The Pennsylvania State University

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ALTERNATIVE METHODS OF RESISTANCE AND HIGH-INTENSITY INTERVAL TRAINING: EFFECTS ON MUSCULOSKELETAL AND PHYSIOLOGICAL HEALTH AND FITNESS.

A Thesis in

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by

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ABSTRACT

The current physical activity recommendations to improve bone mineral density (BMD) and physical fitness are not suitable for all populations. For instance, many older adults cannot perform high load, low repetition resistance training to increase BMD and individuals with orthopedic limitations cannot complete weight bearing, high intensity interval training (HIIT) to increase physical fitness.

STUDY 1: To evaluate an alternative to improve BMD, 20 untrained adults were randomly assigned to 27 weeks of either full body, low load, high repetition strength training (S-WEIGHT) or core focused strength training (S-CORE). BMD increased significantly for S-WEIGHT in the arms (+4%), legs (+8%), pelvis (+6%) and lumbar spine (+4%), but not for S-CORE. Therefore, a low load, high repetition resistance training program may be an effective method to improve BMD in older or untrained adults.

STUDY 2: To evaluate an alternative to improve cardiovascular and musculoskeletal fitness with HIIT, 36 trained adults were assigned to either a 6-week experimental group, in which they replaced one of their current 60-minute cardiovascular exercise sessions with 2, 30-minute HIIT indoor cycling sessions (G-HIIT) or a control group, in which they maintained their current physical activity regimen (G-FIT). Peak oxygen consumption increased significantly for only G-HIIT (+9.7%), while mean leg strength increased (+12.0%) and body fat mass decreased (-5.8%). There were no significant changes with G-FIT. Thus, HIIT cycling may be an efficacious method to enhance physical fitness in trained adults. In summary, low load, high repetition resistance training and non-weight bearing high intensity cycling training could be effective alternatives to improve health and fitness in greater segments of the population.

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CONFLICT OF INTEREST

Jinger S. Gottschall is a co-owner and founder of FITOLOGY, LLC, the studio where the participants completed the classes. While LES MILLS INTERNATIONAL was supportive of the present study they did not have access to the data for analyses.

CHAPTER 1: BACKGROUND AND RATIONALE

Physical inactivity is now compared to smoking in terms of all-cause mortality, it can cut lifespans by at least 2.4 years for US adults (Borrell 2014). In fact, physical inactivity accounts for nearly 1 in 10 deaths in the United States (Danaei et al. 2009). To improve health and quality of life, the US Department of Health and Human Services recommends 150 minutes of moderate or 75 minutes of vigorous activity per week (Health and Services 1996). To develop and maintain cardiorespiratory fitness, the American College of Sports Medicine (ACSM) recommends 20-60 min of continuous or intermittent aerobic activity 3-5 days per week at 65-95% of maximum heart rate (HR_{max}) (Pollock et al. 1998). Despite 82-87% of Americans being aware of the relationship between physical inactivity and mortality (Morrow et al. 1999), only 20% of Americans participate in enough aerobic and strength exercise to meet physical activity guidelines (Harris et al. 2013). While majority of Americans know the benefits of activity, finding a way to start an exercise program can be difficult.

Group exercise classes are an integral part of promoting exercise to inactive individuals. Starting a safe and effective exercise program requires knowledge of the correct duration, frequency and type of exercise. With group exercise classes, these are all pre-determined factors. In 2014, group exercise classes were attended by 44% of health club members in 2009, which is approximately 21.2 million individuals (IHRSA 2014). These classes are implemented on a global scale and are accessible to all ages and training levels. Additionally, both long and short term adherence rates of group exercise are greater than other training methods (Estabrooks and Carron 1999, Frasier and Spink 2002, Spink and Carron 1994). This is likely due to the group cohesion and increased satisfaction associated with participation in group exercise (2002). The aim of this thesis was to evaluate alternative training methods to enhance bone health and measures of physical fitness. My goal was to investigate different training programs that have significant health and fitness benefits, high adherence rates and that can implemented in a real world scenario.

Resistance training improves strength and muscular endurance, which helps reduce the risk of morbidity and mortality, particularly in older adults (Katzmarzyk and Craig 2002, FitzGerald et al. 2004). Additionally, resistance exercise provides mechanical loading on bone, which can increase bone mineral density (BMD) for young adults and also slow the loss of BMD in middle aged adults (Vuori 2001). Both osteoporosis and low bone mass in general are strongly associated with a higher risk of falls, morbidity and mortality in older adults (Alpert 2009). Hip fractures, which are the most common osteoporotic fracture, have a particularly devastating effect: 1 in 5 individuals will die and less than 1/3 of survivors will regain their normal level of functioning (NIH Consensus Development Panel 2001). Thus, low BMD is a life-threatening problem in older populations and is growing rapidly. In fact, the National Osteoporosis Foundation (2002) expects 47 million people over the age of 50 will have low bone mass by 2020. Because the prevalence of low bone mass is expanding, physical activity regimens that increase bone density are becoming even more crucial to improving mortality rates in older adults.

According to the ACSM, resistance training to increase strength and endurance should be performed at least two times per week on nonconsecutive days using major muscle groups (ACSM 1995). Each bout should include 8-10 exercises with moderate-high loads (70-80%1RM) (Haskell et al. 2007). Similarly, resistance training to increase bone mineral density should be performed 2-3 times per week for 30-60 minutes per day (ACSM 1995). The exercises should again involve major muscles and the suggested intensity is moderate to high bone loading forces

(ACSM 1995). Even for older adults, ACSM recommends higher intensity, progressive programs with high strain rates for improving bone health (Pollock et al. 1998, Chodzko-Zajko et al. 2014).

Resistance training and its effects on bone health have been studied in young adults (augmenting peak bone mass), middle-aged adults (maintaining BMD) and older adults (slowing the progression of bone loss) and, in general, high intensity resistance training benefits all of these age groups. If the loads used are above 70% 1RM and the program lasts at least 6 months, high intensity resistance training can increase, maintain, or slow the loss of BMD. Ryan et al. (2004) studied 6 months of a progressive whole body resistance training program on BMD in both younger and older adults. Participants performed 11 machine exercises and eventually progressed to 1-2 sets of 12-15 repetitions at 60-80%1RM. BMD increased significantly at the femoral neck and greater trochanter with both age groups. In middle-aged adults, Gray et al. (2013) investigate the effects of 48 weeks of high load resistance training on BMD in pre-menopausal women. The high load resistance training involved 8-10 whole body exercises, with 2 sets of 8-12 repetitions at 70% 1RM. They found that high load resistance training maintained BMD in comparison to the control group. In older women, the extent of the benefits from high resistance training varies. For example, Marques et al. (2011) studied the effect of a progressive high load resistance training program (8 machine exercises, 2 sets of 6-8 repetitions at 75-80%1RM) versus aerobic training on BMD in older women. After 8 months, trochanteric and total hip BMD increased for only the resistance training group. However, Bocalini et al. (2009) reported that 24 weeks of a high load resistance training program (85%1RM) slowed the rate of demineralization in postmenopausal women. The participants in the high load resistance training group performed 12 free-weight exercises for 3 sets of 10 repetitions at 85%1RM. In short, these past studies show benefits for BMD with high load resistance training. Furthermore, the benefits are not gender specific. Maddalozzo and Snow (2000) found that high load resistance training over 24 weeks increased bone mineral density in the spine and hip for older men. The participants in this study performed 12 free-weight standing exercises for 3 sets of 8 repetitions at 70%1RM. Even in young men, high load resistance training (80-90% 1RM, 5 sets of 4-8 repetitions) increased BMD of the lumbar spine and femoral neck compared to the control group (Tsuzuku et al. 2001). Therefore, resistance training using high loads and low repetitions is widely accepted as a method of BMD maintenance and prevention of bone loss.

Though increases in BMD with high intensity resistance training (loads >70% 1RM) are well documented, these programs may not be an appropriate exercise prescription for everyone. High load resistance training programs have a significantly higher rate of reported adverse effects than low load programs in older, untrained adults (Liu et al. 2010). Adverse effects included musculoskeletal injuries to cardiovascular events. Untrained adults are at a higher risk of bone loss; in fact bone loss starts to occur after just 5 weeks of inactivity (Berg et al. 2007). Additionally, older adults are also susceptible to low bone mass (Mosekilde 1989, Mosekilde and Mosekilde 1990). Because both groups have a high risk for bone loss and therefore osteoporotic fractures, finding an alternative method to improve of bone mass in these groups is critical.

One such alternative would be a resistance training program that utilizes lighter loads with a greater number of repetitions. However, previous literature on the efficacy of low load, high repetition resistance training in increasing BMD is conflicting. For example, Bemben et al. (2011) compared data from adults who completed a 40-week exercise intervention in either a high load or low load resistance training group at either 2 or 3 days per week. The high load, low repetition group performed 3 sets of 8 repetitions at 80%1RM for all 12 exercises, whereas the low load, high repetition performed 3 sets of 16 repetitions at 40%1RM for 12 exercises. They determined that both high and low load resulted in similar increases BMD at the spine and trochanter. Pruitt et al. (1995), however, studied the effect of high intensity versus low intensity resistance training (80%1RM versus 40% 1RM) on older women over the course of one year and found that neither protocol increased BMD in the lumbar spine or the hip. The high intensity group performed 2 sets of 7 repetitions at 80%1RM for 10 exercises and the low intensity group performed 3 sets of 14 repetitions at 40%1RM for 10 exercises. Yet another study by Tsuzuku et al. (2001) reported increases in BMD with high load, but not with low load resistance training. However, the duration of the two interventions and frequency were not consistent between groups, which could confound the results. Similarly, Kerr et al. (1996) stated that high load (3 sets of 8 repetitions at 80%1RM), but not low load (3 sets of 20 repetitions at 50%1RM) resistance training elicited increases in BMD in postmenopausal women. Still there were no significant decreases over 1 year for the low load, high repetition program, which could indicate that BMD was maintained. While low load, high repetition resistance training has been studied, the results are hardly consistent between protocols. Essentially, there is not yet a consensus on low-intensity, high repetition protocols with respect to improving or maintaining bone mass.

My aim was to study a low load, high repetition resistance training program that could meet the needs of those who could not perform the high load, low repetition RT. In general, the loads used in low load, high repetition programs are perceived as more achievable and less daunting than the traditional strength programs. Prior studies used loads of 40%1RM for a total of 420-576 repetitions for low load, high repetition protocols (Pruitt et al. 1995, Bemben and Bemben 2011). For this program, participants self-selected loads and performed 800 repetitions total per one 60-minute exercise bout. The amount of repetitions in this program is nearly double the typical low load program. The substantial increase in repetitions in this program allows participants to use very low loads, on average 20%1RM. The significantly lower loads used in this protocol are more realistic for women and older adults to be able to perform and maintain over the period of time necessary to see improvements in BMD. Adherence and ability to maintain these programs are crucial, as it takes at least 3-4 months for one bone remodeling cycle (bone resorption, formation and mineralization) (Rosen et al. 2009).

Due to the decline in BMD in men and women around age 50, the aim for effectiveness of training protocols on BMD changes for each age group. Peak BMD is reached and plateaus in the mid-twenties. Thus from the mid-twenties until age 50 the goal is to maintain this peak BMD. With older adults (over the age of 50) the goal is to improve BMD as much as possible. Thus, the goal of this study was to evaluate if 27 weeks of alternative low load resistance training protocol can maintain or increase BMD in untrained adults (ages 28-63). This study was conducted as a randomized control trial with two group fitness interventions: low load resistance training and a functional control group (core strength training). I hypothesized that low load, high repetition resistance training would increase BMD over the period of 27 weeks more than the control.

