THESIS

FATIGUE RESISTANCE VS. FALL RESISTANCE: HIGH-INTENSITY INTERVAL TRAINING AND THE DISSOCIATION OF STAMINA AND STABILITY IN OLDER ADULTS

Submitted by

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In partial fulfillment of the requirements

For the Degree of Master of Science

Colorado State University

Fort Collins, Colorado

Fall 2016

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ABSTRACT

FATIGUE RESISTANCE VS. FALL RESISTANCE:
HIGH-INTENSITY INTERVAL TRAINING AND THE DISSOCIATION OF STAMINA AND STABILITY IN OLDER ADULTS

INTRODUCTION: The population of older adults (≥65 years) in the U.S. is growing, and this population faces unique health risks compared to young and middle aged adults. One of the primary health risks for older adults is falling, which is the leading cause of preventable death and injury within this population. Traditional exercise interventions have been effective in reducing fall risk but require significant time commitment. High-intensity interval training (HIIT) requires less time commitment than traditional exercise training and may be a viable alternative to reduce fall risk among older adults.

METHODS: 13 sedentary young (n=7, 4 female; age: 21±1 (mean ± SE)) and older (n=6, 2 female; age; 69±2) adults completed 9 sessions of HIIT over 3 weeks. Balance at rest and after a single bout of HIIT was measured via center-of-pressure (COP) measures, fatigue resistance via a time to exhaustion (TTE) test, maximal aerobic capacity (VO_{2max}) via indirect calorimetry and peak power output via Wingate test. All variables were assessed before and after training.

RESULTS: Short-term HIIT had no effect on balance at rest or following a single bout of HIIT. TTE was greater in both young (25.8±4.0 vs. 37.0±3.1 min) and older (31.5±3.9 vs. 54.0±8.8 min) adults after training ($p<0.05$). VO_{2max} was also greater after training (+1.8 ml/kg/min, $p<0.05$) in both groups. Peak power output during HIIT was greater after training in young ($p<0.001$) but not in older adults.

CONCLUSION: These data do not support HIIT as an effective intervention for reducing fall risk in older adults. Three weeks of HIIT improves fatigue resistance but not balance, indicating a dissociation between stamina and stability in young and older adults.

PREFACE

This document contains two chapters. The first chapter is a literature review. The second chapter is the manuscript for the project completed for this thesis, formatted as a journal article.

TABLE OF CONTENTS

CHAPTER I

LITERATURE REVIEW

The population of adults 65 years and older in the United States is growing. In 2012, there were 43.1 million adults 65 years and older in the U.S.[1]. This number is expected to nearly double by 2050, and by 2060, nearly one quarter of the population will be 65 years or older[1,2]. Of the many associated risks that accompany aging, one of the primary concerns is the increased fall risk. Falls account for 55% of injury-related deaths of those 65 years and older[3]. Additionally, falls are the leading cause of preventable injury, traumatic brain injury and hip fracture among older adults[4]. The direct medical costs of falls alone was $35 billion in 2012[5]. As the population of adults 65 years and older increases, so to do the rates of falls, associated injuries and deaths, all of which are accompanied by greater economic burden[5]. Despite this grim outlook it is possible to attenuate these expected increases, and to prevent falls in older adults. Participating in regular exercise is effective in the prevention of falls in older adults[6]. In addition to the cardiovascular and metabolic benefits, exercise lessens some of the main factors that contribute to the increased fall risk among older adults including balance deficit, neural degeneration, fatigability, sarcopenia and dynapenia[6]. The purpose of this review is to discuss some of the main factors that contribute to increased fall risk in older adults and present current findings regarding the implementation of exercise programs to impact these factors and for fall prevention.

Factors of increased fall risk in older adults

There are multiple factors that contribute to the increased fall risk and subsequent injuries in older adults[7]. These factors include cognitive and visual impairment, medication, neural degeneration and function, balance deficit, gait, fatigability, and loss of muscle mass, strength (the amount of force that can be generated) and power (force x velocity of contraction)[6–10]. Despite the importance of, and likely interaction between many of these factors in any given fall incident, not all can be favorably modified with exercise[6]. Since the focus of this review is the application of exercise to reduce fall risk, the factors that have been shown to improve with exercise will be emphasized. Principally, these factors are balance deficit, neural changes and degradation, fatigability, sarcopenia and dynapenia[6].

Balance, is a complex and integrative physiological act. Balance can be defined as "a multidimensional concept, referring to the ability of a person not to fall"[11]. Although this is a simplistic definition, the concept of balance includes stability and postural control. Stability is the ability of an individual to "maintain, achieve or restore a specific state of balance"[11] which is a dynamic physiological process. The physiological processes that contribute to stability allow for postural control, which is the whole-body manifestation of stability "during any posture or activity"[11]. Moving forward, the term balance will be used with the understanding that it is inclusive of both stability and postural control. Balance deficit, or poor balance, is one of the strongest contributors to fall risk and predictors of future falls among elderly individuals[12,13]. It is clear that balance, whether static (the body remaining in a single, stationary position), or dynamic (the body in motion) declines with adult aging.

Balance is inherently complex because it relies on the integration and proper functioning of multiple physiological systems and processes. These include vestibular and kinesthetic sense, cognition, sensorimotor integration, neural function, motor control, muscle force generation and movement strategies[11–16]. Of course, decrement in any one of these areas can contribute to balance deficit, although it is more likely a combination. The function of the vestibular system declines with age, leading to impaired balance and increased fall risk[17,18]. With aging, there is loss of hair cells within the semicircular canals as well as a reduction in the vestibular afferent and efferent neurons[19–21]. These changes decrease the sensitivity to changes in head position and limit the ability to integrate visual and vestibular sensation[17]. Kinesthetic sense, or proprioception is impaired in older adults[22]. This impairment limits the ability to determine spatial location of the body, which can vitiate the ability to maintain balance, or respond to perturbations in balance[22]. The age-related neural changes and degradation, and declines in motor control and muscle force generation will be discussed further in remaining sections.

Neural changes and degradation are well documented with aging. With increasing age, there is a small decrease in central and peripheral neuronal cell number, as well as a decline in motor unit number, nerve conduction velocity, myelin sheath quality, and neuromuscular junction integrity[23–26]. Together, these changes contribute to cognitive declines and reduced musculoskeletal strength, power and motor unit recruitment, all of which are associated with increased fall risk[6,27–31]. The integration of the motor and sensory systems are dependent upon higher-brain function, and cognition, especially under the circumstance of declining motor function as is common with adult aging[16,28,32]. Indeed, reduced executive function (cognition) as assessed by computerized cognitive testing predicted future fall risk in older adults who did not have any signs of overt or clinical cognitive decline[16,32].

As previously stated, the age-related neural changes and degradation also contribute to reduced musculoskeletal strength and power[30]. Muscle fiber innervation is reduced with the age-associated changes in motor unit size and number, and decreased neuron conduction velocity and firing rate[33]. Muscle innervation is also altered because of decreased neuromuscular junction integrity, which impairs the conduction of locomotive signals from the spinal cord to the motor neuron and muscle. These age-related changes contribute to muscle atrophy and can alter fiber type composition[29,33]. The impairments in neural signaling in conjunction with muscle atrophy[34] directly contribute to reduction in the force generating capacity of aged muscle which, in turn leads to reduction in muscle power.

The role of fatigability in the increased fall risk of older adults is controversial[9,10,35]. This controversy stems from disagreement within the current body of research regarding age-related differences in fatigability (or fatigue resistance) between young and older adults[10,36,37]. Compared to young adults, older adults may show greater skeletal muscle fatigue during repeated, rapid muscle contractions[37] but not during self-paced contractions[38]. During isometric contractions, older adults may fatigue less than young adults[36]. Together, these findings suggest that older adults may only be more fatigable than young adults during repeated, rapid muscular contractions. Possible reasons for these differing responses may be the increased proportion of type-I muscle fibers and greater metabolic efficiency in older adults[39]. Although there may be strong evidence to support the notion that older adults have greater fatigue resistance than young adults (see Kent-Braun, 2009 for review) it remains controversial as to whether increased age independently increases fatigability. However, muscle fatigue, independent of age reduces postural control and balance, and increases fall risk[9,10,40–43]. Following fatiguing activity, young and older adults show impaired kinematic responses to induced falls[9], greater postural sway and center of pressure movement[40,42,43] and worse performance of functional balance activities[10]. However, compared to young adults, older adults have a longer time to recovery following fatiguing activity[10,43]. In addition, compared to age-matched controls, older individuals with impaired balance or history of falling report higher perception of fatigue, reduced muscular endurance and longer time to recovery following exercise[44,45].

Sarcopenia and dynapenia are two related conditions that interact to play a role in the increased fall risk among older adults. Sarcopenia can be defined the age-related decline in muscle mass. Dynapenia, a term coined by Manini and Clark[46] is the age-related reduction in muscle function (strength and power) independent of changes in muscle mass[46]. Although reduced muscle mass (sarcopenia) has been associated with reductions in strength and power, and with increased fall risk[47,48], muscle strength compared to mass was a stronger predictor of performance in older adults, as assessed by repeated sit-to-stand tests[48]. Indeed, in older adults, reductions in muscle strength and power are largely independent of muscle mass[49,50]. These findings suggest that dynapenia may be a more important factor in fall risk than sarcopenia. For this reason, the relationships between muscle strength and power, and fall-risk will be further discussed.

