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UTILIZACIÓN DEL CICLOERGÓMETRO EN EL ENTRENAMIENTO INTERVÁLICO DE ALTA INTENSIDAD PARA LA MEJORA DE LA MARCHA, EL EQUILIBRIO Y LA CAPACIDAD FUNCIONAL DE ADULTOS MAYORES

UTILIZING CYCLE ERGOMETER HIGH-INTENSITY INTERVAL TRAINING TO IMPROVE GAIT, BALANCE, AND FUNCTIONAL CAPACITY IN OLDER ADULTS

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I. **Keating CJ**, Párraga Montilla JA, Latorre Román PÁ, Moreno Del Castillo R. Comparison of High-Intensity Interval Training to Moderate-Intensity Continuous Training in Older Adults: A Systematic Review. J Aging Phys Act. 2020 Apr 16:1-10. doi: 10.1123/japa.2019-0111. PMID: 32303000.

II. **Keating CJ**, Cabrera-Linares JC, Párraga-Montilla JA, Latorre-Román PA, Del Castillo RM, García-Pinillos F. Influence of Resistance Training on Gait & Balance Parameters in Older Adults: A Systematic Review. Int J Environ Res Public Health. 2021 Feb 11;18(4):1759. doi: 10.3390/ijerph18041759. PMID: 33670281; PMCID: 7918150.

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IV. **Keating CJ**, Párraga Montilla JA, Latorre Román PA, Donahue PT. A Single Session of Cycle Ergometer High-Intensity Interval Training (HIIT) Does Not Produce a Transient Elevated Fall Risk in Adults 50 – 70 Years of Age. *Submitted*

Summary

High-intensity intermittent training (HIIT) commonly refers to repeated bouts of high-intensity exercise performed at near maximal efforts (> 80% of aerobic capacity) interspersed with low-intensity recovery periods (< 60% of aerobic capacity). These bouts of high-intensity exercise can last from 5 seconds to 5 minutes, but they are always performed in repeated intervals dispersed with lower intensity recovery periods.

The primary objective of this Ph.D. thesis was to determine the acute and chronic effects that a cycle ergometer HIIT protocol may have in older adults and how it compares to other exercise interventions commonly used in the same population. To achieve that objective, two systematic reviews and two intervention studies were conducted. The first systematic review focused on the effects that HIIT had in older adults ≥ 65 years of age when compared to an equivalent moderate-intensity continuous training (MICT) protocol (Paper I). The second systematic review examined the influence that a resistance training (RT) protocol had on balance and gait parameters in older adults ≥ 65 years of age (Paper II). The first intervention further explored the physiological and biomechanical adaptations that took place after 6 weeks of participating in cycle ergometer HIIT (Paper III). The second intervention investigated the acute gait and balance parameter changes that occurred after a single session of cycle ergometer HIIT and MICT respectively (Paper IV).

The key conclusions from the current thesis suggest that HIIT is an effective and safe exercise regimen that is well-tolerated in older adults and can be prescribed to the broader, non-clinical population by using a simple heart rate maximum (HRmax) calculation and rate of perceived exertion (RPE). Although RT has been commonly used to improve lower limb strength in older adults, cycle ergometer HIIT has demonstrated that it can improve lower limb strength and functional capacity in an already active older adult population comparable to that observed in RT. A single session of cycle ergometer HIIT does not produce an acute risk of falling in the youngest of the older adults and it should not be singled out as a hazardous exercise regimen to participate in when the world's aging population is growing faster than ever and requires time-efficient exercise interventions.

The findings of the current Ph.D. thesis suggest that cycle ergometer HIIT is an effective and safe exercise intervention for older adults to participate in and when compared to a traditional MICT intervention it appears to elicit comparable if not superior results although in a shorter amount of time.

Resumen

El entrenamiento intermitente de alta intensidad (HIIT) generalmente se refiere a series repetidas de ejercicio de alta intensidad realizado con esfuerzos casi máximos (> 80% de la capacidad aeróbica), intercalados con períodos de recuperación de baja intensidad (<60% de la capacidad aeróbica). Estos episodios de ejercicio de alta intensidad pueden durar de 5 segundos a 5 minutos, pero siempre se realizan en intervalos repetidos dispersos con periodos de recuperación de menor intensidad.

El objetivo principal de esta tesis doctoral fue determinar los efectos agudos, y a medio o largo plazo que puede tener un protocolo HIIT de cicloergómetro en adultos mayores y cómo se compara con otras intervenciones de ejercicio comúnmente utilizadas en la misma población. Para lograr ese objetivo, se realizaron dos revisiones sistemáticas y dos estudios de intervención. La primera revisión sistemática se centró en los efectos que tenía el HIIT en los adultos mayores ≥ 65 años en comparación con un protocolo de intensidad moderada continua (MICT) equivalente (Articulo I). La segunda revisión sistemática examinó la influencia que tenía un protocolo de esfuerzo (RT) en los parámetros de equilibrio y marcha en adultos mayores ≥ 65 años (Articulo II). La primera intervención exploró las adaptaciones fisiológicas y biomecánicas que tuvieron la participación en un programa HIIT en cicloergómetro de seis semanas de duración (Articulo III). La segunda intervención investigó los cambios agudos de los parámetros de la marcha y el equilibrio que ocurrieron después de una sola sesión de cicloergómetro HIIT y MICT respectivamente (Articulo IV).

Las conclusiones clave de la tesis actual sugieren que el HIIT es un régimen de ejercicio eficaz y seguro, que es bien tolerado por los adultos mayores y que puede prescribir a una población no clínica más amplia mediante un cálculo simple de la frecuencia cardiaca máxima (FCmáx) y la percepción subjetiva del esfuerzo (RPE). Aunque la RT se ha utilizado comúnmente para mejorar la fuerza de las extremidades inferiores en adultos mayores, el HIIT en cicloergómetro ha demostrado que puede mejorar la fuerza de las extremidades inferiores y la capacidad funcional en una población adulta mayor ya activa comparable a la observada en RT. Además, una sola sesión de HIIT en cicloergómetro no produce un riesgo agudo de caídas en los adultos mayores más jóvenes y no debe señalarse como un régimen de ejercicio peligroso en el que participar, máxime cuando el envejecimiento de la población mundial está creciendo más rápido que nunca y se necesitan intervenciones de ejercicio eficientes y eficaces en el tiempo.

Los hallazgos de esta tesis doctoral sugieren que el cicloergómetro HIIT es una intervención de ejercicio efectiva y segura para los adultos mayores que, en comparación con una intervención MICT tradicional, parece obtener resultados comparables, si no superiores, en un período de tiempo más corto.

Abbreviations (abreviaturas)

Abbreviations	Abreviaturas
ACSM – American College of Sports Medicine	**ACSM –** Colegio Americano de Medicina de Deportes
AP – Anterior-Posterior	**AP** – Anterior-Posterior
BIA – Bioimpedance Analysis	**BIA** – Análisis de Bioimpedancia
BMI – Body Mass Index	**IMC** – Índice de Masa Corporal
BP – Blood Pressure	**BP** – Presión Arterial
CDC – Centers for Disease Control	**CDC** - Centros para el control de enfermedades
COP – Center of Pressure	**COP** – Centro de Presión
EC – Eyes Closed	**EC** – Ojos Cerrados
EO – Eyes Open	**EO** – Ojos Abiertos
GBD – Global Burden of Disease	**GBD** – Global Burden of Disease
HR – Heart Rate	**FC** – Frecuencia Cardiaca
HRmax – Heart Rate Maximum	**FCmax** – Frecuencia Cardiaca Máxima
HIIT – High-Intensity Interval Training	**HIIT** – Entrenamiento de alta intensidad
MET – Metabolic Equivalent	**MET** – Equivalente Metabólico
MICT – Moderate-Intensity Continuous Training	**MICT** – Entrenamiento Interválico de Alta Intensidad
ML – Medial-Lateral	**ML** – Medial-Lateral
PEDro – Physiotherapy Evidence Database	**PEDro** – Physiotherapy Evidence Database
PA – Physical Activity	**AF** – Actividad Física
RCT – Randomized Control Trial	**RCT** - Ensayo de Control Aleatorio
RPE – Rate of Perceived Exertion	**RPE -** Percepción subjetiva del esfuerzo
SL – Single Leg	**SL** – Una Sola Pierna
Watts/kg – Watts per kilogram of body mass	**Watts/kg** – Vatios por kilogramo
WHO – World Health Organization	**OMS** – Organización Mundial de Salud

Introduction

The World Health Organization (WHO) has stated that the number of people aged 65 or older is anticipated to increase from an estimated 703 million in 2019 to 1.5 billion in 2050. The WHO also reports that noncommunicable chronic diseases currently account for 71% of all deaths globally (*WHO | World Health Organization*, 2019). The risk of developing and eventually dying from chronic diseases such as cardiovascular disease and diabetes increases with age (Chodzko-Zajko et al., 2009). Physical inactivity is estimated to be the primary cause of approximately 20-30% of breast, colon cancers, diabetes, and heart disease worldwide. The World Health Organization estimates that in Europe alone physical inactivity accounts for 1 million deaths each year (*WHO | World Health Organization*, 2019). The Global Burden of Disease (GBD) study found that in 2017, over 400,000 people died in Spain, 80% of whom were aged 70 years or older, and that 92.8% of those cases were related to non-communicable diseases. According to the same GBD study, aside from tobacco use, the risk factors that drive the most death and disability in Spain are high fasting plasma glucose, high blood pressure, and high body mass index, all beating out the fifth risk factor being dietary risk.

Physical Activity is a key component of aging well

However, strong evidence points to physical activity (PA) as a primary predictor of all-cause mortality. There is a growing body of evidence confirming that more active persons have lower rates of non-communicable chronic disease (Chodzko-Zajko et al., 2009; Lee et al., 2011; Nes et al., 2014). In addition, PA in an aging population is associated with increased functional health, a lower risk of falling, and better cognitive function (Chodzko-Zajko et al., 2009). The Physical Activity Guidelines for Americans state that "regular physical activity reduces the risk of many adverse health outcomes". The guidelines go even further and suggest that "adults should avoid sedentary behavior, that some physical activity is better than no physical activity, and that adults who participate in any amount of physical activity gain health benefits" (Bushman, 2019). A recent prospective population-based study in Spain found that compared to a sedentary lifestyle, PA is associated with a lower risk of mortality for all causes in older adults after controlling for the effect of several other covariates and that health policies for old age care should include PA as one of the main targets (Llamas-Velasco et al., 2016).

A study by the Centre for Economics and Business Research UK estimated that the direct costs (public and private) of health care expenditure that can be attributed to physical inactivity in Europe is €9.2billion... they further state that the indirect costs across Europe are estimated at €71.1 billion (Centre for Economics and Business Research, 2015). This suggests that the direct and indirect costs of physical inactivity in Europe alone were estimated to exceed €80 billion in the calendar year 2012. Cutting physical inactivity by 20% would save Europe an estimated €16.1 billion, but the societal burden of inactivity in Europe extends beyond simple economic costs (Centre for Economics and Business Research, 2015). Physical inactivity can also impose widespread costs to individuals and families, by contributing to serious diseases and leading to incalculable avoidable deaths each year. These health consequences produce emotional and human costs across society that cannot be reasonably portrayed in monetary figures. The nature of inactivity as a behavior that causes future health problems means that today's inactive population can be expected to give rise to tomorrow's increasing economic costs (Heidenreich et al., 2011). This is a global concern but predominantly in Spain, where an aging population and a rise in health care costs are serious health challenges facing its society (Soriano et al., 2018).

With all this convincing evidence, exercise should be considered a primary focus in the fight against noncommunicable chronic diseases and all-cause mortality. However, the question then arises of which type of PA in an aging population is best and is there an optimal prescription that helps safeguard an individual from disease and premature death. Research studies readily demonstrate that moderate to vigorous aerobic PA performed at least 3 days a week, accruing 150 – 300 minutes produces considerable health benefits (Bushman, 2019; Warburton et al., 2006). Moderate-intensity PA is possibly the most common form and requires a medium level of effort (5-7 on a scale of 1-10, or 3-6 MET's) and produces an obvious increase in breathing and heart rate. Vigorous-intensity physical activity requires a high level of effort (7 or above on a scale of 1-10, or ≥7 MET's) and produces a large increase in breathing and heart rate. The type of exercise performed is not as highly specified and the participant can select from a wide range of modalities (i.e., walking, hiking, jogging, cycling, swimming, etc.).

What are the current guidelines for exercise in older adults?

Guidelines for exercise in older adults suggest that a multidimensional exercise routine (i.e., aerobic, strength, balance, and flexibility) is best (Bushman, 2019; Chodzko-Zajko et al.,

2009; Fragala et al., 2019). The Physical Activity Guidelines for Americans, 2nd edition state, “many interventions combine all types of exercise (aerobic, muscle strengthening, and balance) into one session, and this has been shown to be effective” and that “multicomponent physical activity is important to improve physical function and decrease the risk of falls or injury from a fall” (Bushman, 2019).

However, much of the research regarding the prevention of disease and premature death has focused on a conveniently available population of young and middle-aged adults, not specifically older adults ≥ 60 years of age. Although there may be applicable information in these studies, individuals differ widely in how they age biologically and in how physiologically they may adapt to a specific exercise program (Elliott et al., 2021). This suggests that advancing age is associated with physiologic changes that result in reductions in functional capacity and declines in PA volume and intensity. This diverse interindividual variability seen in older adults can be due to a combination of genetic and lifestyle factors, but either way, one thing is certain, there are differences between older and middle-aged adults and more research needs to be done to tease out those key differences.

When physically active older adults are compared to their non-active counterparts, it is clear that PA is playing a key role in aging well and preventing the early onset of disease (D’antona et al., 2007; Pollock et al., 2014). Although encouraging and supporting older adults to be more physically active has no “one size fits all” solution, raising awareness and educating people about the physical, mental, and social benefits of PA can be part of the solution. Another part of that solution is providing educated and informed exercise prescriptions that are calculated and specific.

The emergence of prescribing HIIT in chronic disease and aging

Although moderate-intensity continuous training (MICT) has historically been the leading exercise recommendation, the U.S. physical activity guidelines also allow for 75 min of vigorous-intensity exercise a week rather than 150 min of moderate-intensity exercise (Bushman, 2019). High-intensity interval training (HIIT) is an exercise regimen that seems to be gaining more popularity in the general population as a quick and effective, yet enjoyable, way to partake in PA. HIIT, just like MICT, can take place in many different forms of exercise from walking to cycling to rowing. The difference is that HIIT consists of alternating short periods of intense exercise with recovery periods of passive or moderate-intensity

movement. Typically, the work intervals vary from 10 s to 4 min at or near an individual's maximum capacity with recovery intervals that are approximately equal to the work interval. The recovery interval can be passive (no exercise) or active (exercise) recovery at a much lower intensity and this combined work to rest interval is repeated several times. Thus, alternating high-intensity with low-intensity intervals allows an individual to spend a longer amount of time at an elevated intensity, therefore, making the total exercise time, less in comparison with MICT. Therefore, although a HIIT regimen can be very strenuous, logistically speaking, the workout takes less time and can be very appropriate in a time-crunched society.

HIIT has also gained considerable attention as a suitable exercise program for patients with chronic diseases such as cardiovascular disease and diabetes due to its increased effect on cardiorespiratory fitness and metabolic function (Hannan et al., 2018; Tjønna et al., 2008). Multiple studies have reported that when compared with MICT, HIIT has been shown to elicit superior improvements in indices of cardiorespiratory fitness (Angadi et al., 2015; Hannan et al., 2018; Hwang et al., 2019; Ramos et al., 2015). Also, a study by Lee et al. (2011) found that cardiorespiratory fitness was more strongly associated with all-cause mortality than PA alone; therefore, improving cardiorespiratory fitness should be encouraged to reduce the risk of all-cause mortality (Lee et al., 2011).

Physiological advantages of HIIT compared to MICT

The benefit of HIIT, when compared to MICT, is that an individual can perform large amounts of high-intensity exercise due to the respite periods that are not otherwise possible in traditional continuous training. The current body of evidence suggests that HIIT can induce equal, if not superior, improvements in cardiovascular fitness and metabolic health when compared to MICT (Angadi et al., 2015; Gibala & McGee, 2008; Gillen & Gibala, 2018; Hood et al., 2011). However, the research investigating the exact physiological parameters that explain the stronger adaptations seems to be lacking although the current explanations state that the time spent at near maximal aerobic capacity and increased muscle fiber recruitment are the keys to making HIIT more advantageous. Literature from Gibala & McGee (2008) suggests that small amounts of HIIT can acutely increase skeletal muscle oxidative capacity and alter metabolic control mechanisms. They further state that their research has observed substantial increases of mitochondrial enzymatic activity of citrate synthase and cytochrome oxidase in as little as 6 sessions of HIIT participation over just two

weeks (Gibala & McGee, 2008). This data suggests that aerobic capacity increases due to HIIT but not MICT are due to the enhanced mitochondrial activity taking place at the local skeletal muscle fiber caused by the increased amount of exercise performed at higher intensities. Consequently, this increased mitochondrial activity elicited by HIIT could have a dual purpose in not only increasing aerobic capacity but also increasing insulin sensitivity as type 2 diabetics have been shown to have impaired mitochondrial capacity (Hood et al., 2011). Similarly, and possibly better understood is the fact that with increasing intensity of activity an individual will recruit a greater number of muscle fibers (motor units) to complete the task (Thomson et al., 1979; VØLLESTAD & BLOM, 1985). Particularly, the individual will first recruit slow-twitch (Type I), followed by fast-twitch II-A type, then by fast-twitch II-X type, and lastly by fast-twitch II-B type fibers (Talbot & Maves, 2016). Therefore, the higher intensity of HIIT in comparison to MICT generally recruits more muscle fibers during the exercise bout inducing greater muscular oxidative capacity in that larger number of muscle fibers thus creating a more positive physiological adaptation.

Are older adults at an increased risk when prescribed HIIT?

When addressing the safety of utilizing HIIT in an aging population and those with chronic conditions, it is always important to note that the intensity of the training is relative to the individuals' level of fitness. Therefore, HIIT is different, yet very specific for everybody taking part in it. That would mean that a physically unfit individual may simply need to walk at a slightly increased pace, whereas an active, fit individual may need to run at a fast pace to achieve the same intensity (%HRmax, %VO2max, etc.).