Another mode of exercise that provides health and fitness benefits is high intensity interval training (HIIT). HIIT has become a new time-efficient way to exercise that can provide similar health and fitness benefits to full length programs. In fact, HIIT has similar fitness benefits to traditional endurance training, despite requiring less than half the time commitment of traditional training (Burgomaster et al. 2008, Gibala and McGee 2008, Macpherson et al. 2011). Adding high intensity exercise to a sedentary or even moderately active lifestyle reduces the risk of mortality by 22% in men and 31% in women (Löllgen et al. 2009). HIIT is an exercise program with periods of high intensity followed by periods of active recovery. While the interval to rest times vary, one bout of HIIT lasts no more than 30 minutes and stimulates similar or greater physical fitness benefits of corresponding 60 minutes bouts moderate-intensity exercise (Burgomaster et al. 2008; Gibala and McGee 2008; Macpherson et al. 2011). Physical fitness has four components: cardiovascular fitness, musculoskeletal fitness (specifically strength), body composition (body fat mass), and metabolic fitness (serum lipids, blood pressure and blood glucose parameters) (Research and Councils 1984, Bouchard and Shepard 1993).

Weight-bearing HIIT as a method of increasing cardiovascular fitness is well documented. For example, Helgerud et al. (2007) studied running at four different intensities 3 days a week for 8 weeks to compare VO_{2max} changes in moderately trained males: running at 70% and 85% HR_{max} as well as HIIT running at 90-95% HR_{max}. They discovered greater increases in Vo_{2max} with HIIT interventions than in the endurance training interventions. In a similar study, Nybo et al. (2010) compared the effects of HIIT running, prolonged running and strength training on VO_{2max} in untrained adults for 12 weeks. VO_{2max} increased significantly more in the HIIT group (+14.0%) versus the other two groups (+7.4% and 3.4%). Thus, HIIT running produces greater benefits than typical endurance running. Using a group exercise intervention, Gottschall et al. (2014) found that replacing just one bout of moderate-intensity exercise with 2 weight-bearing HIIT classes per week for 6 weeks in physically active participants significantly improves the health, fitness and strength benefits over a moderate-intensity training program. All three studies were volume matched; however, even at lower volumes, HIIT can improve cardiovascular fitness. For example, in a 6 week intervention by MacPherson et al. (2011) participants were assigned to sprint interval training (6.75 hrs total) or endurance training (13.5 hrs total). Sprint interval training increased VO_{2max} by 11.5%, whereas endurance training increased VO_{2max} by 9.5%. These protocols used weight-bearing HIIT protocols with high-impact forces that many populations, particularly those with orthopedic limitations, are not able to perform.

Orthopedic limitations, most often characterized by joint or musculoskeletal pain, are common among adults. Frequent knee pain affects 25% of adults (Nguyen 2011). Clinical osteoarthritis, which causes joint pain, affects nearly 27 million adults in the United States (Lawrence et al. 2008). Shoulder pain affects approximately 20-33% of the population, while over 50% are expected to experience low back pain within their lifetime (McBeth and Jones 2007). Joint pain can be exacerbated with high impact exercise, which limits those with these conditions from performing weight-bearing HIIT. Clearly, a low-impact alternative for HIIT is necessary, both for active adults who want to enhance their health benefits with HIIT or for sedentary adults who want the health benefits of moderate-intensity exercise in lower volumes.

Cycling is a low impact form of exercise and an ideal alternative. HIIT cycling has many fitness, performance and health benefits for both trained and untrained adults. For trained, competing cyclists, HIIT cycling can increase performance, as shown by improvements in time trials (Lindsay et al. 1996, Weston et al. 1996, Stepto et al. 1999). For untrained individuals, HIIT cycling improves VO_{2max}. For example, in matched-volume studies, HIIT increases VO_{2max} more than endurance cycling. Esfandiari et al. (2014) studied HIIT cycling for 6 sessions (over 12 days) in untrained young men. Their findings show that VO_{2max} increased by 11.1% for HIIT, while only 4.5% for endurance training. For longer interventions, Trapp et al. (2008) reported that 15 weeks of HIIT cycling increased VO_{2max} by 23.8% versus 19.3% with continuous endurance cycling in inactive women. Both of these studies were performed with inactive adults, the effect of HIIT cycling on trained adults is less established.

In active adults, Astorino et al. (2012) found that a series of repeated Wingate tests (4x30s exercise: 5 min recovery) over 2-3 weeks increased VO_{2max} by 5.5%. Hazell et al. (2010) studied a similar protocol of repeated Wingate tests in active adults, using varying interval to rest ratios, over 2 weeks. For 2 of the 3 HIIT groups, VO_{2max} increased by 9.3% (30s exercise: 4 min rest) and 9.2% (10s exercise: 4 min rest). While these short-term studies using repeated Wingate tests have shown to increase VO_{2max}, the effect of these protocols on other measures of physical fitness are either lacking or have shown no significant changes (Gibala and McGee 2008). Furthermore, the applicability of this study to an exercise protocol that can be implemented as a fitness program is unclear. The nature of these intense protocols may not be safe or practical for untrained or even moderately-trained adults (Gibala and McGee 2008). These studies, while highly controlled, indicate that HIIT on a bike can be effective in increasing VO2max for trained adults. The application of a HIIT cycling protocol that is more accessible to trained adults in the community has not yet been studied.

Additionally, the impact of HIIT on other aspects of fitness is not yet fully understood. For example, changes in metabolic fitness have not been studied as extensively. In long term studies (more than 6-12 weeks) HIIT has shown decreases in total cholesterol, LDL-C, and fasting blood glucose (Gottschall et al. 2014, Sandvei et al. 2012, Keating et al. 2014). However, many studies found that 2-3 weeks of HIIT did not change cholesterol or fasting blood glucose (Babraj et al. 2009, Richards et al. 2010, Whyte et al. 2010). Further investigation is necessary to determine the relationship between changes in metabolic fitness and type or duration of HIIT.

Body composition is yet another aspect of physical fitness in which the previous literature shows conflicting results. While studies have shown HIIT cycling decreases body fat percentage in untrained adults, the magnitude of these changes varies considerably.

Improvements in body fat percentage in sedentary, overweight adults range from 0.8% after 6 weeks of HIIT cycling to 11.2% after 15 weeks of HIIT cycling (Trapp et al. 2008, Gillen et al. 2013). In trained adults, however, 2-3 weeks of repeated Wingate tests did not change body composition (Whyte et al. 2010, Astorino et al. 2012). Six weeks of body-weight HIIT, however, decreased body fat percentage by 1.8-2.1% in trained adults (Macpherson et al. 2011, Gottschall, et al. 2014). Clearly, changes in body fat and magnitude of those changes are not consistent throughout previous studies. More studies are required to get a consensus on the effects of HIIT cycling on body composition.

My aim was to evaluate the effects of 6 weeks of a practical, low-impact HIIT cycling protocol on physical fitness in trained adults. This is the first study to focus on the physical fitness effects of a HIIT cycling protocol in trained adults that does not use repeated Wingate tests. Many of the previous HIIT cycling protocols with trained adults did not investigate the effects on metabolic fitness, isometric leg strength and body composition. To evaluate a low-impact HIIT alternative to improve health and fitness, we enrolled 36 adults, who were exceeding the physical fitness guidelines, for a 6 week HIIT cycling intervention. They were assigned to either a control group, in which they maintained their physical activity regimen (60 minutes of cardiovascular activity four days per week) for 6 weeks, or a HIIT group, in which they replaced one 60-minute bout of their regular activity with 2, 30-minute HIIT cycling classes for 6 weeks.

In summary, alternatives to regular methods of physical activity are becoming increasingly necessary, as the barriers to exercise in populations are more understood. Two common modes of exercise are resistance training and high intensity interval training. High load, low repetition RT is most often prescribed for improving bone health, yet it is not suitable for many women and older adults. HIIT is an effective way to boost physical fitness for trained adults, yet the high impact of weight-bearing HIIT renders it inaccessible to those with orthopedic limitations. Thus, alternative exercise prescriptions will help those populations not attaining the current guidelines to gain similar benefits in ways that are suitable for their specific needs.

CHAPTER 2: ALTERNATIVE TRAINING METHODS FOR IMPROVING BONE HEALTH

Introduction

The prevalence of osteoporosis and osteopenia is increasing nationwide. The National Osteoporosis Foundation reported that by 2020, about 14 million people over the age of 50 are expected to have osteoporosis and another 47 million to have low bone mass (2002). These conditions have a strong correlation with falls, morbidity and mortality in older adults (Alpert 2009). Alarmingly, bone mineral density (BMD) loss can start as early as 35 years old (Lane 2006). There are many methods of preventing bone loss. Frost et al. found that the age-related loss of muscular strength correlates with bone loss (Frost 1997). Muscles can cause bone-loading forces up to 3 or 4 times body weight, thus increases in muscular strength can build up bone mass or prevent bone loss. After the age of 40, BMD declines at an accelerated rate (Riggs et al. 1981); therefore, it is crucial to build a peak bone mass before this rapid reduction and attempt to maintain bone mass later in life.

Typically, a high load, low repetition protocol is recommended for BMD maintenance. Heavy loads (70-85% 1 repetition maximum, 1RM) with low repetitions (6-12 repetitions for 1-3 sets) have been found to increase BMD (Marques et al. 2011, Balsamo et al. 2013, Gray et al. 2013). While this type of resistance training is widely accepted; it may not be a practical exercise prescription for several adult populations. Specifically, many women and older adults find the execution of resistance training programs at these recommended intensities to be outside of their physical capabilities (Niu et al. 2010). There has not yet been specific evidence on the effectiveness of a different protocol with low loads and high repetitions that could be adhered to more easily and by a larger percentage of the population.

Previous studies on exercise protocols using low loads (less than 70% 1RM) have shown conflicting evidence on whether this type of resistance training can increase BMD. Bemben et al. (2011) compared data from adults who completed a 40-week exercise intervention in either a high or low load resistance training group at either 2 or 3 days/ week. They determined that both high and low load resulted in similar increases BMD at the spine and trochanter. In contrast, Pruitt et al. (1995) studied the effect of high intensity versus low intensity resistance training (40% 1RM versus 80%1RM) on older women over the course of one year. They concluded that neither protocol increased BMD in the lumbar spine or the hip of their participants. In short, there is not yet a consensus on low-intensity, high repetition protocols with respect to improving or maintaining bone mass.

The total number of repetitions in prior protocols are 420-576 per session and the loads used are 40%1RM. [9,10] However, a participant in a single, 60-minute session of BODYPUMP™ (created by LES MILLS INTERNATIONAL) performs 800-1000 repetitions. This high number of repetitions in this class allows participants to use very low loads in comparison to previous trials. In fact, the average weight used in this class is 20% 1RM. Because of the focus on repetitions not the weights, this class is highly adhered to by women and older participants, as it is perceived as more achievable and less daunting than traditional strength training using higher loads with less repetitions. Therefore, we developed a randomized control protocol to answer the simple, yet unanswered question. Does this method of low load, high repetition resistance training minimize the development, maximize the prevention and optimize the management of BMD loss? We hypothesize that the low load, high repetition resistance exercises over a sustained period of time will increase BMD more than a core resistance training in untrained adults.