Older adults typically have lower strength than young adults[49,51–53] and, independently, lower muscle strength predicts future falls. In addition, lower muscle strength predicted falls during an intentional slip-perturbation during walking[54] and, among older adults with a history of falling, muscle strength is lower than those without a history of falls[51]. Despite the strong relationship between, and the predictive capacity of muscle strength and fall risk, muscle power may be the best predictor of fall risk[51,53]. Similar to muscle strength, older adults have reduced muscle power compared to young adults[51–53]. Adults with a history of falls also have lower muscle power than those without a history of falling[51,55]. In addition, muscle power may decrease with age to a greater extent than muscle strength[53]. The greater decrease in muscle power compared to strength is due to multiple factors. Reductions in muscle strength directly contribute to reduced power. The neural contributions to reduced muscle strength and power were discussed earlier. Muscle strength (force) is affected by reduced muscle cross-sectional area, or muscle atrophy, which is well documented in adult aging. In muscle power, the reduction of muscle force is compounded by decreased fascicle length[56,57], number and size of type-II muscle fibers[39] and changes in tendon compliance[58–60]. Compared to muscle strength, decrements in muscle power have a stronger association with falls and number of falls among older adults[51,55].

The increased fall risk and associated morbidity and mortality in older adults is likely due to multiple factors and age-related decrements. Some of the factors that contribute to falls, including visual impairment and medication status cannot be favorably modified by exercise. However, exercise can influence other factors such as neural changes and degeneration, sense of balance, fatigability and dynapenia. The following section will address the efficacy of various exercise training paradigms on these factors contributing to fall risk in older adults.

Exercise as an intervention to reduce fall risk

The use of exercise as a preventative measure, and treatment for various diseases is well documented[61,62] (see Pedersen and Saltin, 2015 for full review). The beneficial effects of exercise have been connected to improving, or preventing psychiatric, neurological, metabolic and cardiopulmonary diseases[61,62]. The clinical benefits of exercise are paralleled by improvements in aerobic capacity, muscle strength and power, fatigability and bone health. These benefits have been shown in both young and older populations. Exercise is also recognized and recommended for the prevention of falls and reduction of fall risk[13,62]. The following section will discuss the effects of various exercise interventions on the aforementioned factors (balance deficit, neural changes and degradation, fatigability, sarcopenia and dynapenia) that contribute to increased fall risk in older adults.

Exercise improves balance in older adults[6,13]. These improvements occur following both resistance and endurance training. Although the focus of this review is on traditional exercise programs, it is important to note that programs that focus specifically on balance and flexibility training are also effective in improving balance[6]. 12 weeks of combined resistance training classes and unsupervised at-home exercises using resistance bands significantly improved measures of static (time of posture hold) and dynamic (walking backwards along a line) balance in older adults.[63] Longer term interventions using more traditional weight-lifting are similarly effective, as 25 weeks of training, with a progressive increase from 50-85% of one-repetition maximum (1-RM) during training, significantly reduced postural sway in older women[64]. In agreement, 12 weeks of resistance exercise and stretching significantly improved balance (one-leg posture hold) in older adults, and the improvements were enhanced with subsequent endurance exercise (30-50 min at 60-85% HR_{max}) over one year[65]. Finally, a high-velocity resistance (power) training study in which participants were assigned to either control, or one of three training groups (low 20%, medium 50% or high 80% 1-RM) showed improvements in balance, as assessed by sway area, following each of the various exercise interventions[66]. Three months of either walking, bicycling, or aerobic movement improved functional balance (walking on balance bean, standing on a tilt table) in older adults[67]. However, in the same study there were no improvements in balance as assessed by force plate measurement of sway area.[67] When the effects of a resistance (75% 1-RM), endurance (60-70% HR_{max} for 45 min) and combination training program were compared, all groups improved equally well on measures of functional balance (AAPHERD)[68]. Another combination program improved performance oriented mobility index (POMI, postural holds and dynamic tests) and reduced fall rates in older men[69]. Overall, both resistance (including high-velocity repetition, or power) and endurance training have positive effects on balance and other measures of fall risk and should be combined in the development of exercise programs[68,70]. It is important to note though, that dynamic balance requires greater neural and muscular function and recruitment, and potentially greater demand on sensory function and integration than static balance. As such, measures of static and dynamic are not necessarily equitable or affected similarly.

Exercise can reduce and improve the neural changes and degradation that contribute to increased fall risk in older adults. As stated previously, cognition, motor control and sensorimotor integration are all negatively affected with age. Both endurance and resistance training can improve these age-related declines[71–74]. Compared to endurance exercise, resistance (or strength) training appears to have the greatest effect on motor unit recruitment, control, activation and neuromuscular junction integrity[30,31,75,76]. Resistance training programs of varying duration (10 -26 weeks) and intensity (50-85% 1-RM) significantly increased voluntary neuromuscular electrical activity in older adults[31,77,78]. These increases are indicative of improved motor neuron firing and subsequent muscle activation resulting from improved neuron quality and function. Additionally, resistance exercise appears to improve the integrity of the neuromuscular junction, allowing for better muscle recruitment and excitation contraction coupling[75,76]. However, these findings are limited to animal studies and may not directly mirror human responses. Finally, resistance training was able to increase time to neuromuscular fatigue as assessed by electromyography[79].

Sensorimotor integration and cognition are affected by both resistance and endurance exercise[73,74,80,81]. Meta analyses, and systematic reviews all reveal similar results and consistency across the literature[73,80–82]. First, endurance exercise of varying duration and intensity improved cognition and executive function among older adults – a finding that remains consistent when analyzing resistance exercise. Second, these reviews reveal that improvements are not dependent on baseline cognitive ability. Third, lifelong exercisers had better cognition than those who did not exercise. Potential explanations for the improvements in, and maintenance of, cognition following exercise include increased brain volume, potentially through brain-derived neurotropic factor activity, and greater cerebral blood flow, for which the reasons are not clear[72,83–85].

Improving fatigue resistance, or reducing fatigability in older adults can help to limit the contribution of muscular fatigue to fall risk in older adults. Both resistance and endurance exercise can improve fatigue resistance and/or muscular endurance in older adults. Resistance training, with intensities ranging from 50-80% 1-RM, has been shown to improve walking endurance at 80% aerobic capacity, decrease fatigue index during leg extension, and increase the number of repetitions to exhaustion at 60% 1-RM in older adults (>60 years old)[86–88]. Similarly, endurance training (30-50 min/day at 70-85% HR_{max}) for one year increased fatigue resistance 25% in 60-72 year olds[65]. Longer training sessions (1hr) using 5 minute intervals of higher-intensity exercise (85% HR_{max}) also reduced fatigue in older adults[89]. Combining endurance and resistance training also improves muscular endurance in older adults[69] and may do so to a greater extent than endurance, or resistance exercise alone[67,68].

The effects of various exercise modalities on sarcopenia and dynapenia are well documented. As stated previously, independent of muscle mass, muscle strength and power are greater predictors of falls in older adults. In lieu of this, the focus of this section will be strength and power as outcomes rather than muscle mass. Many studies have shown that resistance, or strength training leads to improvements in both muscle strength and power[66,86,88,90–94]. The exercise programs in these studies ranged in time (2 sessions/wk for 8 weeks to 4 sessions/wk for 1 year) and intensity (20-80% 1-RM). Despite these ranges, all of the training programs improved muscle strength, and power (when measured). Because power is the strongest predictor of fall risk, determination of the most effective type and load of resistance training to increase power in older adults is important. In one study, it was found that regardless of total workload (20, 50 or 80% 1-RM), so long as participants did the exercise with high speed, there were similar improvements in muscle power between the groups after the 8-12 weeks of training[92]. However, they did find a dose dependent relationship with the training load and muscle strength and endurance[92]. Similarly, following a targeted power training regimen in older adults, all groups had improved power, strength and muscular endurance[66].

Endurance training alone is known to have beneficial cardiovascular and metabolic benefits for both young and older adults[61]. However, the effects of endurance training on strength and power among older adults are not well documented. In one study that compared the effects of endurance and resistance training, 12 weeks of endurance training (60-70% HR_{max} for 45 min) equally improved muscle strength compared to a resistance training group[68]. Similarly, a high-intensity endurance training program (5 min intervals at 85% HR_{max} for 1 hr) significantly increased power output in older males[89].

A combination of resistance and endurance exercise is recommended for individuals of all ages for health and fitness[62]. Two different 12-week combination exercise programs consisting of: 1) endurance 60-70% HR_{max} for 45 min and resistance 75% 5-RM[68], or 2) 15min of endurance activity and resistance of ankle weights and resistance bands[69] significantly improved muscular strength in older adults. In addition, the combination programs improved functional measures (POMI, AAPHERD) of balance and physical function[68,69]. However, a combination training program (endurance 20min at 75% heart-rate reserve; resistance 75% 1-RM) found that a combination training program increased strength only slightly in older males and females[67].

