have employed short intervention periods, typically lasting two to seven weeks. The literature consistently reports studies using young, healthy subjects and lacks research on the physiological and metabolic outcomes in a range of populations, including unfit, sedentary individuals at high risk for CVD or other chronic diseases, such as overweight or obese individuals (Whyte et al., 2010, 2013; Trilk et al., 2011), or individuals diagnosed with Type II diabetes (Trilk et al., 2011). All in all, more research on the chronic effects of SIT on risk factors associated with inactivity-related chronic diseases is warranted.

The Effects of SIT on Physiological and Metabolic Indices

Recent studies examined the acute effects of SIT (Freese, Levine, Chapman, Hausman, & Cureton, 2011; Chan & Burns, 2013, Whyte et al., 2010). Subjects performed one session of four Wingate tests, separated by four or four and half minutes active recovery and effects on catecholamine response, postprandial lipemia (triglyceride response), oxygen consumption, substrate utilization, blood pressure, and insulin sensitivity were reported. It is well known that high intensity exercise results in a marked increase in catecholamine release compared to moderate steady state aerobic exercise (Rebuffe-Scrive, Andersson, Olbe, & Bjorntorp, 1989). In accordance, evidence shows that just one bout of SIT has the potential to significantly elevate catecholamine response, as demonstrated by Vincent et al. (2004). Catecholamines have been proven to stimulate lipolysis and are mainly responsible for fat release from visceral fat stores (Rebuffe-Scrive et al., 1989). Over time, these increased responses may enhance weight loss. In regards to the acute response of substrate utilization, the literature suggests an increased capacity for fat metabolism and a reciprocal decrease in carbohydrate metabolism. A substantial increase in resting whole body fat oxidation of 63% was present 18-22 hours after a single session of four Wingate repeats as demonstrated by Whyte et al. (2013). Furthermore, Chan et al. (2013) reported 75% higher fat utilization ($p = 0.033$) two hours after one session of SIT in ten healthy males (age 23.3 ± 1.7 yrs; BMI 22.9 ± 2.8 kg/m²), although demonstrated no difference in carbohydrate metabolism compared to baseline values ($p = 0.249$) as determined by breath to breath pulmonary gas exchange measurements via respiratory masks. Interestingly however, fat oxidation in overweight, obese sedentary men after two weeks of SIT significantly increased 24 hours post

intervention but not at 72 hours (age 32.1 ± 8.7 yrs; BMI 31.2 ± 3.7 kg/m²; $\text{VO}_{2\text{max}}$ 2.98 ± 0.48 L/min) (Whyte et al., 2010). Increases in fat utilization after short term SIT interventions can also be a product of changes in the metabolic profile of skeletal muscle. Burgomaster et al. (2005) indicated substantial increases in glycogen (26%) and citrate synthase activity (38%) in resting skeletal muscle in eight recreationally active college students, in as quickly as 2 weeks of SIT, which is comparable to increases induced after 6-7 days of endurance training at 60% $\text{VO}_{2\text{peak}}$ two hours per day. Further, two seven week studies by Harmer et al. (2008) and MacDougall et al. (1998) add to these findings as similar responses were demonstrated in healthy and type I diabetic individuals. Harmer et al. (2008) demonstrated adaptations in substrate utilization during submaximal exercise. He reported a significant increase in the “glycogen sparing effect”, which is described as an increase in fat oxidation and a similar decrease in carbohydrate oxidation in Type I diabetic patients (n=8) and healthy controls (n=7) who were sedentary or recreationally active ($p < 0.05$). This effect is normally seen after several weeks of endurance training in healthy individuals (Harmer et al., 2008).

Even though these studies suggest an increase in fat oxidation at both rest and during submaximal exercise, it seems interesting that studies that employ the SIT protocol demonstrated little to no change in body composition (Astorino et al., 2012, Trilk et al., 2011, Whyte et al., 2010). For example, two weeks of SIT did not change body fat percent, waist to hip ratio, or body mass in young recreationally active men and women after (age 25 ± 4.5 yrs, body fat $14.3 \pm 6.4\%$) (Astorino et al., 2012). However, it is possible that this may be due to low body fat percent of subjects at baseline. In accordance, Whyte et al. (2010) examined its effects on ten obese individuals aged $31.2 \pm$

8.7 yrs with a BMI of $31.0 \pm 3.7 \text{ kg/m}^2$, and reported significant reductions (although still modest) in body mass, waist circumference, and hip circumference; -1kg, -1.1%, -1% respectively. However, findings have been inconsistent in overweight populations, as suggested by Trilk et al. (2011). He reported no significant differences in the changes of pre- to post-testing measures in body mass, BMI, and body fat percentage in twenty-eight sedentary, overweight/obese women, when compared to changes in control subjects who were instructed to maintain baseline physical activity levels throughout the four week intervention (Trilk et al., 2011). Age and BMI of subjects in the SIT and control group were 30.1 ± 6.8 yrs and $35.7 \pm 6.3 \text{ kg/m}^2$, and 31.4 ± 5.5 yrs and $34.6 \pm 5.9 \text{ kg/m}^2$, respectively. It remains unknown whether changes in substrate utilization is an acute response to the last interval of a SIT session or if chronic SIT sessions are necessary to sustain elevated fat oxidative levels that will essentially lead to weight loss. Additional studies on long term SIT are needed in hopes to determine strategies for long term weight loss or weight maintenance.

The literature suggests that SIT is effective in increasing maximal aerobic capacity, yet the optimal duration of the intervention still remains unknown. Short term SIT studies (two to seven weeks) on recreationally active men and women, physically active men, and overweight/obese subjects have demonstrated significant increases when compared to controls (Trilk et al., 2011; Bayati, Farzad, Gharakhanlou, & Agha-Alinejad, 2011; Whyte et al., 2010; MacDougall et al., 1998; Astorino et al., 2012). Improvements in aerobic capacity were demonstrated after four weeks of SIT in overweight/obese, sedentary women (12%) (Trilk et al., 2011), as well as in young habitually active men (9.6%) (Bayati et al., 2011). Interestingly, in an earlier study by Whyte et al. (2010),

overweight/obese sedentary men demonstrated an improvement of a similar magnitude after an even shorter SIT intervention lasting only two weeks (8.4%; baseline 2.98 ± 0.15 L/min versus post 3.23 ± 0.14 L/min, $p = 0.027$) (Whyte et al., 2010). A seven week intervention demonstrated improvements to a similar extent in physically active young men (MacDougall et al., 1998). Inconsistent with these findings, Burgomaster et al. (2005) reported no changes in VO_{2max} after two weeks of SIT in recreationally active subjects, although endurance performance (time to fatigue during cycling at 80% VO_{2max}) improved by 100%. Endurance performance was also significantly improved after four weeks of SIT in habitually active students (age $25 + 0.8$ yrs, body weight 70 ± 11 kg) (Bayati et al., 2011). These data suggest that participation in short term SIT exercise can effectively increase cardiorespiratory fitness in a time efficient manner, which can be of particular interest in inactive, at risk populations.

Adaptations in heart rate and blood pressure were examined by a small number of SIT studies (Chan & Burns, 2013, Whyte et al., 2013, Astorino et al., 2012, Trilk et al., 2011). Acute blood pressure responses were measured over a two hour period following an exercise trial consisting of four Wingate repeats versus the BP response after a control trial consisting of no exercise (Chan & Burns, 2013). Subjects served as own controls and consisted of young healthy male subjects and trials were completed at least two weeks apart. Significant reductions in SBP and DBP by ~ 8 mmHg and ~ 7 mmHg, respectively, were reported after the single trial of SIT (Chan & Burns, 2013). SBP was reported lower during the second hour following exercise ($p=0.001$), whereas DBP was significantly lower in the first 15 minutes and again between 90-120 minutes post-exercise. Another study using the same protocol reported no difference in BP measured ~ 18 hours

following the exercise trial compared to the control trial in young, overweight/obese, male subjects ($n=10$; aged 26.9 ± 6.2 yrs) (Whyte et al., 2013). Earlier work by Whyte and colleagues (2010) reported a significant 4.7% reduction in SBP 24 hours post-training ($p = 0.02$), but this effect was diminished by 72 hours after a 2 week intervention in a similar population. DBP tended to be lower than baseline values at 24 and 72 hours following training although this was not considered significant (Whyte et al., 2010). Additionally, no changes in resting HR or BP were found when measured 48 hours following the last training session in recreationally active, young male subjects after a 2 week intervention (Astorino et al., 2012). These data might suggest a delay in BP responses and any improved outcomes may be an acute effect to the last exercise session. However, it is probable that subjects were normotensive since they were younger and non-obese than in the previous work by Whyte et al. (2010). While it remains unknown whether or not the acute improvements seen in BP can sustain longer intervention periods that are greater than two weeks, no other study has examined the chronic effects on resting HR following a SIT intervention. Additionally, these studies suggest that individuals will respond differently to a SIT stimulus, therefore further research is needed in order to establish whether or not SIT can generate favorable outcomes on overweight/obese populations.

Other findings include responses in blood lipid profiles (Whyte et al., 2010, 2013; Freese, et al., 2011) and changes in IS (Whyte 2012, Vincent et al., 2004, Freese et al., 2011, Babraj et al., 2009, Whyte et al., 2010; Richards et al., 2010). Evidence has shown that a single SIT session consisting of four Wingate repeats with four minute rest periods does not induce favorable adaptations on fasting glucose, insulin, TG, TC, or HDL-C

levels measured 18 hours following exercise (Whyte et al., 2013). Freese et al. (2011) utilized the same protocol and found postprandial TG levels after consumption of a high fat meal to be 21% lower than controls who did not complete the exercise bout ($p < 0.05$). The high fat meal was consumed by participants ~ 14 hrs after exercise and after a 13 hour overnight fast (Freese et al., 2011). Likewise, fasting TG levels, measured before consuming the high fat meal, showed a trend towards reduction although was not considered significant ($p = 0.068$).

Only one study examined a two week SIT regimen on fasting TG, TC, and HDL-C measured 24 hours and 72 hours following the last sprint interval (Whyte et al., 2010). Results showed reductions in TG and TC however neither were significant, and no change was observed in HDL-C. Only one study examined HbA1c and reported an insignificant decrease after training (pre-training, 8.6%; post-training, 8.1%; $p = 0.09$) (Harmer et al., 2008). Subjects aged 25 ± 4 yrs and consisted of diagnosed type I patients (5 males, 3 females; A1c $8.6 \pm 0.8\%$, BMI 25.4 ± 3.2 kg/m²) and healthy controls (4 males, 3 females; A1c $5.3 \pm 0.3\%$, BMI 23.8 ± 5.0 kg/m²). However, this intervention was only 7 weeks long and may not have been long enough to produce significant results. Although IS was not measured in this study, there is evidence that A1c is inversely related to insulin sensitivity (Harmer et al., 2008). Thus, studies that aim to improve insulin sensitivity in populations at risk of developing metabolic diseases could potentially be of clinical significance as it assists in minimizing their risk. Prospective studies need to examine the effects of long term SIT on HbA1c to determine if SIT can be effective in minimizing risks of developing diabetes and other chronic diseases in these populations.

There is inconclusive evidence on whether IS is affected by an acute single-bout of SIT or a result of short term SIT interventions consisting of three sessions/week for two to four weeks. A single session of SIT comprises of four Wingate repeats. An earlier finding by Whyte et al. in 2010, observed a significantly higher insulin sensitivity index 24 hour post-intervention in a fasted state compared with baseline ($p = 0.037$), although these changes were no longer significant 72 hours post-intervention. This short term intervention lasted two weeks. A more recent study by Whyte and colleagues (2013) indicated no improvement after a single session of SIT, measured between 18 to 22 hours following their session. IS changes were determined using the HOMA-IR equation and insulin sensitivity index. Thus, Whyte et al. (2013) proposed that changes in IS may be a short lived adaptation to short term SIT interventions but not an acute effect of SIT. Consistent with his findings, another study demonstrated a significant improvement in IS after a short term SIT intervention but not after a single session of SIT in twenty-one young, sedentary, recreationally active adults (Richards et al., 2010). Subjects in the single session group included 2 males, 7 females, aged 24 ± 1 yr, BMI 26 ± 1.3 kg/m² and body fat percent $28.3 \pm 2.5\%$. Subjects in the short term SIT group included 5 males, 7 females aged 29 ± 3 yrs, BMI 26.2 ± 1.3 kg/m², and body fat percent $29.6 \pm 1.8\%$. As determined using the hyperinsulinaemic euglycaemic clamp technique prior to and 72 hours post exercise in a fasted state, Richards et al. (2010) observed an insignificant increase in IS after a single SIT session ($+0.82 \pm .93$ mg/kg/min) and a significant increase after 6 sessions of SIT (mean change: $+1.66 \pm 0.61$ mg/kg/min, $p = 0.04$). Another study by Babraj et al. (2009) concluded that insulin sensitivity improved by 23% in healthy sedentary or recreationally active men ($n=16$) aged 21 ± 2 yr with a BMI of

$23.7 \pm 3.1 \text{ kg/m}^2$, after a short term two week SIT study as measured by the Cederholm index ($p < 0.01$). However, in order to determine whether changes were due to acute effects attributable to the last sprint session, Babraj and investigators (2009) tested ten subjects two days post and six subjects three days post the last exercise bout. Results demonstrated that plasma glucose area under the curve (AUC) (-12%) and insulin AUC (-37%) significantly reduced post-training up until at least three days after the last training session (both $p < 0.001$). His findings indirectly indicate an improvement in glycemic control at minimum three days after the last bout of exercise in healthy young males. Collectively, it still remains unclear whether IS is an acute response to a single SIT session or accumulated over multiple SIT sessions. Additionally, there is no evidence whether or not glycemic control, as a result of SIT, can be effective in middle aged women at risk of developing Type II diabetes.