Materials and Methods

Twenty adults (48 ± 10 years old), 6 men and 14 women, completed the 27-week intervention. Of the 24 non-active adults we recruited, 20 individuals completed the protocol. All of the participants gave written informed consent that followed the guidelines of The Pennsylvania State University Institutional Review Board. The Clinical Research Center staff at The Pennsylvania State University completed a physical examination and risk stratification for each of the participants. In order to be included in this study, the participants had to be between the ages of 25 and 65 years without a regular schedule of planned physical activity (completing less than 30 minutes of exercise per week for the previous 6 months). Participants were excluded from this study if they had any of the following conditions: chest discomfort with exertion, unreasonable shortness of breath, symptoms of dizziness, fainting or blackouts, heart medication, asthma or other lung disease, burning or cramping sensations in lower legs with minimal physical exertion, prescription medications, pregnancy, diabetes, smoking, hypertension (blood pressure greater than 140/90 mmHg), or total blood cholesterol greater than 220 mg/dL.

Laboratory Measurements

Musculoskeletal and physiological data were recorded at baseline (Week 3) and final (Week 28) time points during the study. The university Clinical Research Center staff collected height, weight, blood pressure and body composition data. Body composition measurements, including bone density, fat mass, and lean muscle mass, were measured using a total-body scanner (GE Lunar iDXA, Madison, WI). Scan analysis was performed using GE Encore 11.10 software. The FITOLOGY studio staff completed the measures for peak oxygen consumption and isometric strength. Peak oxygen consumption was evaluated with a submaximal cycling test on a stationary bike. Finally, the participants completed a series of strength tests; a maximal number of push-ups in one-minute test, as well as deadlift and squat isometric strength tests. The isometric squats and deadlifts were tested using a dynamometer. Participants stood upright on the dynamometer with feet shoulder-width apart and arms fully extended. They were then instructed to perform three trials of a maximal effort test. The participants were verbally encouraged. The average of three trials was recorded for both squats and deadlifts

All data measurements and scans were completed by the same individuals for consistency. Prior analyses of the iDXA scans show regional coefficients of variation for BMD: 0.5% total body, 1.5% arms, 0.5% legs, and 1.6% trunk (Rothney et al. 2012). For body composition, the coefficient of variation for iDXA is 1.0% (2012).

Physical Fitness Program

This study was conducted as a randomized control trial (RCT). Participants were randomly assigned to one of two experimental groups: total body resistance strength training (S-WEIGHT) or our functional control group utilizing core strength training (S-CORE). Groups were matched for gender and age. The classes used in this intervention were Les Mills BODYPUMP™ (S-WEIGHT), BODYBALANCE/BODYFLOW™ (S-CORE), and RPM™ (both groups). BODYPUMP™ is a full body low-load, high repetition resistance training program, in which the participants used a bar and self-selected weights. BODYBALANCE/BODYFLOW™ is a combination of Pilates and yoga exercises with a focus on core strength, balance and mobility, in which the participants did not use any weights. RPM™ is an indoor cycling class that both experimental groups completed for cardiovascular endurance.

Before initiating the protocol, the participants attended 2 technique sessions to ensure proper form for weight lifting. The intervention began with a 3-week preliminary protocol to gradually increase the duration of physical activity in an effort to reduce the risk of injury. After the familiarization period, the participants completed 2, 12-week exercise blocks. For the first 12-week block, the participants completed 3 cycling classes and 2 strength classes (S-WEIGHT or S-CORE) per week. For the second 12-week block, participants completed 3 cycling classes and 3 strength classes (S-WEIGHT or S-CORE) per week.

For the S-WEIGHT group, participants used approximately 20% 1RM, which is well within the low load range. Participants were encouraged to increase the weight for the next class if the last 15 seconds of the track was not challenging. Each class is 60 minutes in duration, with 800-1000 repetitions per class. There are approximately 100 repetitions per track with a variety of different dynamic resistance training exercises including squats, chest press, dead lifts, clean and presses, dead rows, triceps extensions, biceps curls, lunges and push-ups.

We tracked attendance for each participant as a measure of adherence. In addition, for the S-WEIGHT group, we tracked the weight selections participants used for each class over the course of the intervention. Participants were encouraged every 3 weeks to evaluate their weight selections based upon their rate of perceived exertion and increase when appropriate.

The participants completed Les Mills instructed group fitness classes at FITOLOGY studio in State College, Pennsylvania. The participants were permitted to choose their own schedule, as long as the protocol criteria were met; FITOLOGY has 1-2 of the required classes on the schedule per day. The prescribed fitness classes were the participants' only form of physical activity, aside from daily living activities, during the intervention period.

All data were analyzed between baseline and final values using a two-way ANOVA (training, time). Significance level was defined as $p < 0.05$. In addition, a regression analysis was performed on BMD versus mean leg strength.

Results

There were no significant differences in age, weight and BMD between experimental groups at baseline. Ranges of participant characteristics for age, height, weight, fat percentage, lean mass percentage, and total BMD are displayed in Table 1. Three participants in the S-WEIGHT group and one participant in the S-CORE group were postmenopausal for the duration of this study. In addition, two of the participants had osteopenia (a t-score between -1 and -2.5). Adherence to the study (percentage of participants who completed the entire intervention) was 83.3%. Four participants did not complete the study. Adherence to the classes was 96.7% for S-WEIGHT and 93.8% for S-CORE.

Regional BMD increased significantly for the S-WEIGHT group during the course of this intervention, while regional BMD did not increase for the S-CORE group. Additionally, body fat percentage decreased and mean leg strength increased from baseline to final.

Table 1. Mean and standard deviation (SD) of age (years), height (cm), weight (kg), fat mass percentage (%), lean mass percentage (%) and BMD (g/cm^3) of both groups are depicted. There were no significant differences between experimental groups for the variables tested.

	Age (years)	Height (cm)	Weight (kg)	Fat Mass %	Lean Mass %	BMD (g/cm^3)
S-WEIGHT	48 (10)	168.3 (6.8)	83.1 (16.4)	39.9 (8.3)	60.2 (8.3)	1.158 (0.1)
S-CORE	48 (10)	165.8 (10.7)	83.9 (17.2)	41.6 (8.0)	58.4 (8.0)	1.244 (0.1)

Body Composition

Fat mass percentage decreased significantly for both experimental groups (S-WEIGHT $p<0.01$, S-CORE $p<0.05$), as shown in Figure 1. Lean tissue mass increased correspondingly, as body weight did not change significantly for either group. Final fat mass was less than baseline fat mass by 2.7% ($p<0.01$, $p<0.05$).

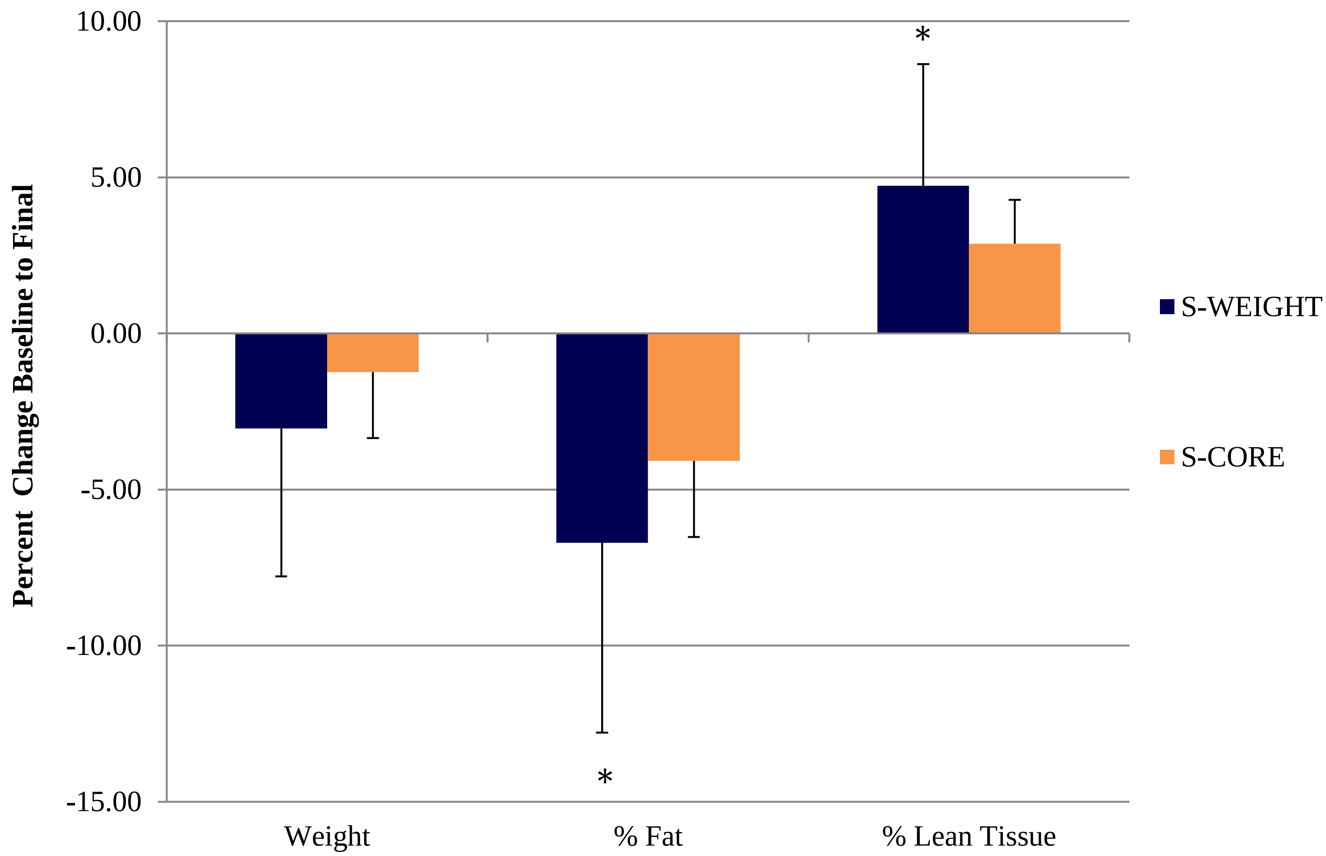

Figure 1. Mean percent change in weight, percent fat, percent lean tissue. While the changes in weight were not significant, there were significant decreases in percent fat and increases in percent lean tissue for both experimental groups (S-WEIGHT and S-CORE). Error bars represent standard deviation. Asterisk represents a significant change from baseline, not between groups.

Bone Mineral Density

Regional BMD increased significantly for the S-WEIGHT group (Figure 2). Arm BMD increased by 4% ($p<0.001$), leg BMD by 8% ($p<0.05$), pelvis BMD by 6% ($p<0.05$), and spine BMD by 4% ($p<0.05$). Individual changes in BMD for the S-WEIGHT group are shown in Figures 3. The S-CORE group BMD did not change significantly ($p>0.05$) for any region. Final total body (including all body regions) BMD was not significantly greater than baseline total BMD for both experimental groups. Head, ribs and trunk BMD did not change for either group.