In summary, the beneficial effects of exercise are clear and hold significance for preventing and treating psychiatric, neurological, metabolic and cardiopulmonary diseases[61]. Beyond the clinical impact, exercise can effectively attenuate the influence of factors that contribute to increased fall risk with aging[6]. Despite the benefits of exercise, many Americans do not engage in, or reach the recommended amount of, physical activity. This holds true for older adults as well, who commonly cite time commitment as a barrier to engaging in regular exercise[95]. One potential way to address this perceived barrier is to employ an exercise program that may yield similar benefits to traditional resistance and endurance exercise, but is not as time consuming. High-intensity interval training (HIIT) is one such exercise program, and the following section will discuss the benefits of HIIT and its potential utility as an intervention for older adults to reduce fall risk.

High-intensity interval training (HIIT); potential benefits and utility for older adults

High-intensity interval training is a type to training during which short periods of high-intensity exercise are repeated and separated by periods of low-intensity recovery. HIIT has become a popular alternative to traditional resistance or endurance training paradigms. One of the main reasons for this is that HIIT requires less time commitment than the traditional exercise programs. Additionally, the current literature suggests that power output is the strongest predictor of falls in older adults and power training has the greatest impact on factors related to fall risk in older adults[51,55,66,96,97]. Sprint-interval training is a type of HIIT in which the high-intensity intervals are maximal effort sprints, may be especially relevant for older adults due to the requirement of, and increases in power output[98]. Finally, HIIT has been shown to yield beneficial exercise performance and cardiometabolic adaptations[99,100].

The effects of HIIT have been well-described in young adults. Six sessions of HIIT (4-7 x 30 second sprints) over two weeks improved both muscular endurance and muscle metabolic capacity in young adults[98]. Similarly, six training sessions over two weeks of either 10 or 30 second intervals significantly improved aerobic capacity and power output[101]. In direct comparison between endurance training and HIIT, six sessions of HIIT (4-6 x 30 second sprints) yielded similar performance and metabolic benefits to endurance training (90-120min at 65%VO_{2peak}) despite a total time commitment of 2.5 hours versus 10.5 hours[100]. However, despite the growing body of research documenting the benefits of HIIT in young adults, fewer studies have focused on using HIIT as an intervention in older adults.

One potential reason for the smaller body of literature regarding older adults and HIIT may relate to safety concerns for older adults. Although this is a valid concern, HIIT studies have been conducted in apparently-healthy older adults. On an acute basis, one session of HIIT (10 x 1min sprints at 95% HR_{max}) was well tolerated and increased muscle protein synthesis in sedentary older men.[102] Over a longer-term, older adults who were either regular exercisers or sedentary, one session of HIIT (6 x 30 sec sprints at 40% peak power) every five days for six weeks significantly improved aerobic capacity and health-related quality of life (HRQL questionnaire)[103]. Among older adults who have been active throughout the lifetime, sprint training (or HIIT) is considered doable, feasible, and provided similar health benefits to those who participated in endurance activity[104]. Finally, studies discussed earlier within this review have shown that older adults can tolerate higher-intensity endurance, power and resistance training which, in combination with the HIIT specific studies, suggests that older adults who are able can participate in, and will benefit from HIIT paradigms[66,89,96].

One area that has received relatively little attention is the potential utility of HIIT to reduce fall risk and improve balance among older adults. A high-velocity resistance (power) training[105] protocol (discussed earlier) did reduce postural sway, but the benefits of the training modality, using weights at high speeds may not be mirrored through HIIT training (i.e. repeated 30 sec maximal sprints). One study did compare the acute effects of a single session of HIIT (4 x 4 min at 90% HR_{max}) to time matched walking on balance in young and older adults[43]. Balance impairments, assessed through postural sway were found in both young and older adults up to ten minutes after the exercise[43]. For young adults, this balance impairment was only apparent during a single-leg posture hold. In comparison, the impaired balance was greater in older adults during the one-leg posture, and was also present during a two-leg posture hold. Finally, the single-leg balance following the HIIT returned to baseline levels for both young and older groups after ten minutes. Older adults needed up to 30 minutes to return to baseline levels for the two-leg posture hold. These results suggest that HIIT may not be a viable alternative to traditional exercise programs to reduce fall risk. The authors suggest that because of the extended time of impaired balance following the HIIT session in older adults, the argument for the utility of HIIT as a time-effective exercise paradigm may be moot.

However, the study included only a single session of HIIT and no training. Previous HIIT paradigms have increased power output and fatigue resistance[98,106]; two factors associated with fall risk. In order to fully determine whether HIIT is viable for reducing fall risk, future research must include a training paradigm to determine whether HIIT training can improve baseline balance as well as reduce the balance impairment following a HIIT session.

Conclusion

The population of the United States is aging, and the proportion of individuals 65 years and older is growing[1,2]. The risk of falling in older adults is high; it is the leading cause of preventable injury within this population[4]. Together, the growing population of older adults and the high fall risk pose a significant economic and healthcare burden. In addition, the risk and prevalence of falling is expected to grow with the population, further adding to these burdens and highlighting the need for the development of effective interventions to reduce fall risk in older adults.

Exercise is a viable and effective tool in the prevention or falls, as it can lower fall risk and lessen some of the main contributors to fall risk in older adults including balance deficit, neural decline and degeneration, fatigability, sarcopenia and dynapenia[6]. Despite these benefits, and the importance of reducing fall risk, many older adults do not engage in exercise or adequate physical activity, citing time commitment as a main barrier[95]. High-intensity interval training is less time consuming than traditional exercise and has been shown to yield similar benefits to traditional exercise programs in younger adults. However, few studies have employed HIIT as an exercise program to decrease fall risk in older adults. This clear gap in the literature must be addressed as it may provide a preferable and viable alternative to traditional exercise programs for fall prevention and risk reduction in the aging population. In summary, the smaller time-commitment, and potential benefits of HIIT for improving factors associated with balance and fall-risk underscore the importance of pursuing HIIT as an exercise program for older adults. Future research should employ a HIIT protocol to determine whether HIIT is an effective intervention for improving balance in older adults.

Hypothesis

High-intensity interval training in older adults will improve balance both at rest, and following a single session of HIIT, and will increase peak power output and fatigue resistance.

Specific aims

1. To quantify and compare, the influence of acute and short-term high-intensity interval training on balance in young and older adults, as assessed by postural sway and center-of-pressure path length, at rest and following exercise.
2. To quantify and compare the influence of short-term high-intensity interval training on power output and fatigue resistance; two factors that are associated with poor balance and increased fall risk, in young and older adults.

CHAPTER II

FATIGUE RESISTANCE VS. FALL RESISTANCE: HIGH-INTENSITY INTERVAL TRAINING AND THE DISSOCIATION OF STAMINA AND STABILITY IN OLDER ADULTS

INTRODUCTION

The population of the United States is aging[1]. By 2050, the number of adults 65 years and older is expected to double, and by 2060 nearly one-quarter of the population will be 65 years or older[2]. One of the greatest health-risks for older adults is falling, which accounts for 55% of injury related deaths and is the leading cause of preventable injury[3,4]. One in three older adults fall each year[4], an incidence rate that is expected to increase with the growing population of older adults[5].

The etiology of increased fall risk among older adults includes both extrinsic and intrinsic factors[107]. Extrinsic factors include: the environment (e.g. unstable surfaces) and medication use[108] whereas intrinsic factors include: balance deficit, cognitive and visual impairment, neural degeneration and function, gait, fatigability, and loss of muscle mass, strength and power[6–10,108]. Since all of these factors interact and contribute to increased fall risk, interventions to reduce fall risk in older adults must address multiple factors[6,13]. Exercise has proven to be one effective intervention for reducing fall risk as it favorably modifies adult-aging associated balance deficit, neural degeneration and impaired function, muscular fatigue, sarcopenia and dynapenia[6].

Resistance, endurance, combination (of resistance and endurance), and power training of varying durations and intensities have been found to improve balance, as assessed by postural sway and functional tests, and reduce fall risk among older adults[6,63,67–69,105]. Similarly, varying exercise interventions lead to reductions in neural degeneration and improvement in neural function[72,79–81,83], decreased fatigability [65,68,69,86–88,109], and greater muscle strength and power [66,68,89,91].

For older adults, the benefits of exercise for reducing fall risk are clear. However, like many Americans, older adults do not engage in regular physical activity. One of the primary barriers cited by older adults as a reason that they do not exercise is the attendant time commitment[95]. Employing an exercise program that is not as time consuming as traditional exercise programs, like high-intensity interval training (HIIT), may help to address this barrier and reduce fall-risk among participating older adults. Additionally, because peak power output is the strongest predictor of fall-risk among older adults, power training (like HIIT) may be especially relevant as an intervention to reduce fall risk[51,55,96,97,105].

In young adults, HIIT has been found to increase muscular endurance (fatigue resistance), peak power output and aerobic capacity, and yield similar metabolic benefits to endurance training[99–101]. Among older adults, one session of HIIT every five days over six weeks improved aerobic capacity and health-related quality of life[103]. Despite the apparent benefits of HIIT, the utility of HIIT as an intervention to reduce fall risk among older adults has not received much attention. One study that employed a single session of HIIT (four, four minute sprints at 90% HR_{max}) found that balance was impaired up to 30 minutes after the exercise in older adults[43]. However, this study only included a single bout of HIIT and no training. In order to appropriately assess whether HIIT may be an effective alternative to traditional exercise training for the reduction of fall risk among older adults, a HIIT paradigm must be used.