SIT versus Prolonged Endurance Training on Health Outcomes

In a similar manner to HIIT, the minimal time requirement for SIT is an attractive characteristic for individuals who are pressed for time and therefore fail to find time for exercise. The following few studies have directly compared low volume SIT versus traditional high volume endurance (ET) training in a standardized manner in healthy young individuals. The outcomes investigated included metabolic and performance adaptations (Gibala et al., 2006), vascular structure and function (Rakobowchuk et al., 2008), and muscle oxidative capacity (Burgomaster et al., 2008). All SIT protocols were performed three days a week, with one to two recovery days between each session. Gibala et al. (2006) compared changes in exercise capacity and molecular and cellular adaptations in skeletal muscle after these two diverse training strategies. Subjects were

characterized as healthy, untrained, but physically active individuals (defined as participating in recreational activity two to three times per week) aged 22 ± 1 yrs and BMI of 23.3 ± 0.5 kg/m². Differences in age, BMI, weight, height, or VO_{2peak} between groups were not significant. The Wingate protocol used in the SIT group (n=8) consisted of a four minute active recovery, compared to four and half minutes in the following two studies. The total time commitment per session was approximately 18-21 minutes. The ET group (n=8) performed 90-120 minutes of moderate intensity (~ 65 VO_{2peak}), separated by one to two recovery days. After two weeks, the SIT group exercised for a total training volume that was $\sim 90\%$ lower than that of the ET group. Despite the lower volume of training and energy expenditure compared to ET, SIT induced remarkably similar adaptations in resting muscle glycogen, exercise performance, and skeletal muscle capacity. Resting muscle glycogen increased after training by 28 and 17% for SIT and ET respectively ($p \leq 0.05$), with no difference between groups. Muscle buffering capacity increased after training by 7.6% and 4.2% for the SIT and ET groups respectively ($p \leq 0.05$), with no difference between groups. Muscle oxidative capacity as determined by COX activity, increased after training ($p = 0.04$), with no difference between groups. Additionally subjects decreased their exercise performance test timed trial to a similar extent ($p < 0.001$), with no difference between groups. Changes in exercise capacity are speculated to have been a result of both an increase in muscle oxidative capacity and muscle buffering capacity. These data suggest that though both training protocols have extremely different total training volume (630 kJ for SIT versus 6500 kJ for ET) and time commitment (~ 2.5 versus 10.5 hrs), SIT is indeed a very time efficient exercise strategy for obtaining the same adaptive responses in oxidative capacity and skeletal adaptations

within a relatively short period of two weeks (Gibala et al., 2006).

Two further studies by Burgomaster et al. (2008) and Rakobowchuk et al. (2008) compared 6 weeks of SIT performed three days/week versus an ET group that progressed to 60 minutes of cycling at 65% $\text{VO}_{2\text{max}}$, five days/week on young healthy recreationally active males and females. In the study by Burgomaster et al. (2008), total energy cost/wk after SIT was 225 kJ compared to 2250 kJ after ET. Likewise, total time commitment after 6 weeks was substantially lower for SIT (1hr compared to 4.5 hrs). Despite these differences, whole body fat oxidation and whole body carbohydrate oxidation in both groups significantly increased and decreased, respectively, with no differences between groups. Aerobic capacity ($\text{VO}_{2\text{peak}}$) also increased significantly after training with no difference between groups ($p < 0.05$). Subjects in the SIT group were aged 24 ± 1 yr and weighed 69 ± 3 kg and in the ET group, 23 ± 1 yr and 75 ± 4 kg, with both groups consisting of 5 males and 5 females. These results confirm the previous findings by Gibala et al. (2006) of similar improvements between SIT and ET, despite different training volumes. Additionally, Rakobowchuk et al. (2008) compared these two training protocols on peripheral artery distensibility and endothelial function adjustments in a similar population. He further supports the previous findings of similar increases in $\text{VO}_{2\text{max}}$ despite diverse training volumes (Burgomaster et al., 2008). Additionally, investigators observed improved peripheral arterial distensibility ($p < 0.01$), with no differences between groups, whereas no group showed significant improvements in central arterial distensibility ($p = 0.29$). Furthermore, endothelial function as assessed by flow-mediated dilation (FMD) significantly increased with training in both groups ($p = 0.05$). This study has important implications that low volume SIT is capable of improving

aerobic capacity as well as peripheral vascular structure and function, which can potentially reduce the risk for cardiovascular disease only after 6 weeks of training.

Seemingly, the intense nature of SIT induces rapid adaptations compared to ET, which may occur more slowly. These data described were of short term duration (two to six weeks) and examined only a few specific parameters (Gibala et al., 2006; Burgomaster et al., 2008; Rakobowchuk et al., 2008). No study examined whether low volume SIT that was matched in respect to exercise mode, training frequency, and duration of intervention, with incomparable total training volumes, can induce similar adjustments on physiological parameters typically associated with ET (i.e. increased capacity for fat oxidation, improvements in cardiorespiratory fitness, changes in blood health status markers, improved body composition, increased insulin sensitivity, etc).

Treadmill Running SIT Protocols

Although studies that have utilized SIT cycling protocols have demonstrated significant improvements in aerobic capacity and exercise performance, total body oxidative capacity, insulin sensitivity and glycemic control, catecholamine response, blood pressure, and metabolic enzyme activity, it is unclear whether these outcomes can be transferred directly to running. A review of the literature proposes only two recent studies that have collected data using a running sprint interval training protocol on promoting health (Macpherson, Hazell, Olver, Paterson, & Lemon, 2011; Sandvei et al., 2012).

Macpherson et al. (2011) was the first study to examine if a running SIT protocol was capable of inducing similar adaptations as endurance training on body composition and cardiovascular function. Twenty, young (age 24 ± 4 yrs), healthy, recreationally

active men (n=12) and women (n=8) participated in this study. Subjects completed 6 weeks of training three days/week with at least one to two days rest between sessions. All sessions were monitored in the laboratory and subjects were tested before and at least two to four days after the last session at the end of 6 wks. Running SIT consisted of ten subjects (body weight 76.0 ± 15.0 kg; body fat 18.4 ± 6.2) who completed four to six Wingate test on a dynamic treadmill separated by four minute recovery periods. The endurance training group consisted of ten subjects (body weight 68.8 ± 9.5 kg; body fat 20.8 ± 9.7) who ran continuously at 65% VO_{2max} , progressing from 30 to 60 minutes/session. SIT and ET both demonstrated significant reductions in fat mass 12.4% versus 5.8% respectively, however, decreases in the SIT group were not seen in women (even though there were only four women in the group). Lean body mass significantly increased after SIT and ET (both, 0.6 kg). Adaptations in body composition after SIT in which occurred to the same extent, or even greater, than ET is of particular interest considering that the total exercise time for SIT was 18 times shorter than that of ET (0.75 versus 13.5 hours) and half the total time commitment (6.5 versus 13.5 hours) over 6 weeks. Despite a short intervention period, VO_{2max} improved in both SIT and ET, 11.5% and 12.5% respectively, which is similar to SIT protocols that employed cycling.

Sandvei et al. (2012) also examined healthy, young, sedentary to moderately trained males (n=8) and females (n=15), aged 18-35 yrs. Unlike Macpherson et al. (2011), these investigators examined the effects of running SIT on insulin sensitivity and cholesterol. Subjects were excluded if they had participated in systematic endurance training during the last two years (defined as endurance training more than twice a week) (mean $VO_{2max} = 49.3 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$) or had a BMI $> 30 \text{ kg/m}^2$ (obese). Subjects

completed either sprint interval training (SIT) or continuous moderate intensity training (CT) for 8 weeks, three days/week and were asked to maintain habitual diet and physical activity throughout the study. The CT group consisted of 8 female and 4 male subjects (body weight 72.2 ± 3.7 ; body fat percent 23.8 ± 1.8) who ran at 70-80% HR_{peak} for 90-180 minutes per week and the SIT group consisted of 7 female and 4 male subjects (body weight 70.2 ± 3.5 kg; body fat percent 23.8 ± 1.4) who ran 5-10 bouts in terrain slightly uphill (5-8% incline), with three minute rest between sprints. All groups performed a 10 minute warm up and 5 minute cool down. Volitional treadmill test, body composition, and an oral glucose tolerance test (OGTT) to assess insulin sensitivity were taken before and after intervention. SIT induced a $5.3 \pm 1.8\%$ increase in VO_{2max} ($p < 0.05$) and CT induced a $3.8 \pm 1.6\%$ ($p < 0.05$) increase, which is a smaller magnitude than demonstrated in Macpherson's study (2011) even though this was a longer intervention duration (8 weeks compared to 6 weeks). Also in contrast to Macpherson's study (2011), weight and body composition remained unchanged in both groups after training. Fasting levels of glucose were significantly reduced in both training groups ($p < 0.05$). SIT demonstrated greater improvements in cholesterol profile by inducing a decrease in TC and LDL-C (9%), but HDL-C and TG remained unchanged. Whereas in the CT group; TC, LDL-C, HDL-C, and TG all remained unchanged.

Subjects' ingested 75g of glucose 60 hours after the last training session, where an OGTT reported that glucose measured 120 minutes after ingestion was significantly lower compared to pre-training levels OGTT test values ($p < 0.05$). In other regards to changes in insulin sensitivity after SIT, glucose AUC was reduced ($p = 0.015$), HOMA Beta-cell index was significantly increased, and HOMA-S% remained unchanged. In

comparison, the CT group demonstrated no change in glucose response after an OGTT when compared to baseline test responses and glucose AUC was decreased, however this was not significant.

The findings for body composition changes to running SIT are inconclusive and suggest that there may be sex differences (Macpherson et al. 2011). A recent study by Hazell, Hamilton, Oliver, and Lemon (2014) utilized an identical running SIT protocol as Macpherson and colleagues (2011) to further examine the effects on body composition fasting BG, and blood lipid profile in solely young recreationally active women (age 22.9 ± 3.6 yrs, body mass: 60.8 ± 5.2 kg). Subjects experienced a significant decrease in body mass, fat mass (-8.0%), body fat percent, and waist circumference, in addition to an increase in VO_{2max} (8.7%). This study suggests that running SIT is a time-efficient strategy to decrease fat mass and improve aerobic capacity in young healthy women.

Collectively, all three studies employing a running SIT protocol demonstrated that this method of exercise may result in improvements in body composition, aerobic capacity, and blood lipid profile, and sometimes even more superior outcomes when compared to endurance training in a healthy, young, adult population (Sandvei et al., 2012, Macpherson et al., 2011, Hazell et al., 2014) Though, to this date, no study has examined the running SIT model in overweight or obese women, nor has directly compared it to traditional endurance training recommendations in a standardized manner. It is unknown whether the precise nature and magnitude of previous health outcomes induced by sprint interval cycling can effectively be translated to treadmill running in sedentary, obese/overweight women. Furthermore, it is unknown whether these adjustments can be sustained for the long term.

Methodology

Subject Selection

Seventeen, pre-menopausal women (defined as being between ages 25 to 45 years) women were recruited by email, flyers, and word of mouth in the Harrisonburg, VA community. Participants were sedentary women as defined by the American College of Sports Medicine, (not participating in at least 30 minutes of moderate intensity, 40-60% $\text{VO}_{2\text{max}}$, physical activity on at least three days of the week for at least three months), free from known cardiovascular disease, metabolic disease, or any musculoskeletal problems that would limit physical activity, and a $\text{BMI} > 25 \text{ kg/m}^2$. All women completed a health status questionnaire prior to participation. Physician's consent (APPENDIX H) was obtained for any subject who had a $\text{BMI} > 35 \text{ kg/m}^2$ before the commencement of any fitness training.

Experimental Design

In this randomized controlled study women were randomized into either a supervised running sprint interval training (R-SIT) or moderate intensity endurance training (MIET) group performed three days per week for 12 weeks, performed on a treadmill. Polar heart rate watches and coded transmitter straps (Lake Success, NY) were used during all training sessions to ensure participants were exercising at the correct intensities indicated by their corresponding training protocol. All training sessions were supervised by the researchers and completed in the exercise and human assessment laboratories on a college campus. All subjects were required to attend a familiarization session before completing the clinical and aerobic testing session. Each subject completed the clinical and aerobic fitness testing session again at 6 weeks and after 12

weeks. Measures included resting heart rate and blood pressure, body composition, blood lipids, aerobic fitness, and dietary intake.

Familiarization Session

Prior to the initial familiarization session, participants were screened for eligibility using the health status questionnaire (APPENDIX C) and International Physical Activity Questionnaire (I-PAQ) (APPENDIX D). Eligible subjects were scheduled for an initial familiarization session where they completed a Physical Activity Readiness Questionnaire (PAR-Q) (APPENDIX B) and the informed consent (APPENDIX A). All subjects were provided detailed instructions on how to complete a Food Intake Record. Subject preparation and testing procedures for all tests performed during the subsequent clinical and aerobic fitness testing sessions were thoroughly explained. Each subject was familiarized with the aerobic fitness testing procedures and oriented walking/running on the treadmill at their self-selected comfortable speed with the appropriate face mask used for testing.

Clinical Testing Session

Subjects returned to the laboratory on a separate day, after a 12 hour fast, to complete clinical tests. All clinical testing was conducted in the Kinesiology Human Performance Lab. Instrumentation of each clinical test is described below.

Body Composition:

Height was measured without shoes to the nearest 0.5 cm with a stadiometer and weight was obtained without shoes using a calibrated balance scale (Detecto, Webb City, MI) and estimated to the nearest 0.1kg. Height and weight were used to calculate body mass index BMI (kg/m^2) and was used to determine if the participant met the inclusion

requirements ($\text{BMI} > 25 \text{ kg/m}^2$) of the study. A Dual-energy x-ray absorptiometry (DXA) scan using the iDXA (General Electric Lunar) was used to determine body fat percentage.

Resting Heart Rate & Blood Pressure:

Resting heart rate (HR) was measured manually at the radial pulse. BP measurements were taken using a sphygmomanometer (American Diagnostic Corporation, Hauppauge, NY) and stethoscope after at least 5 minutes in the supine position. Subjects were instructed to refrain from any physical exertion for at least three hours prior to testing. Resting heart rate and blood pressure was recorded as the mean of two measurements.

Blood Analysis:

Blood samples (approximately $50\mu\text{L}$) were obtained through a finger stick from each participant and analyzed using a CardioChek PA Analyzer with PTS Panels test strips (Polymer Technology Systems, Inc., Indianapolis, IN) to determine fasting BG, total cholesterol (TC), LDL-C, HDL-C, and TG. The Occupational Safety and Health Administration (OSHA) procedures were followed for safety concerns (United States Department of Labor, 2014).

Hemoglobin A1c:

Hemoglobin A1c was analyzed using a capillary holder to collect approximately 1 drop of whole blood and analyzed using a DCA Vantage Analyzer (Siemens Healthcare Diagnostics, Tarrytown, NY). Quality control tests were completed before each subject test.

Aerobic Fitness Testing Session (Maximal Oxygen Uptake)

On a separate day from clinical testing, subjects returned to the Health Science Human Assessment Lab to complete a volitional maximal exercise test on a motorized treadmill (h/p Cosmos, Cosmed, Rome, Italy) using the Quark b² Pulmonary Gas Exchange system (Cosmed, Rome, Italy) or the K⁴ b² Portable Metabolic Unit (Cosmed, Rome, Italy). Subjects were instructed to refrain from any vigorous activity 24 hours prior to testing and from caffeine, alcohol, or tobacco at least 4 hours prior to testing. After a three minute warm-up, participants began the test at a self selected speed and grade increased every three minutes by 2.5% until volitional exhaustion was met. Rating of perceived exertion (RPE) was recorded in the last 30 seconds of each stage. Volitional fatigue was confirmed by incidence of plateau in VO₂ as well as a max respiratory exchange ratio (RER) > 1.15, and rating of perceived exertion (RPE) >18 (ACSM, 2009).