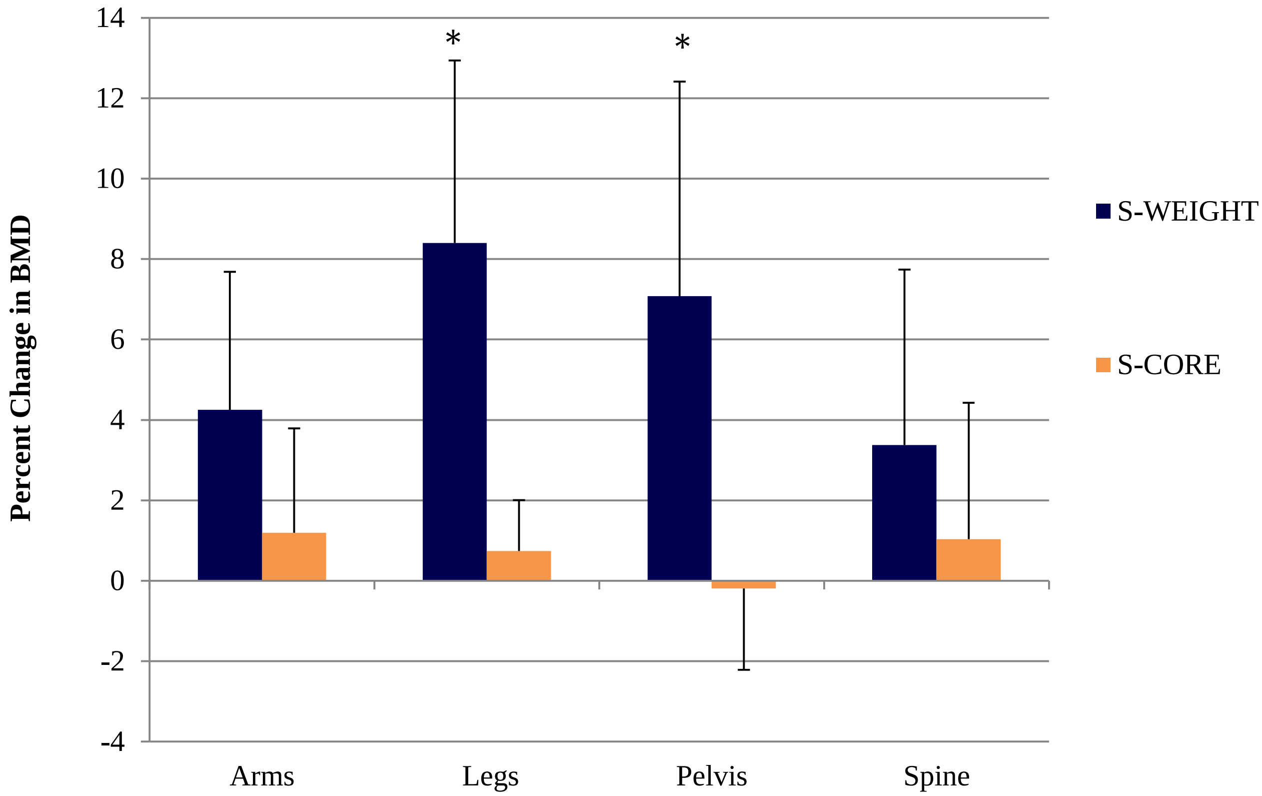

Figure 2. Percent change in regional BMD for each experimental group. Error bars represent standard deviation. Asterisk indicates a significant difference between the S-WEIGHT and S-CORE group ($p<0.05$).

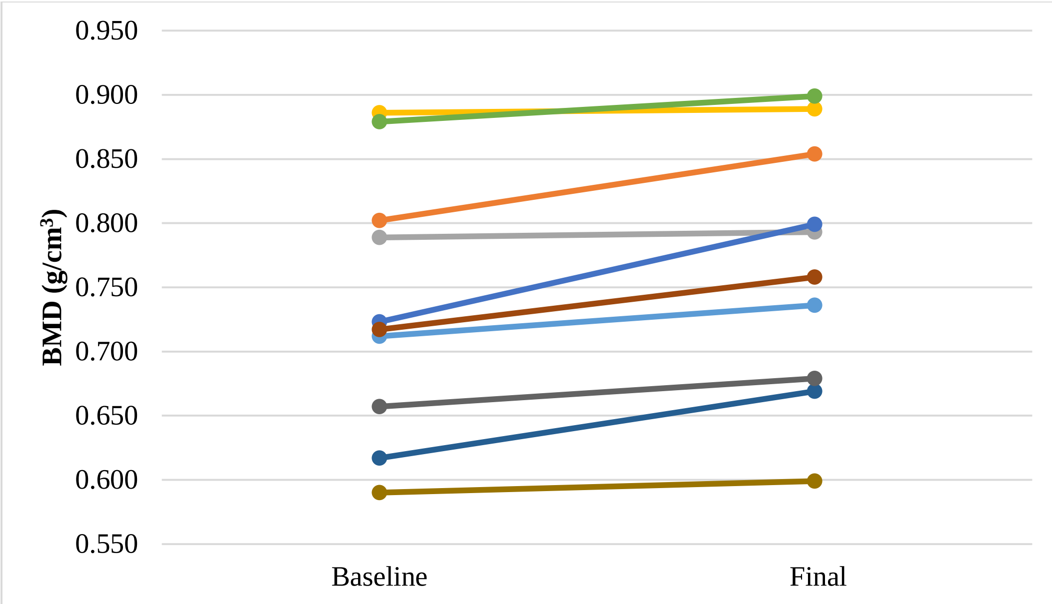

Figure 3. S-WEIGHT individual changes in arm BMD from baseline to final. Average increase in arm BMD was 0.0303 g/cm^3.

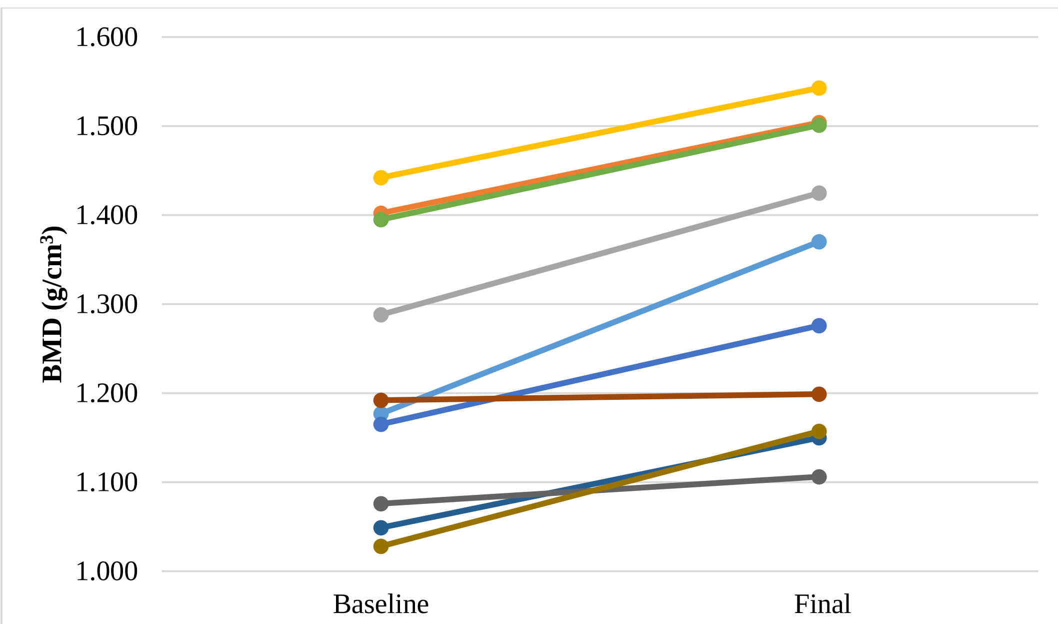

Figure 4. S-WEIGHT individual changes in leg BMD from baseline to final. Average increase in leg BMD was 0.102 g/cm^3.

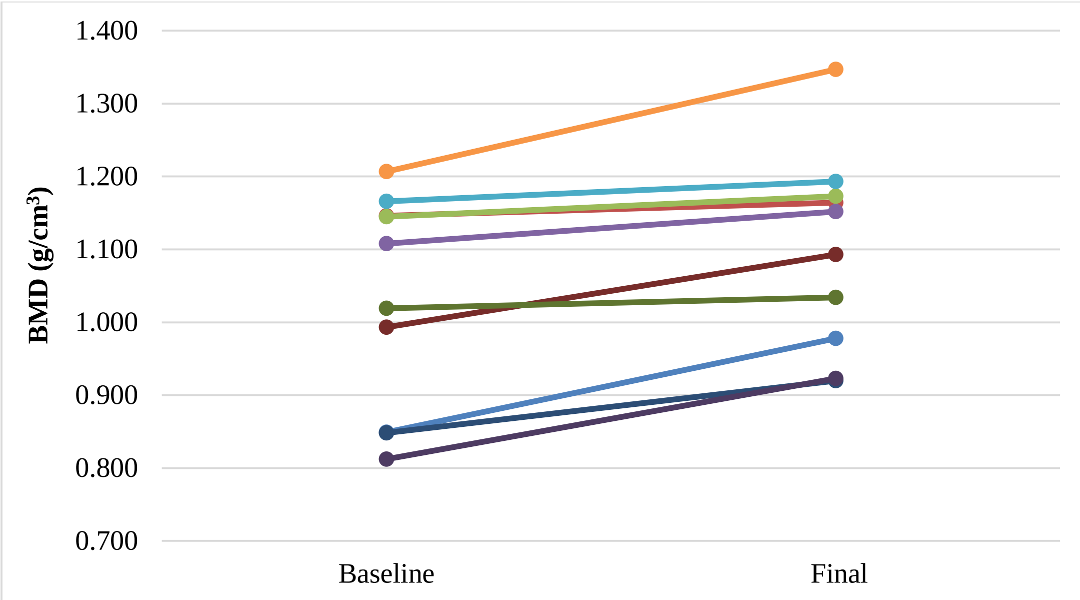

Figure 5. S-WEIGHT individual changes in pelvic BMD from baseline to final. Average increase in BMD at the pelvis was 0.684 g/cm^3.

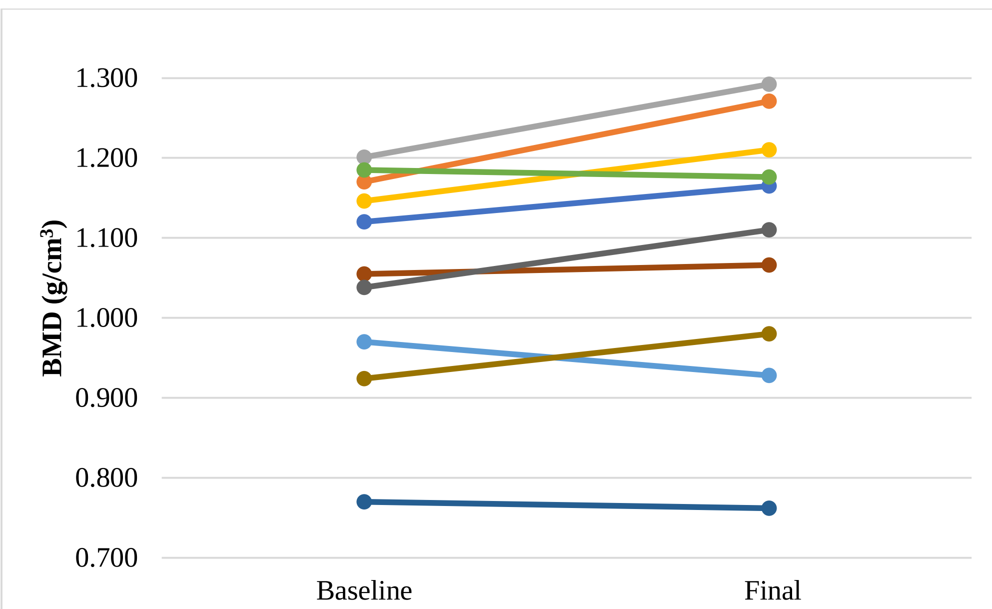

Figure 6. S-WEIGHT individual changes in spinal BMD from baseline to final. Average increase in BMD at the spine was 0.0381 g/cm^3.