The purpose of the present study was to quantify the influence of short-term high-intensity interval training in older adults on measures associated with fall risk including: balance (both at rest and following a single session of HIIT), peak power output and fatigue resistance. It was hypothesized that high-intensity interval training in older adults would: improve balance both at rest, and following a single session of HIIT, increase peak power output and increase fatigue resistance.

METHODS

This study was completed in accordance with the declaration of Helsinki; all procedures were approved by the Institutional Review Board at Colorado State University. All participants received explanation of the purpose, risks and procedures of the study before written consent was obtained.

Participants

Sedentary adults from the local community were invited to participate in this study. Inclusion criteria included: age range 18-30 or 65-80 years, and willingness to perform vigorous exercise. Exclusion criteria included: being physically active (≥30 min/day of moderate to vigorous activity, ≥3 days/week), habitual tobacco use, pregnancy or nursing, overt disease and contraindications to exercise identified by a physician. Following review of a medical history, all participants completed a physician-supervised cardiac stress test to ensure safety during the training program.

Study design

This study was conducted over 15 visits to the Human Performance/Clinical Research Laboratory at Colorado State University (outlined in Figure 1). Each visit was separated by 24-48 hours. The initial visit included completion of a medical history form, body composition measures and a cardiac stress test. Visit 2 was the initial assessment of maximal aerobic capacity (VO_{2max}). Visit 3 was a familiarization for the time to exhaustion (TTE) test to be completed on visit 4. Visit 5 was the initial assessment of balance and initial day of HIIT. Visits 6-12 were the days when only HIIT was conducted. Visit 13 was a repetition of Visit 5, where balance and power output were re-assessed. Visit 14 was the post-training TTE test and Visit 15 included a reassessment of VO_{2max} and body composition.

Visit	1	2	3 + 4	5	6-12	13	14	15
	Med. Hist. Body Comp. Stress Test	VO_{2max}	TTE	Balance 4 Sprints Balance	HIIT	Balance 4 Sprints Balance	TTE	Body Comp. VO_{2max}

Visit	6	7	8	9	10	11	12
# of Sprints	5	6	6	7	7	8	9

Figure 1. Schematic overview of study design.

Anthropometric measurements

Height, weight and body mass index (BMI) were recorded for all participants using an electronic scale and stadiometer. Body composition was assessed using dual-energy x-ray absorptiometry (DEXA; Discovery QDR; Hologic, Inc., Bedford, MA, USA).

Cardiovascular measurements

Heart rate was measured using a watch heart monitor around the chest (Polar Electro Inc., Lake Success, NY, USA.). Blood pressure was measured using a stethoscope and sphygmomanometer.

Maximal Aerobic capacity (VO_{2max})

VO_{2max} was assessed as described previously[110], during visits 2 and 15. Briefly, participants cycled on an electronically braked cycle ergometer (Velotron; Racermate, Inc., Seattle, WA, USA) against increasing resistance until they reached volitional fatigue. Throughout the test, expired gas was collected and analyzed using a metabolic cart (ParvoMedics, Sandy, UT, USA). Oxygen consumption (VO_2) and power output were recorded throughout the test.

Time to exhaustion (TTE)

The TTE test was conducted during visits 3 (familiarization) and 4 before training and during visit 14 after training. Following a ten-minute warm-up, participants cycled against a constant workload and maintain a pedal cadence of 60rpm. The resistance was set at a level that would elicit 75% of participants' VO_{2max}, based on VO_2 and workload results from the VO_{2max} test during visit 2. Participants continued cycling until they were unable to maintain a pedal cadence > 40 rpm; they were given verbal encouragement throughout the test. To ensure that the chosen workload was appropriate and elicited 75% of VO_{2max}, expired gases were collected at 5 and 10 minutes, at each subsequent 10-minute interval, and at the time of exhaustion. The same absolute level of resistance was used both before and after training.

Balance measurements

Balance testing was conducted during visits 5 and 13. Participants stood on two adjacent force platforms (Fully Instrumented Treadmill; Bertec, Columbus, OH) with one foot on each platform, separated by 15% of height for standardization of foot placement. Participants then completed three-30s trials[111] standing quietly with their eyes closed to eliminate differences in visual feedback/impairment, knees slightly bent, and hands resting on their hips. One minute of seated rest separated each of the three trials. The three trials were completed prior to, and repeated immediately following four sprints (described later). Individual foot forces and moments were collected using Vicon Nexus software (Motus 9.2; Vicon, Centennial, CO) at 200 Hz. Individual foot center-of-pressure (COP) and vertical forces were used to calculate net-COP using custom software (Matlab, v12.0; Mathworks, Natick, MA). The main variables calculated and analyzed were: net medial-lateral (ML), net anterior-posterior (AP) and total, path length and sway area (elliptical area that encompasses all COP locations during a trial period) which were all normalized to participant height. ML and AP standard deviation (SD) were also calculated and analyzed.

Sprints and high-intensity interval training (HIIT)

The same protocol was used for the four sprints conducted during visits 5 and 13, and the sprints used for the HIIT training. Following a warm-up, participants completed 30-second Wingate tests on the electronically braked cycle ergometer (Velotron; Racermate) with a resistance of 7.5% of body weight. All sprints were separated by four minutes of pedaling against low resistance for active recovery. A total of four sprints were completed during visits 5 and 13. During the training (Visits 6-12) the number of sprints each day were as follows; 5, 6, 6, 7, 7, 8, 9. Bike settings (seat and handlebar height) were kept consistent for each participant for all trials. Participants were given encouragement during every sprint. Peak power output was measured and recorded for all sprints.

Statistical analysis

All statistical analyses were completed using SigmaStat v3.5 (Systat Software Inc., San Jose, CA, USA). One-way analysis of variance (ANOVA) was used to detect differences between groups at baseline (before training). Two-way repeated measures ANOVA (group x time) was used to determine the effects of training on all collected data except for power output and balance measures. For power output data and balance measures a three-way ANOVA was used. The three factors considered for power data analysis were group (young *vs*. older adults), time (before, visit 5 *vs*. after, visit 13 training) and sprint number (1-4). The three factors considered for balance measure analysis were group, time, and before *vs*. after sprints. When appropriate, post-hoc testing (Student-Newman-Keuls Method) was used for analysis of significant interactions. Significance was set at $p<0.05$.

RESULTS

Anthropometric measures

Anthropometric data for all participants are presented in Table 1. Before training, young adults had lower body weight, body mass index (BMI), fat mass, and blood pressure than older adults. Training decreased body fat percentage (-0.8%) for both groups (main effect of time, $p<0.05$). Training had no effect on body weight, BMI, fat mass or lean mass (Table 1) in either group.

Exercise based measures of training adaptations

Before training, aerobic capacity (VO_{2max}, Figure 2.) of young adults was greater than that of older adults (39.5±2.7 vs. 22.8±1.5 ml/kg/min) ($p<0.001$). No other differences existed between groups prior to training. VO_{2max} increased for both groups following training both when normalized to body weight (+1.8 ml/kg/min) and at absolute levels (+ 0.13 L/min) (main effect of time, $p<0.05$). Time to exhaustion (TTE, Figure 3) was also increased with training for both groups (young; 25.8±4.0 vs. 37.0±3.1 min and older; 31.5±3.9 vs. 54.0±8.8 min) (main effect of time, $p<0.05$). The TTE test was designed to elicit 75% of pre-training VO_{2max}; the average oxygen consumption (VO_2) during the TTE tests for young adults were 78.1 and 75.9% before and after training, respectively, and for older adults was 78.2% both before and after training. The average workload during the TTEs was greater for young adults (142±20 W) compared to older adults (87±10 W; $p<0.05$). No group-by-training interactions were detected for any aforementioned measures.

There were no differences between peak power output of young and older adults before training. Peak power output (Figure 4.) was greater after training for both groups (main effect of time, $p<0.05$). Post-hoc testing revealed post-training peak power was greater than pre-training in young ($p<0.001$) but not in older ($p=0.183$) adults and that after training, young adults had greater peak power output than older adults ($p<0.001$).

Balance measures

One young female participant was not included in balance data analysis due to computer failure during data collection. Before training, young adults had lower ML net sway, total sway area, and ML net SD than older adults ($p<0.05$). For AP net, and total path length, young adults had greater values than older adults (main effect of age, $p<0.05$). There were no effects of training on any measure of balance (Table 2, Figures 5 and 6). However, there were significant increases for path length variables (ML, AP net path length and total path length) after a single bout of HIIT compared to before irrespective of age or visit (Table 2, Figure 5) ($p<0.05$).

Table 1. Anthropometric data for young and older adults pre- and post-training.