Currently, there is no consensus as to whether HIIT puts an older adult at an increased risk of an adverse event or serious injury. However, one study claims that a single session of HIIT can elicit an elevated transient risk of falling (Donath & Roth, 2014). If that were the case then one of the primary reasons HIIT is so beneficial, time efficiency, could be argued. Various other studies suggest that exercise-induced fatigue, no matter the method, is a reality and that fatigue can generate acute impairments in balance and gait parameters (Helbostad et al., 2007; Morrison et al., 2016; Nagano et al., 2014). However, all these studies included an older adult population 70+ years of age, and most of those studies focused on resistance exercise fatigue. A systematic review on the topic asserts that although balance is impaired due to exercise-induced fatigue, the rate of fatigue and recovery from that fatigue varied greatly amongst the participants/studies (Helbostad et al., 2010). Aside from the research by

Donath & Roth (2014), few studies have examined the acute effect that HIIT may have in an aging population.

Although there is no clear consensus on the safety of HIIT, much of the research to date suggests that HIIT is just as safe and possibly more enjoyable than traditional MICT exercise protocols (Marriott et al., 2021; Villelabeitia Jaureguizar et al., 2016). Systematic reviews often claim that there needs to be more long-term research to determine the safety and feasibility of HIIT training in older adults. However, despite those claims, individual studies have concluded that HIIT is safe, feasible, and well-tolerated in an older adult population that consisted of certain individuals with significant divergent comorbidities (Angadi et al., 2015; Hwang et al., 2016).

Introducción

La Organización Mundial de la Salud (OMS) ha declarado que se prevé que el número de personas de 65 años o más aumente de un estimado de 703 millones en 2019 a 1.500 millones en 2050. La OMS también informa que las enfermedades crónicas no transmisibles actualmente representan el 71% de todas las muertes del mundo (WHO | World Health Organization, 2019). El riesgo de desarrollar enfermedades crónicas como las enfermedades cardiovasculares y la diabetes, y eventualmente morir, aumenta con la edad (Chodzko-Zajko et al., 2009). Se estima que la inactividad física es la causa principal de aproximadamente el 21-25% de los cánceres de mama y de colon, el 27% de la diabetes y aproximadamente el 30% de las enfermedades cardíacas en todo el mundo. La OMS estima que solo en Europa la inactividad física representa un millón de muertes cada año (WHO | World Health Organization, 2019). El estudio Global Burden of Disease (GBD) encontró que, en 2017, más de 400.000 personas murieron en España, el 80% tenían 70 años o más y que el 92,8% de esos casos estaban relacionados con enfermedades no transmisibles. Según el mismo estudio de GBD, además del consumo de tabaco, los factores de riesgo que provocan más muertes y discapacidades en España son la glucemia elevada en ayunas, la hipertensión arterial y el índice de masa corporal (IMC) elevado, todos superando al quinto factor de riesgo: el riesgo dietético.

La actividad física es un componente clave para envejecer bien

Sin embargo, hay pruebas contundentes que apuntan a la actividad física (AF) como un factor de predicción principal de la mortalidad por todas las causas. Cada vez hay más evidencia que confirma que las personas más activas tienen tasas más bajas de enfermedades crónicas no transmisibles (Chodzko-Zajko et al., 2009; Lee et al., 2011; Nes et al., 2014). Además, la AF en una población que envejece se asocia con una mayor salud funcional, un menor riesgo de caídas y una mejor función cognitiva (Chodzko-Zajko et al., 2009). La publicación "Physical Activity Guidelines for Americans 2008" indica que "la AF regular reduce el riesgo de muchos resultados adversos para la salud". La publicación va más allá y sugieren que "los adultos deben evitar el comportamiento sedentario, que algo de AF es mejor que ninguna AF, y que los adultos que participan en cualquier cantidad de AF obtienen beneficios para la salud" (Bushman, 2019). Un reciente estudio prospectivo basado en la población en España encontró que, en comparación con un estilo de vida sedentario, la AF se asocia con un menor riesgo de mortalidad por todas las causas en los adultos mayores después de controlar el

efecto de otras covariables y que las políticas de salud para el cuidado de las personas mayores debe incluir la AF como uno de los principales objetivos (Llamas-Velasco et al., 2016).

Un estudio realizado por el Centro de Investigación Económica y Empresarial del Reino Unido estimó que los costos directos (públicos y privados) del gasto en atención médica que pueden atribuirse a la inactividad física en Europa es de 9,2 mil millones de euros. El estudio sigue diciendo que, solo en Europa, se estima el coste alrededor de 71.100 millones de euros (Centro de Investigación Económica y Empresarial, 2015). Esto sugiere que se estimó que los costes directos e indirectos de la inactividad física solo en Europa superaron los 80.000 millones de euros en el año 2012. Reducir la inactividad física en un 20% ahorraría a Europa un estimado de 16.100 millones de euros, pero la carga social de la inactividad en Europa se extiende más allá de los simples costos económicos (Center for Economics and Business Research, 2015). La inactividad física también puede imponer costos generalizados a las personas y las familias, contribuyendo a enfermedades graves y provocando muertes evitables incalculables cada año. Estas consecuencias para la salud producen costos emocionales y humanos en la sociedad que no pueden representarse razonablemente en cifras monetarias. La naturaleza de la inactividad como comportamiento que causa problemas de salud en el futuro significa que se puede esperar que la población inactiva de hoy dé lugar a los crecientes costos económicos del mañana (Heidenreich et al., 2011). Se trata de una preocupación mundial pero predominantemente en España, donde el envejecimiento de la población y el aumento de los costes sanitarios son graves retos sanitarios a los que se enfrenta su sociedad (Soriano et al., 2018).

Con toda esta evidencia convincente, el ejercicio debe considerarse un enfoque principal en la lucha contra las enfermedades crónicas no transmisibles y la mortalidad por todas las causas. Sin embargo, surge la pregunta de qué tipo de AF es mejor en una población que envejece y si existe una receta óptima que ayude a proteger a un individuo de enfermedades y muerte prematura. Los estudios de investigación demuestran fácilmente que la AF aeróbica de moderada a vigorosa realizada al menos 3 días a la semana, acumulando entre 150 y 300 minutos, produce considerables beneficios para la salud (Bushman, 2019; Warburton et al., 2006). La AF de intensidad moderada es posiblemente la forma más común y requiere un nivel de esfuerzo medio (5-7 en una escala de 1-10 RPE, o 3-6 MET) y produce un aumento evidente de la frecuencia cardíaca y respiratoria. La AF de intensidad vigorosa requiere un

alto nivel de esfuerzo (7 o más en una escala de 1 a 10 RPE, o ≥7 MET) y produce un gran aumento de la frecuencia respiratoria y cardíaca. El tipo de ejercicio realizado no está tan especificado y el participante puede seleccionar entre una amplia gama de modalidades (es decir, caminar, hacer senderismo, trotar, andar en bicicleta, nadar, etc.).

¿Cuáles son las pautas actuales para el ejercicio en adultos mayores?

Las pautas para el ejercicio en adultos mayores sugieren que lo mejor es una rutina de ejercicio multidimensional (es decir, aeróbico, fuerza, equilibrio y flexibilidad) (Bushman, 2019; Chodzko-Zajko et al., 2009; Fragala et al., 2019). La “Physical Activity Guidelines for Americans”, segunda edición, afirman que "muchas intervenciones combinan todos los tipos de ejercicio (aeróbico, fortalecimiento muscular y equilibrio) en una sesión, y se ha demostrado que es eficaz" y que "la AF multicomponente es importante para mejorar la función física y disminuir el riesgo de caídas o lesiones por caída” (Bushman, 2019).

Sin embargo, gran parte de la investigación sobre la prevención de enfermedades y muerte prematura se ha centrado en una población convenientemente disponible de adultos jóvenes y de mediana edad, no específicamente en adultos mayores ≥ 60 años. Aunque puede haber información aplicable en estos estudios, los individuos difieren ampliamente en cómo envejecen biológicamente y en cómo fisiológicamente pueden adaptarse a un programa de ejercicio específico. Esto sugiere que la edad avanzada está asociada con cambios fisiológicos que resultan en reducciones en la capacidad funcional y disminuciones en el volumen e intensidad de la AF. Esta variabilidad interindividual diversa, que se observa en los adultos mayores, puede deberse a una combinación de factores genéticos y de estilo de vida, pero, de cualquier manera, una cosa es segura, existen diferencias entre los adultos mayores y los de mediana edad y es necesario realizar más investigaciones para descubrir esas diferencias clave.

Cuando se compara a los adultos mayores físicamente activos con sus contrapartes no activos, queda claro que la AF está desempeñando un papel clave para envejecer bien y prevenir la aparición temprana de enfermedades (D'antona et al., 2007; Pollock et al., 2014). Aunque alentar y apoyar a los adultos mayores para que sean más activos físicamente no tiene una solución única, crear conciencia y educar a las personas sobre los beneficios físicos, mentales y sociales de la AF puede ser parte de la solución. Otra parte de esa solución es proporcionar prescripciones de ejercicio informadas que sean calculadas y específicas.

La aparición de la prescripción de HIIT en enfermedades crónicas y envejecimiento

Aunque el entrenamiento continuo de intensidad moderada (MICT) ha sido históricamente la principal recomendación de ejercicio, las “Physical Activity Guidelines for Americans”, también permiten 75 minutos de ejercicio de intensidad vigorosa a la semana en lugar de 150 minutos de ejercicio de intensidad moderada (Bushman, 2019). HIIT es un régimen de ejercicio que parece estar ganando más popularidad en la población general como una forma rápida y eficaz, pero agradable, de participar en la AF. HIIT, al igual que MICT, se puede realizar en muchas formas diferentes de ejercicio, desde caminar hasta andar en bicicleta y remar. La diferencia es que HIIT consiste en alternar períodos cortos de ejercicio intenso con períodos de recuperación de movimiento pasivo o de intensidad moderada. Por lo general, los intervalos de trabajo varían de 10 a 4 minutos en o cerca de la capacidad máxima de un individuo con intervalos de recuperación que son aproximadamente iguales al intervalo de trabajo. El intervalo de recuperación puede ser una recuperación pasiva (sin ejercicio) o activa (ejercicio) a una intensidad mucho menor, y este intervalo combinado de trabajo a descanso se repite varias veces. Por lo tanto, alternar intervalos de alta intensidad con intervalos de baja intensidad permite que un individuo pase más tiempo a una intensidad elevada, por lo que hace que el tiempo total de ejercicio sea menor en comparación con MICT. Así, aunque un régimen HIIT puede ser muy agotador, desde el punto de vista logístico, el entrenamiento lleva menos tiempo y puede ser muy apropiado en una sociedad con poco tiempo.

HIIT también ha ganado una atención considerable como un programa de ejercicio adecuado para pacientes con enfermedades crónicas, como enfermedades cardiovasculares y diabetes, debido a su mayor efecto sobre la condición cardiorrespiratoria y la función metabólica (Hannan et al., 2018; Tjønna et al., 2008). Múltiples estudios han informado que, en comparación con MICT, se ha demostrado que HIIT produce mejoras superiores en los índices de aptitud cardiorrespiratoria (Angadi et al., 2015; Hannan et al., 2018; Hwang et al., 2019; Ramos et al., 2015). Además, un estudio de Lee et al. (2011) encontró que la aptitud cardiorrespiratoria estaba más fuertemente asociada con la mortalidad por todas las causas que la AF sola; por lo tanto, se debe fomentar la mejora de la aptitud cardiorrespiratoria para reducir el riesgo de mortalidad por todas las causas (Lee et al., 2011).

Ventajas fisiológicas de HIIT en comparación con MICT

El beneficio de HIIT en comparación con MICT es que una persona puede realizar grandes cantidades de ejercicio de alta intensidad debido a los períodos de descanso que no serían posibles en el entrenamiento continuo tradicional. El cuerpo de evidencia actual sugiere que HIIT puede inducir mejoras iguales, si no superiores, en la aptitud cardiovascular y la salud metabólica en comparación con MICT. Sin embargo, parece faltar la investigación que investiga los parámetros fisiológicos exactos que explican las adaptaciones más fuertes, aunque las explicaciones actuales afirman que el tiempo que se pasa cerca de la capacidad aeróbica máxima y el aumento del reclutamiento de fibras musculares son las claves para hacer que el HIIT sea más ventajoso. La literatura de Gibala y McGee (2008) sugiere que pequeñas cantidades de HIIT pueden aumentar de forma aguda la capacidad oxidativa del músculo esquelético y alterar los mecanismos de control metabólico. Además, afirman que su investigación ha observado aumentos sustanciales de la actividad enzimática mitocondrial del citrato sintasa y el citocromo oxidasa en tan solo 6 sesiones de participación en HIIT durante dos semanas (Gibala & McGee, 2008). Estos datos sugieren que los aumentos de la capacidad aeróbica debido al HIIT, pero no al MICT, se deben a la mayor actividad mitocondrial que tiene lugar en la fibra del músculo esquelético local causada por la mayor cantidad de ejercicio realizado a intensidades más altas. En consecuencia, este aumento de la actividad mitocondrial provocado por HIIT podría tener un doble propósito no solo para aumentar la capacidad aeróbica sino también para aumentar la sensibilidad a la insulina, ya que se ha demostrado que los diabéticos tipo 2 tienen una capacidad mitocondrial disminuida (Hood et al., 2011). De manera similar, y posiblemente mejor entendido, es el hecho de que, con el aumento de la intensidad de la actividad, un individuo reclutará una mayor cantidad de fibras musculares (unidades motoras) para completar la tarea. En particular, el individuo primero reclutará fibras de contracción lenta (Tipo I), seguidas por fibras de contracción rápida II-A, luego por fibras de contracción rápida II-X y, por último, por fibras de contracción rápida II-B (Thomson et al., 1979; VÖLLESTAD & BLOM, 1985). Por lo tanto, la mayor intensidad de HIIT en comparación con MICT generalmente recluta más fibras musculares durante la sesión de ejercicio, lo que induce una mayor capacidad oxidativa muscular en ese mayor número de fibras musculares, creando así adaptaciones fisiológicas más positivas.

¿Los adultos mayores tienen un mayor riesgo cuando realizan HIIT?

Al abordar la seguridad de utilizar HIIT en una población que envejece y en personas con afecciones crónicas, siempre es importante tener en cuenta que la intensidad del entrenamiento es relativa al nivel de condición física de las personas. Por lo tanto, HIIT es diferente, pero muy específico para todos los que participan en él. Eso significaría que un individuo físicamente no apto puede simplemente necesitar caminar a un ritmo ligeramente mayor, mientras que un individuo activo y en forma puede necesitar correr a un ritmo rápido para lograr la misma intensidad (% FCmáx, % VO2máx, etc.).

Actualmente no hay consenso sobre si el HIIT pone a un adulto mayor en mayor riesgo de sufrir un evento adverso o una lesión grave. Sin embargo, un estudio afirma que una sola sesión de HIIT puede provocar un riesgo transitorio elevado de caídas (Donath & Roth, 2014). Si ese fuera el caso, se podría argumentar que una de las razones principales por las que el HIIT es tan beneficioso es la eficiencia del tiempo. Otros estudios sugieren que la fatiga inducida por el ejercicio, sin importar el método, es una realidad y que la fatiga puede generar alteraciones agudas en el equilibrio y los parámetros de la marcha (Helbostad et al., 2007; Morrison et al., 2016; Nagano et al., 2014). Sin embargo, todos estos estudios incluyeron una población de adultos mayores de 70 años o más, y la mayoría de esos estudios se centraron en la fatiga por ejercicio de fuerza. Una revisión sistemática sobre el tema afirma que, aunque el equilibrio se ve afectado debido a la fatiga inducida por el ejercicio, la tasa de fatiga y la recuperación de esa fatiga varió mucho entre los participantes / estudios (Helbostad et al., 2010). Aparte de la investigación de Donath & Roth (2014), pocos estudios han examinado el efecto agudo que el HIIT puede tener en una población que envejece.

Aunque no existe un consenso claro sobre la seguridad del HIIT, gran parte de las investigaciones realizadas sugieren que el HIIT es tan seguro y posiblemente más agradable que los protocolos de ejercicio MICT tradicionales (Marriott et al., 2021; Villelabeitia Jaureguizar et al., 2016). Las revisiones sistemáticas a menudo afirman que es necesario realizar más investigaciones a largo plazo para determinar la seguridad y viabilidad del entrenamiento HIIT en adultos mayores. Sin embargo, a pesar de esas afirmaciones, los estudios individuales han llegado a la conclusión de que el HIIT es seguro, factible y bien tolerado en una población de adultos mayores que consta de ciertos individuos con comorbilidades divergentes significativas (Angadi et al., 2015; Hwang et al., 2016).

Objectives

Overall:

The primary objective of this Ph.D. thesis was to determine the acute and long-term effects that a cycle ergometer HIIT protocol may have in older adults and how it compares to other exercise interventions commonly used in the same population.

Specifically:

- Perform a systematic review of randomized control trials (RCT) within an aging population that investigated the overall effect of HIIT versus MICT protocols and assess the general findings of the HIIT interventions (Paper I).
- Evaluate if there is a consensus amongst the published literature as to a general HIIT intervention that works best in an aging population (Paper I).
- Carry out a systematic review of RCT within an aging population that investigated the general impacts of a resistance training (RT) protocol on key outcome measures relating to gait and balance parameters (Paper II).
- Determine the feasibility of a cycle ergometer HIIT protocol prescribed to older adults using heart rate (HR) and rate of perceived exertion (RPE) alone (Paper III).
- Establish what effects a cycle ergometer HIIT protocol may have on strength, balance, and gait variables in an already active older adult population (Paper III).
- Determine if a single session of cycle ergometer HIIT produces a negative, transient effect on balance and gait parameters in older adults when compared to that of a metabolically matched MICT protocol (Paper IV).

Hypotheses:

- *Paper I* – High-Intensity Interval Training will be a safe and effective way to participate in aerobic exercise for older adults that should be utilized by health practitioners when appropriate.
- *Paper II* – Resistance training will increase strength and therefore improve gait and balance parameters in older adults at risk for falls.
- *Paper III* – It will be appropriate and effective to prescribe a cycle ergometer HIIT protocol using HR and/or RPE without aggressive oversight or need for specialized equipment.

- *Paper IV* – There will be no significant difference in acute balance or gait parameters post exercise if the cycle ergometer HIIT and MICT protocols are metabolically matched.

Objetivos

General:

El objetivo principal de esta tesis doctoral fue determinar los efectos agudos y crónicos que puede tener un protocolo HIIT en cicloergómetro en adultos mayores y cómo se compara con otras intervenciones de ejercicio comúnmente utilizadas en la misma población.