Leg strength (squats) and back strength (deadlift) increased for both groups (Figure 4). However, changes in leg and back strength for S-WEIGHT were greater than for S-CORE by

25.3% and 18.4%, respectively ($p<0.01$, $p<0.05$). Arm strength increased significantly for both groups (S-WEIGHT $p<0.01$, S-CORE $p<0.01$). Using regression analysis, we determined that changes in leg strength were strongly correlated (0.5-1.0 R-squared value) with changes in pelvic BMD, as shown in Figure 5.

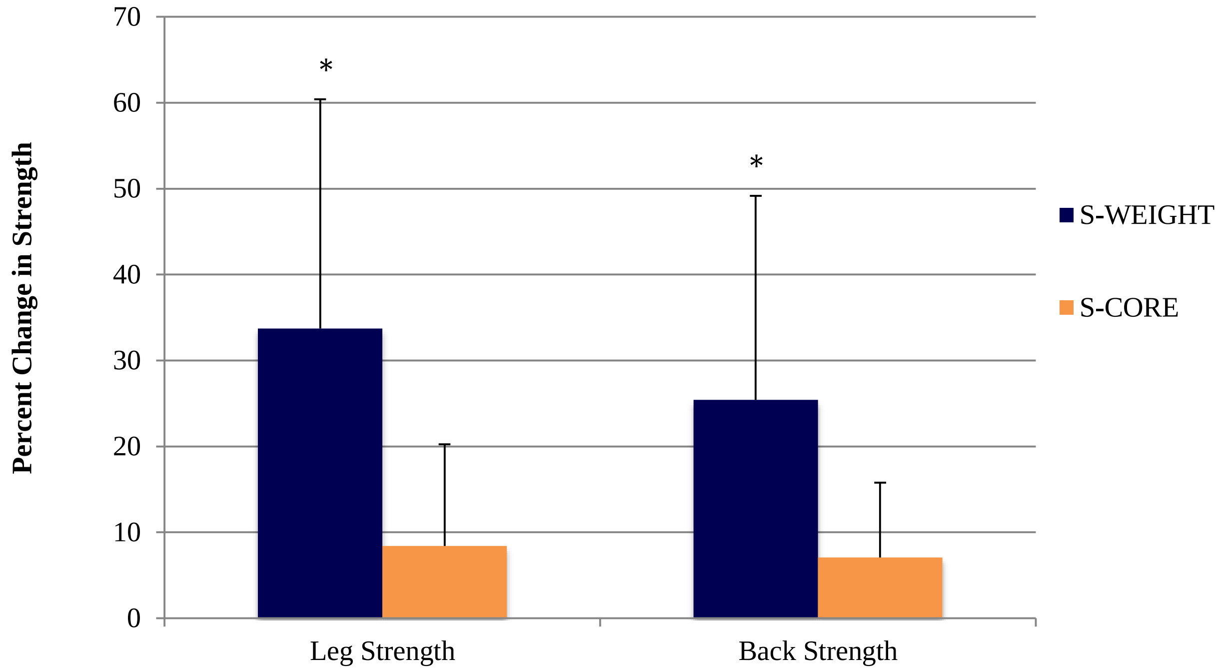

Figure 7. Percent change in leg and back strength for each experimental group. Error bars represent standard deviation. Asterisk indicates a significant difference between the S-WEIGHT and S-CORE group ($p<0.05$).

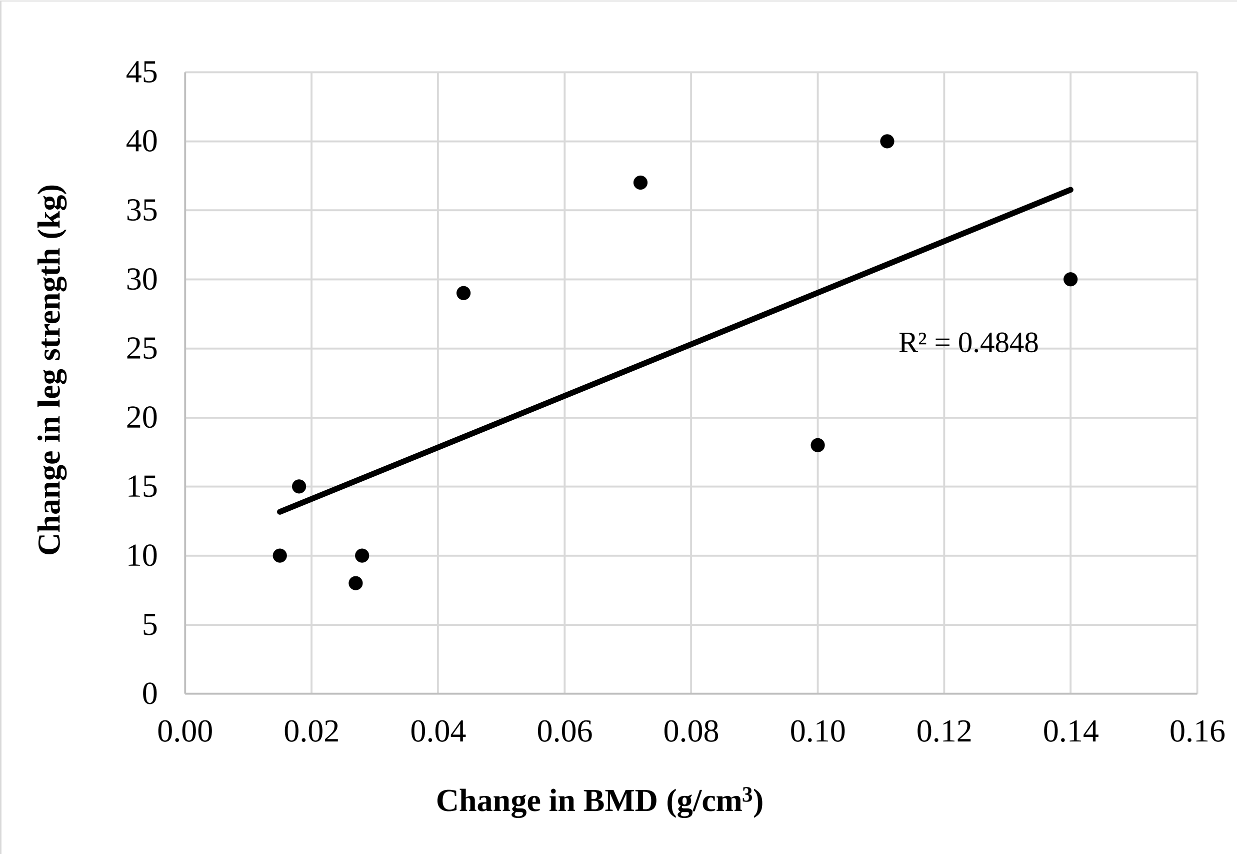

Figure 8. Percent change in pelvis BMD versus percent change in squat strength. The graph depicts a strong correlation between squat strength increases and BMD increases in the pelvis, with an R-squared value of 0.48 ($p<0.05$).

Discussion

Low load, high repetition resistance training increased BMD in the arms, legs, pelvis and spine. These findings indicate that this type of strength training may be an effective and maintainable method of increasing BMD in older and untrained populations.

Both groups improved body composition and muscular strength. The decreases in fat mass for both groups suggest that a combination of cardiovascular and strength training exercises benefits body composition. Similarly, leg, back and upper body strength increased significantly for both groups. Our regression analysis demonstrated that leg strength is a strongly correlated to improvements in BMD, suggesting that the larger gains in strength have larger bone forces and thus corresponding larger increases in BMD. Overall, the larger magnitudes of strength increases in the S-WEIGHT group suggest that, while both protocols (S-WEIGHT and S-CORE) may be beneficial, there were greater gains seen in the S-WEIGHT protocol.

Our BMD results differed from the findings of Pruitt et al. (1995). They found no BMD increases in either high or low-load resistance training, whereas we found BMD increases in our low-load experimental group (S-WEIGHT). However, the results by Pruitt et al. may be confounded by the varying participant characteristics. The significant differences in the results are more likely due to the differences in the design of the resistance training protocol. The low load protocol used by Pruitt et al. had a maximum of 42 repetitions (3 sets x 14 repetitions) per exercise type and used machine exercises, in either standing (3/10 exercises), seated (5/10), prone (1/10) or supine (1/10) positions. In contrast, our low load protocol used approximately 100 repetitions per track (e.g. 100 repetitions total for chest press and 100 repetitions total for squats) and none of the exercises were using machines, in order to focus on weight-bearing strength training.

Our findings were similar to the increased regional BMD found by Bemben et al. (2011). Both studies reported increased regional BMD at femur and lumbar spine. However, our protocol elicited much larger increases in BMD (0.5-1.8% for Bemben). We also saw increases in BMD at the pelvis and arms. These additional increases could again be due to differences in protocol. Bemben et al. had a 40-week study and utilized machine exercises for both resistance-training protocols, instead of the full body protocol used in this study. The full body protocol provides weight-bearing on bones with has been found to improve BMD. Thus, the effectiveness of protocols using machine weights, many of which are seated or supine, may not be practical for improvements in BMD. The low intensity (40%1RM) group had a maximum of 576 repetitions per bout of exercise, which is again significantly lower than our protocol's maximum repetitions. The differences in our results from previous studies may indicate that this full body resistance training program with higher repetitions is more effective at increasing BMD than traditional low load, high repetition resistance training programs with weight machines.

An increased BMD as a result of this program could effectively decrease the relative risk of an osteoporotic fracture. The BMD increases at the pelvis and legs are particularly important to fracture risk. The hip is the most common osteoporotic fracture in elderly adults (NIH Consensus Development Panel 2001). However, both men and women with high femoral neck bone mineral density have a lower incidence rate of hip fractures (De Laet et al. 1997). Thus, this program may be effective in decreasing the relative risk of hip fractures in older adults. Currently, the resistance training suggestions for increasing BMD in these older adults at risk are the high load training protocols, which may be unsafe for older adults to perform (Liu et al. 2010).

A key factor of the importance of this study is that the S-WEIGHT protocol (Les Mills BODYPUMP™) is a more feasible option than high load, low repetition intensity resistance training for the older and untrained adults. Since the participants were allowed to self-select their weights (approximately 20% 1 RM), it is likely participants could perform this protocol more easily than high load protocols, which use up to 80% 1RM (Ryan et al. 2004). Liu et al.

(2010) determined that older adults and untrained adults cannot perform or maintain the high intensity regimen. In this study, the loads were low and not considered maximal effort in accordance with previous studies. Because of the difference in magnitude of BMD changes from our findings to previous findings, BMD may have increased as a function of the type of exercise (full body instead of specific sites) and/or the number of repetitions used. Our protocol was intended to be a functional class (involving a bar and fully body exercises) that participants could take at local gyms so it is accessible to a larger percentage of the population. These factors could also affect adherence, as the adherence to protocols that were site specific or higher loads were significantly lower, 65%-81.0% for other studies (Pruitt et al. 1995, Marques et al. 2011).

Another factor that could affect these changes in BMD and adherence is the group nature of these classes. Both the S-WEIGHT and S-CORE classes were group exercise classes. Group cohesion coincides with greater satisfaction with the class, which leads to greater short and long-term adherence to the classes (Spink and Carron 1994, Estabrooks and Carron 1999, Fraser and Spink 2002). This could be another added benefit from a population perspective, as it will help participants adhere to the program for a period of time long enough to see increases in BMD (27 weeks in this study). BMD takes time to improve, thus long-term adherence is crucial to increasing BMD in exercise programs.