	Young n=7 (4 Female)		Older n=6 (2 Female)	
	Pre	Post	Pre	Post
Age (yr)‡	21 (1)		69 (2)	
Height (m)	1.68 (0.04)		1.74 (0.03)	
Mass (kg)‡	61.1 (4.7)	61.1 (4.6)	73.7 (3.0)	73.0 (3.1)
BMI (kg/m^2)‡	21.3 (0.7)	21.3 (0.7)	24.2 (1.1)	24.0 (1.1)
Resting HR (bpm)	68 (4)	66 (3)	67 (2)	66 (3)
Sys BP (mmHg)‡	117 (1)	117 (2)	129 (2)	130 (3)
Dia BP (mmHg)‡	76 (1)	73 (1)	82 (1)	82 (2)
Body Fat (%)	25.9 (2.2)	25.1 (2.2)*	31.1 (2.6)	30.3 (2.7)*
Fat Mass (kg)‡	15.2 (0.8)	14.4 (0.9)	22.4 (1.6)	22.1 (1.2)
Lean Mass (kg)	43.0 (4.4)	43.5 (4.3)	48.1 (3.3)	48.2 (3.4)

* Post training body fat % lower than pre training (main effect of time $p<0.05$)

‡ Young values significantly lower older values ($p<0.05$)

BMI, Body mass index. HR, Heart rate. Sys, systolic. Dia, Diastolic. BP, Blood pressure

Table 2. Balance data for young and older adults pre- and post four sprints and before (visit 5) and after (visit 13) training.

	Young				Older			
	n=6 (3 Female)				n=6 (2 Female)			
	Visit 5		Visit 13		Visit 5		Visit 13	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
ML Net Sway (mm/m)	4 (0)‡	7 (1)	5 (1)	6 (1)	8 (1)	6 (1)	6 (1)	8 (1)
AP Net Sway (mm/m)	11 (1)	15 (2)	14 (2)	12 (2)	12 (1)	12 (1)	13 (2)	13 (1)
Total Sway Area (mm^2/m)	37 (4)‡	105 (21)	71 (17)	75 (26)	92 (15)	73 (17)	79 (27)	98 (16)
ML Net Path Length (mm/m)†	68 (3)	85 (4)	85 (11)	101 (18)	75 (6)	75 (5)	63 (4)	79 (5)
AP Net Path Length (mm/m)†€	146 (10)	217 (18)	183 (28)	233 (55)	145 (7)	161 (11)	124 (7)	167 (21)
Total Path Length (mm/m)†€	214 (13)	302 (21)	268 (38)	334 (72)	230 (10)	235 (14)	186 (10)	246 (22)
ML Net SD (mm)	1 (0)‡	2 (0)	1 (0)	2 (0)	3 (1)	2 (0)	2 (0)	3.0 (1)
AP Net SD (mm)	4 (1)	5 (1)	6 (1)	4 (1)	5 (0)	5 (1)	5 (1)	5 (0)

† Post-sprint values significantly greater than pre-sprint values (main effect $p<0.05$)
€ Young values significantly greater than older values (main effect $p<0.05$)
‡ Young value significantly lower than corresponding older value ($p<0.05$)
ML, Medial-Lateral. AP, Anterior-Posterior. SD, Standard deviation.
All sway and path length variables normalized to height (m)

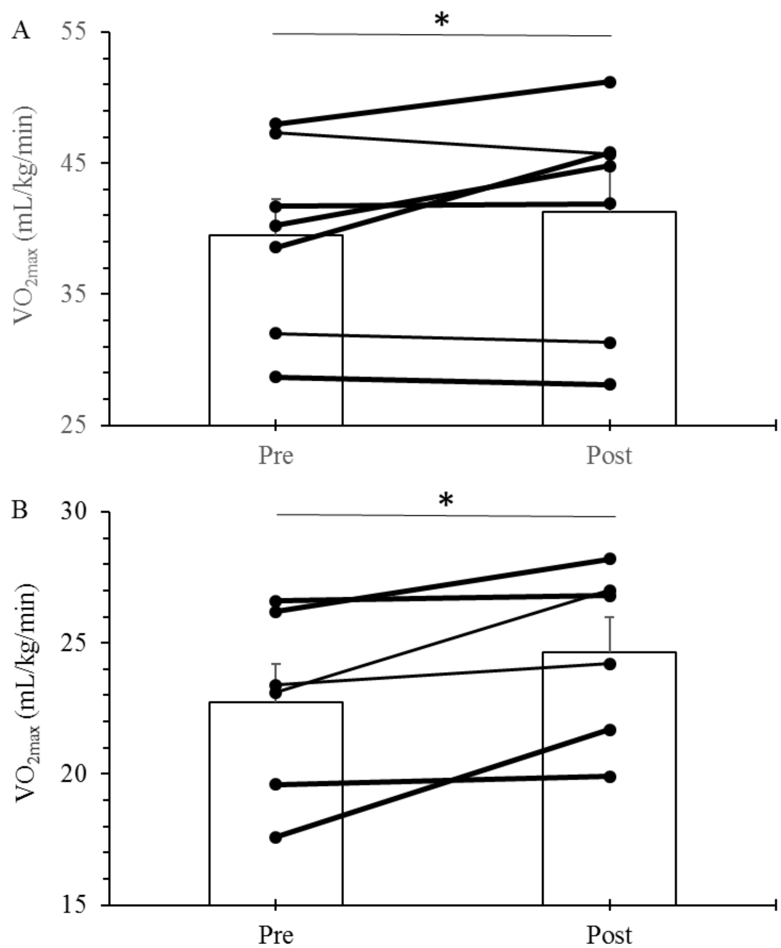

Figure 2. Maximal oxygen consumption (VO_{2max}) of young (A) and older (B) adults pre- and post-training. Lines represent individual data and bars represent means ± SE.
* Post training VO_{2max} was greater than pre training VO_{2max} (main effect of time p=0.02)

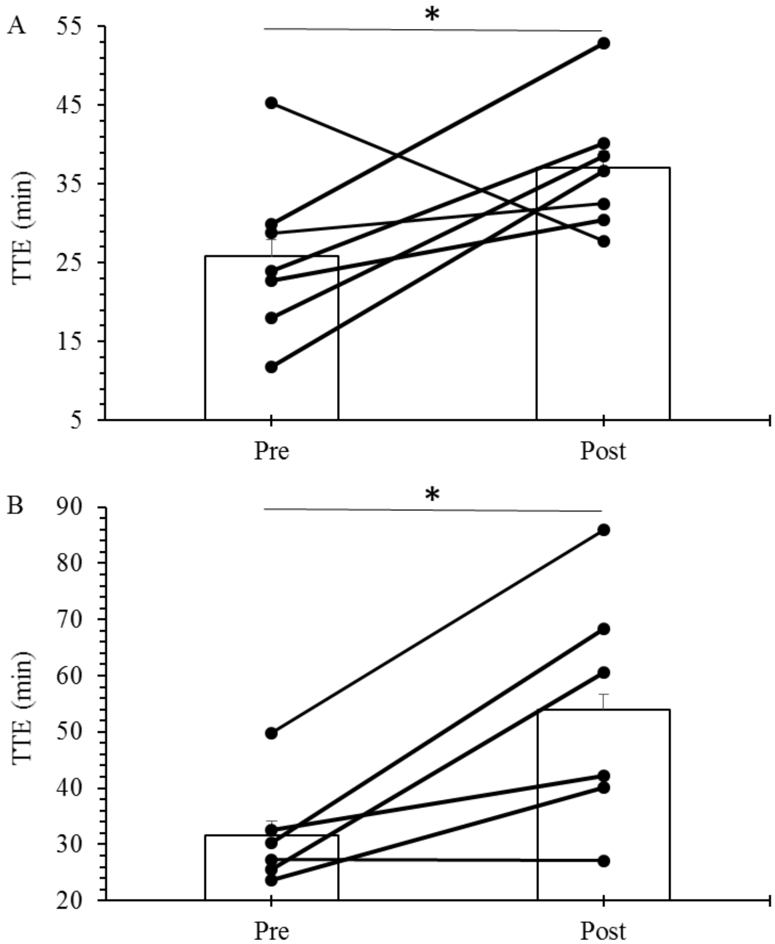

Figure 3. Time to exhaustion (TTE) of young (A) and older (B) adults pre- and post-training. Lines represent individual data and bars represent means ± SE.
* Post training TTE was greater than pre training TTE (main effect of time p=0.002)

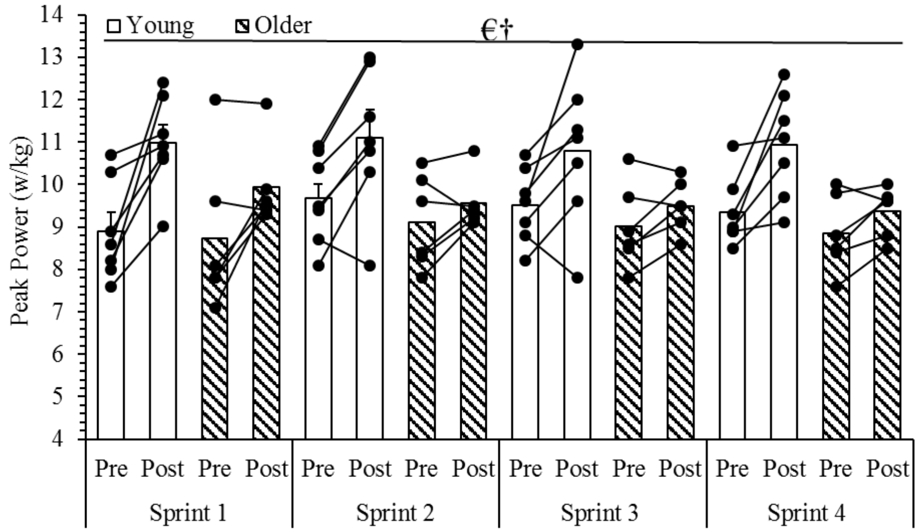

Figure 4. Peak power output of young and older adults for sprints 1-4 pre- (visit 5) and post- (visit 13) training. Lines represent individual data and bars represent means ± SE.
€ Young adults post- training values greater than pre- training. (p <0.001)
† Young adult post-training values greater than older adult post training values. (p<0.001)