Diet

Women were instructed to maintain their usual diet throughout the intervention period. Nutritional intake (caloric intake and macronutrient balance) was analyzed using *Nutrition Data System for Research* (Nutrition Coordinating Center, University of Minnesota, Minneapolis, MN). Analysis of nutritional intake was checked for quality assurance by randomly pulling 50% of analyzed records and assessing accuracy. Food Intake Records were administered at pretesting, 6 weeks, and at post-testing. Subjects were instructed to record all food, drinks, and supplements, etc. as detailed as possible on two weekdays and one weekend day. Detailed instructions were provided to each subject (APPENDIX E). Upon completion, the researcher reviewed the food records with the subject to ensure accurate recordings.

Training Protocol

All subjects completed three, non-consecutive training sessions per week. Heart rate and blood pressure were measured before every training session to ensure no exercise contraindications before their training session commenced. All sessions began with a five minute dynamic exercise warm-up, followed by stretches and a five minute walk on the treadmill at a self-selected pace. Warm-up exercises included stability ball squats, marching in place, leg swings, wall pushups, and hamstring and calf stretches. After each session, a five minute walking cool down was completed at a self-selected pace, followed by stretching exercises. Speed and grade were recorded after each session for the purpose of determining the correct speed and grade for their next training session.

Running-Sprint Interval Training Protocol:

The R-SIT protocol began with four, 30 seconds “all out” sprints, increasing by two sprints every three weeks, to ten sprints in the final three weeks (Table 1). Each sprint was interspersed with a four minute active recovery period. Immediately after each sprint, maximum heart rate achieved was recorded using a Polar FT1 Heart Rate Monitor Watch and Polar T31 coded transmitter strap that the subject wore during training. An objective measure of exercise intensity for each sprint was individualized for each subject based on her HR_{max} obtained during the VO_{2max} test. HR_{max} was determined as the highest HR achieved during their maximal oxygen consumption test. Each sprint bout was performed on a motorized treadmill (Cybex International, Inc., Medway, MA, USA or Quinton, Bothell, WA, USA). The researcher simultaneously adjusted speed and grade 10 seconds before they were required sprint in order to elicit their individualized HR_{max} . In addition, ratings of perceived exertion (RPE) were collected after each sprint using the 10

point BORG scale (Borg, 1982). This information served to confirm that all subjects exerted themselves maximally. Verbal encouragement was given during each sprint since positive feedback was associated with higher levels of self-efficacy, which ensures an individuals' perceived satisfaction and enjoyment to perform a vigorous exercise task (Tritter et al., 2013). At the end of their last sprint interval, subjects were instructed to cool down by walking on the treadmill at a self-selected pace for 5 minutes. Following the cool down, subjects were asked to give their session overall RPE using the 10 point BORG scale. In order to adjust for any improvements in fitness level, aerobic capacity was reassessed at 6 weeks and a new HR_{max} objective was implemented for the remainder of the study.

Moderate Intensity Endurance Training Protocol (MIET):

Beginning training sessions consisted of 30 minutes of moderate-intensity exercise (45-55% heart rate reserve (HRR)) based on their aerobic fitness test, and progressed up to 60 min of moderate intensity exercise by week 12. Exercise duration per session increased by 10 minutes every three weeks (Table 1). All subjects wore a polar heart rate monitor and watch and the researchers recorded HR every 5 minutes to ensure they were staying within 45-55% of their HRR. Immediately after each session, subjects were instructed to cool down for 5 minutes, walking at a self-selected pace. Following the cool down, subjects were asked to give their session overall RPE using the 10 point BORG scale. In order to adjust for any improvements in fitness level, aerobic capacity was reassessed at 6 weeks and a new objective range for 45-55% HRR was implemented for the remainder of the study.

Statistical Analysis

IBM SPSS Statistics 21.0 (Armonk, NY) was used to analyze and compare the physiological responses to each exercise intervention. ANOVA with repeated measures was used to compare the effects on each parameter between the two training groups. A paired samples *t*-test was used to compare changes in physiological variables over the 12 weeks. Independent samples *t*-test was used to compare the effects between training groups. Data with a *p* value < 0.05 level is considered statistically significant. LDL-C values that were not provided during testing due to missing HDL-C or TG values were calculated using the formula: $(TC - HDL-C) - (TG/5)$. Ambiguous values of HDL-C or TG (ie. TG value of < 50 mg/dL) were entered for analysis by either adding or subtracting 1 mg/dL from the given value. For example, if the analyzer output indicated TG < 50 mg/dL then 1 mg/dL was subtracted from this value and was recorded as 49 mg/dL. Adherence rate was calculated as the total number of sessions completed by each subject out of a possible 36 sessions over 12 weeks. The difference in adherence between groups was analyzed using an independent *t*-test.

Results

Participants

The purpose of this study was to compare the responses of resting HR, BP, VO_{2max} , body composition, TC, LDL-C, HDL-C, TG, BG, and HbA1c in low volume, R-SIT versus traditional moderate intensity endurance running (MIET) in overweight and obese, sedentary adult women. 15 women were enrolled into the study. Three of the 15 women did not complete the training: two withdrew due to aggravated previous related injuries and one withdrew due to time commitment. Thus, a total of 12 subjects completed the training. Subject demographic is presented in Table 2. There were no significant differences between groups at baseline ($p > 0.05$). Baseline data for blood lipid profile, blood glucose, and HbA1c between groups is presented in Table 3.

Training Adherence

Subjects in the R-SIT completed 34.6 ± 0.51 (96%) of their total 36 sessions, whereas subjects in the MIET group completed 33.0 ± 1.23 (92%). There was no significant difference between the number of sessions completed among each group throughout the study ($p > 0.05$).

Physiological Variables

Body Composition

Body fat significantly decreased pre- to post-training with R-SIT, but not with MIET ($p=0.016$ versus $p=0.139$, respectively) (Figure 3). Average body fat percentage at pre-, mid-, and post-testing is presented in Table 4. Although not statistically significant, body fat in the R-SIT group decreased from mid- to post-training ($p=0.05$).

There was no significant main effect for time or differences between groups for weight (WT) (Figure 1), BMI (Figure 2), FM (Figure 4), LM (Figure 5), FFM (Figure 6), with either group ($p > 0.05$). Average WT, BMI, FM, LM and FFM for both groups are presented in Table 5. Although not statistically significant, R-SIT decreased fat mass from pre- to post-training ($p = 0.08$) and mid- to post-training ($p = 0.074$).

Maximal Oxygen Uptake

VO_{2max} significantly increased for both groups pre- to post-training (R-SIT: $p = 0.02$, t-test; MIET: $p = 0.005$) (Figure 7). No group experienced a significant change from pre- to mid-training ($p > 0.05$), but both groups experienced a significant increase from mid- to post-training (R-SIT $p = 0.04$; MIET $p = 0.02$), with no difference between training groups ($p > 0.05$). Average VO_{2max} was not different between training protocols ($p = 0.75$). Average maximal oxygen uptake at pre-, mid-, and post-testing is presented in Table 6.

Resting Heart Rate

R-SIT and MIET noted a decrease in RHR from pre- to post-training, but these did not reach a level of statistical significance (R-SIT: $p = 0.16$; MIET: $p = 0.054$; Figure 8). Decreased HR from pre- to mid-training was only significant with MIET ($p = 0.02$). No significant difference was found between groups ($p = 0.63$).

Resting Blood Pressure

Neither SBP nor DBP were different between groups or changed significantly over time ($p > 0.05$) (Figure 9 and 10, respectively).

Blood Lipid Analysis

TC ($p=0.54$, Figure 11), HDL-C ($p=0.78$, Figure 12), or LDL-C ($p=0.43$, Figure 13) did not change significantly over time. MIET decreased TG significantly from mid- to post-training ($p=0.048$), whereas R-SIT was approaching significance from pre- to post-training ($p=0.05$, Figure 14). Although not significant, MIET increased TC slightly from pre- to mid- training ($p=0.05$). No significant differences in any parameter were found between groups ($p>0.05$).

Glucose and HbA1c Analysis

Neither BG nor HbA1c were different between groups or changed significantly over time ($p>0.05$). Although not significant, R-SIT decreased BG slightly from pre- to mid-training ($p = 0.08$, Figure 15) and HbA1c mid- to post- training ($p = 0.052$, Figure 16). Average BG values at pre-, mid-, and post-training are presented in Table 7.

Discussion

Introduction

The primary objective of the present study was to examine the effects of a 12 week R-SIT protocol on markers related to chronic disease, including resting heart rate and blood pressure, body composition, blood glucose, hemoglobin A1C, cholesterol, and triglycerides levels in previously sedentary, overweight or obese women. Secondly, we compared these training effects to traditional, high-volume endurance training. The majority of the literature focuses on the effects of high intensity interval training on aerobic capacity in healthy, young adults, but only few have examined this type of training in populations that are at high risk for developing chronic disease (Heydari et al., 2012; Tjonna et al., 2008; Harmer et al., 2008; Whyte et al., 2010; Whyte et al., 2013; Trilk et al., 2011; Schjerve et al., 2008; Sijie et al., 2013). Additionally, previous literature examined high intensity training programs conducted against a high braking force on a specialized cycle ergometer, which is not a practical method of exercise to the general population. Therefore, a third objective for this study was to determine if R-SIT would elicit the same benefits previously demonstrated with Wingate SIT tests on a cycle ergometer. While current literature utilizes protocols between two to seven weeks, to the authors' knowledge, this is the first study to extend the effect of SIT type training to 12 weeks. Additionally, only a few studies examine the effects of Wingate sprint training performed on a treadmill (Macpherson et al., 2011, Sandvei et al., 2012, & Hazell et al., 2014), which may elicit different physiological or metabolic effects than reported after cycling. Furthermore, only two R-SIT studies directly compared the outcomes of R-SIT to a training group abiding by the traditional recommended guidelines for improving health, based on ACSM and AHA, although subjects consisted of a mixed sample of

recreationally active, or sedentary to moderately trained males and females (Macpherson et al., 2011; Sandvei et al., 2012). Only one R-SIT study examined similar health measures as the present study (Hazell et al., 2014), including body composition and blood lipids, although these subjects were healthy and were a lot younger (mean \pm SD; 22.9 ± 3.6 y versus 33.6 ± 5.8 y), and within a normal body fat range ($22.9 \pm 3.6\%$).

Physiological Variables

Our study demonstrated that 12 weeks of R-SIT improves body composition and aerobic capacity in previously sedentary middle-aged women. Specifically, R-SIT significantly reduced body fat by 1.6% and increased VO_{2max} by 5.98 ± 4.6 ml/kg/min. Additionally, R-SIT induced a rapid increase in lean body mass (+1.4kg) and decrease FM (-2.3kg). Although these improvements were not statistically significant, perhaps a longer intervention may have produced significant results. Improvements in body composition are similar to findings of previous R-SIT interventions (Hazell et al., 2014, Macpherson et al., 2010) in young, healthy sample of both males and females, although these studies were of shorter duration. Thus, more rapid improvements elicited in the previous R-SIT studies may be a result of differences in modality. Hazell (2014) and Macpherson et al., (2011) both utilized treadmills set in dynamic mode which forces the subject to be the source of the power, which conceivably may elicit different physiological responses than motorized treadmills used in the present study. Though, our data suggests that inclined running, can utilize enough energy to elicit reductions in body fat and have good implication for increased lean mass, though more definitive research should be conducted to determine any physiological differences to modality. Our findings are novel because this is the first study, to the author's knowledge, to demonstrate that R-

SIT program can be effective for fat loss in women whom were previously sedentary and overweight/obese. Our findings differ from previous SIT studies implemented in overweight/obese adults, who either reported little or no change in body composition after 2-4 weeks (Astorino et al., 2012; Whyte et al., 2010). Though, the short nature of these studies may have precluded subjects from experiencing any apparent reductions in fat loss. However, no body fat improvements were also observed after chronic HIIT interventions lasting 12 weeks in sedentary males and females (BMI <25 kg/m²) (Astorino et al., 2013; Nybo et al., 2010), yet fat loss was observed after 12 weeks of HIIT implemented in sedentary, overweight adults (BMI>25kg/m²) (Heydari et al., 2012; Sijie et al., 2012). It is conceivable that greater improvements were seen with overweight subjects due to their higher initial body fat, thus have greater room for improvement.

Remarkably, the body fat loss demonstrated in our women subjects was observed despite the lower total minutes of exercise (2-5 minutes versus 30-60 minutes), with total training sessions (30s sprints plus 4 minute recovery) still amounting to less than the current guidelines for promoting good health (135 minutes versus 150 minutes) and far less than the recommended minutes of moderate physical activity for weight loss (135 minutes versus 250 minutes) (Donnelly et al., 2009). Given that “lack of time” is the number one cause for inactivity among Americans, our findings have great implications for providing an effective exercise alternative for weight loss in overweight/obese women. Further, high intensity type exercise seems to require a great deal of motivation, thereby might not be well tolerated by unfit, overweight individuals when compared to low intensity, prolonged exercise. However, it is conceivable that the short periods of high intensity exercise involved with SIT, may help make training sessions more

tolerable for sedentary, overweight populations. However, further research should examine different interval and recovery periods that may produce significantly shorter overall training sessions and perhaps help increase adherence. Further, due to the required high levels of motivation, it is unknown whether or not subjects would elicit the same benefits if they completed this training program unsupervised. Perhaps this population is more likely to continue MIET. Therefore, prospective studies should examine whether or not R-SIT would be tolerable in a more “real world” setting.

Furthermore, mechanisms for significant fat losses with R-SIT despite the lower training volume when compared to MIET are not fully understood. Increased fat oxidation at rest, as well as during exercise was reported after two weeks of high intensity type training and may play a role in fat loss (Whyte et al., 2010; Talanian et al., 2007). Additionally, numerous SIT studies reported substantial increases in skeletal muscle oxidative enzymes, typically associated with endurance type training, which play a key role in fat metabolism (Perry et al., 2008; Burgomaster et al., 2005; Burgomaster et al., 2008; Whyte et al., 2013; MacDougall et al., 1998). Moreover, increased post exercise oxygen consumption (EPOC) after SIT is likely to contribute to our observed improvements in body composition (Hazell et al., 2012; Chan and Burns, 2013).

The present study concluded that 4-10 running interval sprints dramatically improved aerobic capacity in previously sedentary, overweight and obese women, which is consistent with previous cycling SIT studies (Burgomaster et al., 2005; Burgomaster et al., 2008; Bayati et al., 2011; Whyte et al., 2010; Astorino et al., 2012), and other forms of high intensity interval training (Boutcher, 2011; Gibala et al., 2006; Gibala et al., 2012; Gibala, 2008). Our findings are in agreement with previous R-SIT (Macpherson et

al., 2011; Hazell et al., 2014; Sandvei et al., 2012), but is the first to examine the effects of R-SIT on cardiorespiratory fitness of sedentary, overweight women with poor aerobic capacity. Collectively, these findings provide evidence that R-SIT can produce similar aerobic benefits to that of cycling SIT. The reported increase in aerobic capacity is promising given that high intensity exercise is typically perceived as “too difficult” for sedentary, overweight individuals which is why most studies that utilize this type of training has been implemented on young, active individuals. Moreover, the magnitude of effect of R-SIT on Vo_{2max} in our study was slightly higher than those reported from previous R-SIT studies (~19% versus ~10%) (Macpherson et al., 2011; Hazell et al., 2014; Sandvei et al., 2012). However, this could be due to the longer intervention design (12 weeks compared to 6 weeks) and lower baseline fitness levels of our subjects (~27 ml/kg/min compared to ~46 ml/kg/min), since rapid improvements are more likely to occur in sedentary, unfit individuals who begin exercise (Bassett & Howley, 2000). Our findings provide preliminary evidence for utilizing R-SIT as a means of enhancing cardiovascular fitness in sedentary, overweight/obese women of middle-age.