Two of the populations that would benefit most from an increase in BMD are osteopenic and postmenopausal populations. Both of these populations were present in our sample. Two participants (both in the S-WEIGHT group) had a t-score indicative of osteopenia ($-1 \leq t \leq -2.5$) and three women (2 in S-WEIGHT and 1 in S-CORE) were postmenopausal. While our sample of participants with osteopenia was too limited to evaluate statistically, the magnitude of the changes in BMD was much higher for participants with osteopenia than the rest of the group. For example, leg BMD increased by 29% for participants with osteopenia, which is much larger than the 8% increase for the whole group. Pelvis BMD increased by 29%, as well, for the osteopenic participants, but only 7% for the whole group. Similarly, the postmenopausal participants' BMD increases were much higher in magnitude for arms, legs, pelvis and spine BMD (+10%, +22%, +22%, +5%, respectively). A larger sample is necessary in order to investigate further in order to determine statistically significant results.

Future studies could include an investigation of the relationship between percent BMD change and osteopenia or postmenopausal status, as well as the effect on young adults. Studying adults with osteoporosis (t-score<-2.5) could help determine if this protocol could be used as a means of treatment for low bone mass. Conversely, studying young adults (approximate ages 18-30) could determine if this low-load, high repetition protocol can increase peak BMD. If a higher peak BMD can be maintained, there is a decreased risk of low bone mass later in life, therefore providing an alternative method for young adults to prevent osteopenia and osteoporosis later in life.

There were several limitations to this study. We did not have a large enough sample size to be able to adequately analyze differences in changes in BMD by age and gender. In order to detect these differences, we would need to have additional participants of each gender and age category within each intervention condition. Additionally, participants were permitted to self-select their weights. While they were encouraged to increase weight with time to maintain their percentage of their 1RM, it was not required for the intervention. Specifying weights for the participants to use could have controlled for possible effects of the different loads on BMD percent change. It also would have provided a standard weight to be considered low load for this protocol.

The results from this 27-week intervention suggest that this functional low load, high repetition resistance programs may be an effective method to increase BMD in older adults. The high adherence, low loads, and added health benefits of this program provides a more reasonable alternative to the standard high load, low repetition training.

CHAPTER 3: ALTERNATIVE METHODS OF HIGH INTENSITY INTERVAL TRAINING

Introduction

High intensity exercise lowers cardiovascular disease risk and can even reduce the risk of mortality by 22% in men and 31% in women (Paffenbarger Jr et al. 1993, Lee et al. 1995, Myers et al. 2002, Swain and Franklin 2006, Löllgen et al. 2009). High intensity interval training (HIIT) is a specific type of vigorous intensity exercise. HIIT is characterized by periods of high intensity exercise followed by periods of active recovery or rest (Laursen and Jenkins 2002). One session of HIIT lasts no more than 30 minutes (Laursen and Jenkins 2002). However, many studies show that as little as 15 minutes of HIIT per week has similar improvements in cardiorespiratory fitness to moderate intensity programs (Burgomaster et al. 2008, Gibala and McGee 2008, Kemmler et al. 2014, Giannaki et al. 2015).

Physical fitness consists of cardiovascular, musculoskeletal, and metabolic fitness, as well as body composition. One of the key indicators of improvements in cardiovascular fitness is a change in maximal oxygen consumption (VO_{2max}). Individuals with higher cardiorespiratory fitness have significantly lower risks of mortality (Blair et al. 1989, Farrell et al. 1998, Myers et al. 2002). Weight-bearing HIIT protocols have shown greater or similar increases in VO_{2max} versus traditional endurance training across several populations. For instance, in untrained adults, Nybo et al. (2010) studied the effects of equal volumes of HIIT running, prolonged running and strength training on VO_{2max} for 12 weeks. VO_{2max} increased significantly more in the HIIT group (+13.2%) versus the other two groups (+7.4% and +3.0%). In another volume-matched intervention with moderately trained adults, Helgerud et al. (2007) studied running at four different intensities (70% and 85% HR_{max}, as well as HIIT running at 90-95% HR_{max}) 3 days a week for 8 weeks to compare changes in VO_{2max}. High intensity interval running increased VO_{2max} more than the two endurance training interventions. Additionally, Gottschall et al. (2014) found that replacing just one 60-minute bout of moderate-intensity exercise with 2, 30-minute weight-bearing HIIT classes per week for 6 weeks in physically active participants significantly improves the cardiorespiratory, metabolic and musculoskeletal measures more than maintaining a moderate-intensity training program.

Low-volume HIIT can also elicit significant changes in VO_{2max} in comparison to endurance training. In a 6-week intervention in recreationally active adults, MacPherson et al. (2011) investigated the effects of either sprint interval running (6.75 hrs total) or endurance running (13.5 hrs total). Sprint interval training increased VO_{2max} by 11.5%, whereas endurance training increased VO_{2max} by 9.5%. The documented benefits of both low-volume and volume-matched weight-bearing HIIT are extensive.

The high impact nature of these HIIT sessions creates additional stress on joints, which restricts individuals with orthopedic limitations from participating in these exercises. Musculoskeletal pain affects a large percentage of the population; knee pain affects 25% of adults, shoulder pain affects 20% of adults, and over half of Americans will face low back pain in their lifetime. The stress on joints from high impact exercises, such as weight-bearing HIIT, can exacerbate joint pain. The increased joint loading of high impact activities can increase the risk of both knee pain and low back pain (Cooper and Coggon 1999, Vuori 2001, Robbins et al. 2011). Cycling is a low-impact form of exercise that does not exacerbate, but rather decreases knee pain at both high and low intensities (Mangione et al. 1999). Thus, a low-impact alternative, such as HIIT cycling, that has similar benefits to weight-bearing HIIT is an imperative option for these populations who want the added fitness benefits that are best obtained through HIIT (Laursen and Jenkins 2002).

Originally, HIIT programs were first performed on a cycle ergometer. Traditional low-volume HIIT cycling utilizes a series of repeated Wingate tests (10-30s of all-out effort followed by rest). While these protocols in trained adults have been evaluated, the practicality and application of these protocols is unclear. VO_{2max} increased by 5.5-9.3% depending on interval to rest ratios of the protocols (Bailey et al. 2009, Hazell et al. 2010, Astorino et al. 2012). Additionally, Burgomaster et al. studied the oxidative capacity and skeletal muscle adaptations in response to either low-volume repeated Wingate tests (1.5 hrs/wk) or endurance training (4.5 hrs/wk) using a cycle ergometer (Burgomaster et al. 2008). After 6 weeks, VO_{2max} increased by 7.3% for sprint training and 9.8% for endurance training. Both endurance training and low-volume sprint interval training elicited similar gains in skeletal muscle oxidative capacity, even with the large difference in volume of exercise. Therefore, low-volume HIIT cycling using repeated Wingate tests has the potential to stimulate significant changes in skeletal muscle and oxygen consumption similar to those of moderate-intensity training. While these protocols are efficient for highly trained individuals, they cannot be easily generalized to the rest of the population. In addition, the tight control of these studies allows for exact measurements in a laboratory, but confounds the application of the protocol to an exercise program in the community. The previous literature on HIIT lacks definitive evidence of the effects of a low-impact HIIT cycling protocol on the other components of physical fitness.

There is not yet a consensus on the effects of HIIT on other aspects of physical fitness. Specifically, previous studies on the metabolic effects of HIIT, both cycling and weight bearing, show conflicting results. In general, long term studies involving at least 6 weeks of HIIT have shown decreases in total cholesterol and LDL-C (Sandvei et al. 2012, Gottschall et al. 2014, Keating et al. 2014), while short terms studies have shown no changes in cholesterol (Babraj et al. 2009, Richards et al. 2010, Whyte et al. 2010). Similarly, many short studies determined that HIIT did not stimulate any significant changes in fasting blood glucose (Babraj et al. 2009, Richards et al. 2010, Whyte et al. 2010). However, 12 weeks of weight-bearing HIIT decreased fasting blood glucose by 8.8% (Nybo et al. 2010). Other studies reported metabolic changes in insulin sensitivity, but have not evaluated blood serum concentrations (Babraj et al. 2009, Richards et al. 2010). Likewise, body composition and musculoskeletal fitness changes with HIIT cycling are indecisive. While most studies show a decrease in body fat percentage, the magnitude of these changes range from 0.6% over 12 weeks to 11.2% over 15 weeks (Moreira et al. 2008, Trapp et al. 2008, Gillen et al. 2013). Many studies have evaluated the effects of HIIT on anaerobic power, however few have studied leg strength, specifically isometric leg strength. In summary, the effects HIIT cycling on metabolic fitness, body composition, and musculoskeletal fitness require further investigation. This study will evaluate these aspects of physical fitness in response to a practical, low-impact HIIT cycling intervention that can be implemented as an exercise program for a variety of populations.

A HIIT cycling program would provide a low-impact alternative to weight-bearing HIIT programs. This is particularly useful for populations with orthopedic limitations who cannot complete the typical HIIT programs because of the weight-bearing or plyometric exercises. This exercise program could potentially provide a low-impact alternative with the same physiological benefits as a typical HIIT protocol. We hypothesize that a 6-week intervention where trained individuals replace one 60-minute bout of cardiovascular training with two 30-minute bouts of HIIT cycling, can improve health and fitness more than maintaining their moderate-intensity cardiovascular exercise routine. More specifically, we expect to see an increase in peak oxygen consumption and leg strength, with accompanying decreases in blood pressure, triglycerides, cholesterol (total, HDL, and LDL), blood glucose, and body fat percentage.

Materials and Methods

Participants

We recruited 36 healthy, trained adults (41 ± 11 years). The participants were exceeding current physical fitness recommendations prior to the start of the study (Pollock et al. 1998). They were involved in regular cardiovascular activity more than 3 times per week for at least 60 minutes per bout of exercise. Additionally, participants all had experience cycling either outdoors or on a stationary bike in the last 3 months. All of the participants gave written informed consent that followed the guidelines of The Pennsylvania State University. Individuals with cardiovascular conditions, chronic medical conditions, or with cardiovascular risk factors were not included.

Data Measurements

We collected data at initial (Week 0) and final (Week 6) points of the study. The following physiological variables were measured: oxygen consumption, blood pressure, blood lipid profile, and fasting blood glucose. All data measurements and scans were completed by the same individuals for consistency. We conducted a submaximal oxygen consumption cycle ergometer test using the Astrand-Rhyming protocol. The participant warmed up for 10 minutes cycling at 60 rpm until their heart rate reached 130-160 bpm. They maintained their heart rate in this range for 6 minutes pedaling at 60 rpm, adjusting the wattage accordingly. We then calculated VO_{2peak} from the participants' final work rate wattages. Additionally, following a 12-hour food, alcohol and exercise fast, the following variables were measured with a finger prick blood draw: total cholesterol (TC), triglycerides (TRG), high density lipoprotein cholesterol (HDL-C), low density lipoprotein cholesterol (LDL-C), and fasting blood glucose. The blood sample was analyzed using a Cholestech LDX system. Previous studies have shown coefficients of variation less than 9% between and within measurement runs (Santee 2002).

Body composition variables was also measured at baseline and final: height, weight, fat mass, and lean mass. We used the BodPod to measure the participant's body composition. The BodPod is a dual chamber air displacement plethysmograph, Lean mass, fat mass, and fat percentage are determined through analyses of density. From prior studies, the calculated coefficient of variation of the BodPod was 0.8% body fat (Collins and McCarthy 2003).