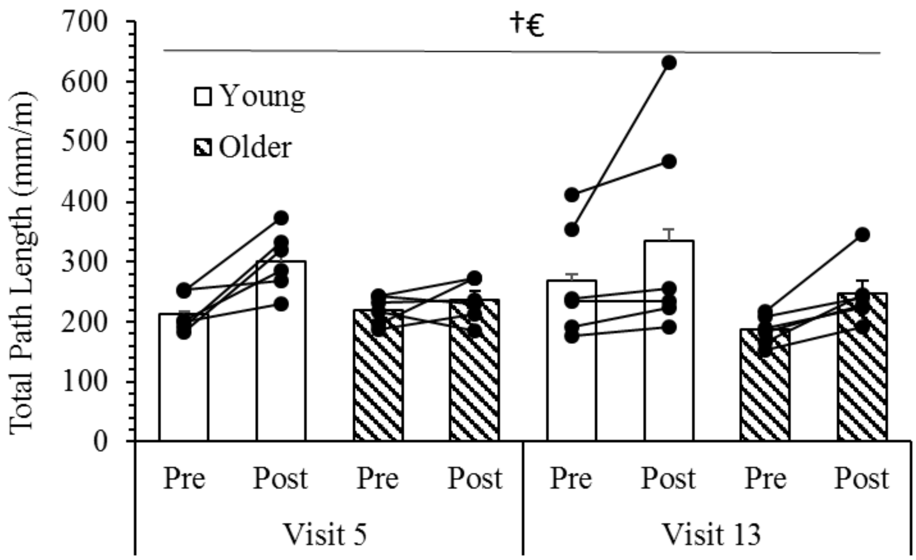

Figure 5. Total path length of young and older adults pre- and post-four sprints during visits 5 (before training) and 13 (after training). Lines represent individual data and bars represent means ± SE. Values normalized to participant height.

† Post-sprints total path length greater than pre-sprints. (p=0.015)

€ Young adults had greater total path length than older adults. (Main effect of age, p =0.015)

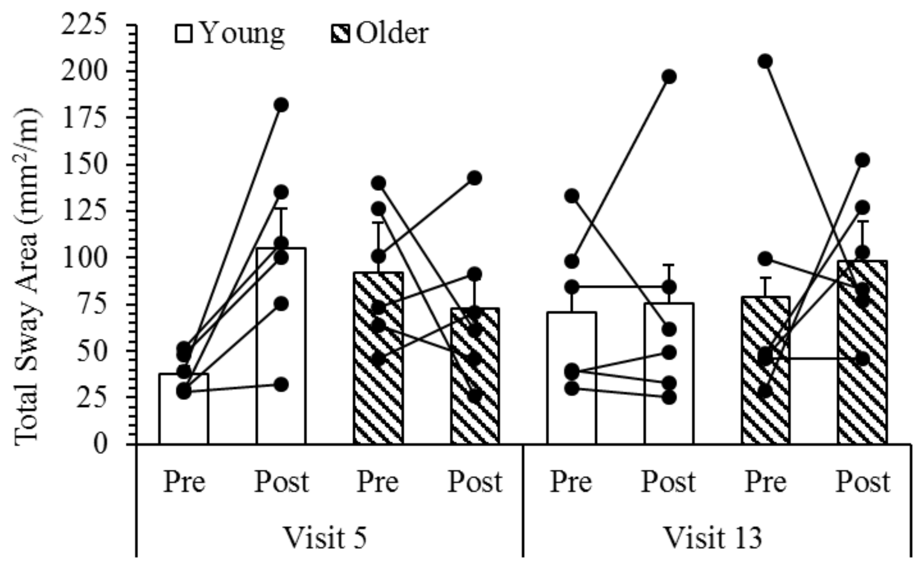

Figure 6. Total sway area of young and older adults pre- and post-four sprints during visits 5 (before training) and 13 (after training). Lines represent individual data and bars represent means ± SE. Values normalized to participant height.

DISCUSSION

This was the first study to determine the effects of HIIT on measures related to fall risk in older adults. The results show that there were no training effects of HIIT on balance or peak power output among older adults. An acute bout of HIIT reduced balance (increased path length) in both young and older adults. However, HIIT did improve fatigue resistance. The most noteworthy finding was the dissociation between the improvement in fatigue resistance (stamina) and lack thereof in balance (stability). The reasons for the dissociation require further investigation but may be due to the type of balance measure being non fatiguing or minimally affected by muscle fatigue, or different time-courses of neural and muscular adaptations to HIIT.

Balance at rest (prior to exercise) was unaffected by HIIT regardless of age. To our knowledge, this is the first study to use a short-term HIIT protocol with the aim of improving balance in older adults. As such, there are no studies that are directly comparable. Before training, there were no differences in AP net sway, or any path length variable between young and older adults. This lack of differences could indicate that the young adults in this study had poor balance, or that the older adults had very good balance prior to training. If the older adults within this study did have good balance, the potential for improvement due to HIIT may have been limited. However, although there were only few differences, our values for both young[43,111] and older adults[43] are similar to previously reported values. One previous study employed a power training protocol using high velocity resistance exercises over 8-12 weeks in a similar population of older adults[66]. Following the power training, resting balance, assessed via postural sway, was significantly improved among older adults[66] whereas the present study showed no effect of training on postural sway. The improvements in resting balance following power training are similar to improvements seen following more traditional resistance or endurance training of varying modalities, durations and intensities[63–65,68,69]. One primary difference between the present study, and previous exercise-based interventions to improve balance was the duration of training. In the current study, training was conducted during nine visits over three weeks (including visits 5 and 13) whereas previous studies' training paradigms lasted from eight weeks[66] to over one-year[65]. This may indicate that the duration of the training in the present study was not long enough to improve balance. Additionally, the current study's HIIT paradigm was conducted with participants seated on a stationary bicycle. Previous work suggests that non-weight bearing, or seated exercises are less effective than weight bearing and standing exercises for improving balance and reducing fall risk[112,113]. These differences may be due to a greater number of muscles recruited and a greater demand for postural control during standing[114,115]. Finally, the lack of HIIT on balance in the present study may be due to the choice of balance assessment. Although prior work regarding HIIT and balance utilized a similar protocol[43], static balance does not require power output for success as it does not include rapid reactive motion.

We also showed that following an acute bout of HIIT, balance (ML, AP and total path length) was significantly worse than balance at rest, and that this impairment was not attenuated by training. The finding that balance was impaired following an acute bout of HIIT agrees with previous work. Following a single bout of HIIT (4 x 4 min intervals at 90% HR_{max}) balance, as assessed by center-of-pressure path length, was significantly worse than balance at rest, or following control exercise up to 30 minutes following HIIT among older adults[43]. Similar balance impairments following exercise also exist for young adults[43,116]. Although not measured in the present study, previous work suggests that muscular and neuromuscular fatigue, along with proprioceptive impairment and increased ventilation contribute to poor balance and postural control following exercise[43,116–120]. Counter to what was expected, the balance impairment after a single bout of HIIT was not lower following training. Since muscular fatigue reduces stability and postural control[40,42,43], the training was designed in part to increase fatigue resistance (successfully based upon TTE results) it was expected that the acute balance impairment due to a single bout of HIIT at least would be partially attenuated. This may indicate that while the training increased muscular fatigue resistance, it did not affect the neuromuscular fatigue or proprioceptive impairment following exercise. Additionally, we only collected balance data immediately following the cessation of the single bout of HIIT. This leaves open the possibility that there were changes in the duration of balance impairment following the exercise that were not captured by our design. Finally, because the balance test used was static, the influence of muscle fatigue may have been limited.

Low peak power output is strongly associated with poor balance, increased fall risk and is predictive of future falls[53,55]. Since power is strongly associated with fall risk, power training may be an effective exercise program for fall risk reduction. We found that overall, peak power was increased following HIIT. Further analysis revealed that the improvements in peak power were present in young but not older adults and that young adults had greater peak power than older adults after training. Although the increase in older adults' peak power output was not significant, more subjects may increase the statistical power of the apparent trend showing that the trend is real. Before training, young adults' peak power was lower than values previously reported for the same population[98,106] and the peak power of the older adults was greater than values previously reported[121,122]. This may suggest that the young adults in this study had greater room for improvement compared to the older adults, who were relatively stong compared to similar populations.