Específicos:

- Realizar una revisión sistemática para compararla eficacia de dos métodos de entrenamiento, HIIT vs. MICT, en la capacidad funcional de adultos mayores (Artículo I).
- Evaluar si existe un consenso entre la literatura publicada en cuanto a una intervención HIIT general que es más eficaz en una población que envejece (Articulo I).
- Realizar una revisión sistemática de los efectos de un protocolo de entrenamiento de resistencia (RT) sobre las medidas de resultado clave relacionadas con los parámetros de la marcha y el equilibrio de adulto mayores (Articulo II).
- Comprobar la eficacia del uso frecuencia cardiaca (FC) y percepción subjetiva del esfuerzo (RPE) al emplear un protocolo HIIT de cicloergómetro prescrito a adultos mayores (Articulo III).
- Establecer qué efecto tiene un protocolo un protocolo HIIT en cicloergómetro sobre las variables de fuerza, equilibrio y marcha en una población adulta mayor activa (Articulo III).
- Determinar si una sola sesión de cicloergómetro HIIT produce un efecto negativo y transitorio en los parámetros de equilibrio y marcha en adultos mayores en comparación con el de un protocolo MICT de semejante incidencia metabólica (Articulo IV).

Hipótesis:

- Artículo I – El entrenamiento de intervalos de alta intensidad será una forma segura y eficaz de participar en ejercicios aeróbicos para adultos mayores que los profesionales deben utilizar cuando corresponda.

- Articulo II – El entrenamiento de resistencia aumentará la fuerza y, por lo tanto, mejorará los parámetros de la marcha y el equilibrio en adultos mayores con riesgo de caídas.
- Articulo III – Se verificará que es apropiado y eficaz prescribir un protocolo HIIT en cicloergómetro utilizando HR y/o RPE sin supervisión agresiva o necesidad de equipo especializado.
- Artículo IV – Se confirmará que no hay diferencias significativas en el equilibrio agudo o los parámetros de la marcha después del ejercicio si los protocolos HIIT y MICT del cicloergómetro coinciden metabólicamente.

Methods

The most relevant methods and materials used in the papers included in this Ph.D. thesis are summarized in the following table (Table 1).

The ethical recommendations approved in the Declaration of Helsinki (2013) were observed throughout the completion of the current Ph.D. thesis. In addition, we followed the instructions of the European Union on Good Clinical Practice (111/3976/88 of July 1990), as specified in a national legal framework for human clinical research (Royal Decree 561/1993 on clinical essays). Individual research projects were presented and approved by two separate University Ethics Committees (University of Jaen - Reference: NOV.19/5.TES; and University of Southern Mississippi Institutional Review Board, #IRB-20-519). All participants signed informed written consent prior to the start of all data collection.

Table 1. Methodology used in the current thesis

<table>
<tr><th>Manuscript</th><th>Objective</th><th>Design</th><th>Participants</th><th>Protocol</th><th>Outcome Measures</th></tr>
<tr><td>I. Comparison of High-Intensity Interval Training to Moderate-Intensity Continuous Training in Older Adults: A Systematic Review</td><td>Investigate the overall effect of HIIT versus MICT protocols and assess the general findings of the HIIT interventions and if there is a more appropriate protocol for older adults.</td><td>Systematic Review</td><td colspan="3">• Three electronic databases (PubMed, Scopus, and Web of Science [MEDLINE]) were searched for RCT comparing the effect of HIIT and MICT in older adults. Jan. 2008 to December 2018
• Search terms included: HIIT OR HIT OR high-intensity training OR interval training. The search terms were limited to TITLE/ABSTRACT/KEYWORDS.
• Inclusion criteria included full-length research articles published from January 2008 up to December 2018. Participants' age of 60 years and older and interventions comparing the effects of 4 weeks or more of HIIT versus MICT aerobic exercise.
• 22 articles were identified as meeting the inclusion criteria. PEDro was used to assess the quality and seven did not score five or greater and were removed. Fifteen studies remained and all were included in this systematic review</td></tr>
<tr><td>II. Influence of Resistance Training on Gait & Balance Parameters in Older Adults: A Systematic Review</td><td>Determine the general impacts of a RT protocol on key outcome measures relating to gait and balance parameters in older adults.</td><td>Systematic Review</td><td colspan="3">• Two electronic databases (PubMed, Scopus) were searched for that trials that measured at least one key outcome measure focusing on gait and/or balance in older adults.
• Search terms used included: resistance training OR strength training AND balance OR gait. The search terms were limited to TITLE/ABSTRACT/KEYWORDS.
• Inclusion criteria were full-length RCT published from January 2010 up to June 2020 that included participants with a median age of 60+ years. Resistance training interventions that measured at least one variable relating to gait and/or balance were included
• 20 articles were identified as meeting the criteria for inclusion. The remaining 20 studies were assessed for quality using PEDro, 8 of the studies did not score ≥ 5 and were removed. 12 studies remained, and all were included in the systematic review.</td></tr>
</table>

III. Utilizing Heart Rate and RPE to prescribe Cycle Ergometer HIIT in Older Adults: A Feasibility Study	Establish the feasibility of a cycle ergometer HIIT protocol using only HR and RPE as a guide to prescribing exercise intensity.	Intervention: Feasibility Study	N = 10 Age = 64.2 ± 6.1 Active	HIIT – 4 x 4-minute (33 minutes total) cycle ergometer intervals at 85% of HRmax 2 days per week 6 weeks	• Cycling parameters (HR, RPE, watts, RPM) • Blood parameters (glucose, total cholesterol) • Strength • Balance • Gait
IV. A Single Session of Cycle Ergometer High-Intensity Interval Training (HIIT) Does Not Produce a Transient Elevated Fall Risk in Adults 50 – 70 Years of Age.	Determine if a single session of cycle ergometer HIIT produces a negative, transient effect on balance and gait parameters when compared to that of a metabolically matched MICT protocol	Intervention: Within subjects repeated measures randomized cross-over	N = 20 Age = 58.2 ± 6.93 Active, healthy	HIIT – 4 x 4-minute (33 minutes total) cycle ergometer intervals at 85% of HRmax MICT – 42 minutes of continuous cycle ergometer exercise at 60% of HRmax.	• COP (Sway velocity & range) • Gait Speed • TUG • Cycling parameters (watts & RPM)

Instruments and procedures:

<u>*Anthropometrics:*</u>

- *Body composition*: Participants wore light, exercise-type clothing and were assessed barefoot during this test; they were asked to wear the same or similar clothing for both the pre- and post-tests. InBody 270 bio-impedance analysis (BIA) device was used to determine fat/fat-free mass and % body fat (InBody Co. Ltd. InBody Bldg., 625, Eonju-ro, Gangnam-gu, Seoul, 06106 Korea) in Paper II and the TANITA MC-780U (Arlington, IL, USA) multifrequency BIA device was used in Paper IV.
- *Body mass index (BMI)*: calculated by taking the weight in kilograms divided by height in meters squared (kg/m^2).
- *Height*: was measured to the nearest millimeter using a SECA 274 (Mount Pleasant, SC, USA) freestanding stadiometer with a digital display and an average of three measures was used.
- *Weight*: was measured to the nearest 0.1 kg using the InBody 270 BIA device in Paper II and the TANITA MC-780U BIA device in Paper IV.

<u>*Balance:*</u>

- *Center-of-pressure (COP):* data from a single force platform (AMTI, Watertown, MA) were acquired at 120Hz using a fixed, below-ground system. The COP trace was separated into medial/lateral (ML) and anterior/posterior (AP) components. Two postural sway measures were then computed from the exported COP data in the ML and AP directions: 1) sway range and 2) sway velocity. Both postural sway measures were calculated using a customized Excel spreadsheet (Microsoft, Redmond, WA) using similar equations as those reported previously reported (Bailey et al., 2021). The sway range is the maximum distance between any two points on the COP path in their respective direction (AP or ML). The sway velocity is the average velocity between each time point within the respective trial. Both velocity and range are reported as the average between the two trials. The battery of COP tests consisted of the double-leg eyes closed (EC) and single-leg eyes opened (SL) scenarios and the order of the scenarios for individual participants remained constant. However, the order of the test per participant was assigned on a rotating basis to minimize the possible effect of order bias (i.e., participant 1 started with EC while participant 2 started with SL). Prior to data collection, the investigators determined the participants' dominant foot by rolling a ball to the participant and asking them to kick it back to the investigator multiple times. The foot that dominated the receiving and passing of the ball was identified as the dominant leg and used for the SL scenario. Participants were then shown the proper stance, by always aligning the outside of their dominant foot with right or left side markers on the force platform. The bilateral stance was then demonstrated by placing the non-dominate foot shoulder-width apart on the force platform, toes facing forward, hands by your side but not touching any part of their body, and eyes fixed on their preferred location on the wall in front of them. Before starting and between conditions, the participants were asked to reposition themselves in the stance they had originally. Participants were then addressed "starting from your

original position, eyes looking at the spot on the wall in front of you, ready, 3,2,1… eyes closed/one foot". Each measure was recorded during a 10 second period and the average of two tests was used for data analysis. The participants were accessed with tennis shoes on, and the same pair of shoes was worn for both days.

- *Dynamic balance:* Timed up & go (TUG) was measured in seconds and reflects agility and dynamic balance (Podsiadlo & Richarson, 1991). To complete this test, the participant started sitting and stood from a standard 42cm chair. After a countdown (ready, set, go), a timer was initiated, and the participant started the test. They were asked to rise from the seated position, walk at a self-selected pace toward a marker on the floor 3 meters away from the chair, turn around the marker, return to the chair and sit down again. Timing stopped when the participant sat back down in the chair.
- *Static balance:* To perform this test, the participants stood unassisted on one leg (dominant and no dominant) with their arms folded across their chest. Time was recorded with a stopwatch and time started when the participant lifted one foot off the ground and stopped when that same foot touched the ground again or when the participant reached 60 seconds. The test was performed with eyes open and with tennis shoes. Before testing, the evaluator demonstrated the position to assume during the test (Iverson et al., 1990).

<u>Blood Parameters:</u>

- *Glucose:* Fasting serum blood samples were analyzed by using a handheld device using standard procedures; glucose was analyzed with the Accu-Check® Aviva (Roche Diabetes Care Spain, S.L. Avda. de la Generalitat, 171-173. 08174 Sant Cugat del Vallès, Barcelona).
- *Lipids:* Fasting serum blood samples were analyzed by using a handheld device using standard procedures; total cholesterol levels were analyzed with the Accutrend® Plus System (Roche Diagnostics International AG, Forrenstrasse 26343, Rotkreuz, Switzerland).

<u>Physical Fitness</u>:

- *Cardiorespiratory fitness:* 6 Minute walk test measured in distance (m) was used to assess aerobic endurance. The original version of this test is included in the Senior Fitness Test which has exhibited high reliability (Rikli & Jones, 1998). To complete the test, the participants walk for 6 minutes in a flat rectangular course (30 x 10 m) which is marked with a red line every 5 meters. Bright-colored cones were used to mark the four corners of the course which indicated to the participant the point at which they turn left. The participants were instructed to cover the maximum distance possible walking as fast as they comfortably could without running, and without overexerting or pushing themselves beyond their limits. Furthermore, the evaluators used encouragement phrases (e.g., You are doing well, keep up the good work, you can do it...) each time that the participants passed the starting point. When the time was complete, the evaluators announced the word "stop". At this moment, the evaluator recorded the total distance completed by each participant to the nearest 5 meters.

- *Strength – Upper body:* Hand grip dynamometry was used to measure isometric grip force. Both the right- and left-hand grip forces were measured. Two measures were performed for each hand, and the highest value was used for statistical analysis. Recovery was allowed between attempts. the TKK.5101 adaptive manual pressure dynamometer was used, with a precision of 0.1 Kg.
- *Strength – Lower body:*
  - *30-second Chair sit-to-stand (S-t-S):* To conduct the test, we used a standard 42 cm chair without arms. The chair was situated against a wall to avoid any movement during the test. To start the test, the participant was seated on the chair, back straight, feet approximately shoulder-width apart, and placed on the floor at an angle slightly back from the knees. The test started at the signal of "ready, set, go", then the participant would rise to a full stand (body erect and straight) and then return to the seated position. They were encouraged verbally to complete as many full stands as possible in 30 seconds. The evaluator silently counted each correct stand. Before the participant began the test, the evaluator conducted a demonstration and a practical trial of 1-2 repetitions was allowed. The total number of repetitions executed properly was recorded per previous research (Jones et al., 1999).
  - *10-repetition Chair S-t-S:* 10-repetition chair S-t-S was conducted in the same way as the 30-second chair S-t-S. We recorded the time required to complete 10 full stands from the sitting position. We allowed one practice trial before starting the test to learn the task and perform it properly. The participants were encouraged to complete the test as quickly as possible (Csuka & McCarty, 1985).
  - *Power:* was calculated using the method presented by Baltazar et al. (Baltasar-Fernandez et al., 2021). Using both the 30-second S-t-S and the 10 repetition S-t-S, we calculated power (watts). Mechanical Power (W) = Force x Velocity.

$$\textbf{Estimated Power} = (BM \times 0.9\ \times g) \times \frac{([Body\ h\ \times 0.5] - Chair\ h)}{\left(\frac{Total\ STS\ t}{n\ STS\ reps}\right) \times 0.5}$$

<u>Locomotion:</u>

- *Gait:* we used the OptoGait device (Microgate, Bolzano, Italy). It is an optical data acquisition system, composed of a transmitter and a receiver optical bar. Each bar contains 96 Infrared LEDs (1,041 cm resolution). These LEDs are located on the transmitter bar and communicate continuously with the LEDs located on the receiver bar. The system detects the eventual interruptions and their duration. It is a valid measurement device for the assessment of spatiotemporal gait parameters (Lienhard et al., 2013). The protocol used to carry out the test was 5 meters in which they had to walk within the walkway formed by the OptoGait. They made 6 roundtrip passes in which they had to walk comfortably at a normal pace, like that used in their everyday life. Participants started walking 2.5 meters before the start of the OptoGait system and turned around 2.5 meters from the end of the Optogait system. The total travel in

each pass was 10 m, as the Optogait covers the 5 m in the center, where the measurement takes place. The variables that were considered in this research were step length (cm), coefficient of variation of step (%), and gait speed (m/s).

- *Gait velocity:* was measured using the 10-meter walk test. The participant walked along a 10-meter path marked by a starting white line and a finishing white line. The timed section was the intermediate 6 meters to allow for acceleration in the first 2 meters and deceleration in the last 2 meters. The time in the intermediate 6 meters was measured using a wireless electronic timing system (Dashr Systems, Lincoln, NE) with the record time being transmitted via Bluetooth to a handheld device. The participant's comfortable, preferred walking speed was used, and they were instructed as such; "I want you to walk at a comfortable walking speed thru the white line on the opposite side of the walkway "I will say comfortable walking speed thru the white line, ready, set, go! When I say go, walk at your preferred walking speed until you cross the opposite white line". Two measures were taken at each of the five time points and the average of the two measures was used for data analysis. As the participants' time was taken over 6 meters, gait velocity was calculated as displacement over time.

<u>*Vital Measures:*</u>

- *Blood Pressure (BP):* Measured over the brachial artery using an automated oscillometric device (Omron M2 - HHEM-7121-E, OMRON Healthcare Europe B.V. Scorpius 33, 2132 LR Hoofddorp, The Netherlands) while the participant was seated with both feet placed on the ground. The lowest of two measurements was used.

Métodos

Los métodos y materiales más relevantes utilizados en los trabajos incluidos en esta Tesis Doctoral se resumen en la siguiente tabla (Tabla 1).

Las recomendaciones éticas aprobadas en la Declaración de Helsinki (2013) fueron respectadas a lo largo de la realización de la tesis actual. Además, seguimos las instrucciones de la Unión Europea sobre Buenas Prácticas Clínicas (111/3976/88 de julio de 1990), tal como se especifica en el marco legal nacional para la investigación clínica en humanos (Real Decreto 561/1993 sobre ensayos clínicos). Los proyectos de investigación individuales fueron presentados y aprobados por dos Comités de Ética Universitarios separados (Universidad de Jaén - Referencia: NOV.19/5.TES; y la Universidad del Sur de Mississippi, #IRB-20-519). Todos los participantes firmaron un consentimiento informado por escrito antes del inicio de toda la recopilación de datos.