Lastly, we measured musculoskeletal strength through a maximal leg strength test using a dynamometer. Participants stood upright on the dynamometer with feet shoulder-width apart, knees flexed to 110 degrees, and arms fully extended. They were then instructed to pull upwards with maximal effort on the chain attached to the platform. Verbal encouragement was given and participants performed three trials. The average and maximum readings were recorded.

Intervention

The participants were assigned to one of two groups: group HIIT or group FIT. Group HIIT participants replaced a single $\geq$ 60 minute cardiovascular training session with 2, 30-minute high intensity interval cycling sessions on 2 non-consecutive days. Group FIT participants served as controls and maintained their current physical fitness routine. Groups were matched for age, gender and physical activity level.

Group HIIT replaced one of their 60 minute training sessions with 2, 30-minute Les Mills RPM SPRINT™. SPRINT™ is an indoor cycling session, utilizing high intensity intervals accompanied by periods of rest. The total workload of one 30-minute class of SPRINT™ is similar to the total workload of a 60-minute moderate intensity class.

Statistics

We evaluated the differences between groups (baseline to final) and within groups (Group HIIT vs Group FIT) using a two-way, repeated measures ANOVA with a Tukey post-hoc test. Significance was defined at $p<0.05$.

Results

Six weeks of the HIIT intervention significantly improved all measured variables ($p<0.05$) except HDL cholesterol. Maximal oxygen consumption and leg strength increased significantly for the HIIT group, but not for the FIT group. There were significant decreases in the HIIT group for blood pressure, fat mass, fasting blood glucose, total cholesterol, triglycerides and LDL cholesterol.

Systolic blood pressure was significantly higher for Group HIIT than Group FIT at baseline (131 mmHg HIIT, 119 mmHg FIT; $p<0.05$). Other baseline measures did not vary significantly between groups. Means and standard deviations of participant characteristics for age, height weight, fat mass, and VO_{2peak} are displayed in Table 2.

Table 2. Participant Baseline Characteristics. Groups did not differ significantly in age, height, weight, fat mass and oxygen consumption. Measures are reported as mean (standard deviation).

	Age (yrs)	Height (m)	Weight (kg)	Fat Mass (kg)	VO_{2peak} (ml/kg/min)
Group FIT	41 (11)	1.71 (0.10)	73.18 (15.01)	42.65 (16.63)	39.37 (5.55)
Group HIIT	41 (11)	1.68 (0.09)	73.51 (16.39)	44.23 (23.98)	41.11 (4.50)

Oxygen Consumption (VO_{2peak})

Oxygen consumption increased significantly for the HIIT group from 41.1ml/kg/min to 45.1 ml/kg/min ($p<0.01$), a 9.7% increase from baseline to final. Figure 6 depicts changes in VO_{2peak}. Maximal oxygen consumption did not change significantly with group FIT.

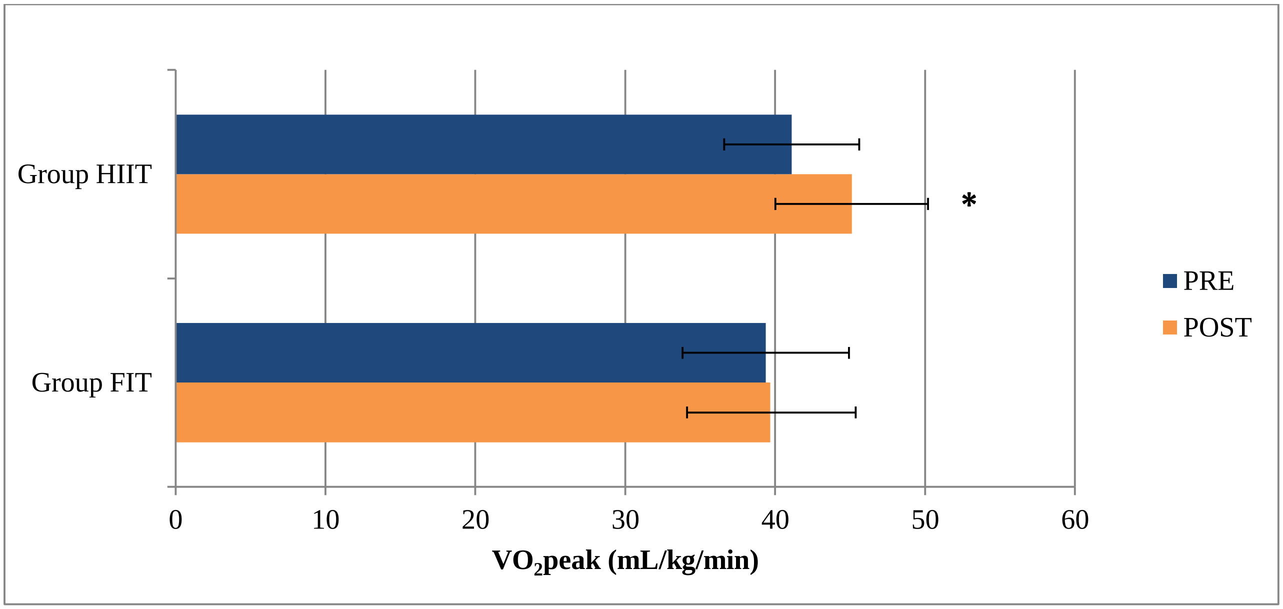

Figure 9. Peak Oxygen Consumption for Group FIT and Group HIIT. VO_{2peak} increased significantly for Group HIIT ($p<0.01$), but not Group FIT. Similarly, there was a significant difference between post-intervention VO_{2peak} for Group HIIT and Group FIT ($p<0.05$). (*= significant difference between pre- and post-intervention)

Musculoskeletal Fitness

Mean leg strength (the average of three trials) increased significantly by 11.9% for the HIIT group from baseline to final (9.0 kg, p<0.01, Figure 7). Group FIT showed no change in mean leg strength.

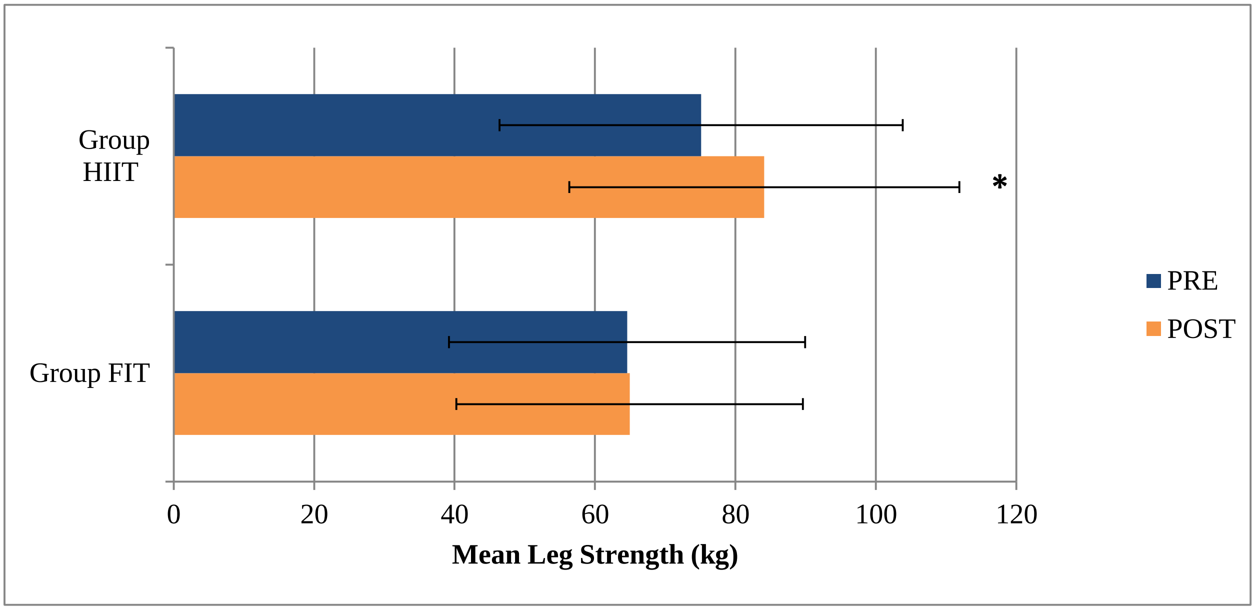

Figure 10. Changes in mean leg strength for Group HIIT and Group FIT. There were significant differences between pre- and post-intervention for Group HIIT (p<0.01), and the final measurements for Group HIIT were significantly larger than Group FIT (p<0.01). (*= significant difference between pre- and post-intervention)

Body Composition

Body fat percentage decreased significantly by 1.1% for the HIIT group (p<0.01) through the 6-week intervention. The FIT group body fat percentage did not change significantly from baseline to final (p<0.05). In addition, weight decreased significantly by 1.3% for the HIIT group (0.9 kg, p<0.01), but not for the FIT group.

Blood Profile

For the HIIT intervention group, all of the blood cholesterol concentrations (except HDL-C) and fasting blood glucose decreased significantly throughout the intervention (Figure 8). TC decreased by 11 mg/dL (6.0%, p<0.01), LDL-C decreased by 7 mg/dL (7.8%, p<0.05), TRG decreased by 17 mg/dL (16.3%, p<0.05), and glucose decreased by 7 mg/dL (7.0%, p<0.05).

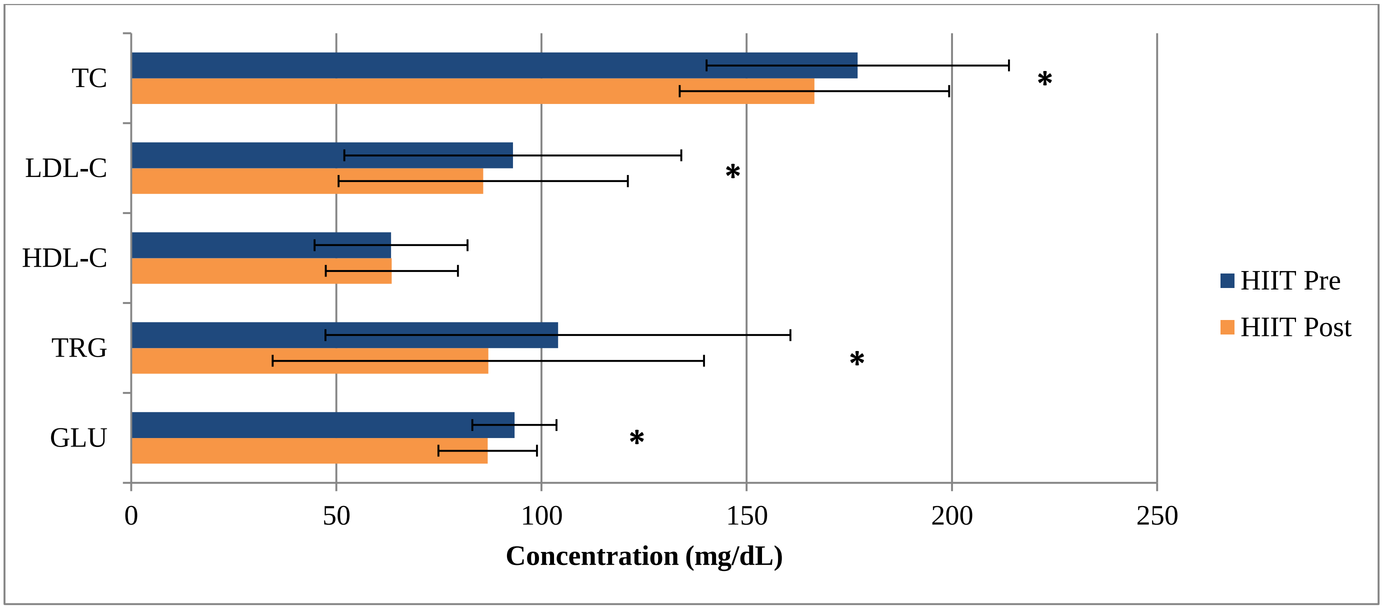

Figure 11. Blood panel profile measures pre- and post intervention. Total cholesterol (TC), low density lipoprotein cholesterol (LDL-C), triglycerides (TRG), and glucose (GLU), decreased significantly for Group HIIT from baseline to final. High density lipoprotein cholesterol (HDL-C) is the only variable that did not change for the HIIT intervention group. (*: significant change from baseline to final (p<0.05).