Our findings that HIIT increased peak power output of young adults are consistent with previous work using a similar (repeated 30s sprints) training paradigm[101,123]. Among older adults, power training, in the form of high-velocity repetition resistance training over 8-12 weeks has been shown to increase peak power[66]. The age-related differences in response to training in the present study may indicate that older adults do not adapt to power training as quickly as young adults. However, a single bout of HIIT induced significantly elevated muscle protein synthesis in older adults[102], which is consistent with the longer-term effects in young adults[123]. Additionally, changes in muscle power are largely independent of changes in muscle mass[49,50]. Together, these suggest that in the present study, the age-related difference in peak power adaptability is likely driven by neural rather than muscular sources. However, this is only speculative as we have no measures of muscle, or neuromuscular adaptation. Finally, it may be that muscle power is more applicable to dynamic balance and fall recovery where we only measured static balance[51].

Although balance and peak power output were unaffected by HIIT in older adults, both VO_{2max} and fatigue resistance were improved following HIIT in both young and older adults. The finding that HIIT increased VO_{2max} is consistent with previous work[124]. A similar training paradigm increased VO_{2max} by 9.3% in physically active young adults[101] and longer-term HIIT of one session/week over 12 weeks increased VO_{2max} 29% in sedentary young adults[89]. Similarly, one session of HIIT every five days for six weeks significantly improved VO_{2max} of sedentary and physically active older adults[103]. The increases in VO_{2max} may be due to increased muscle oxidative capacity[98] and/or increases in ventricular contractility, cardiac output and vascular conductance[89,125].

Fatigue resistance, assessed by cycling time to exhaustion at 75% VO_{2max} was increased in both young and older adults after HIIT. HIIT has been found to improve both endurance performance and fatigue resistance in young and older adults[89,98,100,101,103,124]. Following six sessions of HIIT, recreationally active young adults were able to sustain cycling at 80% of VO_{2max} 25 minutes longer than before training[98]. In the present study, sedentary young and older adults sustained cycling at 75% of VO_{2max} for 12 and 23 minutes, respectively. Since muscular fatigue reduces postural control and balance, and increases fall risk[9,10,40–43], it was surprising that despite the increased fatigue resistance among our participants, there were no improvements in balance measures, especially following a single bout of HIIT. Previous studies that implemented power[66], resistance[93], or endurance[65] exercise training that recorded both muscular endurance (fatigue resistance) and some indices of balance consistently found that both fatigue resistance and balance were improved after training in older adults. However, the duration of training in these studies ranged from eight weeks to over one year whereas the current study's training lasted only two weeks. Together, this may indicate that the time-courses for balance and muscular endurance adaptations to exercise are different. To our knowledge, we are the first to report on this dissociation between fatigue resistance and fall resistance. Although we did not collect any mechanistic or neuromuscular data that might explain the dissociation, the different time courses of muscle versus neural adaptation may explain it. As mentioned previously, a single bout of HIIT induced significant increases in muscle protein sysnthesis in older adults[102]. Additionally, two-weeks of HIIT has been shown to increase muscle oxidative capacity and muscle endurance in young adults[98,101]. These are indicative of relatively rapid muscular adaptation to HIIT. In comparison, neural adaptations to exercise, specifically to resistance training begin 2-4 weeks into exercise training[126–130]. The dissociation between stamina and stability may also be due to the balance test used in this study, as it did not require muscular fatigue resistance for success.

There are important limitations to consider within the current study. First, the sample size of this study was very small including only 13 (7 young, 6 older) participants. This small sample size increases group variability and limits the power of statistical analysis. Second, we did not collect any muscle samples or neuromuscular measures that may explain some of our findings. As such, any discussion of potential mechanisms is purely speculative. Third, there were no measures of dynamic balance or postural control. Without any dynamic measures it remains unknown whether the HIIT had an impact on fall-risk or balance while in motion, or ability to recover from a balance perturbation. However, the present study did employ balance measures previously utilized to assess balance before and after an acute bout of HIIT[43].

In conclusion, HIIT did not improve balance at rest, or following a single bout of high-intensity interval training. However, the training did improve fatigue resistance among both young and older adults. The reason(s) for the dissociation between fall resistance and fatigue resistance require further attention, although they may be artifact of the balance testing used in this study. Finally, the small sample size, lack of muscular or neuromuscular, and lack of dymanic balance measures does not allow us to fully determine whether high-intensity interval training could be an effective intervention for fall-prevention in older adults.

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APPENDIX

Consent form

Consent to Participate in a Research Study
Colorado State University

TITLE OF STUDY: A Comparison of The Effects of High Intensity Interval Training On Balance and Stamina in Young and Older Adults

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WHY AM I BEING INVITED TO TAKE PART IN THIS RESEARCH?

You are a healthy adult aged between 18 and 30 years, or 65 and 80 years. You are willing and able to perform very difficult exercise.

WHO IS DOING THE STUDY?

Christopher Bell and Raoul Reiser, two associate professors in the Department of Health and Exercise Science at Colorado State University, will perform this research. Colleagues at Colorado State University, a physician, appropriately qualified staff, and trained graduate and undergraduate students will assist Drs. Bell and Reiser. The College of Health and Human Sciences is funding the study.

WHAT IS THE PURPOSE OF THIS STUDY?

The purpose of the study is to determine if very difficult exercise training (high intensity interval training) will improve balance and stamina in adults aged between 65 and 80 years. Potential improvements in balance and stamina will be compared with changes measured in young adults aged between 18 and 30 years.

WHERE IS THE STUDY GOING TO TAKE PLACE AND HOW LONG WILL IT LAST?

All of the procedures will take place at Colorado State University (Fort Collins main campus) in the Department of Health & Exercise Science (Moby Complex) in either the Human Performance Clinical/Research Laboratory (HPCRL), the Clinical Biomechanics Laboratory (2nd floor of Moby B-Complex).This whole research project will take place over a period of approximately 1 year. You will be asked to be involved for approximately 4-6 weeks. The total time of your participation will be approximately 18 hours, spread over 4-6 weeks, including 15 visits to our laboratories. Most visits will last 1-2 hours.

WHAT WILL I BE ASKED TO DO?

OVERVIEW

After a health-screening visit, you will complete tests of stamina and balance. You will then complete 3 weeks of very difficult exercise training, after which you will repeat the tests of stamina and balance.

Visit	Activity	Duration
1	Health-screening, body composition, blood pressure, exercise stress test	2 Hours
2	Maximal exercise test	1 Hour
3	Exercise test to exhaustion – Practice test	1 Hour
4	Exercise test to exhaustion	1 Hour
5	Balance testing, very difficult exercise, balance testing	2 Hours
6	Very difficult exercise	1 Hour
7	Very difficult exercise	1 Hour
8	Very difficult exercise	1 Hour
9	Very difficult exercise	1 Hour
10	Very difficult exercise	1 Hour
11	Very difficult exercise	1 Hour
12	Very difficult exercise	1 Hour
13	Balance testing, very difficult exercise, balance testing	2 Hours
14	Exercise test to exhaustion	1 Hour
15	Blood pressure, maximal exercise test, body composition	1 Hour

Visits 5-13 will take place over 3 weeks. Visit 14 will take place 2 days after visit 13. Visit 15 will take place 1 day after visit 14.

Visit 1 - Health-Screening, Body Composition, Exercise Stress Test, Blood Pressure – Duration: 2 Hours

The first visit to the HPCRL will be a screening visit. During this visit we will make sure that participation in this study is right for you.

Medical Questionnaire
You will be asked to answer several pages of questions related to your health, any illness you may have or have had, and medications and/or supplements you use or have used in the past. If you are pregnant you will not be able to participate in the study.

Body Composition
We will measure the different compositions of your body including how much fat mass, non-fat mass and total bone density total, as well as where fat mass is concentrated on your body. We will be using a test called dual energy x-ray absorptiometry (DEXA). The DEXA test requires you to lie quietly on a padded table while a small probe gives off low-level x-rays and sends them over your entire body. This test gives very accurate measurements of your body fat and bone mineral density. We will verify that you are not currently pregnant by conducting a pregnancy test using a urine sample. We will measure your height and weight using a physician's scale.

Blood Pressure
We will measure your blood pressure using a standard blood pressure cuff (the same as in a doctor's office). There are no known risks associated with this procedure.

Exercise Stress Test
You will be asked to perform a vigorous exercise test. This test will tell us if your heart is healthy. You will be asked to walk on a motorized treadmill or ride an exercise cycle (cycle ergometer) for approximately 10-12 minutes. The exercise will become more difficult every 2 minutes. While you are walking/riding we will measure your heart rate with an electrocardiogram (ECG) and your blood pressure with a cuff placed around your upper arm. We will ask you to wear a nose clip (something that stops you breathing through your nose) and ask you to breathe through a mouthpiece. This will let us measure the gases you breathe. Depending on your age, a physician may supervise the test. If we do not think your heart is healthy you will be referred to your primary care physician for further testing. There is a chance that you may not be allowed to take part in our study.

Visit 2 - Maximal Exercise Test (Also known as a VO_{2max} test) – Duration: 1 Hour

This test will tell us how fit you are and is very similar to the exercise stress test. You will be asked to ride an exercise bike until you are too tired to continue. It will become more and more difficult to keep exercising. While you are riding we will measure your heart rate. We will ask you to wear a nose clip (something that stops you breathing through your nose) and ask you to breathe through a mouthpiece. This will let us measure the gases you breathe.