Tabla 1. Metodología utilizada en la tesis doctoral

Manuscrito	Objetivo	Designo	Participantes	Protocolo	Medidas de Resultado
I. Comparison of High-Intensity Interval Training to Moderate-Intensity Continuous Training in Older Adults: A Systematic Review	Realizar una revisión sistemática para compararla eficacia de dos métodos de entrenamiento, HIIT vs. MICT, en la capacidad funcional de adultos mayores	Revisión sistemática	• Se realizaron búsquedas de RCT en tres bases de datos (PubMed, Scopus y Web of Science [MEDLINE]) que compararan el efecto de HIIT y MICT en adultos mayores. Enero de 2008 a diciembre de 2018 • Los términos de búsqueda incluyeron: HIIT OR HIT OR entrenamiento de alta intensidad OR entrenamiento a intervalos. Los términos de búsqueda se limitaron a TÍTULO / RESUMEN / PALABRAS CLAVE. • Los criterios de inclusión incluyeron RCT completos publicados desde enero de 2008 hasta diciembre de 2018. Edad del participante de 60 años o más e intervenciones que comparan los efectos de 4 semanas o más de ejercicio aeróbico HIIT con ejercicio aeróbico MICT. • Se identificaron 22 artículos que cumplían con los criterios de inclusión. Se utilizó PEDro para evaluar la calidad y siete no puntuaron cinco o más y fueron eliminados. Quedaron 15 estudios y todos se incluyeron en esta revisión sistemática		
II. Influence of Resistance Training on Gait & Balance Parameters in Older Adults: A Systematic Review	Realizar una revisión sistemática de los efectos de un protocolo de entrenamiento de resistencia (RT) sobre las medidas de resultado clave relacionadas con los parámetros de la	Revisión sistemática	• Se realizaron búsquedas en dos bases de datos electrónicas (PubMed, Scopus) de ensayos que midieron al menos una medida de resultado clave que se centra en la marcha y / o el equilibrio en adultos mayores. • Los términos de búsqueda utilizados incluyeron: entrenamiento de resistencia OR entrenamiento de fuerza AND equilibrio OR marcha. Los términos de búsqueda se limitaron a TÍTULO / RESUMEN / PALABRAS CLAVE. • Los criterios de inclusión fueron RCT completos publicados desde enero de 2010 hasta junio de 2020 que incluyeron participantes con una edad promedio de 60 años o más. Se incluyeron intervenciones de entrenamiento de resistencia que midieron al menos una variable relacionada con la marcha/equilibrio.		

	marcha y el equilibrio de adulto mayores		• Se identificaron 20 artículos que cumplían los criterios de inclusión. Se evaluó la calidad de los 20 estudios restantes mediante PEDro, 8 de los estudios no obtuvieron una puntuación ≥ 5 y se eliminaron. Quedaron 12 estudios y todos se incluyeron en la revisión sistemática.		
III. Utilizing Heart Rate and RPE to prescribe Cycle Ergometer HIIT in Older Adults: A Feasibility Study	Comprobar la eficacia del uso frecuencia cardiaca (FC) y percepción subjetiva del esfuerzo (RPE) al emplear un protocolo HIIT de cicloergómetro prescrito a adultos mayores	Estudio de intervención	N = 10 (7 mujeres; 3 hombres) Edad = 64.2 ± 6.1 años Activo	HIIT – 4 x 4-minutos (33 minutos en total) al 85% de la FCmáx. 2 días a la semana Por 6 semanas	• Parámetros de ciclismo (HR, RPE, vatios y RPM) • Parámetros sanguíneos (glucosa, colesterol) • Fuerza • Equilibrio • Marcha
IV. A Single Session of Cycle Ergometer High-Intensity Interval Training (HIIT) Does Not Produce a Transient Elevated Fall Risk in Adults 50 – 70 Years of Age.	Determinar si una sola sesión de cicloergómetro HIIT produce un efecto negativo y transitorio en los parámetros de equilibrio y marcha en adultos mayores en comparación con el de un protocolo MICT de semejante incidencia metabólica	Estudio de intervención	N = 20 (10 mujeres; 10 hombres) Edad = 58.2 ± 6.93 años Activo	HIIT - intervalos de 4 x 4 minutos (33 minutos en total) al 85% de la FCmáx. MICT - 42 minutos en total de ejercicio continuo al 60% de la FCmáx.	• Equilibrio - COP (velocidad y rango) • Velocidad de la marchabe • Timed Up-and-Go (TUG) • Parámetros de ciclismo (vatios y RPM)

Instrumentos y procedimientos:

<u>*Antropometría:*</u>

- *Composición corporal:* los participantes vestían ropa liviana de ejercicio y fueron evaluados descalzos durante esta prueba; se les pidió que usaran la misma ropa o una similar para las pruebas previas y posteriores. Se utilizó el dispositivo de análisis de bioimpedancia (BIA) InBody 270 para determinar la masa grasa/sin grasa y el % de grasa corporal (InBody Co. Ltd. InBody Bldg., 625, Eonju-ro, Gangnam-gu, Seúl, 06106 Corea) en El Paper II y el dispositivo BIA multifrecuencia TANITA MC-780U (Arlington, IL, EUA) se utilizó en Articulo IV.
- *Índice de masa corporal (IMC):* se calcula dividiendo el peso en kilogramos por la altura en metros al cuadrado (kg/m2).
- *Estatura:* se midió al milímetro más cercano utilizando un estadiómetro independiente SECA 274 (Mount Pleasant, SC, EE. UU.) con una pantalla digital y se utilizó un promedio de tres medidas.
- *Peso:* se midió con una precisión de 0,1 kg utilizando el dispositivo InBody 270 BIA en Articulo III y el dispositivo TANITA MC-780U BIA en Articulo IV.

<u>*Equilibrio:*</u>

- *Centro de presión (COP):* se utilizó una plataforma de fuerza única (AMTI, Watertown, MA) para recopilar datos, que se adquirieron a 120 Hz mediante un sistema subterráneo fijo. El trazo de COP se separó en componentes medial/lateral (ML) y anterior/posterior (AP). Luego se calcularon dos medidas de balanceo postural a partir de los datos COP exportados en las direcciones ML y AP: 1) rango de balanceo y 2) velocidad de balanceo. Ambas medidas de balanceo postural se calcularon usando una hoja de cálculo de Excel personalizada (Mircosoft, Redmond, WA) usando ecuaciones similares a las reportadas previamente (Bailey et al., 2021). El rango de balanceo es la distancia máxima entre dos puntos cualesquiera en la ruta COP en su dirección respectiva (AP o ML). La velocidad de balanceo es la velocidad promedio entre cada punto de tiempo dentro de la prueba respectiva. Tanto la velocidad como el alcance se informan como el promedio entre las dos pruebas. La batería de pruebas COP consistió en escenarios de dos piernas con los ojos cerrados (EC) y de una sola pierna con los ojos abiertos (SL) y el orden de los escenarios para los participantes individuales se mantuvo constante. Sin embargo, el orden de la

prueba por participante se asignó de forma rotatoria para minimizar el posible efecto del sesgo de orden (es decir, el participante 1 comenzó con EC mientras que el participante 2 comenzó con SL). Antes de la recopilación de datos, los investigadores determinaron el pie dominante de los participantes haciendo rodar una pelota hacia el participante y pidiéndole que la pateara al investigador varias veces. El pie que dominaba la recepción y el pase del balón se identificó como la pierna dominante y se utilizó para el escenario SL. Luego, a los participantes se les mostró la postura adecuada, siempre alineando la parte exterior de su pie dominante con los marcadores del lado derecho o izquierdo en la plataforma de fuerza. Luego se demostró la postura bilateral colocando el pie no dominante al ancho de los hombros en la plataforma de fuerza, los dedos de los pies mirando hacia adelante, las manos a los costados, pero sin tocar ninguna parte del cuerpo y los ojos fijos en su ubicación preferida en la pared frente a ellos. Antes de comenzar y entre las condiciones, se pidió a los participantes que se reposicionaran en la postura que tenían originalmente. Luego se dirigió a los participantes "comenzando desde su posición original, los ojos mirando a un lugar en la pared frente a usted, listo, 3, 2, 1… ojos cerrados/un pie". Cada medida se registró durante un período de 10 segundos y se utilizó el promedio de dos pruebas para el análisis de datos. Se accedió a los participantes con las zapatillas de deporte puestas, y se usó el mismo par de zapatos para ambos días.

- *Equilibrio dinámico:* Timed up & go (TUG) se midió en segundos y refleja agilidad y equilibrio dinámico (Podsiadlo & Richarson, 1991). Para completar esta prueba, el participante comenzaba sentado y se paraba en una silla estándar de 42 cm. Después de una cuenta regresiva (preparado, listo, ya), se inició un cronómetro y el participante comenzó la prueba. Se les pidió que se levantaran de la posición sentada, caminaran a un ritmo elegido por ellos mismos hacia un marcador en el suelo a 3 metros de distancia de la silla, dieran la vuelta al marcador, regresaran a la silla y se sentaran nuevamente. El tiempo se detuvo cuando el participante volvió a sentarse en la silla.
- *Equilibrio estático:* Para realizar esta prueba, los participantes se pararon sin ayuda sobre una pierna (dominante y no dominante) con los brazos cruzados sobre el pecho. El tiempo se registraba con un cronómetro y el tiempo comenzaba cuando el participante levantaba un pie del suelo y se detenía cuando ese mismo pie tocaba el suelo de nuevo o cuando el participante llegaba a los 60 segundos. La prueba se

realizó con los ojos abiertos y con zapatillas de deporte. Antes de la prueba, el evaluador demostró la posición a asumir durante la prueba (Iverson et al., 1990).

Parámetros de sangre:

- *Glucosa:* Las muestras de sangre sérica en ayunas se analizaron utilizando un dispositivo portátil utilizando procedimientos estándar; la glucosa se analizó con Accu-Check® Aviva (Roche Diabetes Care Spain, S.L. Avda. de la Generalitat, 171-173. 08174 Sant Cugat del Vallès, Barcelona).
- *Lípidos:* Se analizaron muestras de sangre sérica en ayunas usando un dispositivo portátil usando procedimientos estándar; los niveles de colesterol total se analizaron con el sistema Accutrend® Plus (Roche Diagnostics International AG, Forrenstrasse 26343, Rotkreuz, Suiza).

Aptitud física:

- *Aptitud cardiorrespiratoria:* se utilizó la prueba de caminata de 6 minutos medida en distancia (m) para evaluar la resistencia aeróbica. La versión original de esta prueba está incluida en el Senior Fitness Test que ha mostrado una alta fiabilidad (Rikli & Jones, 1998). Para completar la prueba, los participantes caminan durante 6 minutos en un recorrido rectangular plano (30m x 10m) que está marcado con una línea roja cada 5 metros. Se usaron conos de colores brillantes para marcar las cuatro esquinas del recorrido que indicaban al participante el punto en el que debían girar a la izquierda. Se instruyó a los participantes para que cubrieran la distancia máxima posible caminando lo más rápido que pudieran cómodamente sin correr, y sin sobre esforzarse o empujarse más allá de sus límites. Además, los evaluadores utilizaron frases de aliento (p. ej., lo estás haciendo bien, sigue así, puedes hacerlo...) cada vez que los participantes superaban el punto de partida. Cuando se completó el tiempo, los evaluadores anunciaron la palabra "stop". En ese momento, el evaluador registró la distancia total recorrida por cada participante con una aproximación de 5 metros.
- *Fuerza - Parte superior del cuerpo:* Se utilizó dinamometría de prensión manual para medir la fuerza de prensión isométrica. Se midieron las fuerzas de agarre tanto de la mano derecha como de la izquierda. Se realizaron dos medidas para cada mano, y el valor más alto se utilizó para el análisis estadístico. Se permitió la recuperación entre intentos. Se utilizó el dinamómetro de presión manual adaptativo TKK.5101, con una precisión de 0,1 Kg.

- *Fuerza – Parte inferior del cuerpo:*
  - Sit-to-Stand de 30 segundos en silla (S-t-S): Para realizar la prueba, se utilizó una silla estándar de 42 cm sin brazos. La silla se colocó contra una pared para evitar cualquier movimiento durante la prueba. Para comenzar la prueba, el participante estaba sentado en la silla, con la espalda recta, los pies separados aproximadamente al ancho de los hombros y colocado en el suelo en un ángulo ligeramente hacia atrás desde las rodillas. La prueba comenzaba con la señal de "preparados, listos, ya", luego el participante se ponía de pie completamente (cuerpo erguido y recto) y luego volvía a la posición sentada. Se les animó verbalmente a completar tantas paradas completas como fuera posible en 30 segundos. El evaluador contó en silencio cada parada correcta. Antes de que el participante comenzara la prueba, el evaluador realizó una demostración y se permitió una prueba práctica de 1-2 repeticiones. El número total de repeticiones ejecutadas correctamente se registró según investigaciones previas (Jones et al., 1999).
  - S-t-S de 10 repeticiones: la silla S-t-S de 10 repeticiones se realizó de la misma manera como la silla de 30 segundos S-t-S. Registramos el tiempo requerido para completar 10 soportes completos desde la posición sentada. Permitimos una prueba de práctica antes de comenzar la prueba para aprender la tarea y realizarla correctamente. Se animó a los participantes a completar la prueba lo más rápido posible (Csuka & McCarty, 1985).
  - Potencia: se calculó mediante el método presentado por Baltazar et al. (Baltasar-Fernández et al., 2021). Utilizando tanto el S-t-S de 30 segundos como el S-t-S de 10 repeticiones, calculamos la potencia (vatios). Potencia Mecánica (W) = Fuerza x Velocidad.

<u>*Locomotor:*</u>

- *Marcha:* utilizamos el dispositivo OptoGait (Microgate, Bolzano, Italia). Es un sistema óptico de adquisición de datos, compuesto por un transmisor y una barra óptica receptora. Cada barra contiene 96 LED infrarrojos (resolución de 1041 cm). Estos LED están ubicados en la barra del transmisor y se comunican continuamente con los LED ubicados en la barra del receptor. El sistema detecta las eventuales interrupciones y su duración. Es un dispositivo de medición válido para la evaluación de parámetros espaciotemporales de la marcha (Lienhard et al., 2013). El protocolo

utilizado para realizar la prueba fue de 5 metros en los que debían caminar dentro de la pasarela formada por el OptoGait. Hicieron 6 pases de ida y vuelta en los que debían caminar cómodamente a un ritmo normal, como el que utilizaban en su día a día. Los participantes comenzaron a caminar 2,5 metros antes del inicio del sistema OptoGait y dieron la vuelta 2,5 metros después del final del sistema Optogait. El recorrido total en cada pasada fue de 10 m, ya que el Optogait cubre los 5 m del centro, donde se realiza la medición. Las variables que se consideraron en esta investigación fueron longitud del paso (cm), coeficiente de variación del paso (%), y velocidad de la marcha (m/s).

- *Velocidad de la marcha:* se midió mediante la prueba de marcha de 10 metros. El participante caminó por un camino de 10 metros marcado por una línea blanca inicial y una línea blanca final. La sección cronometrada fue la intermedia de 6 metros para permitir la aceleración en los primeros 2 metros y la desaceleración en los últimos 2 metros. El tiempo en los 6 metros intermedios se midió utilizando un sistema de cronometraje electrónico inalámbrico (Dashr Systems, Lincoln, NE) y el tiempo récord se transmitió a través de Bluetooth a un dispositivo portátil. Se utilizó la velocidad de marcha preferida y cómoda de los participantes, y se les instruyó como tal; “Quiero que camine a una velocidad de caminata cómoda a través de la línea blanca en el lado opuesto de la pasarela” Diré velocidad de caminata cómoda a través de la línea blanca, preparado, listo, ¡adelante! Cuando te diga, camina a la velocidad que prefieras hasta que cruces la línea blanca opuesta”. Se tomaron dos medidas en cada uno de los cinco puntos de tiempo y se usó el promedio de las dos medidas para el análisis de datos. Como el tiempo de los participantes se tomó en 6 metros, la velocidad de la marcha se calculó como el desplazamiento en el tiempo.

<u>*Medidas Vitales:*</u>

- *Presión arterial (BP)*: medida sobre la arteria braquial mediante un dispositivo oscilométrico automatizado (Omron M2 - HHEM-7121-E, OMRON Healthcare Europe BV Scorpius 33, 2132 LR Hoofddorp, Países Bajos) mientras el participante estaba sentado con ambos pies sobre el suelo. Se utilizó la más baja de dos mediciones.

Results

The following results section is presented just as the articles were submitted and/or published in their respective scientific journal. Also, the primary findings from each article are presented in Table 2.

Table 2. Results

Manuscript	Results
I. Comparison of High-Intensity Interval Training to Moderate-Intensity Continuous Training in Older Adults: A Systematic Review	15 studies were included in this systematic review. Intervention duration ranged from 4 to 16 weeks. Most of the studies were conducted for 8 weeks (range of 4-16 weeks) and averaged 3 days per week (range of 2 to 5 days/week). Cycle ergometer HIIT was the most common mode of exercise however treadmill walking was close behind. There was a 2:1 male to female ratio amongst the participants and most participants were between the age of 60 – 65 years. Most of the participants had an underlying condition and many of the studies recruited participants with specific chronic conditions. 7 of the 15 studies reported that HIIT was superior to MICT whereas 8 of the 15 studies reported that HIIT and MICT demonstrated similar benefits. Not one study reported a lessened effect of HIIT in comparison to MICT.
II. Influence of Resistance Training on Gait & Balance Parameters in Older Adults: A Systematic Review	12 studies were included in this review, and all were published in the English language. The total number of participants analyzed in all studies was 499 (including resistance-trained participants only). Eleven of the twelve studies had reported the gender of the participants and approximately 60% of them were female. Three studies reported mean ages of 65–69.9 years, 6 studies reported mean ages between 70–79.9 years, two studies reported mean ages between 80–89.9 years, and one study reported a mean age of >90 years. Intervention duration ranged greatly from 6 to 32 weeks and the studies were evenly split between 2 days per week and 3 days per week for training frequency. All twelve studies observed a positive effect of the RT intervention in at least one of the studies' outcome measures. All eleven studies that analyzed balance specified an improvement in either static and/or dynamic balance. All five studies reporting on gait measures reported a positive effect of the RT intervention, and particularly an improvement in gait speed.
III. Utilizing Heart Rate and RPE to prescribe Cycle Ergometer HIIT in Older Adults: A Feasibility Study	Significant correlations were found between %HRmax and W/kg in seven of the ten participants. Only two participants had significant correlations between RPE and W/kg. Five of the ten participants demonstrated a significant correlation between %HRmax and RPE. The observation of all exercise sessions reveals a significant correlation between RPE and W/kg (r=0.144) and %HRmax and RPE (r=0.147). Pearson correlation was not significant between %HRmax and W/kg when compared across all exercise sessions. The participants lower limb strength demonstrated by the 10 repetition Sit-to-Stand (p=0.004, Cohen's D=0.660) and 30 second Sit-to-Stand (p=0.021, Cohen's D=0.635) displayed significant differences pre- to post-intervention. Increased functional capacity demonstrated by TUG (p=0.001, Cohen's D=0.940) and SB (p=0.034,

	Cohen's D=0.292) also presented significant differences pre- to post-intervention. No significant differences pre- to post-intervention were assessed for the other outcome measures reported in this study.
IV. A Single Session of Cycle Ergometer High-Intensity Interval Training (HIIT) Does Not Produce a Transient Elevated Fall Risk in Adults 50 – 70 Years of Age.	There was a total of twenty participants that completed both exercise sessions with an average age of 58.2 years ± 6.93. The two exercise modes were metabolically matched as demonstrated in the amount of energy expended in kilocalories (kcal) at 242.95 ± 87.95 for HIIT and 234.41 ± 87.18 for MICT ($p = 0.519$). No significant difference for condition or condition x time effects were found for all outcome variables. However, significant time effects were found for sway velocity in the AP-SL ($F [4] = 4.78$, $p = 0.002$, $\eta p2 = 0.23$) and ML-SL ($F [2.69] = 3.65$, $p = 0.023$, $\eta p2 = 0.186$) positions and significant difference for time in sway range in the ML-EC ($F [4] = 4.52$, $p = 0.003$, $\eta p2 = 0.21$) position. There was also a significant effect for time in gait speed ($F [1.86] = 4.66$, $p = 0.018$, $\eta p2 = 0.197$).

Resultados

La siguiente sección de resultados se presenta tal como los artículos fueron presentados y / o publicados en sus respectivas revistas científicas. Además, los hallazgos principales de cada artículo se presentan en la Tabla 2.