It is of note that R-SIT did not elicit any significant improvements in VO_{2max} during the first 6 weeks of training which agrees with Burgomaster et al. (2005) who also reported no improvements in aerobic capacity after two weeks of cycling SIT in recreationally active young adults. It may be conceivable that a significant dose-response relationship exists between R-SIT and its effects on aerobic capacity. This is interesting considering previous studies have shown improvements in aerobic capacity in as little as 2 or 4 weeks of cycling SIT in recreationally active men and women (Astorino et al., 2012; Bayati et al., 2011) and overweight/obese sedentary men and women (Whyte et al.,

2010; Trilk et al., 2011).

While we did not examine changes at the muscular cellular level in response to R-SIT, the increase in VO_{2max} may be attributable to peripheral or central adaptations in our subjects. Mitochondrial volume and oxidative potential, suggested by increases in resting muscle citrate synthase (CS) activity, commonly exist in proportion with other mitochondrial enzymes (Burgomaster et al., 2005). An upregulation of CS and COX II has been demonstrated in as little as 2 weeks of cycling SIT in recreationally active individuals, as well as in 2 weeks of HIIT in sedentary, overweight middle aged adults (Gibala et al., 2006; Burgomaster et al., 2005, 2006, 2007, 2008; Hood et al., 2011). These rapid increases in metabolic and oxidative properties attribute to increases in VO_{2max} , therefore it remains unclear why our data showed no significant improvements within the first 6-weeks of training.

Our study is the first study, to the author's knowledge, to examine health parameters associated with CVD risk markers, in addition to examining body composition and aerobic capacity in women. The absence of significant improvements in RHR, BP, blood lipids, and HbA1c is likely due to the fact that all subjects were relatively healthy at baseline, despite them being overweight. Traditionally, aerobic training is recommended to lower the risk for developing chronic diseases by lowering LDL-C which is a direct predictor for CVD risk, as well as increasing HDL-C, lowering blood pressure, triglycerides, and improving autonomic tone and unregulated glucose (Donnelly et al., 2009). However, no reported changes in blood lipids in our study is likely due to having normo-cholesterolemic subjects at baseline, which agrees with a previous study (Tjonna et al., 2008) who reported significant increases (25%) in HDL-C

in subjects diagnosed with Metabolic Syndrome, thus were likely to have abnormal lipid profiles. The effects of previous R-SIT on blood lipid profiles are inconclusive (Sandvei et al., 2012; Hazell et al., 2014) thus further research is necessary to understand its effects on blood lipid results. Although not statistically significant, our study observed a dose-response relationship with TG concentration and R-SIT. Specifically, TG decreased with an increase in R-SIT exercise volume. Perhaps a longer intervention or larger sample size would have produced improvements in TG of statistical significance. Furthermore, absence of changes in RHR and BP is in agreement with other SIT work lasting two weeks (Rakowbowchuk et al., 2008; Astorino et al., 2012). However several longer (12 week) HIIT studies reported significant improvements in RHR in overweight adults (Sijie et al., 2012; Heydari et al., 2012) and normal weight men (Nybo et al., 2010). Perhaps interventions of longer duration are necessary in order to produce enough stimuli to reduce sympathetic activity. While there is some evidence that SIT can elicit an acute reduction in BP (measured 24 hours post exercise, but diminished by 72 hours) (Chan & Burns, 2013; Whyte et al., 2010), the present study was the first to examine the chronic effects of SIT type training on BP, and we found no improvement. Absence of any change in BP is likely due to subjects' being within healthy BP ranges at baseline.

Even though R-SIT didn't produce any significant change in blood glucose and HbA1c, a reduction in HbA1c began during the last 6 weeks of training. Because HbA1c represents an individuals' three-month average blood glucose concentration, future research should utilize a longer R-SIT research design to examine its effects on glucose regulation and possible implications for Type 2 diabetes treatment or prevention.

Limitations and Considerations

Although our withdrawals from the study consisted of subjects from the R-SIT group, it should not be assumed that R-SIT is not safe and an effective means of exercise for previously sedentary and overweight individuals. Reasons for dropouts included, irritation of preexisting injury (n=2), scheduling conflict (n=1), and one subject was asked to discontinue the study because recurrent missed training sessions due to sickness. The two studies in which employed SIT with overweight/obese men (Whyte et al., 2010) and sedentary, overweight women (Trilk et al., 2011) reported no adverse effects to this type of training. Thus, our drop out subjects may indicate this type of training may not be tolerable in women with preexisting injury.

Even though we conclude that SIT type training is effective and tolerable with overweight/obese women, it does require a great degree of motivation to complete on their own. It remains unknown whether or not the nature of this training would be tolerable and continued when unsupervised in this population. Thus, we hope to address this with a three-month follow up session to determine such behaviors and any physiological changes that may have occurred since the termination of our study.

One limitation of our study might be that VO_{2max} values could be that subjects may not have provided a true maximal effort during their baseline or midline test, which could be contributed to a possible “learning effect”. However, all subjects underwent a familiarization session before completing their baseline test, reducing the influence of this learning effect. Additionally, this study provides preliminary data that running type SIT can elicit improvements in some physiological and metabolic variables in overweight/obese women, though a larger sample size may support these assumptions.

Another limitation was that our study was conducted over the holiday months of Thanksgiving and Christmas. This time period is commonly known for more frequent poor diet choices (Yanovski, J, Yanovski, S., Sovik, B., Nguyen, M., O'Neil, P., Sebring, N., 2003), which could have minimized the magnitude of body composition improvement or changes in subjects' lipid profile. In order to control the possibility of this effect, subjects were analyzed at baseline, 6 weeks, and 12 weeks; however, we know that self-reported records can be inaccurate (Yang, Kim, Hwang, Ahn, Shim, Kim, 2010). To minimize variation in their blood lipid tests, subjects should have replicated baseline three-day diet records for midline and post testing measurements.

Conclusion

Contrary to previous belief that high intensity exercise is too difficult for previously sedentary, overweight or obese individuals, our findings support that running sprint interval training performed on the treadmill is tolerable and effective for reducing cardiovascular and metabolic risk markers in this population. Despite the reduction in total exercise time with low volume, high intensity exercise protocol, subjects demonstrated a significant reduction in body fat percent whereas subjects who abided to traditional ACSM health guidelines (150 minutes of moderate physical activity per week) did not report any differences. Even though R-SIT utilized a total of 54 to 135 minutes of exercise time per week with only 6-15 minutes totaling vigorous intensity exercise, R-SIT was capable of enhancing cardiorespiratory fitness comparable to that of MIET, which consisted of 90-180 minutes of continual exercise. Furthermore, R-SIT seemed inclined to provide improvements in other health parameters, including TG, HbA1c, LM, FFM, FM, and RHR, which may elicit more profound improvements if R-SIT is

implemented in individuals who have abnormal blood lipid profiles, uncontrolled glucose, or hypertension or for a longer duration. Together, this data is promising considering 49% of the population fails to meet current physical activity guidelines due to lack of time (Troost et al., 2002). Although our data supports that low volume, high intensity training is a safe and effective alternative to exercise in unfit individuals, further research is necessary to make a definitive conclusion on the effects of high intensity training performed by a similar population.

All in all, 12 weeks of running sprint interval training reduced body fat while increasing aerobic fitness capacity in previously sedentary, overweight/obese women in a lower amount of time than previously suggested by ACSM. These findings are promising since walking/running is a more practical means of exercise which may help increase activity levels among women in the general public, and further implemented to reduce physiological and metabolic indices related to cardiovascular disease that is commonly associated with overweight or obese, sedentary, middle-aged women.

Table 1. Training Progression for R-SIT and MIET Groups over 12 Weeks

Week	1	2	3	4	5	6	7	8	9	10	11	12
R-SIT	4	4	4	6	6	6	8	8	8	10	10	10
MIET	30	30	30	40	40	40	50	50	50	60	60	60

Note: R-SIT represented in number of sprints per session for the corresponding week. MIET represented in exercise time per session (minutes) for the corresponding week.

Table 2. Baseline Demographic Data for R-SIT and MIET Groups*

SUBJECTS (n)	TOTAL (12)	R-SIT (5)	MIET (7)
Age (yrs)	33.6 ± 5.8	36.8 ± 7.5	31.3 ± 3.2
Weight (kg)	84.5 ± 22.1	87.3 ± 33.9	82.5 ± 10.8
Height (cm)	166.0 ± 6.3	163.0 ± 5.5	168.1 ± 6.4
BMI (kg/m²)	30.7 ± 7.4	32.3 ± 10.4	29.5 ± 4.9
Body Fat (%)	45.0 ± 7.7	44.6 ± 9.1	45.3 ± 7.2
Fat Mass (kg)	37.7 ± 16.4	39.5 ± 24.4	36.5 ± 9.5
Lean Mass (kg)	43.9 ± 5.7	44.4 ± 2.3	43.6 ± 2.3
Fat Free Mass (kg)	46.5 ± 5.9	47.1 ± 8.8	46.1 ± 3.5
Resting HR (bpm)	78.9 ± 7.6	77.0 ± 8.1	80.3 ± 7.5
SBP (mmHg)	113.4 ± 8.2	114.0 ± 11.4	113.0 ± 5.9
DBP (mmHg)	78.6 ± 8.8	77.6 ± 13.0	79.3 ± 5.3
VO₂max (ml/kg/min)	27.9 ± 6.5	29.6 ± 7.3	26.7 ± 6.2

*mean ± standard deviation

No significant differences at baseline between training groups ($p > 0.05$); R- SIT = Running Sprint Interval Training Group; MIET = Moderate Intensity Endurance Training Group; HR – Heart rate; SBP – Systolic blood pressure; DBP – Diastolic blood pressure; VO₂max – Volitional maximal oxygen consumption

Table 3. Baseline Blood Lipid Profile, Blood Glucose, and HbA1c for R-SIT and MIET groups*

SUBJECTS (n)	TOTAL (12)	R-SIT (5)	MIET (7)
Total Cholesterol (mg/dL)	206.5 ± 42.5	194.2 ± 18.8	215.3 ± 53.5
High Density Lipoproteins (mg/dL)	60.1 ± 18.3	62.0 ± 28.8	58.7 ± 7.3
Low Density Lipoproteins (mg/dL)	118.2 ± 37.1	107.8 ± 16.1	124.1 ± 45.3
Triglycerides (mg/dL)	155.4 ± 94.0	146.2 ± 73.8	162.0 ± 111.6
Fasting Blood Glucose (mg/dL)	80.1 ± 8.9	80.2 ± 7.5	80.0 ± 10.4
HbA1c (%)	4.8 ± 1.2	4.4 ± 1.9	5.2 ± 0.2

*mean ± standard deviation

No significant difference between training groups at baseline ($p > 0.05$); R-SIT = Running Sprint Interval Training Group; MIET = Moderate Intensity Endurance Training Group

Table 4. Comparison of Body Fat Percent at Pre-, Mid-, and Post- training between R-SIT and MIET groups*

	Pre	Mid	Post	Post – Pre	% Change
R-SIT	44.6 ± 9.1	43.8 ± 8.8	42.9 ± 8.9**	-1.6 ± 0.9	-3.7 ± 2.1
MIET	45.3 ± 7.2	44.8 ± 6.2	44.2 ± 6.7	-1.0 ± 1.1	-2.2 ± 2.1

*mean ± standard deviation

**Denotes a significant effect for time: pre and post-training $p < 0.05$, R-SIT = Running Sprint Interval Training Group (n=5); MIET = Moderate Intensity Endurance Training Group (n=7).

Table 5. Comparison of Body Composition Changes at Pre-, Mid-, and Post- training between R-SIT and MIET groups*

	R-SIT			MIET		
	Pre	Mid	Post	Pre	Mid	Post
BMI (kg/m²)	32.3 ± 10.4	32.3 ± 10.4	31.9 ± 10.3	29.5 ± 4.9	29.1 ± 4.4	28.9 ± 4.3
WT (kg)	87.3 ± 33.9	87.4 ± 35.1	86.6 ± 33.2	82.5 ± 10.8	82.3 ± 11.1	81.7 ± 10.9
FM (kg)	39.5 ± 24.4	39.4 ± 25.1	37.2 ± 24.7	36.5 ± 9.5	36.2 ± 8.9	36.0 ± 9.6
LM (kg)	44.4 ± 2.3	45.7 ± 3.3	45.8 ± 3.1	43.6 ± 2.3	43.6 ± 2.8	44.9 ± 2.7
FFM (kg)	47.1 ± 8.8	48.4 ± 11.1	48.5 ± 10.4	46.1 ± 3.5	46.2 ± 3.6	47.4 ± 3.8

* mean ± standard deviation

No significant effect over time ($p > 0.05$). No difference between groups ($p > 0.05$). R-SIT = Running Sprint Interval Training Group (n=5); MIET = Moderate Intensity Endurance Training Group (n=7). WT = Weight (kg), FM= Fat Mass (kg), LM= Lean Mass, FFM= Fat Free Mass.

Table 6. Comparison of VO_{2max} (ml/kg/min) at Pre-, Mid-, and Post- training between R-SIT and MIET groups*

	Pre	Mid	Post	Post - Pre	Percent Change
R-SIT	29.6 ± 7.3	29.8 ± 6.4	35.6 ± 10.4**†	5.9 ± 4.6	19.8 ± 14.9%
MIET	26.7 ± 6.2	29.5 ± 4.3	35.3 ± 6.6**†	8.6 ± 6.1	38.6 ± 41.3%

* mean ± standard deviation

**Denotes significant effect for time between pre- and post-training ($p < 0.05$); † denotes significant difference between mid- and post-training. R-SIT = Running Sprint Interval Training Group (n=5); MIET = Moderate Intensity Endurance Training Group (n=7);

Table 7. Comparison of Fasting Blood Glucose (mg/dL) and HbA1c (%) at Pre-, Mid-, and Post- Training between R-SIT and MIET groups*

	R-SIT			MIET		
	Pre	Mid	Post	Pre	Mid	Post
BG (mg/dL)	80.2 ± 7.6	74.8 ± 9.9	84.2 ± 13.9	80 ± 10.3	75.7 ± 9.5	85.1 ± 12.6
HbA1c (%)	5.2 ± 0.3	5.3 ± 0.2	5.1 ± 0.3	5.2 ± 0.2	5.2 ± 0.3	5.1 ± 0.3

* mean ± standard deviation

No significant mean effect for time $p > 0.05$. R-SIT = Running Sprint Interval Training Group (n=5); MIET = Moderate Intensity Endurance Training Group (n=7); BG = Blood Glucose.