Visits 3 & 4 - Exercise Test to Exhaustion – Duration: 1 Hour Per Visit

Visits 3 and 4 will be almost identical. Visit 3 is a practice for Visit 4. You will be asked to ride an exercise bike without stopping until you are exhausted and cannot continue. The goal of this test is that you perform the exercise for as long as possible. We will ask you to wear a nose clip (something that stops you breathing through your nose) and ask you to breathe through a mouthpiece. This will let us measure the gases you breathe.

Visit 5 – Balance Testing, Very Difficult Exercise, Balance Testing – Duration: 2 Hours

This visit will take place in the Clinical Biomechanics Laboratory (2nd floor of Moby B-Complex). Park your vehicle at the Human Performance Clinical Research Laboratory as normal; you will be escorted to the Clinical Biomechanics Laboratory.

Balance Testing

This type of testing is also known as Stability Testing. Your balance will be tested while standing on two legs with your eyes closed and also on one leg with your eyes open. During the two-leg eyes closed test you will stand on a platform for 30-seconds. When your eyes are closed the platform will measure how much you sway from side-to-side and backwards/forwards. You will repeat this test three times. During the one-leg eyes open test you will stand on a platform for 15-seconds. You will stand on your dominant leg (the leg you use to kick a ball). We will measure how much you sway from side-to-side and backwards/forwards. You will also repeat this test three times. You will be asked to sit for one minute between each test. “Spotters” (laboratory assistants) and railings will be present to keep you from falling during these tests.

Very Difficult Exercise

This type of exercise is also known as High-Intensity Interval Training, or Sprint Interval Training. You will be asked to perform 4 sprints on a cycle ergometer. Each bout will last 30-seconds and will be separated by 4-minutes. The exercise intensity during these 30-seconds will be very, very high.

Balance Testing

You will repeat the balance testing you performed before the very difficult exercise.

Visits 6, 7, 8, 9, 10, 11 and 12 - Very Difficult Exercise – Duration: Approximately 1 Hour (less for some visits, a little more for others)

This type of exercise is also known as High-Intensity Interval Training, or Sprint Interval Training. You will be asked to report to the lab on 7 separate occasions, each visit separated by 1-2 days. You will be asked to perform 5 sprints during the visit 6, 6 sprints during visits 7 and 8, 7 sprints during visits 9 and 10, 8 sprints during visit 11, and 9 sprints during visit 12. Each bout will last 30-seconds and will be separated by 4-minutes. The exercise intensity during these 30-seconds will be very, very high.

You will be asked to sit and rest in the lab for 30 minutes after each of these visits. During this time you will be allowed to chat, read, watch the television, check your email, etc.

Visit 13 – Balance Testing, Very Difficult Exercise, Balance Testing – Duration: 2 Hours

This visit will be exactly the same as Visit 5.

Visit 14 - Exercise Test to Exhaustion – Duration: 1 Hour

This visit will be exactly the same as Visit 4.

Visit 15 – Body Composition, Blood Pressure, Maximal Exercise Test (Also known as a VO_{2max} test) – Duration: Approximately 1 Hour

This visit will be almost exactly the same as Visit 2 except you will also complete tests of body composition and blood pressure (as described in Visit 1).

ARE THERE REASONS WHY I SHOULD NOT TAKE PART IN THIS STUDY?

You should not take part in this study for any of the following reasons:

1) You are not aged 18-30, or 65-80 years.
2) You are pregnant.
3) You are a nursing mother.
4) You smoke or have smoked during the previous two years.
5) You are not free of overt disease as assessed by medical history, ECG and blood pressure at rest and during incremental exercise.
6) Your participation has not been approved by a physician and by a senior member of the research team.
7) You are taking medications that would confound interpretation of the results of the studies.
8) You are participating in another research study that may confound interpretation of the results of this study.
9) You are unable or unwilling to perform repeated vigorous exercise.

WHAT ARE THE POSSIBLE RISKS AND DISCOMFORTS?

It is not possible to identify all potential risks in research procedures, but the researcher(s) have taken reasonable safeguards to minimize any known and potential, but unknown, risks. The Human Performance Clinical Research Laboratory has emergency supplies including a medicine trolley equipped with heart machines and supplemental oxygen. The investigator has a great deal of experience with all of the procedures. Some of the procedures for which you are being asked to volunteer have a number of associated risks:

Body Composition
The risks associated with the DEXA are very low. The maximum radiation dose you will receive in this study is less than 1/1000th of the federal and state occupational whole body dose limit allowed to radiation workers (5,000 mrem). Put another way, the maximum dose from any scan we utilize with this DEXA ranges from 1.2 mrem (Whole body scan) to 12.2 mrem (for several of the regional scans, such as lumbar, femur, and forearm scans). The average annual background radiation you already receive is at least 620 mrem/year. The more radiation you receive over the course of your life, the more the risk increases of developing a fatal cancer or inducing changes in genes. The radiation in this scan is not expected to significantly increase these risks, but the exact increase in such risks is not known. There are no discomforts associated with this procedure. Women who are or could be pregnant should receive no unnecessary radiation and should not participate in this study.

All Exercise Testing and Exercise Training
There is a very small chance of an irregular heartbeat during exercise (< 1% of all subjects). Other rare risks of a stress test are heart attack (< 5 in 10,000) and death (<2 in 10,000). Wearing a mouthpiece and nose-clip can sometimes cause dryness in the mouth and mild discomfort. Exercise can make you feel very tired. Very difficult exercise might make you feel dizzy or queasy; you may faint or vomit. Further, very difficult exercise is likely to induce considerable muscle soreness and increase the risk of minor musculoskeletal injuries (sprains and strains). Your balance may be decreased for a brief time after difficult exercise.

Balance Testing
"Spotters" (laboratory assistants) and railings will be present to keep you from falling during these tests.

ARE THERE ANY BENEFITS FROM TAKING PART IN THIS STUDY?

As a result of the exercise training, you may improve your stamina and balance (stability). You will be provided with a copy of your results, including your DEXA scan and exercise stress test; you may wish to share your DEXA scan and exercise stress test results with your doctor.

DO I HAVE TO TAKE PART IN THE STUDY?

Your participation in this research is voluntary. If you decide to participate in the study, you may withdraw your consent and stop participating at any time without penalty or loss of benefits to which you are otherwise entitled.

WHAT WILL IT COST ME TO PARTICIPATE?

Other than transport to and from the lab and on-campus dining facilities, your participation should incur no costs.

WHO WILL SEE THE INFORMATION THAT I GIVE?

We will keep private all research records that identify you, to the extent allowed by law. For this study, we will assign a code to your data (provide example) so that the only place your name will appear in our records is on the consent and in our data spread-sheet which links you to your code. Only the research team will have access to the link between you, your code, and your data. The only exceptions to this are if we are asked to share the research files for audit purposes with the CSU Institutional Review Board ethics committee, if necessary. In addition, for funded studies, the CSU financial management team may also request an audit of research expenditures. For financial audits, only the fact that you participated would be shared, not any research data. When we write about the study to share with other researchers, we will write about the combined information we have gathered. You will not be identified in these written materials. We may publish the results of this study; however, we will keep your name and other identifying information private.

Your identity/record of receiving compensation (NOT your data) may be made available to CSU officials for financial audits.

CAN MY TAKING PART IN THE STUDY END EARLY?

Your participation in the study could end if you become pregnant, or if you miss any of the scheduled appointments.

WILL I RECEIVE ANY COMPENSATION FOR TAKING PART IN THIS STUDY?

If you complete the entire study you may receive up to $100. This payment will be prorated as follows: You will not receive compensation if you only complete screening visit (visit 1). If you complete visits 1-5 you will receive $20. If you complete visits 1-13 you will receive $70. If you complete visits 1-15 you will receive $90. If you arrive for every visit within 10 minutes of the scheduled time you will be provided with a bonus of $10.

WHAT HAPPENS IF I AM INJURED BECAUSE OF THE RESEARCH?

The Colorado Governmental Immunity Act determines and may limit Colorado State University's legal responsibility if an injury happens because of this study. Claims against the University must be filed within 180 days of the injury. The research team will not cover any injury resulting from this study. You and/or your health insurance will be responsible for paying any study-related injury.

WHAT IF I HAVE QUESTIONS?

Before you decide whether to accept this invitation to take part in the study, please ask any questions that might come to mind now. Later, if you have questions about the study, you can contact the investigators: Christopher Bell via email at physiology@cahs.colostate.edu, or Raoul Reiser via email at Raoul.Reiser@ColoState.edu. If you have any questions about your rights as a volunteer in this research, contact the CSU IRB at: RICRO_IRB@mail.colostate.edu; 970-491-1553. We will give you a copy of this consent form to take with you.

WHAT ELSE DO I NEED TO KNOW?

Your signature acknowledges that you have read the information stated and willingly sign this consent form. Your signature also acknowledges that you have received, on the date signed, a copy of this document containing _9_ pages.

____ ____________________

Signature of person agreeing to take part in the study Date

____

Printed name of person agreeing to take part in the study

____ ____________________

Name of person providing information to participant Date

____

Signature of Research Staff