Tabla 2. Resultados

Manuscrito	Resultados
I. Comparison of High-Intensity Interval Training to Moderate-Intensity Continuous Training in Older Adults: A Systematic Review	Se incluyeron 15 estudios en esta revisión sistemática. La duración de la intervención varió de 4 a 16 semanas. La mayoría de los estudios se realizaron durante 8 semanas (rango de 4 a 16 semanas) y un promedio de 3 días por semana (rango de 2 a 5 días por semana). El cicloergómetro HIIT era el modo más común de ejercicio, sin embargo, caminar en cinta rodante estaba muy cerca. Había una proporción de 2:1 de hombre a mujer entre los participantes y la mayoría de los participantes tenían entre 60 y 65 años. La mayoría de los participantes tenían síntomas subyacentes y muchos de los estudios reclutaron participantes con enfermedades crónicas. 7 de los 15 estudios informaron que HIIT era superior a MICT, mientras que 8 de los 15 estudios informaron que HIIT y MICT demostraron beneficios similares. Ningún estudio informó una disminución del efecto de HIIT en comparación con MICT.
II. Influence of Resistance Training on Gait & Balance Parameters in Older Adults: A Systematic Review	Se incluyeron 12 estudios en esta revisión y todos se publicaron en inglés. El número total de participantes analizado en todos los estudios fue 499 (incluidos los participantes entrenados solamente en resistencia). 11 de los 12 estudios habían informado el sexo de los participantes y aproximadamente el 60% de ellos eran mujeres. 3 estudios informaron edades medias de 65 a 69,9 años, 6 estudios informaron edades medias de 70 a 79,9 años, 2 estudios informaron edades medias de 80 a 89,9 años y un estudio informó una edad media de > 90 años. La duración de la intervención varió en gran medida de 6 a 32 semanas y los estudios se dividieron uniformemente entre 2 días a la semana y 3 días a la semana para la frecuencia de entrenamiento. Todos los estudios observaron un efecto positivo de la intervención de RT en al menos una de las medidas de resultado de los estudios. Los once estudios que analizaron el equilibrio especificaron una mejora en el equilibrio estático y / o dinámico. Los cinco estudios que informaron sobre las medidas de la marcha informaron un efecto positivo de la intervención de RT y, en particular, una mejora en la velocidad de la marcha.
III. Utilizing Heart Rate and RPE to prescribe Cycle Ergometer HIIT in Older Adults: A Feasibility Study	Se encontraron correlaciones significativas entre % FCmax y W / kg en siete de los diez participantes. Solo dos participantes tuvieron correlaciones significativas entre RPE y W / kg. Cinco de los diez participantes demostraron una correlación significativa entre el% FCmax y el RPE. La observación de todas las sesiones de ejercicio revela una correlación significativa entre el RPE y W / kg (r = 0,144) y el % FCmax y RPE (r = 0,147). La correlación de Pearson no fue significativa entre % FCmáx y W / kg en comparación con todas las sesiones de ejercicio. La fuerza de las extremidades inferiores de los participantes demostrada por el Sit-to-Stand de 10 repeticiones (p = 0,004, D de Cohen = 0,660) y el Sit-to-

	Stand de 30 segundos (p = 0,021, D de Cohen = 0,635) mostraron diferencias significativas antes y después de la intervención. El aumento de la capacidad funcional demostrada por TUG (p = 0,001, D de Cohen = 0,940) y SB (p = 0,034, D de Cohen = 0,292) también presentó diferencias significativas antes y después de la intervención.
IV. A Single Session of Cycle Ergometer High-Intensity Interval Training (HIIT) Does Not Produce a Transient Elevated Fall Risk in Adults 50 – 70 Years of Age.	Hubo un total de veinte participantes que completaron ambas sesiones de ejercicio con una edad promedio de 58,2 años ± 6,93. Los dos modos de ejercicio se emparejaron metabólicamente como se demostró en la cantidad de energía gastada en kilocalorías (kcal) a 242,95 ± 87,95 para HIIT y 234,41 ± 87,18 para MICT (p = 0,519). No se encontraron diferencias significativas para la condición o los efectos de condición x tiempo para todas las variables de resultado. Sin embargo, se encontraron efectos de tiempo significativos para la velocidad de oscilación en AP-SL (F [4] = 4.78, p = 0.002, $\eta p2$ = 0.23) y ML-SL (F [2.69] = 3.65, p = 0.023, $\eta p2$ = 0.186) posiciones y diferencia significativa para el tiempo en el rango de oscilación en la posición ML-EC (F [4] = 4.52, p = 0.003, $\eta p2$ = 0.21). También hubo un efecto significativo del tiempo en la velocidad de la marcha (F [1,86] = 4,66, p = 0,018, $\eta p2$ = 0,197).

Papers (Artículos)

I. Comparison of High-Intensity Interval Training to Moderate-Intensity Continuous Training in Older Adults: A Systematic Review

Christopher J. Keating, Juan A. Párraga -Montilla,
Pedro Á. Latorre Román, and Rafael Moreno del Castillo

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SCHOLARLY REVIEW

Comparison of High-Intensity Interval Training to Moderate-Intensity Continuous Training in Older Adults: A Systematic Review

Christopher J. Keating, Juan Á. Párraga Montilla, Pedro Á. Latorre Román, and Rafael Moreno del Castillo

High-intensity interval training (HIIT) is emerging as a safe and effective means to combat chronic diseases. The objective of this work was to perform a systematic review of the effect of HIIT interventions in an aging population. Three electronic databases were searched for randomized trials comparing the effect of HIIT and moderate-intensity continuous training in older adults. After a thorough screening process, 15 articles were identified as meeting the inclusion criteria. All studies expressed a comparable or superior effect of HIIT in cardiorespiratory fitness measures. No studies reported a lessened effect of HIIT in comparison with moderate-intensity continuous training. This systematic review demonstrates that HIIT is a useful exercise regimen, which can be used in older adults to increase cardiorespiratory fitness. More research is needed to determine the effects of HIIT in an aging, predominately female population.

***Keywords**:* aging, cardiorespiratory fitness, exercise

The World Health Organization (WHO) has stated that the number of people aged 65 years or older is anticipated to increase from an estimated 524 million in 2010 to 1.5 billion in 2050. The WHO also reports that noncommunicable chronic diseases currently accounts for almost 60% of all deaths, and it is expected to rise to 73% of all deaths by 2020 (WHO, 2019). The risk of developing and eventually dying from chronic diseases such as cardiovascular disease and diabetes increases with age (Chodzko-Zajko et al., 2009). Physical inactivity is estimated to be the primary cause of approximately 21–25% of breast and colon cancers, 27% of diabetes, and approximately 30% of heart disease worldwide (WHO, 2019). The WHO estimates that in Europe alone physical inactivity accounts for 1 million deaths each year (WHO, 2019). However, strong evidence points to physical activity as a primary predictor of all-cause mortality. There is a growing body of evidence confirming that more active persons have lower rates of heart disease, diabetes, certain cancers, and depression (Chodzko-Zajko et al., 2009; Lee et al., 2011; Nes, Vatten, Nauman, Janszky, & Wisløff, 2014). Also, physical activity in an aging population is associated with increased functional health, a lower risk of falling, and better cognitive function (Chodzko-Zajko et al., 2009).

Considering all the convincing evidence, exercise should be considered a primary focus in the fight against noncommunicable chronic diseases and specifically the leading cause of death worldwide, heart disease. Although moderate-intensity continuous training (MICT) has historically been the leading exercise recommendation, the U.S. physical activity guidelines also allow for 75 min of vigorous-intensity exercise a week rather than 150 min of moderate-intensity exercise. High-intensity interval training (HIIT) is an exercise regimen that seems to be gaining more popularity in the general population as a quick and effective, yet enjoyable, way to partake in physical activity.

High-intensity interval training, just like MICT, can take place in many different forms of exercise from walking to cycling to rowing. The difference is that HIIT consists of alternating short periods of intense exercise with recovery periods of passive or moderate-intensity movement. Typically, the work intervals vary from 10 s to 4 min at or near an individual's maximum capacity with recovery intervals that are approximately equal to the work interval. The recovery interval can be passive rest (no exercise) or moderate activity at a much lower intensity, and this combined work to rest interval is repeated several times. Thus, alternating high-intensity with low-intensity intervals allows an individual to spend a longer amount of time at an elevated intensity, therefore, making the total exercise time, less in comparison with MICT. So, although a HIIT regimen can be very strenuous, logistically speaking, the workout takes less time and can be very appropriate in a time-crunched society.

High-intensity interval training has also gained considerable attention as a suitable exercise program for patients with chronic diseases such as cardiovascular disease and diabetes due to its increased effect on cardiorespiratory fitness and metabolic function (Hannan et al., 2018; Tjønna et al., 2008). Multiple studies have reported that when compared with MICT, HIIT has been shown to elicit superior improvements in indices of cardiorespiratory fitness (Angadi et al., 2018; Hannan et al., 2018; Hwang et al., 2017; Ramos, Dalleck, Tjonna, Beetham, & Coombes, 2015). Also, a study by Lee et al. (2011) found that cardiorespiratory fitness was more strongly associated with all-cause mortality than physical activity alone; therefore, improving cardiorespiratory fitness should be encouraged to reduce the risk of all-cause mortality.

Objective

This work aimed to perform a systematic review of randomized control trials (RCTs) within an aging population that investigated the overall effect of HIIT versus MICT programs and to measure the general results of the HIIT interventions. The secondary objective was to assess if there is a consensus of a general HIIT intervention that works best in an aging population.

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Methods

This review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-analyses statement guidelines (Moher, Liberati, Tetzlaff, Altman, & PRISMA Group, 2009). Three electronic databases (PubMed, Scopus, and Web of Science [MEDLINE]) were searched for RCTs comparing the effect of HIIT and MICT in older adults. Search terms used included: HIIT OR HIT OR high-intensity training OR interval training. The search terms were limited to TITLE/ABSTRACT/KEYWORDS. The search was further limited to "clinical trials," in "humans," published in the" last ten (10) years" (January 2008 to December 2018), "adult: 65+ years" of age, and published in "English" or "Spanish."

Study Selection

Inclusion criteria. The inclusion criteria for this systematic review were full-length research articles published in peer-reviewed academic journals in the English or Spanish language. Only RCTs published from January 2008 up to December 2018 were eligible. Studies included participants with a median age of 60 years and older. Interventions comparing the effects of 4 weeks or more of HIIT versus MICT aerobic exercise were included. Specifically, HIIT was characterized by repeated higher intensity sprint-like intervals subsequently followed by rest/recovery periods (active or passive). MICT was characterized by a single, continued, moderate-intensity exercise regimen.

Exclusion criteria. Abstracts, conference presentations, poster presentations, letters to the editor, books or book chapters, unpublished papers, proposed protocols, validation studies, or retrospective designs were excluded. Studies were also excluded if there was no comparison group participating in MICT, or if the participants were taking supplements, or if the median age of participants was ≤60 years. In addition, studies that did not achieve a score of five or greater on the Physiotherapy Evidence Database (PEDro) scale were also excluded.

Results

The initial search resulted in 380 studies; after duplicates were removed, 144 studies remained, and the abstracts were reviewed for meeting the inclusion and exclusion criteria. Following the initial screening process, 104 records were removed due to the abstract not meeting the inclusion/exclusion criteria. Forty full-text articles were assessed further, and 22 of the articles were identified as meeting the criteria for inclusion. The 22 remaining studies were assessed for quality using the PEDro scale, seven of the studies did not score five or greater and were removed. Fifteen studies remained and all were included in this systematic review (Figure 1).

The PEDro scale is an 11-item scale that rates RCTs from 0 to 10. One item (eligibility criteria) is included in the scale, because it influences external validity but not the internal or statistical validity of the trial; thus, it is not counted toward the final score. Therefore, the PEDro score is generated from an 11-item scale resulting in a final score of 0–10. Nineteen of the 22 studies were scored directly from the PEDro results (Maher, Sherrington, Herbert, Moseley, & Elkins, 2003). The remaining three studies were not included in the database and were scored separately by two authors (C.J. Keating and J.Á. Párraga Montilla); there was a full consensus among the authors' scores (Table 1).

Study Characteristics

Fifteen studies were included in the review and all were published in the English language. The RCTs were conducted in the following countries: United States = 3 (Angadi et al., 2018; Hwang et al., 2017; Mador et al., 2009), Canada = 2 (Currie et al., 2013; Terada et al., 2013), United Kingdom = 1 (Cassidy et al., 2016), Norway = 1 (Brønstad et al., 2013), South Africa = 1 (Coetsee & Terblanche, 2017), Taiwan = 1 (Fu et al., 2013), Italy = 1 (Iellamo et al., 2014), France = 1 (Maillard et al., 2016), Thailand = 1 (Mitranun et al., 2014), Australia = 1 (Northey et al., 2019), Austria = 1 (Tschentscher et al., 2016), and one study that took place in nine different sites across Europe (Ellingsen et al., 2017). The total number of participants analyzed in all studies was 259 (only HIIT participants included). Fourteen of the 15 studies reviewed had reported the gender of the participants, there was approximately a 2:1 male to female ratio (157 males to 81 females). The one study that did not report the actual number of males to females did report that the most participants were male (Mador et al., 2009). Five studies reported mean ages of ≥65 years (Angadi et al., 2018; Ellingsen et al., 2017; Iellamo et al., 2014; Mador et al., 2009; Maillard et al., 2016), and 10 studies reported mean ages between 60 and 64.9 years (Brønstad et al., 2013; Cassidy et al., 2016; Coetsee & Terblanche, 2017; Currie et al., 2013; Fu et al., 2013; Hwang et al., 2017; Mitranun et al., 2014; Northey et al., 2019; Terada et al., 2013; Tschentscher et al., 2016).

Four of the studies recruited heart failure participants (Angadi et al., 2018; Ellingsen et al., 2017; Fu et al., 2013; Iellamo et al., 2014). Four of the studies recruited type 2 diabetic participants (Cassidy et al., 2016; Maillard et al., 2016; Mitranun et al., 2014; Terada et al., 2013). Two studies recruited coronary artery disease participants (Currie et al., 2013; Tschentscher et al., 2016). Two Studies recruited chronic obstructive pulmonary disorder (Brønstad et al., 2013; Mador et al., 2009). One study recruited breast cancer survivors (Northey et al., 2019). One study recruited "aging" participants (Coetsee & Terblanche, 2017). One study recruited "healthy" participants (Hwang et al., 2017) (Table 2).

Intervention duration ranged from 4 to 16 weeks, with one study reporting data for 4 weeks of intervention (Angadi et al., 2018), one study reporting for 6 weeks (Tschentscher et al., 2016), two studies reporting data for 8 weeks (Hwang et al., 2017; Mador et al., 2009), one study reporting for 10 weeks (Brønstad et al., 2013), eight studies reporting data for 12 weeks (Cassidy et al., 2016; Currie et al., 2013; Ellingsen et al., 2017; Fu et al., 2013; Iellamo et al., 2014; Mitranun et al., 2014; Northey et al., 2019; Terada et al., 2013), and two studies reporting data for 16 weeks (Coetsee & Terblanche, 2017; Maillard et al., 2016). All 15 studies described the frequency of training in "days/week;" two studies conducted the intervention 2 days/week (Currie et al., 2013; Maillard et al., 2016), 11 studies conducted the intervention 3 days/week (Angadi et al., 2018; Brønstad et al., 2013; Cassidy et al., 2016; Coetsee & Terblanche, 2017; Ellingsen et al., 2017; Fu et al., 2013; Iellamo et al., 2014; Mador et al., 2009; Mitranun et al., 2014; Northey et al., 2019; Tschentscher et al., 2016), one study conducted the intervention 4 days/week (Hwang et al., 2017), and one study conducted the intervention 5 days/week (Terada et al., 2013). All studies reported the mode of exercise used during the training sessions. Of which, six studies used cycle ergometry (Cassidy et al., 2016; Currie et al., 2013; Fu et al., 2013; Maillard et al., 2016; Northey et al., 2019; Tschentscher et al., 2016), five studies utilizing the treadmill (Angadi et al., 2018; Brønstad et al.,

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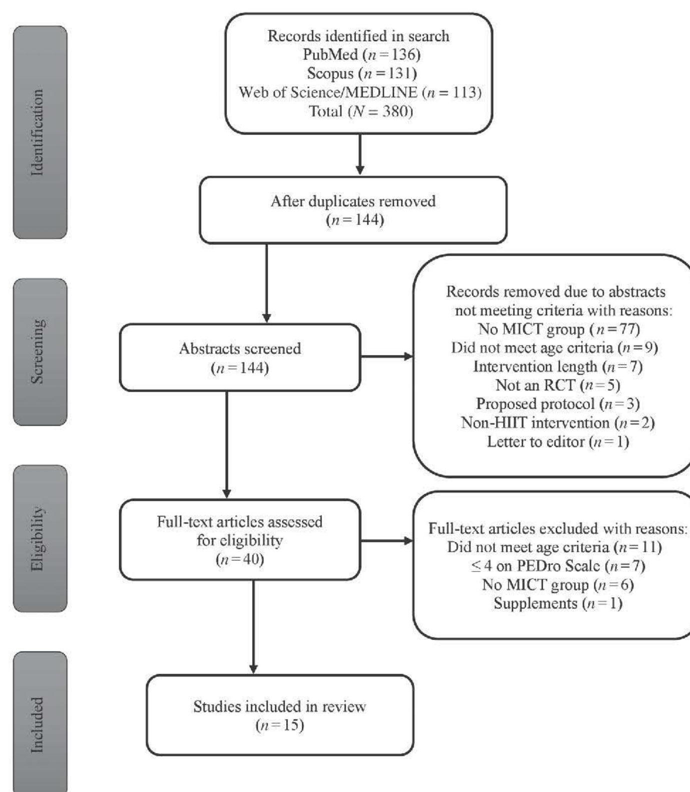

Figure 1 — Article selection flowchart. MICT = moderate-intensity continuous training; HIIT = high-intensity interval training; PEDro = Physiotherapy Evidence Database.

2013; Coetsee & Terblanche, 2017; Iellamo et al., 2014; Mitranun et al., 2014), three studies utilizing both a cycle ergometer and treadmill (Ellingsen et al., 2017; Mador et al., 2009; Terada et al., 2013), and one study utilizing an air-braked all-extremity ergometer (Hwang et al., 2017). All studies reported how they calculated the proper exercise intensity for each respective HIIT intervention. Four studies utilized peak heart rate (HR_{peak}; Angadi et al., 2018; Brønstad et al., 2013; Hwang et al., 2017; Tschentscher et al., 2016), four studies utilizing HR_{max} (Coetsee & Terblanche, 2017; Ellingsen et al., 2017; Maillard et al., 2016; Northey et al., 2019), two studies utilized HR reserve (Fu et al., 2013; Iellamo et al., 2014), one study utilized VO_2peak (Mitranun et al., 2014), one study utilized peak power output (Currie et al., 2013), one utilized rate of perceived exertion (Cassidy et al., 2016), one study utilized VO_2 reserve (Terada et al., 2013), and one study utilized estimated safe speed/workload (Mador et al., 2009) (Table 3).