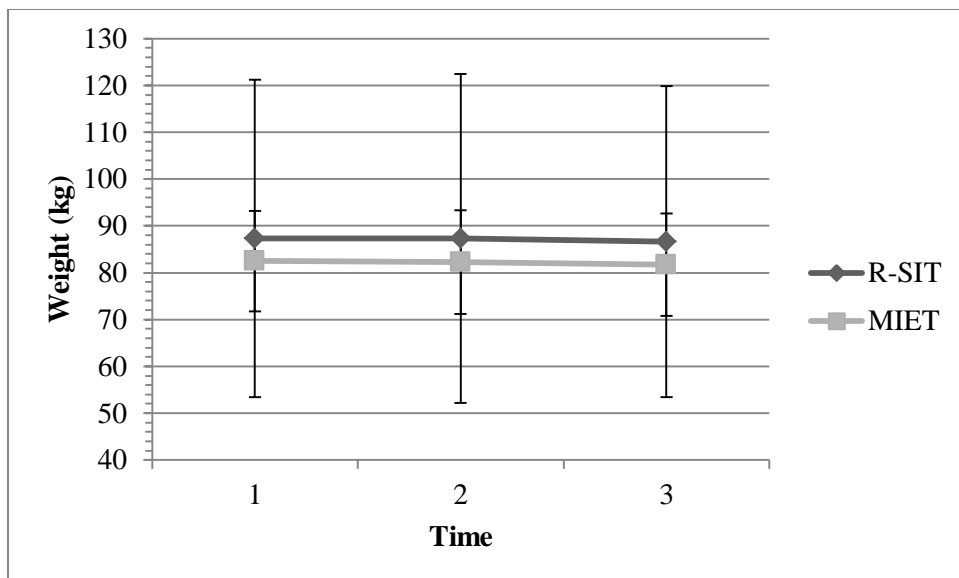


Figure 1. Comparison of Weight (kg) between R-SIT and MIET groups at Pre-, Mid-, and Post-Training. Values are mean \pm standard deviation. R-SIT = Running Sprint Interval Training Group (n=5); MIET = Moderate Intensity Endurance Training Group (n=7).

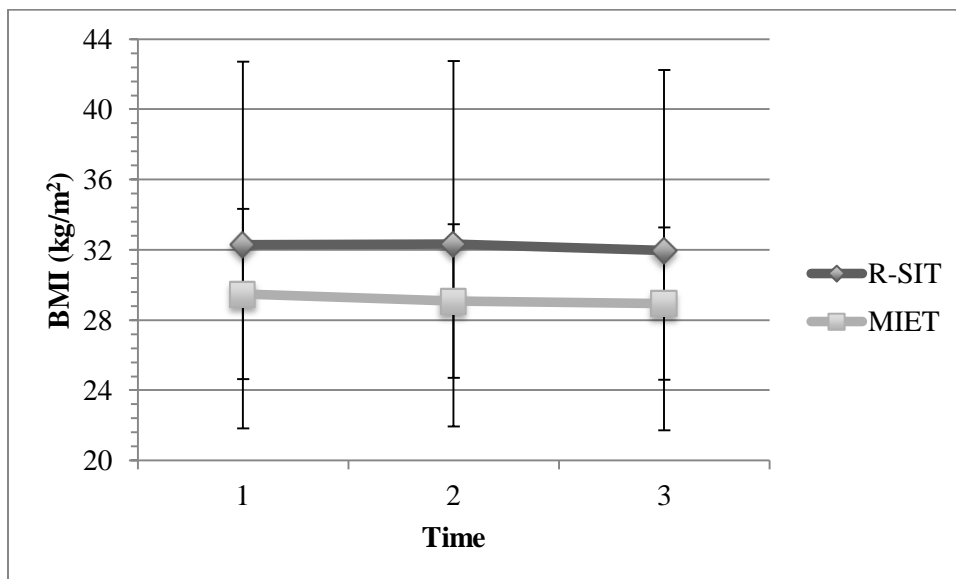


Figure 2. Comparison of BMI (kg/m²) between R-SIT and MIET groups at Pre-, Mid-, and Post- Training. Values are mean \pm SD. R-SIT = Running Sprint Interval Training Group (n=5); MIET = Moderate Intensity Endurance Training Group (n=7).

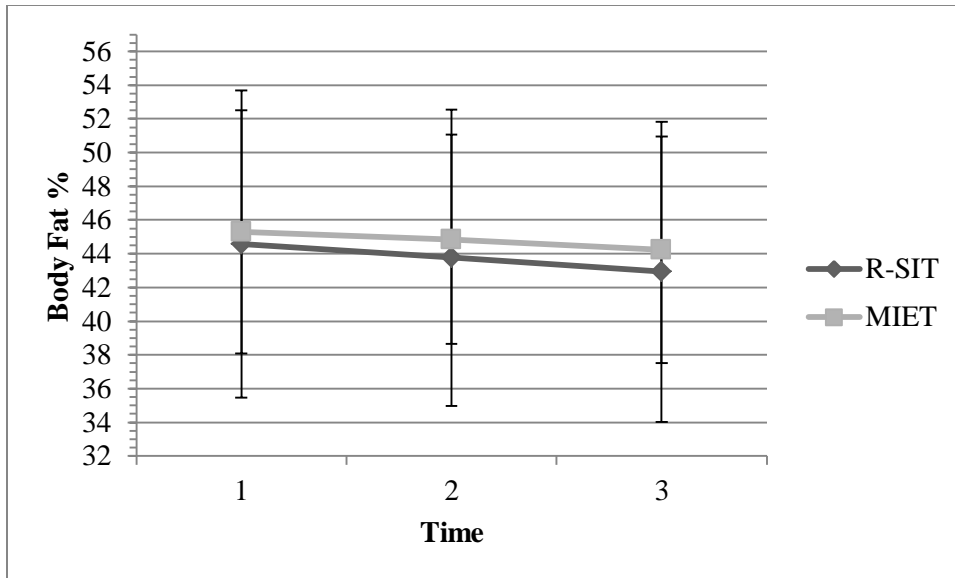


Figure 3. Comparison of Percent Body Fat between R-SIT and MIET groups at Pre-, Mid-, and Post- Training. Values are mean \pm SD. R-SIT = Running Sprint Interval Training Group (n=5); MIET = Moderate Intensity Endurance Training Group (n=7). *Denotes significant difference ($p < 0.05$); Mean Effect for Time $p = 0.001^*$; R-SIT: Pre-post $p = 0.016^*$

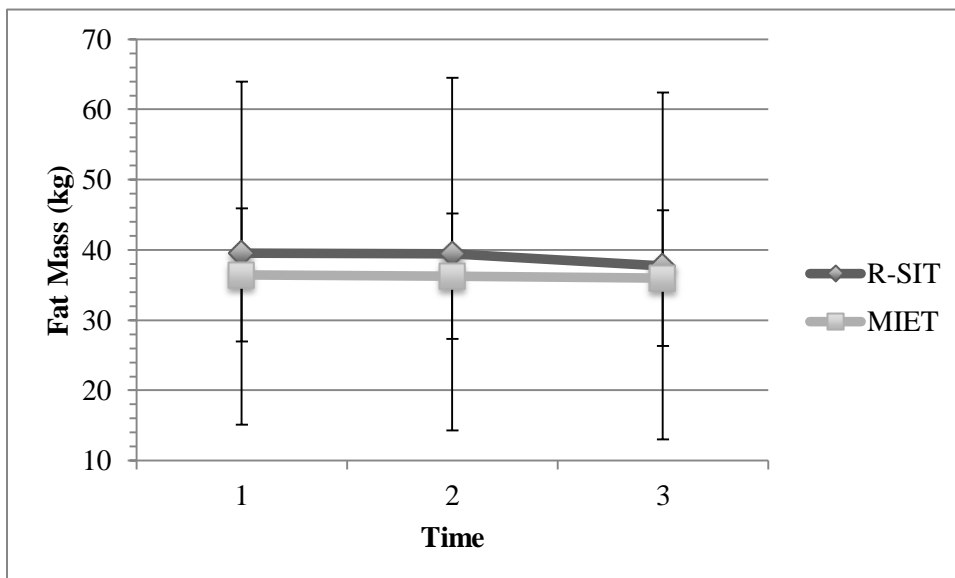


Figure 4. Comparison of Fat Mass between R-SIT and MIET groups at Pre-, Mid-, and Post- Training. Values are mean \pm SD. R-SIT = Running Sprint Interval Training Group (n=5); MIET = Moderate Intensity Endurance Training Group (n=7). *Denotes significant difference ($p < 0.05$); Mean Effect for Time $p = 0.021^*$

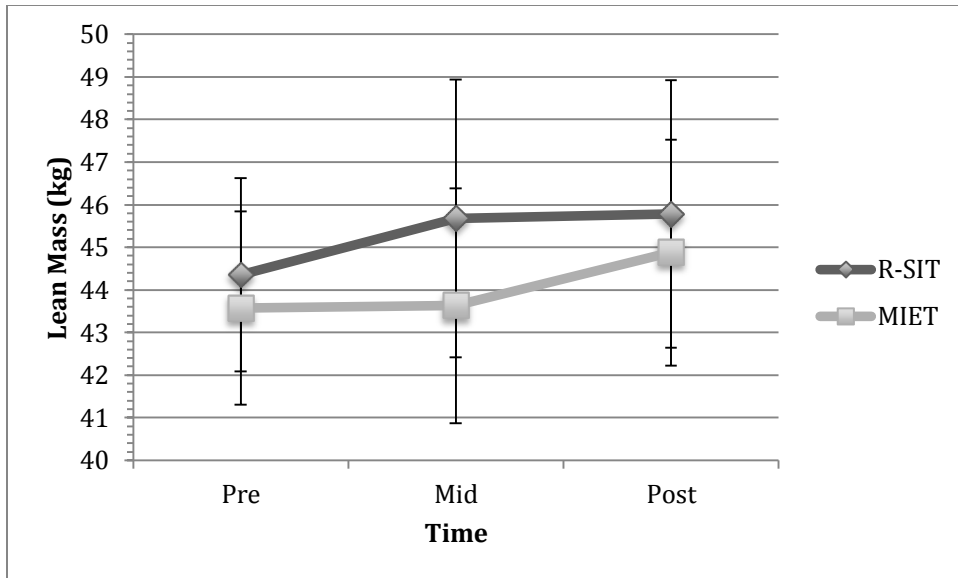


Figure 5. Comparison of Lean Mass between R-SIT and MIET groups at Pre-, Mid-, and Post- Training. Values are mean \pm SD. R-SIT = Running Sprint Interval Training Group (n=5); MIET = Moderate Intensity Endurance Training Group (n=7)

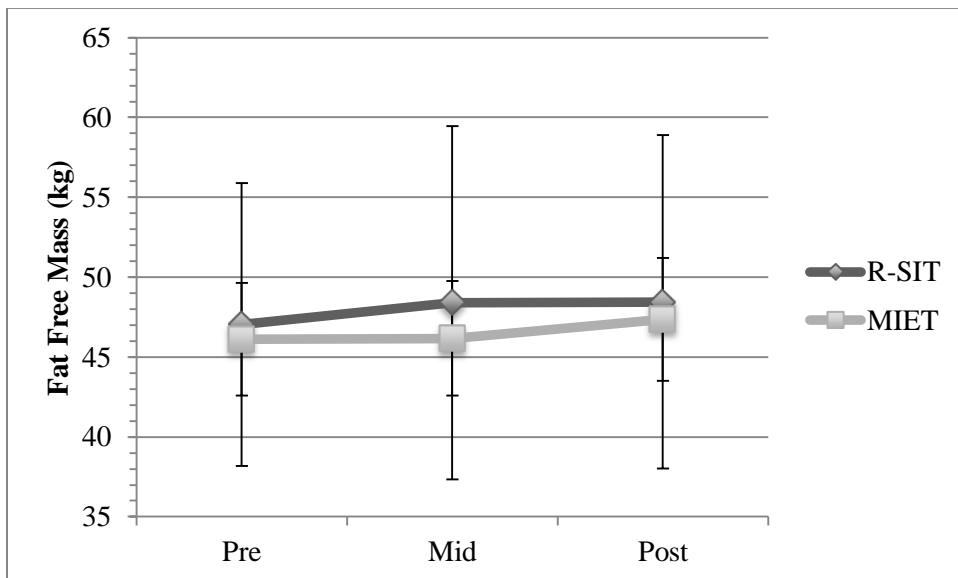


Figure 6. Comparison of Fat Free Mass between R-SIT and MIET groups at Pre-, Mid-, and Post- Training. Values are mean \pm SD. R-SIT = Running Sprint Interval Training Group (n=5); MIET = Moderate Intensity Endurance Training Group (n=7)

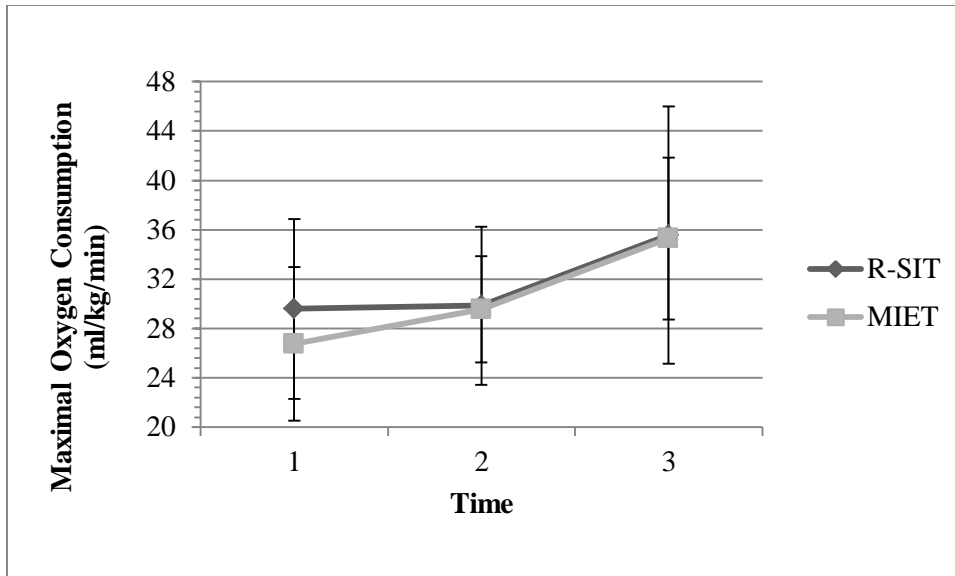


Figure 7. Comparison of Maximal Oxygen Consumption (ml/kg/min) between R-SIT and MIET groups at Pre-, Mid-, and Post- Training. Values are mean \pm SD. R-SIT = Running Sprint Interval Training Group (n=5); MIET = Moderate Intensity Endurance Training Group (n=7). *Denotes significant difference ($p < 0.05$); Main Effect for Time $p = 0.000^*$; MIET: Mid-post $p = 0.02^*$, Pre-post $p = 0.005^*$; R-SIT: Mid-post $p = 0.04^*$, Pre-post $p = 0.041^*$