Blood pressure

Systolic and diastolic blood pressure were significantly less after training for Group HIIT. Systolic decreased by 11 mmHg (8.4%, p<0.01) and diastolic decreased by 8 mmHg

(9.9%, $p<0.01$). Blood pressure did not change significantly for Group FIT, nor did final values differ significantly between intervention groups.

Discussion

Adding high intensity interval training cycling to the routine of active adults improved cardiorespiratory fitness, strength, and metabolic fitness. Overall these results suggest that replacing one bout of moderate intensity exercise with two 30-minute bouts of HIIT is an effective way to increase physiological, metabolic and musculoskeletal health.

The substantial increase in peak oxygen consumption (9.7%) for the HIIT intervention falls above the ranges of previous data using repeated Wingate tests (5.5-7.3%) in trained adults (Burgomaster et al. 2008, Hazell et al. 2010, Astorino et al. 2012). Because of the differences in protocol, the larger increases in cardiorespiratory fitness seen in this study are particularly noteworthy. While both protocols use high intensity intervals, the Wingate tests are 10-30s of all-out effort, whereas this study uses high intensity intervals up to 120 seconds long. The longer intervals in this study likely contributed to the larger increases in VO_{2peak}. Studies with untrained adults had larger improvements in oxygen consumption than seen in this study. HIIT cycling increased VO_{2max} by 11.1% after 2 weeks, 15.2% after 12 weeks, and 23.8% after 15 weeks in untrained adults (Trapp et al. 2008, Heydari et al. 2013, Esfandiari et al. 2014). Based on previous literature and the results of this study, untrained individuals may attain larger gains in VO_{2max} with this protocol, without the added impact involved in weight-bearing HIIT.

In comparison to weight-bearing HIIT protocols, VO_{2max} gains were similar in this intervention. Studies with similar protocols, that replaced or added HIIT to previous physical activity regimens, found that VO_{2max} increased by 6.4-6.9% with HIIT versus 1.8-2.7% with maintaining their previous physical activity routine (Gottschall et al. 2014, Ouerghi et al. 2014). In recreationally active adults, weight-bearing HIIT increases of VO_{2max} between 4.9% and 10.3% (Macpherson et al. 2011, Sandvei et al. 2012). In summary, the improvements in cardiovascular fitness seen in this study most closely match the improvements in trained and recreationally active adults with either cycling or weight-bearing HIIT protocols.

Metabolic fitness improved substantially with HIIT cycling in the current study. The decreases in total cholesterol, triglycerides, and LDL-C confirm our hypothesis yet conflict with previous findings. Following 12-week interventions, no changes in any blood lipid concentrations were seen with either treadmill HIIT protocols in untrained adults (Thomas et al. 1984, Nybo et al. 2010). However, our results do seem to match the results of Ouerghi et al. (2014). After 12 weeks of HIIT training, TC decreased by 3 mg/dL, LDL-C decreased by 2 mg/dL, TRG by 7 mg/dL in trained male soccer players. However, these results were not statistically significant due to the small sample size (n=8 in each intervention). The decreases in triglycerides (17mg/dL) and LDL-C (7mg/dL) were similar to previous findings in 6-12 week studies (Sandvei et al. 2012, Gottschall et al. 2014, Keating et al. 2014). HDL-C concentrations did not change for our intervention, which mimics previous findings with HIIT interventions, both cycling and weight-bearing (Frey et al. 1982, Keating et al. 2014). These varying results are likely due to differences in type of HIIT (weight-bearing versus cycling) and the physical activity level of the participants. Additional studies on HIIT cycling in trained adults are necessary to confirm a pattern between these findings.

Another measure of metabolic fitness is fasting blood glucose, which decreased 7mg/dL in this intervention. This supported our hypothesis and confirms the effect, but not the magnitude of changes reported in previous long-term studies. Sandvei et al. (2012) found that 8 weeks of HIIT decreased fasting blood glucose by 3.8% in healthy, untrained adults. After 12 weeks of HIIT, Nybo et al. (2010) determined that HIIT decreased fasting blood glucose by 9.6%. However, these studies were with untrained adults. With trained adults, our results do not support the findings of studies over 2-3 weeks, in which HIIT did not change fasting blood glucose (Babraj et al. 2009, Richards et al. 2010, Whyte et al. 2010). These results suggest that longer HIIT cycling interventions and studies with untrained individuals have greater benefits for blood glucose control. Changes in fasting blood glucose may be a response to increased adrenaline associated with HIIT, which regulates glucose metabolism, as well as changes in body composition favoring higher post-exercise metabolism (Yoshioka et al. 2001, Trapp et al. 2007, Jensen et al. 2011).

In support of our hypothesis, body composition improved significantly with HIIT. Comparatively, decreases in body fat percentage in this study were more similar to results from treadmill HIIT studies than cycling HIIT studies. Body fat percentage decreased by 1.1% with HIIT in this study, previous studies in untrained adults found decreases in body fat percentage ranging from 0.6% after 12 weeks of HIIT to 11.2% after 15 weeks of HIIT (Moreira et al. 2008, Trapp et al. 2008, Gillen and Gibala 2013). While the literature with untrained adults shows improvements of varying magnitude in body composition, 2-3 weeks of HIIT cycling does not elicit significant changes in body fat with trained adults (Whyte et al. 2010, Astorino et al. 2012). For 6 weeks of a body weight HIIT intervention, however, body fat percentage decreased by 2.1% in 6 weeks in trained adults (Gottschall et al. 2014) and by 12.4% in 6 weeks in active, younger adults (Macpherson et al. 2011). The reduction in body fat percentage in this study follows the general trend of HIIT in trained adults over a period of 6 weeks. The lack of change with only 2-3 weeks seems to indicate that at least 6 weeks are necessary to achieve improvements in body composition. Thus, for best results with body composition and fasting blood glucose, a longer intervention may be more effective in trained adults.

The training sessions used in this study could function as an effective option for populations that cannot complete weight-bearing HIIT due to orthopedic pain and discomfort. Frequent knee pain affects 25% of adults, indicating that a large percentage of the population that have difficulty performing weight-bearing HIIT (Nguyen et al. 2011). Active adults with joint pain or orthopedic restrictions need an alternative low-impact HIIT in order to get the fitness benefits of a HIIT routine. This HIIT cycling protocol provides similar benefits to weight-bearing HIIT, without the high-impact or increased risk of injury. In fact, both high and low intensity cycling have been shown to reduce knee pain (Mangione et al. 1999). Additionally, the sessions used in this intervention were not performed in a strictly regulated laboratory and therefore can be completed by the general public.

There were several limitations to this study. While our goal was to evaluate a practical alternative that can be performed by a greater segment of the population, this allows less control over environmental and lifestyle factors. For example, we asked that the participants not change their diet, however we did not strictly measure their dietary intake over the 6 weeks. Additionally, for the HIIT classes, participants during classes were asked to follow the cadence of the instructor, we did not analyze the specific wattages for each participant. Future studies could investigate heart rate data on this protocol in order to determine the high intensity to recovery ratio that elicits the greatest improvements in physical fitness. In conclusion, these results suggest that replacing a bout of moderate-intensity exercise with 2-30 minute bouts of HIIT cycling bouts is an effective way to improve endurance, strength and cardiovascular health.

CHAPTER 4: CONCLUSION

The present study investigated the effects of alternative methods of resistance training and high intensity interval training. Both programs could be effective means of improving BMD and physical fitness for those who are not able to perform traditional resistance training or weight-bearing HIIT. Evaluating the benefits of training that can be performed by a larger segment of the population is particularly important with the current rates of physical inactivity. While many barriers to becoming active are present, many have limitations that may prevent them from performing the traditional types of training; in this case, resistance training and high intensity interval training. Therefore, alternatives for populations that cannot perform these traditional means of exercise should be investigated in hopes of eventually improving these activity rates.

Resistance training increases BMD in young adults and also slows the decline of BMD in middle-aged adults (Vuori 2001). The traditional means of improving BMD with resistance training is performing 8-10 exercises at least 2 times per week, using an 8-12 RM (~70-80% 1RM) (ACSM 1995, Brzycki 1995). While this high load, low repetition method increases BMD in adults, older adults and untrained adults report that the high loads used in these programs are outside of their physical capabilities (Niu et al. 2010). Thus, low load, high repetition resistance training that can increase BMD is critical. In this study, we found that, after 27 weeks of low load high repetition resistance training, BMD increased significantly in the arms, legs, spine and pelvis. These results suggest that this protocol may be an ideal alternative to high load, low intensity resistance training. One of the most important aspects of the protocol used in this study was that participants self-selected their weights (which in general were no more than 20%1RM). Because the loads used in this study were substantially lower than typical low load protocols

(40%1RM), the full-body nature of these classes and the high number of repetitions most likely attributed to the significant improvements in bone health. In general, participants are likely to see these low-load, high repetition protocols as less intimidating and a more feasible option to improving or maintaining BMD.

An additional type of training that has limitations for several populations is high intensity interval training (HIIT). Weight-bearing HIIT protocols have significant benefits over moderate-intensity protocols, however, the high impact nature of weight-bearing HIIT poses a problem for those with orthopedic limits. Knee pain affects one quarter of adults and lower back pain affects over half of the population (McBeth and Jones 2007, Nguyen et al. 2011). These, and other origins of musculoskeletal pain are worsened by the impact of weight-bearing HIIT on joints (Cooper and Coggon 1999, Vuori 2001, Robbins et al. 2011). HIIT cycling is a low-impact program that could serve as an alternative of boosting health and fitness. In this study, trained adults replaced one of their 60 minute cardiovascular bouts of exercise with 2, 30-minute bouts of HIIT cycling. After 6 weeks, peak oxygen consumption (VO_{2peak}), isometric leg strength, body fat percentage, blood serum lipids and fasting blood glucose improved significantly. These findings indicate that HIIT cycling for 6 weeks improves physical fitness more than maintaining a moderate-intensity exercise regimen. Thus, it appears that HIIT cycling is an effective alternative means of improving fitness without the added impact of traditional HIIT.

This study is unique in that the effects of HIIT cycling on trained adults in the past have exclusively used repeated Wingate tests. This study is the first to study a functional protocol in trained adults that can be implemented in fitness centers on a global scale. This protocol, unlike repeated Wingate tests, can be generalized to moderately trained and inactive adults. Additionally, this was one of the first studies to evaluate a broad spectrum of physical fitness effects as a result of HIIT cycling in this population. In conclusion, HIIT cycling may be an ideal low-impact method of improving physical fitness, in trained and untrained adults.

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