Six of the 15 studies neither stated that they had tracked adverse events nor that adverse events had taken place in their respective studies (Brønstad et al., 2013; Cassidy et al., 2016; Coetsee & Terblanche, 2017; Fu et al., 2013; Mador et al., 2009; Terada et al., 2013). Eight of the 15 studies stated that they had tracked adverse events as part of the RCT, but that no such incidence had occurred (Angadi et al., 2018; Currie et al., 2013; Hwang et al., 2017; Iellamo et al., 2014; Maillard et al., 2016; Mitranun et al., 2014; Northey et al., 2019; Tschentscher et al., 2016). Only one study had tracked and reported adverse events, which were directly related to the HIIT intervention. That study reported three adverse events related to the HIIT intervention, the adverse events related to the intervention were as follows: *light-headedness/dizziness* = 1, *ventricular arrhythmia with cardiac arrest* = 1, and *inappropriate implantable cardioverter-defibrillator discharge unrelated to arrhythmia* = 1 (Ellingsen et al., 2017). It was reported that the patient those had experienced a ventricular arrhythmia with cardiac arrest had a prior medical history and had refused cardioverter-defibrillator implantation that was recommended by medical professionals prior to the intervention (Table 4).

Six of the studies reported that no participants had dropped out of the HIIT intervention group (Angadi et al., 2018; Brønstad et al., 2013; Currie et al., 2013; Maillard et al., 2016; Northey et al., 2019; Terada et al., 2013), and five studies had reported the dropout rate

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Table 1 Physiotherapy Evidence Database—Quality Assessment

Authors	Item 1[a]	Item 2	Item 3	Item 4	Item 5	Item 6	Item 7	Item 8	Item 9	Item 10	Item 11	Total score
Angadi et al. (2018)		1		1			1			1	1	5
Benda et al. (2015)[b]				*1*				*1*		*1*	*1*	*4*
Brønstad et al. (2013)	1	1		1			1			1	1	5
Cassidy et al. (2016)		1	1	1			1			1	1	6
Coetsee and Terblanche (2017)[b]	1	1		1				1		1	1	5
Currie, Dubberley, McKelvie, and Macdonald (2013)	1	1		1				1		1	1	5
Currie, Bailey, Jung, McKelvie, and MacDonald (2015)	*1*	*1*		*1*						*1*	*1*	*4*
Ellingsen et al. (2017)	1	1		1			1			1	1	5
Fu et al. (2013)	1	1		1				1		1	1	5
Gremeaux et al. (2011)	*1*			*1*						*1*	*1*	*3*
Hwang et al. (2017)[b]	1	1	1	1			1			1	1	6
Iellamo et al. (2014)	1	1		1				1		1	1	5
Kim, Choi, and Lim (2015)		*1*		*1*						*1*	*1*	*4*
Lamina (2010)	*1*	*1*		*1*						*1*	*1*	*4*
Mador et al. (2009)	1	1	1	1			1	1		1	1	7
Maillard et al. (2016)	1	1		1				1		1	1	5
Mitranun, Deerochanawong, Tanaka, and Suksom (2014)	1	1		1				1		1	1	5
Northey et al. (2019)	1	1	1	1				1	1	1	1	7
Rodríguez et al. (2016)[b]	*1*			*1*				*1*		*1*	*1*	*4*
Terada et al. (2013)	1	1		1			1	1	1	1	1	7
Tschentscher et al. (2016)		1		1				1		1	1	5
Prado et al.	*1*	*1*		*1*						*1*	*1*	*4*

Note. Item 1 = eligibility criteria specified; Item 2 = subjects randomly allocated; Item 3 = allocation concealed; Item 4 = groups similar at baseline; Item 5 = blinding of subjects; Item 6 = blinding of therapists; Item 7 = blinding of assessors; Item 8 = measure attained from ≥85% of subjects; Item 9 = intention to treat; Item 10 = between group comparison; Item 11 = treatment effect; Total score = sum of scores of Items 2–11. Studies in italic were not included in the review.
[a]Not counted toward total score. [b]Scored by reviewers.

Table 2 Participant Characteristics

Authors	Population	Age	*n*	Male	Female
Angadi et al. (2018)	Heart failure	70 ± 8.3	9	8	1
Brønstad et al. (2013)	COPD	64.8 ± 7.7	10	7	3
Cassidy et al. (2016)	Type 2 diabetes	61 ± 9	14	11	3
Coetsee and Terblanche (2017)	Aging	64.5 ± 6.3	13	3	10
Currie et al. (2013)	CAD	62 ± 11	11	10	1
Ellingsen et al. (2017)	Heart failure	65	77	63	14
Fu et al. (2013)	Heart failure	64.3 ± 1.5	14	9	5
Hwang et al. (2017)	Healthy sedentary	64.8 ± 1.8	17	6	11
Iellamo et al. (2014)	Heart failure	67.2 ± 6	18	16	2
Mador et al. (2009)	COPD	72.1 ± 6.8	21	NR	NR
Maillard et al. (2016)	Type 2 diabetes	68.2 ± 1.9	8	0	8
Mitranun et al. (2014)	Type 2 diabetes	61.2 ± 2.8	14	5	9
Northey et al. (2019)	Cancer survivors	60.3 ± 8.1	6	0	6
Terada et al. (2013)	Type 2 diabetes	62 ± 3	7	4	3
Tschentscher et al. (2016)	CAD	62.1 ± 9.5	20	15	5

Note. NR = not reported; CAD = coronary artery disease; COPD = chronic obstructive pulmonary disorder.

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Table 3 HIIT Interventions

Authors	Exercise modality	Days/ week	Weeks	Intensity (of)	Interval time (HIIT)	Total time (HIIT)	Total time (exercise)
Angadi et al. (2018)	Treadmill	3	4	85–90% (HR_{peak})	4	16	40
Brønstad et al. (2013)	Treadmill	3	10	90–95% (HR_{peak})	4	16	38
Cassidy et al. (2016)	Cycle ergometer	3	12	16–17 (RPE)	2–3:50 s	10–19:10 s	28–40
Coetsee and Terblanche (2017)	Treadmill	3	16	90–95% (HR_{max})	4	16	30
Currie et al. (2013)	Cycle ergometer	2	12	89% (PPO)	1	10	40–50
Ellingsen et al. (2017)	Treadmill and cycle ergometer	3	12	90–95% (HR_{max})	4	16	38
Fu et al. (2013)	Cycle ergometer	3	12	80% (HRR)	3	15	33
Hwang et al. (2017)	All-extremity ergometer	4	8	90% (HR_{peak})	4	16	40
Iellamo et al. (2014)	Treadmill	3	12	75–80% (HRR)	4	16	45
Mador et al. (2009)	Treadmill and cycle ergometer	3	8	150% (estimated workload)	1	7	21
Maillard et al. (2016)	Cycle ergometer	2	16	80% (HR_{max})	8 s	8	30
Mitranun et al. (2014)	Treadmill	3	12	80% (VO_2peak)	1	4–6	30
Northey et al. (2019)	Cycle ergometer	3	12	90% (HR_{max})	30 s	2–3.5	20–30
Terada et al. (2013)	Treadmill and cycle ergometer	5	12	100% (VO_2 reserve)	1	7	30, 45, 60
Tschentscher et al. (2016)	Cycle ergometer	3	6	85–95% (HR_{peak})	4	16	25

Note. HR = heart rate; HIIT = high-intensity interval training; HRR = heart rate reserve; RPE = rate of perceived exertion; PPO = peak power output.

Table 4 Dropouts and Adverse Events

Authors	Dropouts	Explanation	Adverse events	Explanation
Angadi et al. (2018)	0		0	
Brønstad et al. (2013)	0		DNR	
Cassidy et al. (2016)	2	Medical reasons (n = 2)	DNR	
Coetsee and Terblanche (2017)	2		DNR	
Currie et al. (2013)	0		0	
Ellingsen et al. (2017)	7	Died (n = 3) Adverse events (n = 3) Adverse event NR (n = 1)	3	Ventricular arrhythmia (n = 1) Inappropriate implantable cardioverter-defibrillator discharge (n = 1) Dizziness (n = 1)
Fu et al. (2013)	1		DNR	
Hwang et al. (2017)	2	Schedule issue (n = 1) Family issue (n = 1)	0	
Iellamo et al. (2014)	1	Unwillingness (n = 1)	0	
Mador et al. (2009)	3		DNR	
Maillard et al. (2016)	0		0	
Mitranun et al. (2014)	1		0	
Northey et al. (2019)	0		0	
Terada et al. (2013)	0		DNR	
Tschentscher et al. (2016)	3	Medication (n = 2) Personal reasons (n = 1)	0	

Note. DNR = did not report; NR = not related (to intervention).

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of its HIIT participants with explanations (Cassidy et al., 2016; Ellingsen et al., 2017; Hwang et al., 2017; Iellamo et al., 2014; Tschentscher et al., 2016; Table 3).

Seven of the 15 studies noted a superior effect of the HIIT intervention when compared with the MICT in at least one of the studies outcome measures (Angadi et al., 2018; Cassidy et al., 2016; Fu et al., 2013; Hwang et al., 2017; Maillard et al., 2016; Mitranun et al., 2014; Northey et al., 2019). The remaining eight studies reported a comparable effect of the two interventions (Brønstad et al., 2013; Coetsee & Terblanche, 2017; Currie et al., 2013; Ellingsen et al., 2017; Iellamo et al., 2014; Mador et al., 2009; Terada et al., 2013; Tschentscher et al., 2016). However, of the eight studies reporting similar outcomes of HIIT versus MICT, five of those studies concluded both interventions had significantly improved at least one of the studies outcome measures (Brønstad et al., 2013; Iellamo et al., 2014; Mador et al., 2009; Terada et al., 2013; Tschentscher et al., 2016). Not one of the studies reported a lessened effect of the HIIT intervention when compared with MICT. Of the seven studies that reported a superior training effect from HIIT, all specified an improvement in cardiovascular structure and/or function. Three of the seven studies specified further improvements in metabolic function (Cassidy et al., 2016; Hwang et al., 2017; Maillard et al., 2016), one study further specified a decreased amount of liver fat (Cassidy et al., 2016), one study specified further improvements in quality of life outcome measures (Fu et al., 2013), and one study further concluded that HIIT reduced cognitive impairment in its study population (Northey et al., 2019) (Table 5).

Discussion

The main objective of this systematic review was to identify and describe the results of HIIT interventions in older adults. Although all studies included in the systematic review expressed a comparable or superior effect of HIIT versus MICT, the outcome measures reveal heterogenous results. Two similar studies in heart failure patients showed differing results in pre versus post VO_2peak measures; Angadi et al. (2018) demonstrated that there was a significant improvement in VO_2peak in heart failure patients with just 4 weeks of HIIT intervention, whereas Ellingsen et al. (2017) stated that there was no difference in VO_2peak in similar heart failure patients after 12 weeks of a HIIT intervention. However, there is a strong consensus between the studies in this review that HIIT does have a positive influence on cardiovascular function and structure in older adults. This is echoed by a recent systematic review and meta-analysis performed in the study by Hannan et al. (2018), which concluded that HIIT is a superior exercise model in comparison with MICT in improving cardiorespiratory fitness in cardiac rehabilitation patients. A systematic review and meta-analysis by Ramos et al. (2015) also advocate HIIT as a "powerful form of exercise to improve vascular function," especially the 4 × 4 method, which was used by seven of the 15 studies included in this review.

In addition, this review intended to assess if there was a consensus on a universal HIIT intervention in an aging population. Of the 15 studies included in this review, seven had a similar 4 × 4

Table 5 Study Conclusions

Authors	Variables	Tools	Conclusion
Angadi et al. (2018)	VO_2peak, ventricular function	GXT and echocardiography	Significant improvements in VO_2peak and diastolic function in HIIT group. HIIT was well-tolerated in older, overweight/obese individuals with significant contributory comorbidities.
Brønstad et al. (2013)	Ventricular function	Echocardiography	Both HIIT and MICT have significant benefits with respect to cardiac function.
Cassidy et al. (2016)	Cardiac structure and function and liver fat	3.0 T MRI and tagging, 1H-magnetic resonance spectroscopy	Improvement in cardiac structure and function, as well as a significant reduction in liver fat. HIIT should be considered by clinical care teams as a therapy to improve cardiometabolic risk in type 2 diabetics.
Coetsee and Terblanche (2017)	Cerebral oxygenation and walking endurance	Near-infrared spectroscopy and treadmill submaximal (Bruce)	HIIT and MICT proved to be superior to RT for task-efficient cerebral oxygenation and improved oxygen utilization during cortical activation in older individuals.
Currie et al. (2013)	VO_2peak, brachial artery endothelial function	GXT and Duplex ultrasound	HIIT elicited similar improvements in fitness and FMD when compared with MICT, despite shorter exercise duration and higher intensity in the HIIT group.
Ellingsen et al. (2017)	LVEDD, EF, and VO_2peak	Echocardiography and GXT	HIIT was not superior to MICT in changing left ventricular remodeling or aerobic capacity, and its feasibility remains unresolved in HF patients.
Fu et al. (2013)	VO_2peak, cardiac hemodynamics, and quality of life	GXT, NICOM, and SF-36	HIIT effectively improves oxygen uptake efficiency by enhancing cerebral/muscular hemodynamics and suppresses oxidative stress/inflammation associated with cardiac dysfunction, and it also promotes generic/disease-specific qualities of life in patients with HF.
Hwang et al. (2017)	VO_2peak and EF	GXT and echocardiography	HIIT, but not MICT, improved aerobic fitness, ejection fraction, and insulin resistance. All-extremity HIIT is feasible and safe in older adults.
Iellamo et al. (2013)	24-hr BP profile, insulin resistance	Oscillometric device (BP one) and homeostasis model assessment	HIIT and MICT reduce BP throughout a day and improve glucose metabolism and insulin resistance, with a small additive effect of HIIT on day time diastolic BP and insulin resistance.
Mador et al. (2009)	Maximal work capacity and quality of life	Cycle ergometry and chronic respiratory questionnaire	Compared with MICT, HIIT was well tolerated and produced similar improvements in exercise performance and quality of life.

Note. EF = ejection fraction; HIIT = high-intensity interval training; MICT = moderate-intensity continuous training; GXT = graded exercise test; MRI = magnetic resonance imaging; RT = resistance training; FMD = flow-mediated dilation; LVEDD = left ventricular end-diastolic diameter; HF = heart failure; NICOM = noninvasive cardiac output monitoring; SF-36 = short form health survey; BP = blood pressure.

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(four high-intensity intervals × 4 min, interspersed by three lower intensity intervals × 3 min) HIIT intervention model regardless of the exercise modality (Angadi et al., 2018; Brønstad et al., 2013; Coetsee & Terblanche, 2017; Ellingsen et al., 2017; Hwang et al., 2017; Iellamo et al., 2014; Tschentscher et al., 2016). The exercise prescription guidelines varied greatly from one study to the next. The study by Cassidy et al. (2016) had a progressive 10-s increase in interval time from 2 min in Week 1 to 3 min and 50 s in Week 12. This meant that the HIIT intervention group exercised for a total of 28 min in Week 1 and 40 min and 10 s in Week 12. The measurement of exercise intensity between studies was also highly heterogenous, ranging from peak power output in the study by Currie et al. (2013), to estimated maximum workload in the study by Mador et al. (2009) As demonstrated, the exercise intensity for HIIT interventions can be prescribed using many different methods, the most common method utilized in this review was using HR_{peak} and HR_{max}. However, the use of rate of perceived exertion, VO_2peak, maximum workload, maximum safe speed, and peak power output was also utilized and should be considered for further validation investigations.

The most common mode of exercise utilized among the studies included in this review was cycle ergometry. It is important to note that four of the six studies using cycle ergometry alone demonstrated a positive effect of their respective HIIT interventions. This does highlight that there may be an increased effect of using cycle ergometry as a training modality in an aging population. This is highlighted in a recent systematic review exploring the health benefits of cycle ergometry in older adults by Bouaziz, Schmitt, Kaltenbach, Geny, and Vogel (2015) which concluded that ". . . it is worth emphasizing that this form of exercise is not only safer, but puts less stress on the joints of older adults than other typical components of exercise programs," thus a more enjoyable experience for the participants. The study by Tschentscher et al. (2016) did not report an increased effect of the HIIT intervention in comparison with MICT, yet a comparable and significant effect of the two interventions. However, one conclusion of the authors is that there was a 99.2% attendance rate among its cycle ergometer participants, suggesting "impeccable" compliance in comparisons with other trials (Tschentscher et al., 2016). It is possible that cycle ergometry in an aging population is a more efficient and effective mode of exercise and it would be of interest to investigate this topic further.

As mentioned in the introduction, a HIIT intervention can take place in many different forms, if the work intensity during the high-intensity interval component is increased and measurable. This is demonstrated in the study by Hwang et al., which used an air-braked all-extremity ergometer in its training intervention. This exercise modality is unique, because the participant is not just using muscles of the lower body but rather using all extremities to complete the intervention, and therefore, a possible increased effect on cardiovascular outcomes. There are many different modalities of exercise that exist, and further research is needed to determine if there are others which could be utilized among differing populations.