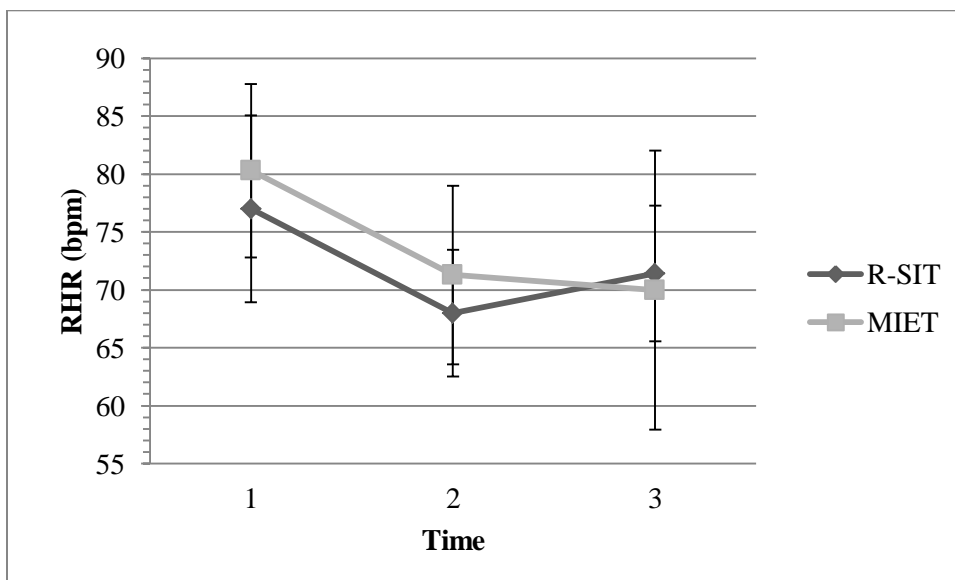


Figure 8. Comparison of Resting Heart Rate between R-SIT and MIET groups Pre-, Mid-, and Post- Training. Values are mean \pm SD. R-SIT = Running Sprint Interval Training Group (n=5); MIET = Moderate Intensity Endurance Training Group (n=7). *Denotes significant difference ($p < 0.05$); MIET: Pre-mid $p = 0.021^*$

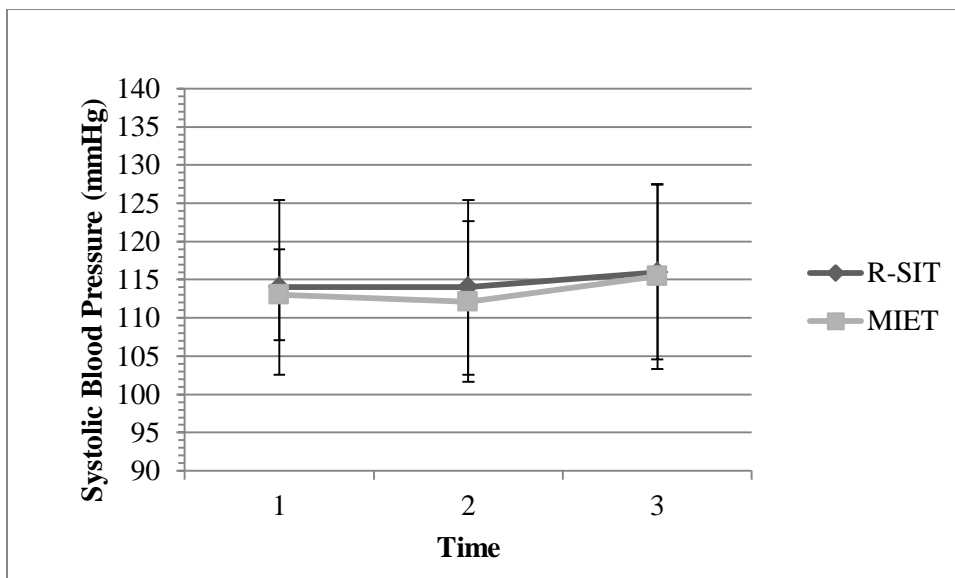


Figure 9. Comparison of Systolic Blood Pressure between R-SIT and MIET groups at Pre-, Mid-, and Post- Training. Values are mean \pm SD. R-SIT = Running Sprint Interval Training Group (n=5); MIET = Moderate Intensity Endurance Training Group (n=7)

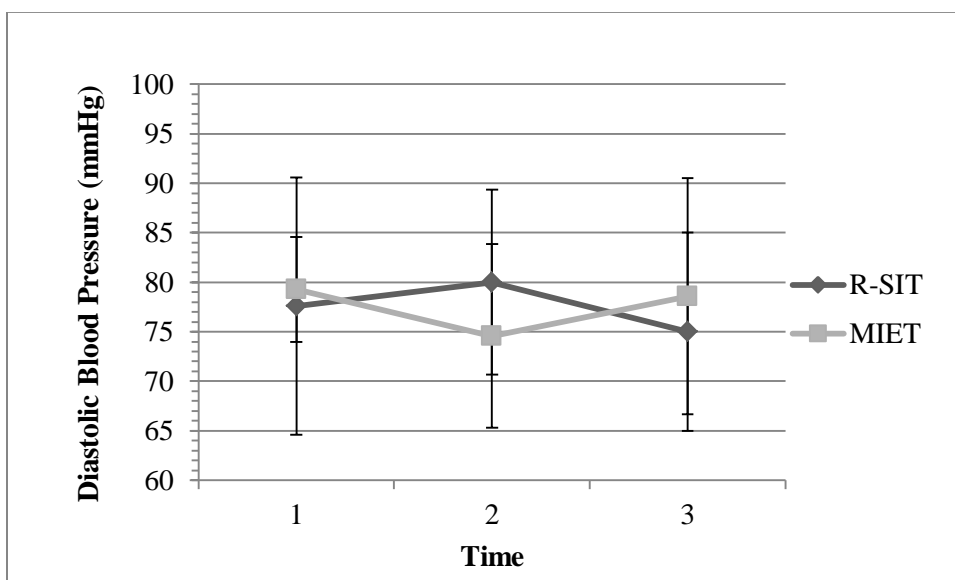


Figure 10. Comparison of Diastolic Blood Pressure between R-SIT and MIET groups at Pre-, Mid-, and Post- Training. Values are mean \pm SD. R-SIT = Running Sprint Interval Training Group (n=5); MIET = Moderate Intensity Endurance Training Group (n=7)

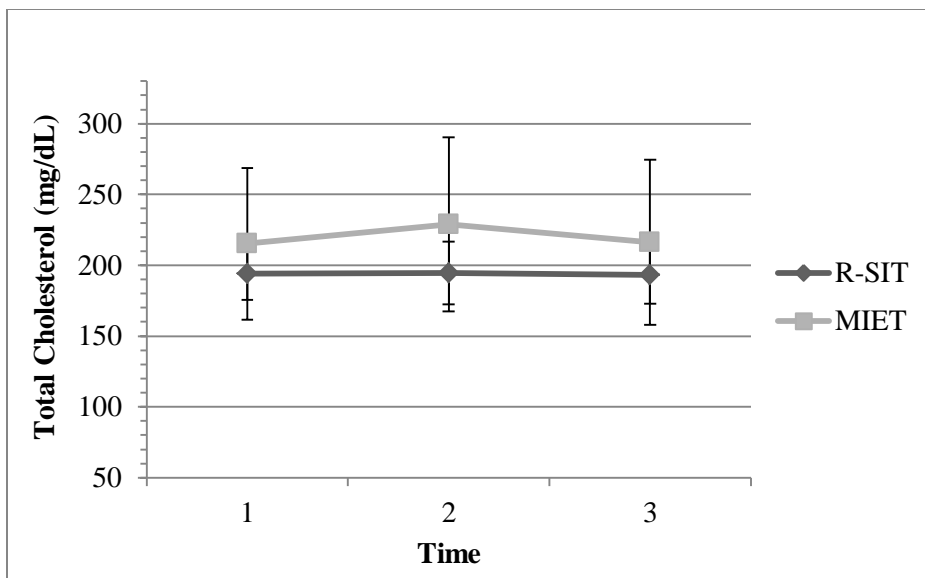


Figure 11. Comparison of Total Cholesterol (mg/dL) between R-SIT and MIET groups Pre-, Mid-, and Post- Training. Values are mean \pm SD. R-SIT = Running Sprint Interval Training Group (n=5); MIET = Moderate Intensity Endurance Training Group (n=7)

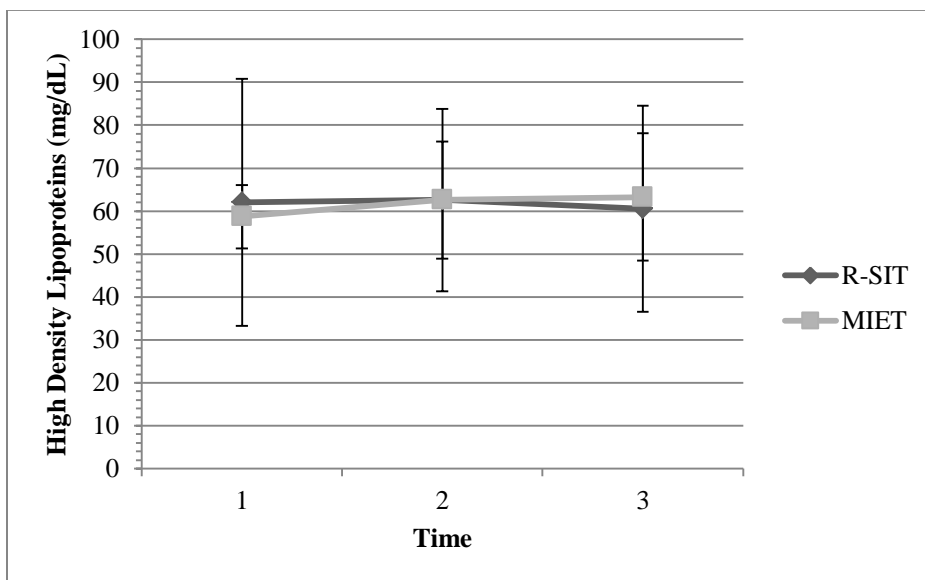


Figure 12. Comparison of High-Density Lipoproteins (mg/dL) between R-SIT and MIET groups at Pre-, Mid-, and Post- Training. Values are mean \pm SD. R-SIT = Running Sprint Interval Training Group (n=5); MIET = Moderate Intensity Endurance Training Group (n=7)

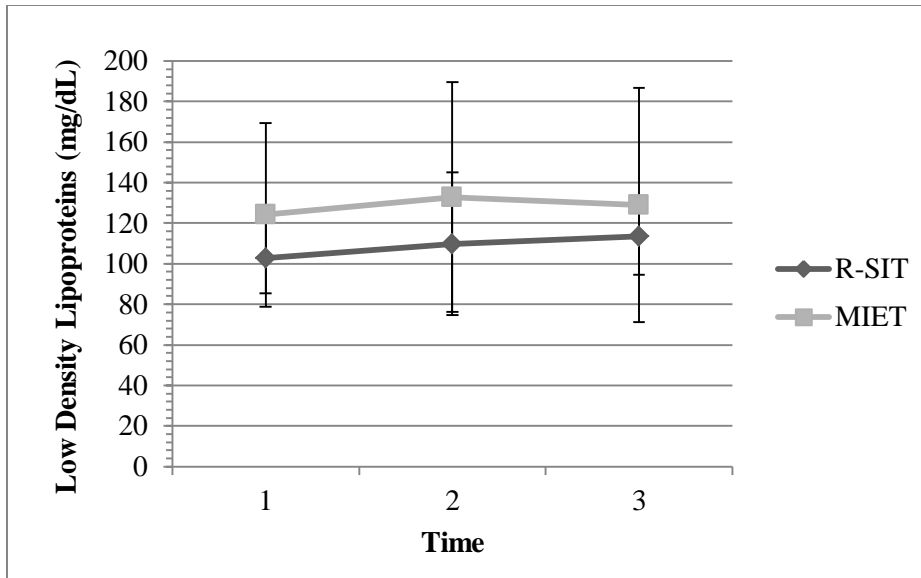


Figure 13. Comparison of Low-Density Lipoproteins (mg/dL) between R-SIT and MIET groups at Pre-, Mid-, and Post- Training. Values are mean \pm SD. R-SIT = Running Sprint Interval Training Group (n=5); MIET = Moderate Intensity Endurance Training Group (n=7)

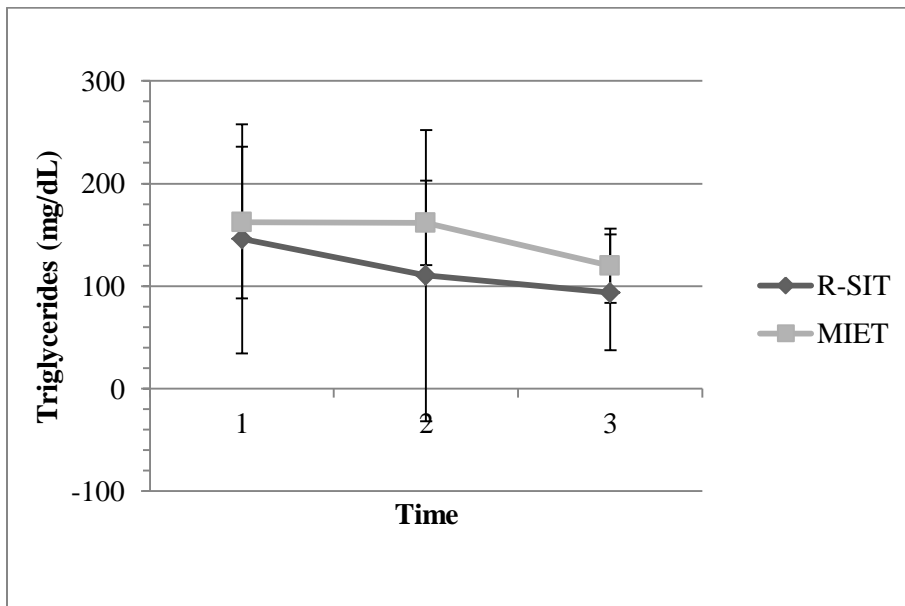


Figure 14. Comparison of Triglycerides (mg/dL) between R-SIT and MIET groups at Pre-, Mid-, and Post- Training. Values are mean \pm SD. R-SIT = Running Sprint Interval Training Group (n=5); MIET = Moderate Intensity Endurance Training Group (n=7)

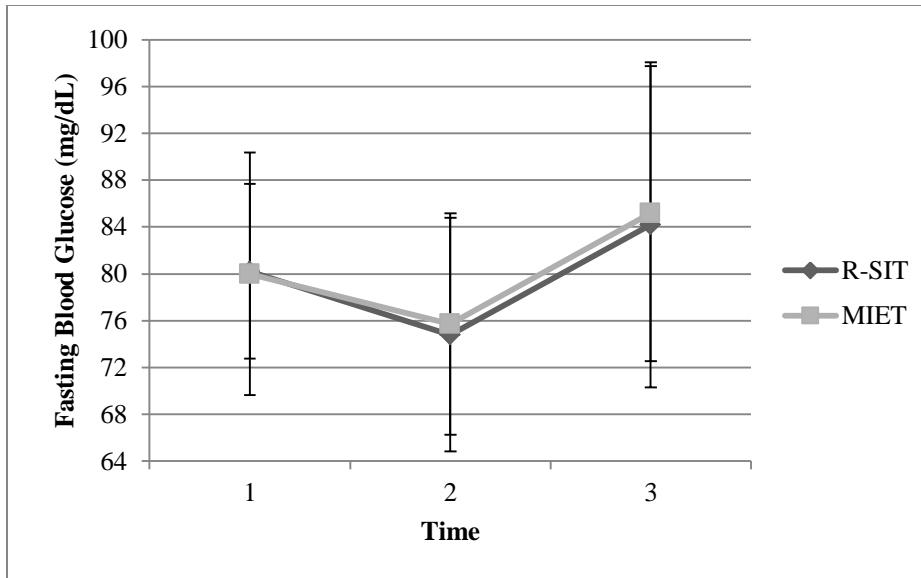


Figure 15. Comparison of Fasting Blood Glucose (mg/dL) between R-SIT and MIET groups at Pre-, Mid-, and Post- Training. Values are mean \pm SD. R-SIT = Running Sprint Interval Training Group (n=5); MIET = Moderate Intensity Endurance Training Group (n=7)

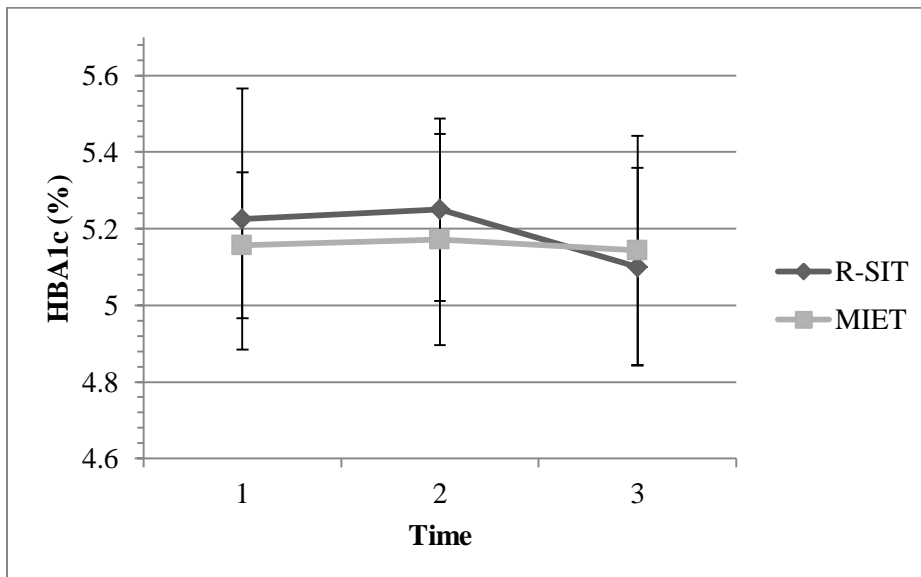


Figure 16. Comparison of HbA1c (%) between R-SIT and MIET groups at Pre-, Mid-, and Post- Training. Values are mean \pm SD. R-SIT = Running Sprint Interval Training Group (n=5); MIET = Moderate Intensity Endurance Training Group (n=7)

Appendices

Appendix A

James Madison University
Departments of Kinesiology and Health Sciences

Consent for Investigative Procedure (Informed Consent)

You are being asked to participate in a research study conducted by Drs. Elizabeth S. Edwards, Jeremy D. Akers, David A. Edwards, David L. Wenos, and graduate students Jennifer Espinoza and Taylor Wenos from the Departments of Kinesiology and Health Sciences at James Madison University and the University of Virginia. The purpose of this study is to determine the effect of low volume, high intensity training on physical fitness, physical activity enjoyment, and physical activity adherence, along with factors known to increase a women's risk for chronic disease (blood lipids, etc.) by conducting an experimental study in a cohort of premenopausal women.

Research Procedures. The study will consist of a 12-week supervised exercise program. Prior to beginning the training, at the mid-point of training, and upon completion of the training, you will complete various supervised tests and questionnaires to measure the physical fitness, health status, lifestyle behaviors, body composition, blood lipids, and blood glucose levels. Additionally, as part of this study, you will be contacted three months following the completion of the exercise intervention. At this point, we will ask you to fill out the same questionnaires that were completed during the study, as well as invite you back to the lab for an optional maximal oxygen uptake test (VO_{2max}).

Note: *In the event you discover that any of the following information is not clear, please ask one of the investigators to explain immediately.*

Blood Pressure. Blood pressure measurements will be taken using a sphygmomanometer and stethoscope. A blood pressure cuff will be placed over the upper portion of your right arm, slightly above the elbow. The cuff will be inflated to approximately 200mmHg and then slowly released, while a researcher uses a stethoscope to listen to sounds of blood flow through the vein on this inside of your elbow.

Blood Draws. A blood sample (10 milliliters, appr. 2 teaspoons) will be obtained from you via a blood draw from the vein on the inner part of your elbow during pre and post testing. In order to minimize the transfer of blood-borne pathogens, the investigators will wear latex gloves at all times during blood sampling and testing. For each venous blood draw, we will be measuring several different substances in the blood related to health and disease risk.

Preparation for Blood Draw. You will be asked to fast for 8-10 hours before the session. This includes coffee, tea, alcohol, or tobacco products.

Body Composition and Bone Mineral Density. Your height and weight will be measured and used to calculate body mass index BMI (kg/m^2). Additionally, the size of your waist and hips will be measured with a cloth tape measure. Your waist measurement is important in determining your risk for cardiovascular disease and diabetes. Dual-energy x-ray absorptiometry (DEXA) will be used to estimate body composition data and bone mineral density through the whole body scan. For the DEXA scan, you'll be asked to lie on your back and remain still for the whole scan; the scan will last approximately 6 minutes.

Volitional Maximal Exercise Test. The purpose of the volitional maximal graded exercise test, also known as the VO_2max test, is to measure cardiorespiratory fitness. Cardiorespiratory fitness is the ability to engage in dynamic moderate- to high-intensity exercise for a prolonged period of time. Cardiorespiratory fitness is an important consideration when health risks and overall exercise capability are assessed. High levels of cardiorespiratory fitness are correlated with reduced risk coronary artery disease.

Preparation for Exercise Testing. Prior to exercise testing, we will ask you to not eat or drink anything, except water for three hours prior to the test. Please note that this includes caffeinated beverages – such as coffee or tea! Use of tobacco products should be avoided at least three hours prior to testing as well. Please avoid heavy exercise on the testing day. Try to get to get at least six hours of sleep the night before, to ensure that you are well rested. Wear clothing that is comfortable and allows you to move freely, such as shorts, a t-shirt, and comfortable running shoes. Be aware that the test is fatiguing, so you may wish to be fully hydrated before the test.

Procedure for Exercise Testing. Resting heart rate and blood pressure will be taken prior to testing. The treadmill test follows a predetermined protocol to obtain a maximal oxygen uptake. You will run on a treadmill, with the speed and/or grade increasing as the test progresses, until you're working as hard as you can. You will be fitted with a heart rate monitor chest strap and a pulmonary facemask. Nonverbal cues will be used to communicate during the test. Hand signals include "yes," "no," and/or "stop the test." This is a volitional exercise test, so it is important to realize that you may stop the test when you wish because of feelings of fatigue or any other discomfort. Additionally, we may stop the test at any time due to signs of fatigue or abnormal physiological responses. These may include failure for heart rate increase with increased workload, dizziness, chest pains, or muscular fatigue. Please note that both protocols and procedures are in adherence with the guidelines set forth by the American College of Sports Medicine for exercise testing.

You will be permitted to leave once post exercise heart rate drops below 100 beats per minute or resting heart rate levels. Avoid a hot shower and a heavy meal for at least an hour after the exercise test.

Health Status. Your health status will be determined via questionnaires and ACSM's Risk Stratification for Cardiovascular Disease Risk (ACSM, 2010). Assessment of your risk for cardiovascular disease will be made using the ACSM's Coronary Artery Disease Risk Factor Thresholds along with the ACSM Risk Stratification. Risk stratification is based upon age, family history, smoking habits, blood lipid levels, and fasted blood glucose values, resting blood pressure, body mass index and physical activity habits. We will also be asking about current and previous conditions, surgeries, and medications, so that we may ensure that you are healthy enough to participate in this study.

Lifestyle Behaviors

a. Exercise Behavior – You will be asked to fill out the International Physical Activity Questionnaire (IPAQ), which estimates how much activity you have participated in over the previous seven days. It will ask about your physical activity as part of your daily life, including work, as well as leisure time activity.

b. Perceived Enjoyment– You will be asked to complete the Physical Activity Enjoyment Scale (*PACES*), a questionnaire that asks you about your perceptions and feelings about physical activity.

c. Dietary Behavior – You will be asked to complete a 3-day dietary record, where you will record what you consumed for 3 nonconsecutive days.

d. Physical Activity Behavior Change Questionnaire – You'll be asked to complete a questionnaire that asks you about your feelings towards structured physical activity, your perceptions of others' feeling regarding your physical activity, and how important physical activity is in your life.

Time Required. You will be asked to commit to up to three hours per week, for twelve weeks for the training segment of this project. Additionally, you will be asked to commit to seven testing and informational sessions that will each last up to one hour, in addition to the optional follow-up sessions to be conducted 3-months post-training. Testing and training will take place as follows:

- **Familiarization Session:** This is the familiarization session. During this session, all tests and procedures will be explained, after which we'll ask you to complete the appropriate health and medical status questionnaires and an Informed Consent Form. Additionally, participants will be asked to complete the questionnaires pertaining physical activity levels, health behavior, and perceived enjoyment. This session is estimated to last approximately 1 hour. You will also be given dietary record forms to be completed and returned to the researchers at the next meeting. After this session, future questionnaires will be completed during the clinical testing sessions.
- **Clinical Testing:** For this session, you will need to be fasted for (12-hours), as you'll have your blood drawn. We'll also measure your blood pressure and heart rate and complete a dual x-ray absorptiometry (DEXA) scan for the assessment of body composition and bone mineral (hip) density. Diet record will also be collected. This session is estimated to last approximately 50 minutes (30 minutes

for testing, 20 minutes for dietary records. All clinical testing will take place in the Kinesiology Human Performance Lab. These sessions will occur at the beginning, mid-point, and end of the training session. Additionally, you will be invited back 3-months after the completion of the training study to have her body composition, height, weight, and blood pressure evaluated again. For the mid-point, post-training, and optional follow-up sessions, you will also be asked to complete the study questionnaires at this session. This is expected to add approximately 15 minutes to the session.

- **Fitness Testing:** You will be asked to come in on a separate day to complete a volitional maximal exercise test (VO_{2max} test). Maximal testing will be completed in the Health Sciences Human Assessment Lab. These testing sessions will occur at the beginning, mid-point, and end of the exercise training. You'll also be invited back 3-months post-training to complete another fitness testing session if they would like.
- **Training Protocol:** As the main portion of the study, you will participate in a training session 3 days per week that will progress from 30 minutes per session, to 60 minutes per session for the next 12 weeks. Your group assignment will determine exactly what these exercise session will consist of. In brief, you will either be participating in moderate-intensity physical activity, short high-intensity intervals, or a combination of the two. All groups are expected to see improvements in fitness.

Risks. There is minimal risk associated with submaximal exercise testing in individuals who are “low” or “moderate” risk according to guidelines established by the American College of Sports Medicine. There is a minimal level of discomfort that may be experienced during the exercise testing, which includes muscle soreness and fatigue. Muscle soreness may be felt 24-48 hours following the testing.

The risks of venipuncture blood sampling include possible mild bruising and the risk of transfer of blood-borne pathogens. This risk is considered to be minimal, and all safety precautions for handling blood samples will be followed according to OSHA protocols.

According to the manufacture's specifications (i.e., GE Healthcare), whole body DXA analysis exposes participants to 1.5 mrem of radiation. The exposure to radiation during a single chest x-ray (i.e., 5 mrem) is more than 3 times greater than radiation from DEXA. Also, background radiation from DEXA is about equal to the amount of radiation one experiences during a flight from New York to London. Please note that the effects of the DEXA scan are cumulative depending on your prior exposure to radiation. If you have questions regarding your risk from the scan please consult with the investigators.

Benefits. Potential benefits from participation in this study include free testing of cardiorespiratory fitness, body composition, lipid profile, and bone mineral density. You will receive the results from your individual tests, including a rating of how you compare to females within your age category. Along with these results, you'll receive information

regarding the importance and meaning of measure, as well as what steps you could take to improve these measures if you would like to.

You will also receive free monitored workout sessions and motivation from the researchers. The researchers expect to see positive metabolic changes for participants in all training protocols that may result in improved health and general well-being. You will also have the opportunity to learn about habitual dietary intake and your percentages of energy nutrients and total caloric intake. Participation in this study will also help investigators understand metabolic responses and adherence to long-term exercise. Finally, if you complete the study, you'll receive a free dietary consultation.

Confidentiality. All data and results will be kept confidential. You will be assigned an identification code. All of your questionnaires and other results will be filed only according to your identification code, with your full name not located in that file. For the duration of the study, your first name will be stored with this data, so that research staff may address you, but this will be removed at the completion of the study. These results will be stored in a locked cabinet in a locked office. Electronic copies of the data will be password protected and kept only on secure servers. Only research personnel, who may include students, will have access to this data in either hard or electronic format. Any forms that link your name with your identification number, including this form, will be kept in a different file, which will be located in the office of one of the head researchers on this study. Additionally, any electronic formats of this information will be kept by one of the head researchers and will be password protected with a different password than the data. None of your test results or data will be located in this file. Access to these files will be limited to the head researchers on this staff and will only be used for the purposes of matching up your data to previous results and to contact you for the follow-up measures. After the second follow-up measure, any form that links your name to your identification number will be destroyed.

Participation and Withdrawal. Your participation is entirely voluntary. You are free to choose not to participate. Should you choose to participate, you can withdraw at any time without consequences of any kind. If at any time you choose to withdraw from the study, any identifying information that links your name to your data will be destroyed at that time.