It is fascinating to note that there is very little in common between the seven studies, which demonstrated a positive effect from their respective HIIT interventions. When cross referencing the seven studies with their respective exercise guidelines, one would expect to find the possibility of a higher training intensity, increased total time spent in HIIT, or total exercise time per week. However, there is no noticeable pattern in the exercise prescriptions that would suggest one prescription versus another elicit better results (Table 6). Due to the heterogeneity of the exercise prescriptions and a general lack of effect size calculations presented in the individual studies, we have presented effect size for some of the individual studies outcome measures (Table 7). Nevertheless, there is sufficient data provided by all studies suggesting that HIIT is effective at improving cardiovascular structure and function. This is observed in the effect size

Table 6 HIIT Intervention and Study Conclusion

Authors	Intensity (of)	Days/ week	Total time (HIIT)	Total time (HIIT/week)	Total time (exercise)	Total time (exercise/week)	HIIT vs. MICT
Angadi et al. (2018)	85–90% (HR_{peak})	3	16	48	40	120	[a]
Brønstad et al. (2013)	90–95% (HR_{peak})	3	16	48	38	114	[b]
Cassidy et al. (2016)	16–17 (RPE)	3	10–19:10 s	30–57:30	28–40	84–121	[a]
Coetsee and Terblanche (2017)	90–95% (HR_{max})	3	16	48	30	90	[b]
Currie et al. (2013)	89% (PPO)	2	10	20	40–50	80–100	[b]
Ellingsen et al. (2017)	90–95% (HR_{max})	3	16	48	38	114	[b]
Fu et al. (2013)	80% (HRR)	3	15	45	33	99	[a]
Hwang et al. (2017)	90% (HR_{peak})	4	16	64	40	160	[a]
Iellamo et al. (2014)	75–80% (HRR)	3	16	48	45	135	[b]
Mador et al. (2009)	150% (estimated workload)	3	7	21	21	63	[b]
Maillard et al. (2016)	80% (HR_{max})	2	8	16	30	60	[a]
Mitranun et al. (2014)	80% (VO_2peak)	3	4–6	4–6	30	90	[a]
Northey et al. (2019)	90% (HR_{max})	3	2–3:30	6–10:30	20–30	60–90	[a]
Terada et al. (2013)	100% (VO_2 reserve)	5	7–15	35	30, 45, 60	150, 225, 300	[b]
Tschentscher et al. (2016)	85–95% (HR_{peak})	3	16	48	25	75	[b]

Note. MICT = moderate-intensity continuous training; HIIT = high-intensity interval training; HRR = heart rate reserve; RPE = rate of perceived exertion; PPO = peak power output; HR = heart rate.
[a]HIIT superior to MICT in RCT outcome measures. [b]HIIT comparable with MICT in RCT outcome measures.

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Table 7 Individual Effect Size

Authors	Intervention	Mean	*SD*	*n*	*p*	Cohens' *d*	Hedges' *g*
Angadi et al. (2018)		VO_2peak					
	HIIT	21.0	5.2	9	.04**	0.9054	0.8797
	MICT	16.8	4.0	6	.93		
Brønstad et al. (2013)		VO_2peak					
	HIIT	23.0	7.2	10	.02*	0.3085	0.2978
	MICT	24.9	4.9	7	.003*		
Cassidy et al. (2016)		EF%					
	HIIT	70	6	12	.02**	0.8489	0.8585
	MICT	63	10	11	.62		
Coetsee and Terblanche (2017)		Time to target HR (Bruce)					
	HIIT	1.4	1.3	13	.04*	0.6898	0.6898
	MICT	0.6	1.0	13	.7		
Currie et al. (2013)		VO_2peak					
	HIIT	24.5	4.5	11	≤.001*	0.4104	0.4104
	MICT	22.3	6.1	11	≤.001*		
Ellingsen et al. (2017)		VO_2peak					
	HIIT	18.2	3.7	77	.7***	0.3157	0.3164
	MICT	17.0	3.9	65			
Fu et al. (2013)		VO_2peak					
	HIIT	19.6	1.2	14	<.05**	2.6504	2.6621
	MICT	16.0	1.5	13	<.05*		
Hwang et al. (2017)		VO_2peak					
	HIIT	25.7	0.8	15	<.0001*	0.2372	0.2399
	MICT	26.0	1.6	14	≥.3		
Iellamo et al. (2014)		VO_2peak					
	HIIT	18.2	3.0	18	<.05*	0.2000	0.2000
	MICT	18.8	3.0	18	<.05*		
Mador et al. (2009)		Total CRQ					
	HIIT	102.0	16.0	21	<.05*	0.2164	0.2173
	MICT	97.8	22.3	20	<.05*		
Maillard et al. (2016)		Visceral fat mass (kg)					
	HIIT	3.1	0.6	8	≤.01*	2.6870	2.6870
	MICT	5.0	0.8	8	>.05		
Mitranun et al. (2014)		Body fat (%)					
	HIIT	30.4	2.3	14	<.05*	0.3318	0.3318
	MICT	31.1	1.9	14	<.05*		
Northey et al. (2019)		VO_2peak					
	HIIT	22.0	3.5	6	*NR*	0.2806	0.2838
	MICT	23.1	4.3	5	*NR*		
Terada et al. (2013)		VO_2peak					
	HIIT	24.3	7.4	7	>.05	0.9027	0.9217
	MICT	18.9	4.1	8	>.05		
Tschentscher et al. (2016)		PPO (Watts)					
	HIIT	171.1	69.8	20	<.001*	0.1176	0.1176
	MICT	163.4	60.8	20	<.001*		

Note. MICT = moderate-intensity continuous training; HIIT = high-intensity interval training; NR = not reported; EF = ejection fraction; HR = heart rate; PPO = peak power output; CRQ = chronic respiratory questionnaire.
*Significant difference within group, pre vs. post. **Significant difference between group, HIIT vs. MICT. ***Between-group *p* value, within-group *p* value *NR*.

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calculations when looking at the primary outcome measures focusing VO_2peak and ejection fraction.

This review does help identify the feasibility and safety of employing a HIIT intervention in older adults. Out of the 259 participants across the 15 included studies, only one study documented a total of three adverse events related to the HIIT Intervention (Ellingsen et al., 2017). When addressing safety in an aging population, it is always important to note that the intensity of HIIT is relative to the participants' level of fitness. Therefore, HIIT for a previously inactive older adult might involve walking at a slightly increased pace, whereas an active participant who partakes in regular exercise might need to run at a fast pace to achieve the same intensity.

The targeted population in this review focused on older adults, although only five of the 15 studies had a mean population of ≥65 years of age (Angadi et al., 2018; Ellingsen et al., 2017; Iellamo et al., 2014; Mador et al., 2009; Maillard et al., 2016). Also, out of the 259 total participants, there were only 81 female participants reported. Future research should focus specifically on recruiting older female adults, to confirm or reject that HIIT is superior to MICT in improving cardiorespiratory fitness in this population. Likewise, further research is needed to investigate the long-term effects of HIIT and whether the reported cardiovascular adaptations can be maintained over time.

The authors of this systematic review were unable to identify a consensus among the trials regarding the best HIIT regimen for older adults. However, the authors would suggest that cycle ergometry may be the most appropriate mode of exercise in this population due to many factors such as safety, ease of use, and adjustability of intensity. The most frequent and possibly the simplest exercise prescription among the trials was the 4×4 method; four, 4-min high-intensity intervals interspersed by three, 3-min low-intensity intervals. The participants' HR_{max} was used to measure the high-intensity intervals at 85–95% and low-intensity intervals at 60–70%. This exercise prescription is also one of the most time efficient models lasting only 38 min, including 5 min for warm-up and 5 min for cooldown. If an individual completed this exercise regimen 3 days/week, they would partake in 48 min of vigorous physical activity and 66 min of moderate physical activity for a total of 114 min.

Conclusion

This systematic review demonstrates that HIIT is a useful exercise regimen, which can be used in older adults to increase cardiorespiratory fitness. HIIT can take place in many different forms and in differing environments. More research is needed to determine if there are additional exercise modalities that can be used and if one is better than another in differing populations. The safety of HIIT in comparison with MICT is still undecided, though this review helps demonstrate that HIIT was well-tolerated in an older population with significant, divergent comorbidities. More research is needed to determine the effects of HIIT in comparison with MICT in the older (≥65 years of age), predominately female, world population base that is growing larger year after year.

References

Angadi, S.S., Mookadam, F., Lee, C.D., Tucker, W.J., Haykowsky, M.J., & Gaesser, G.A. (2018). High-intensity interval training vs. moderate-intensity continuous exercise training in heart failure with preserved ejection fraction: A pilot study. *Journal of Applied Physiology, 119*(6), 753–758. doi:10.1152/japplphysiol.00518.2014

Benda, N.M.M., Seeger, J.P.H., Stevens, G.G.C.F., Hijmans-Kersten, B.T.P., Van Dijk, A.P.J., Bellersen, L., . . . Thijssen, D.H.J. (2013). Effects of high-intensity interval training versus continuous training on physical fitness, cardiovascular function and quality of life in heart failure patients. *PLoS One, 10*(10), 1–16. doi:10.1371/journal.pone.0141256

Bouaziz, W., Schmitt, E., Kaltenbach, G., Geny, B., & Vogel, T. (2015). Health benefits of cycle ergometer training for older adults over 70: A review. *European Review of Aging and Physical Activity, 12*(1), 8. doi:10.1186/s11556-015-0152-9

Brønstad, E., Tjonna, A.E., Rognmo, Ø., Dalen, H., Heggli, A.M., Wisloff, U., . . . Steinshamn, S. (2013). Aerobic exercise training improves right- and left ventricular systolic function in patients with COPD. *COPD: Journal of Chronic Obstructive Pulmonary Disease, 10*(3), 300–306. doi:10.3109/15412555.2012.745843

Cassidy, S., Thoma, C., Hallsworth, K., Parikh, J., Hollingsworth, K.G., Taylor, R., . . . Trenell, M.I. (2016). High intensity intermittent exercise improves cardiac structure and function and reduces liver fat in patients with type 2 diabetes: A randomised controlled trial. *Diabetologia, 59*(1), 56–66. doi:10.1007/s00125-015-3741-2

Chodzko-Zajko, W.J., Proctor, D.N., Fiatarone Singh, M.A., Minson, C.T., Nigg, C.R., Salem, G.J., & Skinner, J.S. (2009). Exercise and physical activity for older adults. *Medicine & Science in Sports & Exercise, 41*, 1510–1530. PubMed ID: 19516148 doi:10.1249/MSS.0b013e3181a0c95c

Coetsee, C., & Terblanche, E. (2017). Cerebral oxygenation during cortical activation: The differential influence of three exercise training modalities. A randomized controlled trial. *European Journal of Applied Physiology, 117*(8), 1617–1627. PubMed ID: 28567669 doi:10.1007/s00421-017-3651-8

Currie, K.D., Bailey, K.J., Jung, M.E., McKelvie, R.S., & MacDonald, M.J. (2015). Effects of resistance training combined with moderate-intensity endurance or low-volume high-intensity interval exercise on cardiovascular risk factors in patients with coronary artery disease. *Journal of Science and Medicine in Sport, 18*(6), 637–642. doi:10.1016/j.jsams.2014.09.013

Currie, K.D., Dubberley, J.B., McKelvie, R.S., & Macdonald, M.J. (2013). Low-volume, high-intensity interval training in patients with CAD. *Medicine & Science in Sports & Exercise, 45*(8), 1436–1442. PubMed ID: 23470301 doi:10.1249/MSS.0b013e31828bbbd4

Ellingsen, Ø., Halle, M., Conraads, V., Støylen, A., Dalen, H., Delagardelle, C., ... Linke, A. (2017). High-intensity interval training in patients with heart failure with reduced ejection fraction. *Circulation, 135*(9), 839–849. PubMed ID: 28082387 doi:10.1161/CIRCULATIONAHA.116.022924

Fu, T.C., Wang, C.H., Lin, P.S., Hsu, C.C., Cherng, W.J., Huang, S.C., ... Wang, J.S. (2013). Aerobic interval training improves oxygen uptake efficiency by enhancing cerebral and muscular hemodynamics in patients with heart failure. *International Journal of Cardiology, 167*(1), 41–50. PubMed ID: 22197120 doi:10.1016/j.ijcard.2011.11.086

Gremeaux, M., Hannequin, A., Laurent, Y., Laroche, D., Casillas, J.M., & Gremeaux, V. (2011). Usefulness of the 6-minute walk test and the 200-metre fast walk test to individualize high intensity interval and continuous exercise training in coronary artery disease patients after acute coronary syndrome: A pilot controlled clinical study. *Clinical Rehabilitation,25*(9), 844–855. doi:10.1177/0269215511403942

Hannan, A.L., Hing, W., Simas, V., Climstein, M., Coombes, J.S., Jayasinghe, R., ... Furness, J. (2018). High-intensity interval

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II. Influence of Resistance Training on Gait and Balance Parameters in Older Adults: A Systematic Review

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Systematic Review

Influence of Resistance Training on Gait & Balance Parameters in Older Adults: A Systematic Review

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Abstract: In this work we aimed to perform a systematic review of randomized controlled trials within an aging population that investigated the general impacts of a resistance training (RT) protocol on key outcome measures relating to gait and/or balance. Following the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) statement guidelines, two electronic databases (PubMed, and Scopus) were searched for randomized controlled trials that measured at least one key outcome measure focusing on gait and/or balance in older adults. 3794 studies were identified, and after duplicates were removed, 1913 studies remained. 1886 records were removed due to the abstract not meeting the inclusion criteria. 28 full-text articles were assessed further, and 20 of the articles were identified as meeting the criteria for inclusion. The remaining 20 studies were assessed for quality using the Physiotherapy Evidence Database (PEDro) scale; 12 studies remained and were included in this systematic review. Our review suggests that RT has a positive effect on both gait and balance in an elderly population. RT improves gait, specifically straight-line walking speed in older adults. RT is an adequate training method to improve balance in an aging population. Improvements in strength, attributed to RT, may allow for greater autonomy and independence to carry out activities of daily living as we age.

Keywords: resistance training; strength training; aging; gait; balance; walking speed

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1. Introduction

The world's population is aging and it is creating a unique situation in which the population over 65 years of age exceeds that of children under 5 years of age [1]. Currently, 11% of the world population is over 60 years of age. The population aging trend continues and it is projected that by 2050 this population will include more than 22% of the world population [2]. In light of these calculations, active aging is presented as one of the best options to allow the elderly to enjoy a higher quality of life and a higher level of health to be the protagonists of their own lives in advanced age. By doing so they can avoid spending excessive life years and money on costly medical care and treatment [3].

Physical activity (PA) is presented as an alternative to medicine in terms of improving quality of life since it has been proven to have positive physiological effects in an aging population (i.e., prevents chronic diseases and reduces the risk of non-communicable diseases) [4]. In this sense, the lack of physical activity is what causes the adverse effect, resulting in what is known as frailty. This is a syndrome that appears when 3 or more of the following criteria are present in a person who suffers from it: weight loss, weakness, slowness, exhaustion, and low levels of PA. Therefore, the term frailty encompasses various aspects such as gait, mobility, balance, muscle mass, motor processing, cognition, nutrition, endurance, and PA [5]. In those individuals over the age of 65, frailty causes a greater risk

of falling, which is the second cause of death and injury in the world population and it is becoming a serious public health problem for the elderly [6]. One-third of the aging population falls at least once a year, and a fall in an elderly individual can have serious consequences such as life-threatening injury, hospitalization, fractures, and/or a loss of independence [7]. Falling or simply the fear of falling can result in a restriction of physical activity levels, and indirectly in the reduction of social interactions. This causes a paradox in which the fear of falling can increase the risk of future falls due to the deterioration of physical abilities from not participating in everyday life [8].

The physical inactivity derived from a fall can accentuate the loss of muscle mass and strength to a greater extent than that caused alone by age-associated loss. It is often reported that muscle mass decreases by roughly 2% each year after the age of 50 or, similarly, by 15% for every 10 years after the age of 50 [9]. This progressive loss of strength and muscle mass is known as Sarcopenia [10]. The term Dynapenia can also be used to further describe the age-related loss of muscle strength and power that is not caused by neurologic or muscular diseases [11]. Sarcopenia/Dynapenia and frailty cause a progressive deterioration of functional ability that is heightened in older ages. A gait speed greater than 1.20 m/s is associated with greater independence in older adults, while a speed less than 0.8 m/s is a predictor of future dependence that can lead to hospitalization, medical care, cognitive decline, and mortality at these ages [12].

Traditionally, aerobic training programs have been used to reverse the effects of the above-mentioned pathologies, as well as an improvement in the health status of the elderly [13]. This has been shown to improve cardiorespiratory function, decrease hypertension, and improve functional activities (e.g., muscle strength, physical performance, and decrease the risk of falls). In the same way, it can also improve cognitive function, while also having a positive impact on improving quality of life [14]. However, resistance training (RT) is also an appropriate exercise training method to improve health parameters and when used in combination with aerobic exercise it has been shown to improve functional capacity in an aging population [15]. In this regard, resistance training is defined as any exercise that causes the muscle to contract against resistance (weights, bands, external objects, body weight, etc.) with the intention of provoking physiological and/or morphological changes.

Recent pilot data and theoretical reviews have suggested that RT in the elderly could be an effective and safe method of participating in PA that is capable of reversing the effects of sarcopenia [16], as well as an improvement in body posture, balance, and physical resistance [17,18]. Therefore, resistance training must be a key component to be introduced in training programs for the elderly since, in addition to the benefits mentioned, it may produce neuromuscular improvements such as increased muscle mass, strength, and functional capacity [19]. However, a large amount of this information is based upon outdated data sets. A systematic review from 2004 suggested that RT is a promising exercise regimen for older adults but more research was needed to determine its effectiveness [20]. Another systematic review and meta-analysis from 2010 found promising results, but concluded that further research is needed to provide more considerable conclusions regarding the effect that RT has on the functional performance of older adults [21].

Therefore, this work aimed to perform a systematic review of randomized controlled trials within an aging population that investigated the general impacts of a resistance training protocol on key outcome measures relating to gait and/or balance.

2. Methods

This review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) statement guidelines [22]. Two electronic databases (PubMed, and Scopus) were searched for randomized controlled trials that measured at least one key outcome measure focusing on gait and/or balance in older adults. Search terms used included: resistance training OR strength training AND balance OR gait. The search terms were limited to TITLE/ABSTRACT/KEYWORDS. The search was further

limited to "clinical trials", in "humans", published in "the last ten (10) years" (January 2010 to June 2020), "adult: 65+ years" of age, and published in "English".

2.1. Study Selection—Inclusion Criteria

The inclusion criteria for this systematic review were full-length research articles published in peer-reviewed academic journals in the English language. Only randomized controlled trials published from January 2010 up to June 2020 were eligible. Studies that included participants with a median age of 60+ years. Resistance training interventions that measured at least one variable relating to gait and/or balance were included.

2.2. Study Selection—Exclusion Criteria

Abstracts, conference presentations, poster presentations, letters to the editor, books or book chapters, unpublished papers, proposed protocols, validation studies, or retrospective designs were excluded. Studies were also excluded if the participants were taking supplements, or if the average age of participants was ≤60 years. Also, studies that met the inclusion criteria yet later did not achieve a score of 5 or greater on the PEDro scale were also excluded from the review.