Reporting Procedures. You will be provided health and fitness tests data at the completion of each test and will receive the results of your blood tests after they have been processed. The findings of the study will be presented at regional and national organizations conferences and submitted for publication in professional journals

Questions about the Study. If you have questions or concerns during the time of your participation in this study, or after its completion or you would like to receive a copy of the final aggregate results of this study, please contact:

Dr. Elizabeth Skidmore Edwards
Department of Kinesiology
James Madison University
edwardes@jmu.edu
540-568-5220

Questions about Your Rights as a Research Subject

Dr. David Cockley
Chair, Institutional Review Board
James Madison University
(540) 568-2834
cocklede@jmu.edu

Giving of Consent

I have read this consent form and I understand what is being requested of me as a participant in this study. I freely consent to participate. I have been given satisfactory answers to my questions. The investigator provided me with a copy of this form. I certify that I am at least 18 years of age.

Name of Participant (Printed)

_____ _____
Name of Participant (Signed) Date

Demographic Information

Full Name: _____ Nickname: _____

ID# _____ (Research personnel use)

Address: _____

Preferred phone: _____ Is this your: Work Home
 Cell Other: _____

Email address: _____ Date of Birth: _____
(Month/ Day/ Year)

Optional Additional Consent

I understand that new risk factors are constantly emerging and that further analysis of my blood samples, beyond those tests outlined in this consent form may provide valuable information. I consent to having my blood samples stored indefinitely, so that they may be used in future analyses. If my blood is used in these tests and yields information that would be pertinent to my health, the research team will attempt to contact me to give me these results.

Name of Participant (Printed)

Name of Participant (Signed)

Date

Appendix B

Physical Activity Readiness
Questionnaire - PAR-Q
(revised 2002)

PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	NO	
<input type="checkbox"/>	<input type="checkbox"/>	1. Has your doctor ever said that you have a heart condition <u>and</u> that you should only do physical activity recommended by a doctor?
<input type="checkbox"/>	<input type="checkbox"/>	2. Do you feel pain in your chest when you do physical activity?
<input type="checkbox"/>	<input type="checkbox"/>	3. In the past month, have you had chest pain when you were not doing physical activity?
<input type="checkbox"/>	<input type="checkbox"/>	4. Do you lose your balance because of dizziness or do you ever lose consciousness?
<input type="checkbox"/>	<input type="checkbox"/>	5. Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?
<input type="checkbox"/>	<input type="checkbox"/>	6. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?
<input type="checkbox"/>	<input type="checkbox"/>	7. Do you know of <u>any other reason</u> why you should not do physical activity?

**If
you
answered**

YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

NO to all questions

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active — begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal — this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

DELAY BECOMING MUCH MORE ACTIVE:

- if you are not feeling well because of a temporary illness such as a cold or a fever — wait until you feel better; or
- if you are or may be pregnant — talk to your doctor before you start becoming more active.

PLEASE NOTE: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

Informed Use of the PAR-Q: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

No changes permitted. You are encouraged to photocopy the PAR-Q but only if you use the entire form.

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

"I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction."

NAME _____

SIGNATURE _____

DATE _____

SIGNATURE OF PARENT
or GUARDIAN (for participants under the age of majority) _____

WITNESS _____

Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.



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Appendix C

Health Status Questionnaire

Part I Medical History

1. Has anyone in your family had a heart attack, heart surgery, or sudden death due to cardiovascular disease prior to the age of 65? (Circle one) Yes No

If yes, who? _____

How old were they? (Circle one) 54 or younger 55-59 60-64

2. Date of last medical exam: _____ Last physical fitness test: _____

3. Please list any operations that you have had:

4. Please list any condition for which you have been diagnosed or are being treated for by a physician or health professional:

5. Please list all medications taken in the last six months:

6. The occurrence of any of these health symptoms frequently is the basis for medical attention. Please check how often you have each of the following:

Symptom	1 Rarely	2 Infrequently	3 Sometimes	4 Fairly Often	5 Very Often
Cough up blood					
Abdominal pain					
Low back pain					
Leg pain					
Arm or shoulder pain					
Chest pain					
Swollen joints					
Feel faint					
Dizziness					
Breathless on slight exertion					

Appendix D

INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE

LONG FORM: LAST 7 DAYS SELF-ADMINISTERED FORMAT

FOR USE WITH YOUNG AND MIDDLE-AGED ADULTS (15-69 years)

The International Physical Activity Questionnaires (IPAQ) comprises a set of 4 questionnaires. Long (5 activity domains asked independently) and short (4 generic items) versions for use by either telephone or self-administered methods are available. The purpose of the questionnaires is to provide common instruments that can be used to obtain internationally comparable data on health-related physical activity.

Background on IPAQ

The development of an international measure for physical activity commenced in Geneva in 1998 and was followed by extensive reliability and validity testing undertaken across 12 countries (14 sites) during 2000. The final results suggest that these measures have acceptable measurement properties for use in many settings and in different languages, and are suitable for national population-based prevalence studies of participation in physical activity.

Using IPAQ

Use of the IPAQ instruments for monitoring and research purposes is encouraged. It is recommended that no changes be made to the order or wording of the questions as this will affect the psychometric properties of the instruments.

Translation from English and Cultural Adaptation

Translation from English is encouraged to facilitate worldwide use of IPAQ. Information on the availability of IPAQ in different languages can be obtained at www.ipaq.ki.se. If a new translation is undertaken we highly recommend using the prescribed back translation methods available on the IPAQ website. If possible please consider making your translated version of IPAQ available to others by contributing it to the IPAQ website. Further details on translation and cultural adaptation can be downloaded from the website.

Further Developments of IPAQ

International collaboration on IPAQ is on-going and an ***International Physical Activity Prevalence Study*** is in progress. For further information see the IPAQ website.

More Information

More detailed information on the IPAQ process and the research methods used in the development of IPAQ instruments is available at www.ipaq.ki.se and Booth, M.L. (2000). *Assessment of Physical Activity: An International Perspective*. Research Quarterly for Exercise and Sport, 71 (2): s114-20. Other scientific publications and presentations on the use of IPAQ are summarized on the website.

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** and **moderate** 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. **Moderate** activities refer to activities that take moderate physical effort and make you breathe somewhat harder than normal.

PART 1: JOB-RELATED PHYSICAL ACTIVITY

The first section is about your work. This includes paid jobs, farming, volunteer work, course work, and any other unpaid work that you did outside your home. Do not include unpaid work you might do around your home, like housework, yard work, general maintenance, and caring for your family. These are asked in Part 3.

1. Do you currently have a job or do any unpaid work outside your home?

Yes

No **→**

Skip to PART 2: TRANSPORTATION

The next questions are about all the physical activity you did in the **last 7 days** as part of your paid or unpaid work. This does not include traveling to and from work.

2. During the **last 7 days**, on how many days did you do **vigorous** physical activities like heavy lifting, digging, heavy construction, or climbing up stairs **as part of your work**? Think about only those physical activities that you did for at least 10 minutes at a time.

_____ **days per week**

No vigorous job-related physical activity **→**

Skip to question 4

3. How much time did you usually spend on one of those days doing **vigorous** physical activities as part of your work?

_____ **hours per day**

_____ **minutes per day**

4. Again, think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **moderate** physical activities like carrying light loads **as part of your work**? Please do not include walking.

_____ **days per week**

No moderate job-related physical activity



Skip to question 6

5. How much time did you usually spend on one of those days doing **moderate** physical activities as part of your work?

_____ **hours per day**

_____ **minutes per day**

6. During the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time **as part of your work**? Please do not count any walking you did to travel to or from work.

_____ **days per week**

No job-related walking



Skip to PART 2: TRANSPORTATION

7. How much time did you usually spend on one of those days **walking** as part of your work?

_____ **hours per day**

_____ **minutes per day**

PART 2: TRANSPORTATION PHYSICAL ACTIVITY

These questions are about how you traveled from place to place, including to places like work, stores, movies, and so on.

8. During the **last 7 days**, on how many days did you **travel in a motor vehicle** like a train, bus, car, or tram?

_____ **days per week**

No traveling in a motor vehicle



Skip to question 10

9. How much time did you usually spend on one of those days **traveling** in a train, bus, car, tram, or other kind of motor vehicle?

_____ **hours per day**

_____ **minutes per day**

Now think only about the **bicycling** and **walking** you might have done to travel to and from work, to do errands, or to go from place to place.

10. During the **last 7 days**, on how many days did you **bicycle** for at least 10 minutes at a time to go **from place to place**?

_____ **days per week**

No bicycling from place to place



Skip to question 12

11. How much time did you usually spend on one of those days to **bicycle** from place to place?

_____ **hours per day**

_____ **minutes per day**

12. During the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time to go **from place to place**?

_____ **days per week**

No walking from place to place



***Skip to PART 3:
HOUSEWORK, HOUSE
MAINTENANCE, AND
CARING FOR FAMILY***

13. How much time did you usually spend on one of those days **walking** from place to place?

_____ **hours per day**

_____ **minutes per day**

PART 3: HOUSEWORK, HOUSE MAINTENANCE, AND CARING FOR FAMILY

This section is about some of the physical activities you might have done in the **last 7 days** in and around your home, like housework, gardening, yard work, general maintenance work, and caring for your family.

14. Think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **vigorous** physical activities like heavy lifting, chopping wood, shoveling snow, or digging **in the garden or yard**?

_____ **days per week**

No vigorous activity in garden or yard



Skip to question 16

15. How much time did you usually spend on one of those days doing **vigorous** physical activities in the garden or yard?

_____ **hours per day**

_____ **minutes per day**

16. Again, think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **moderate** activities like carrying light loads, sweeping, washing windows, and raking **in the garden or yard**?

_____ **days per week**

No moderate activity in garden or yard → **Skip to question 18**

17. How much time did you usually spend on one of those days doing **moderate** physical activities in the garden or yard?

_____ **hours per day**
 _____ **minutes per day**

18. Once again, think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **moderate** activities like carrying light loads, washing windows, scrubbing floors and sweeping **inside your home**?

_____ **days per week**

No moderate activity inside home → **Skip to PART 4:
 RECREATION, SPORT AND
 LEISURE-TIME PHYSICAL
 ACTIVITY**

19. How much time did you usually spend on one of those days doing **moderate** physical activities inside your home?

_____ **hours per day**
 _____ **minutes per day**

PART 4: RECREATION, SPORT, AND LEISURE-TIME PHYSICAL ACTIVITY

This section is about all the physical activities that you did in the **last 7 days** solely for recreation, sport, exercise or leisure. Please do not include any activities you have already mentioned.

20. Not counting any walking you have already mentioned, during the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time **in your leisure time**?

_____ **days per week**

No walking in leisure time → **Skip to question 22**

21. How much time did you usually spend on one of those days **walking** in your leisure time?

_____ **hours per day**
 _____ **minutes per day**

22. Think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **vigorous** physical activities like aerobics, running, fast bicycling, or fast swimming **in your leisure time**?

_____ **days per week**

No vigorous activity in leisure time → **Skip to question 24**

23. How much time did you usually spend on one of those days doing **vigorous** physical activities in your leisure time?
 _____ **hours per day**
 _____ **minutes per day**
24. Again, think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **moderate** physical activities like bicycling at a regular pace, swimming at a regular pace, and doubles tennis **in your leisure time**?
 _____ **days per week**
- No moderate activity in leisure time **→ Skip to PART 5: TIME SPENT SITTING**

25. How much time did you usually spend on one of those days doing **moderate** physical activities in your leisure time?
 _____ **hours per day**
 _____ **minutes per day**

PART 5: TIME SPENT SITTING

The last questions are about the time you spend sitting while 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. Do not include any time spent sitting in a motor vehicle that you have already told me about.

26. During the **last 7 days**, how much time did you usually spend **sitting** on a **weekday**?
 _____ **hours per day**
 _____ **minutes per day**
27. During the **last 7 days**, how much time did you usually spend **sitting** on a **weekend day**?
 _____ **hours per day**
 _____ **minutes per day**

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

Appendix E

Three Day Food Intake Record Instructions

- Please keep your record for three days on the forms provided.
- The days should include two weekdays and one weekend day.
- Select days that will most closely resemble your eating habits.
- This record should include all meals, snacks, and beverages including water and cocktails. Anything you put in your mouth should be listed.
- If possible, weigh and/or measure your food before you eat it.
- Record what you eat and drink as soon as you can to reduce the chance of forgetting. Be as specific as possible by writing down brand names, food preparation methods and anything added to the foods such as condiments, spices and other seasonings.
- Also record the time you consume each food and the meal (i.e. Breakfast, snack etc.).
- Your food intake will be analyzed using Nutrition Data for System Research software in the Sensory and Diet Evaluation Lab.

Appendix F

Dear Dr: _____

Your patient _____ would like to participate in study that I am currently conducting through the Department of Kinesiology and Health Sciences at James Madison University. This study is entitled "Perceived Satisfaction and Metabolic Effects of Sprint Interval Training. The intent of this study is to determine practical and sustainable physical activity intervention strategies that will effectively reduce the risk of chronic disease in sedentary, overweight women.

Participation in this study includes:

- Participation in either moderate-intensity or high-intensity interval training, 3 times per week, for 12 weeks. These sessions will be monitored by exercise physiology and/or health and promotion students who are trained in monitoring the warning signs of an adverse event associated with exercise and how to respond to these situations.
- Physical fitness assessment:
 - Maximal physical fitness tests for aerobic capacity. Tests include: A maximal, graded exercise test on the treadmill, in which workload will be increased every three minutes until termination of the test. The protocol will end when the participant reaches age-predicted maximal heart rate, volitional fatigue, asks to stop, or experiences adverse signs or symptoms (ACSM, 2010). All tests will be completed following American College of Sports Medicine guidelines.
- Other aspects of the study include:
 - Blood draw to screen for lipids, glucose, hematocrit, hemoglobin, and HbA1c; Body composition and bone mineral density assessment via dual x-ray absorptiometry; Questionnaires to assess: physical activity levels, health status, health behavior, diet, and perceived enjoyment of physical activity.

_____ reported _____, which led us to seek your approval for her participation in the physical fitness assessment portion of this study. If you feel that it would be safe for _____ to participate in this study, please complete the attached form and return it to _____ or to me, at:

Elizabeth Skidmore Edwards, PhD
540-568-5220
edwardes@jmu.edu

Thank you for your consideration



Elizabeth Skidmore Edwards, PhD
Assistant Professor, Department of Kinesiology
Executive Director, Morrison Bruce Center

**Cardiovascular Risk, Exercise, and Women
Physician Approval Form**

Patient Name: _____

1. Are there specific concerns or conditions we should be aware of before this individual engages in the physical fitness assessment for this study??

2. If this individual has completed a graded exercise test (stress test) please provide the following:

a. Date of Test:

b. A copy of the final exercise report and interpretation.

3. Please provide the following information so that we may contact you if we have any further questions:

____ I AGREE to the participation of this individual in the herein described study.

____ I DO NOT AGREE that this individual is a candidate for this study.

Physician's Signature _____

Physician's name (printed)

Address

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