3. Results

The initial search resulted in 3794 studies; after duplicates were removed, 1913 studies remained, and the abstracts were reviewed for meeting the inclusion criteria. Following the initial screening process, 1886 records were removed due to the abstract not meeting the inclusion criteria. 28 full-text articles were assessed further and 20 of the articles were identified as meeting the criteria for inclusion. The remaining 20 studies were assessed for quality using the Physiotherapy Evidence Database (PEDro) scale, 8 of the studies did not score 5 or greater and were consequently removed. 12 studies remained, and all were included in the systematic review. (Figure 1)

The Physiotherapy Evidence Database (PEDro) scale is an 11-item scale that rates randomized controlled trials from 0 to 10. One item (eligibility criteria) is included in the scale because it influences external validity but not the internal or statistical validity of the trial, thus it is not counted toward the final score. Therefore, the PEDro score is generated from an 11-item scale resulting in a final score of 0 to 10. Seventeen of the twenty studies were scored directly from the Physiotherapy Evidence Database [23]. The remaining three studies were not included in the database and were scored separately by 2 authors (CJK and JCCL); there was full consensus amongst the authors' scores. (Table 1)

Table 1. PEDro—Quality Assessment.

Authors	1 *	2	3	4	5	6	7	8	9	10	11	Total Score
Alfieri et al., (2012)	1	1	0	1	0	0	0	0	1	1	1	5
Cancela Carral et al., (2019)	1	1	0	1	0	0	0	1	0	1	1	5
De Sousa et al., (2013) ■	1	1	0	0	0	0	0	0	0	1	1	**3**
Fahlman et al., (2011)	1	1	0	1	0	0	1	1	0	1	1	6
Forte et al., (2013)	1	1	0	0	0	0	0	0	0	1	1	**3**
Gonzalez et al., (2014) ■	1	1	0	1	0	0	0	1	1	1	1	6
Hewitt et al., 2018	1	1	1	1	0	0	1	1	1	1	1	8
Iuliano et al., (2015)	0	1	0	1	0	0	0	0	0	1	1	**4**
Marques et al., (2011)	1	1	1	1	0	0	1	0	1	1	1	7
Martins R, et al. (2011)	1	1	0	1	0	0	0	1	0	1	1	5
Nicholson et al., (2015)	1	1	0	1	0	0	0	0	0	1	1	**4**
Nicklas et al., (2016) ■	1	1	1	1	0	0	1	1	1	1	1	8
Pamukoff et al., 2014	1	1	0	1	0	0	0	0	0	1	1	**4**
Ramirez-Campillo, Rodrigo, et al. (2016)	0	1	0	1	0	0	1	1	0	1	1	6

Table 1. *Cont.*

Authors	1 *	2	3	4	5	6	7	8	9	10	11	Total Score
Roma et al., (2013)	1	1	0	1	0	0	0	0	0	1	1	4
Sahin et al., (2018)	1	1	0	1	0	0	0	0	0	1	1	4
Shiotsu & Yanagita, (2018)	1	1	0	1	0	0	0	1	0	1	1	5
Sparrow et al., (2011)	1	1	0	1	0	0	1	1	1	1	1	7
Sylliaas et al., (2011)	1	1	1	1	0	0	1	1	1	1	1	8
Yoon et al., (2018)	0	1	0	1	0	0	0	0	0	1	1	4

* Not counted toward total score; ■ Scored by reviewers; Bolded Total Score ≤4 and therefore not included in this review.

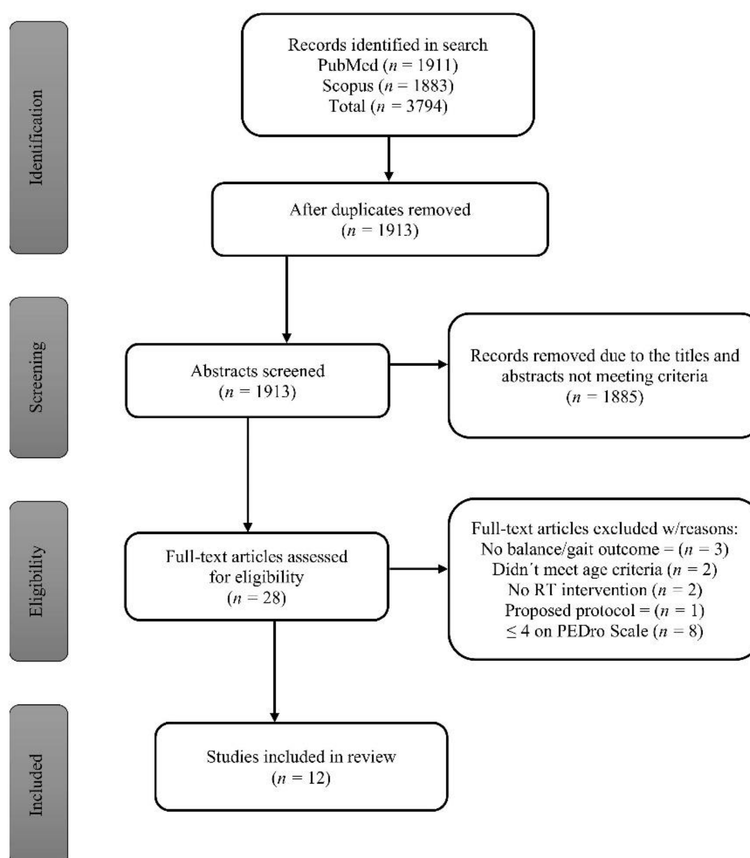

Figure 1. Article selection flow-chart.

Study Characteristics

Twelve studies were included in the review, and all were published in the English language. The randomized controlled trials were conducted in the following countries: USA = 4 [24–27], Portugal = 2 [28,29], Australia = 1 [30], Brazil = 1 [31], Chile = 1 [32], Japan = 1 [33], Norway = 1 [34], and Spain = 1 [35]. The total number of participants analyzed in all studies was 499 (only including resistance-trained participants). Eleven of the twelve studies had reported the gender of the participants and approximately 60% of

them were female (149 males to 304 females). Three studies reported mean ages of ≥65–69.9 years [27,28,33], 6 studies reported mean ages between 70–79.9 years [24–26,29,31,32], two studies reported mean ages between 80–89.9 years [30,34], and one study reporting a mean age of >90 years [35].

Nine of the twelve studies recruited participants that were community-dwelling [24–28,31–34], whereas three studies recruited participants from residential care facilities [29,30,35]. Of those studies that had recruited participants from the community, only two had reported further underlying conditions; Nicklas et al. included participants that were overweight or obese and Sylliaas et al. investigated hip fracture patients [27,34]. Only one study with participants from residential care facilities reported further underlying conditions, and they reported on "frail" nonagenarians [35]. (Table 2)

Table 2. Participant characteristics.

Authors	Population	Population (Cont.)	Age	*n* =	Male	Female
Alfieri et al., (2012)	Community-dwelling		70.18 ± 4.8	23	1	22
Cancela Carral et al., (2019)	Residential care	Frail	90.8 ± 4.02	13	0	13
Fahlman et al., (2011)	Community-dwelling		74.8 ± 1	46	NR	NR
Gonzalez et al., (2014)	Community-dwelling		71.1 ± 6.1	23	12	11
Hewitt et al., 2018	Residential care		86 ± 7	113	42	71
Marques et al., (2011)	Community-dwelling		67.3 ± 5.2	23	0	23
Martins et al. (2011)	Residential care		73.4 ± 6.4	23	10	13
Nicklas et al., (2016)	Community-dwelling	Overweight/Obese	69.4 ± 3.6	63	34	29
Ramirez-Campillo et al., (2016)	Community-dwelling		70 ± 6.9	8	0	8
Shiotsu & Yanagita, (2018)	Community-dwelling		69.0 ± 4.1	12	0	12
Sparrow et al., (2011)	Community-dwelling	Vets & Spouses *	70.3 ± 7.5	52	35	17
Sylliaas et al., (2011)	Community-dwelling	Hip Fracture	82.1 ± 6.5	100	15	85

* US Military Veterans and Spouses, NR = not reported.

Resistance training intervention duration ranged greatly from 6 to 32 weeks, with one study reporting data for 6 weeks [25], one study reporting for 10 weeks [33], four studies reporting for 12 weeks [31,32,34,35], two studies reporting for 16 weeks [24,29], one study reporting for 20 weeks [27], one study reporting for 25 weeks [30], one study reporting for 26 weeks [26], and one study reporting for 32 weeks [28]. All twelve studies described the frequency of training in "days/week"; the studies were split evenly with six studies conducting the intervention 2 days/week [25,30–33,35] and six studies conducting the interventions 3 days/week [24,26–29,34].

Regarding the number of sets and repetitions used in the RT interventions, the research appears to be relatively diverse. The number of sets used in the interventions included three interventions using 2 sets [24,26,28], six interventions using 3 sets [25,27,31–34], one study using 2–3 sets [30], and two studies simply using a "varied" use of sets [29,35]. The number of repetitions used per set of exercise in the respective interventions included one study using 6 to 8 [28], two studies using 8 to 12 [33,34], one study using 8 to 15 [25], one study using 10 to 15 [30], one study only using 10 [27], two studies only using 12 [24,26], one study using a fixed 12, 10, and 8 repetitions model [31], and three studies using "varied" repetitions [32,35,36].

All studies reported the type of resistance modalities used during the training sessions. Of which, four studies reported using resistance machines [27,28,31,33], two studies utilizing elastic bands [24,35], two studies utilizing both body weight and machines [25,34],

one study utilizing high-speed resistance training with free weights [32], one study utilizing a combination of pneumatic machines and balance training [30], one study utilizing a combination of calisthenics and elastic bands [29], and one study utilizing both body weight and free weights [26]. (Table 3)

Table 3. Resistance training intervention details.

Authors	Exercise Modality	Days/Week	Weeks	Sets	Reps	Rest-time	Load	Total Time
Alfieri et al., (2012)	Machines	2	12	3	12,10,8	NR	50%, 75%, MTL	60
Cancela Carral et al., (2019)	Elastic Bands	2	12	varied	varied	30–60 sec	progressive	60
Fahlman et al., (2011)	Elastic Bands	3	16	2	12	NR	progressive	NR
Gonzalez et al., (2014)	Body Weight/Machines	2	6	3	8 to 15	NR	NR	NR
Hewitt et al., 2018	Pneumatic/Balance	2	25	2 to 3	10 to 15	NR	Moderate (CR10)	60
Marques et al., (2011)	Machines	3	32	2	6 to 8	≥2 min	75–85% 1RM	60
Martins et al. (2011)	Calesthetics/Elastic Bands	3	16	varied	varied	3 min	progressive	45
Nicklas et al., (2016)	Machines	3	20	3	10	±1 min	70% 1RM	NR
Ramirez-Campillo et al., (2016)	High-speed RT	2	12	3	varied	±1 min	75% 1RM	50 to 70
Shiotsu & Yanagita, (2018)	Machines	2	10	3	8 to 12	NR	60–70% 1RM	NR
Sparrow et al., (2011)	Body Weight/Free Weights	3	26	2	12	NR	varied	60
Sylliaas et al., (2011)	Body Weight/Machines	3	12	3	8 to 12	NR	80% 1RM	45 to 60

NR = not reported, progressive = article only stated progressive resistance training when referring to the load applied, 1RM = 1 repetition maximum, CR10 = Borg rating of perceived exertion CR10, MTL = maximum tolerated load.

All twelve studies reported the dropout rates of their respective participants; three of the studies reported that no participants had dropped out of the resistance training group [25,29,32], two studies reported its dropouts but did not provide explanation [24,26], and seven studies had reported the dropout rate of its resistance training participants with explanations [27,28,30,31,33–35]. On the other hand, only three studies reported on adverse events related to the resistance exercise intervention [26,27,30]. Of those three studies that reported adverse events, there was a total of fourteen individual events; thirteen of those events were related to musculoskeletal aches and pains and only 1 event was related to a non-injurious fall [30]. (Table 4)

Seven of the twelve studies reported on variables related to balance alone [25,26,28,29,31,32,35], whereas only one study reported on gait alone [24]; the remaining four studies reported on both gait and balance variables [27,30,33,34]. The most common test used to assess balance was the Timed Up and Go (TUG) or the 8 foot Timed Up and GO (8ftTUG) variation; other tests included the single-leg stance, tandem or bilateral stance, as well as the body's center of oscillation. Tests assessing gait alone included velocity (m/min), step time (seconds), and step length (cm). Tests in the studies that provided measures for both gait and balance were mixed and included assessments such as the Short Physical Performance Battery (SPPB), 10-m walk speed, Functional Reach Test (FRT), Berg Balance Scale (BBS), the center of oscillation, and the 400-m walk test for time (Table 5).

Table 4. Reported dropouts & adverse events.

Authors	Drop-outs	Explanation	Adverse Events	Explanation
Alfieri et al., (2012)	5	1 ankle fracture, 1 rib fracture, 1 uncontrolled HF, 1 knee pain, 1 gave up	NR	
Cancela Carral et al., (2019)	2	death	NR	
Fahlman et al., (2011)	4	NR	NR	
Gonzalez et al., (2014)	0		0	
Hewitt et al., 2018	16	15 deceased, 1 moved away	4	3 musculoskeletal aches/pains, 1 noninjurious fall.
Marques et al., (2011)	8	Medical issues unrelated (n = 3) Disinterest (n = 3) Personal reasons (n = 2)	0	
Martins et al. (2011)	0		NR	
Nicklas et al., (2016)	7	3 personal health issues, 2 caretaking, 1 changed mind, 1 lost to follow-up	2	2 musculoskeletal complaints
Ramirez-Campillo et al., (2016)	0		0	
Shiotsu & Yanagita, (2018)	3	3 private reasons	NR	
Sparrow et al., (2011)	3	NR	8	8 musculoskeletal
Sylliaas et al., (2011)	5	1 nursing home, 1 died, 3 illness	NR	

NR = not reported.

Table 5. Study conclusions.

Authors	Variable	Tools	Conclusion
Alfieri et al., (2012)	Balance	Timed Up and Go (TUG); Berg; Oscillation of the body's center of pressure	Both multisensory and RT interventions improved static and dynamic mobility in healthy elderly subjects.
Cancela Carral et al., (2019)	Balance	TUG	Muscle strength intervention programs may help promote healthy lifestyles by maintaining autonomy, improving function, and balance.
Fahlman et al., (2011)	Gait	Velocity (m/min), step time (seconds), step length (cm): GAITRite mat	Eight weeks of RT increased the parameters of velocity and step length. Additional emphasis on gait training could improve gains even further.
Gonzalez et al., (2014)	Balance	Single leg balance	These findings support the use of progressive resistance training for untrained older adults to improve balance.
Hewitt et al., 2018	Gait & Balance	Short Physical Performance Battery (SPPB)	Moderate-intensity PRT and high-level balance exercise significantly reduced falls and improved SPPB performance.
Marques et al., (2011)	Balance	8-foot Up and Go (8-ft UG)	8-month RT, but not AT, can induce significant bone adaptation in older women and both regimens elicited significant gains in balance.
Martins et al., (2011)	Balance	8-ft UG	Both AT and RT interventions improved functional fitness.

Table 5. *Cont.*

Authors	Variable	Tools	Conclusion
Nicklas et al., (2016)	Gait & Balance	gait speed; SPPB; chair rise	Both RT and RT + Calorie Restriction groups increased in gait speed, SPPB score, and chair rise time.
Ramirez-Campillo et al., (2016)	Balance	8-ft UG; Bilateral balance w/Bertec BP5050 balance plate platform	2 or 3 training sessions/week of RT (equated for volume and intensity) are equally effective for improving physical performance and quality of life of older women.
Shiotsu & Yanagita, (2018)	Gait & Balance	10-m walk speed; TUG; single-leg balance with eyes open; Functional Reach Test (FRT)	10-m walk speed significantly increased in all training groups; Combined AT & moderate-intensity RT resulted in significant improvements in dynamic balance capacity.
Sparrow et al., (2011)	Balance	Single leg balance (eyes open) and Tandem stance	A home-based RT program for older adults resulted in significant improvements in muscular strength and balance.
Sylliaas et al., (2011)	Gait & Balance	Berg; TUG; 10-m walk speed	Significant improvements in BBS, sit-to-stand, TUG, and 10 m walk speed.

All twelve studies observed a positive effect of the RT intervention in at least one of the studies' outcome measures; none of the studies reported a negative effect due to the RT intervention. All eleven studies that analyzed balance specified an improvement in either static and/or dynamic balance. All five studies reporting on gait measures reported a positive effect of the RT intervention, and particularly an improvement in gait speed.

4. Discussion

The main objective of this work was to examine the general impact that an RT program has on key outcome measures relating to gait and balance. According to the studies included in this review, it is evident that RT has a positive effect on both gait and balance in an elderly population.

Regarding gait, only five studies were found to investigate gait parameters. All five of those studies used some form of a timed walking test, four of which evaluated the 10-m walking test, whereas the other measured gait as part of the SPPB (3/4-m walking test). This may be due to the common belief that gait speed itself is the best indicator of gait function, which does fall in line with the findings from Guralnik et al. that suggest that gait speed could be the best predictor of frailty and disability in older adults [37]. However, unidirectional walking speed is simply one of the many methods to analyze gait. This sentiment is echoed by M.W. Whittle, who indicates that walking is only one of the many functions of the musculoskeletal system and that we should "broaden our horizons and use the power of the modern measurement systems to study a wide range of other activities" [38]. Although the authors of this review believe that unidirectional gait assessment is an essential measurement, we also suggest that further research needs to include multidirectional and/or double task scenarios to better understand their utility in analyzing gait in older adults.

It is interesting to note that only one study examined the effects of RT on gait parameters alone and they concluded that eight weeks of resistance training improved the measures of velocity and step length; however, there was no significant increase in step time measured in seconds. Those authors also indicated that it could be possible to see additional gains if an emphasis were placed specifically on gait training and that it is necessary to design programs with a specific objective centered on the target population and/or individual rather than a standardized or "one size fits all" model [24]. The other four studies analyzing gait measured the time of a 10-m walking test, and all of them found significant improvements from baseline to post RT intervention.

According to the findings included in this review, resistance training undoubtedly improves gait parameters in older adults, but specifically unidirectional walking speed. It is interesting to note that there are other forms of gait parameter tests that are not simply straight-line walking tests [39]. The authors suggest that more research needs to be done on the effects of an RT program on a complex gait or a dual-task scenario. Research has found an association between gait variables and cognitive function in older adults [39]. In this regard, a complex gait test when measuring the time to completion would allow researchers to get a better understanding of the relationship between the functional and cognitive state of the individual. Furthermore, a complex gait test would be a more accurate representation of a real-life scenario, and therefore a better predictor of future adverse events. However, irrespective of straight-line walking speed, more research is needed to determine if RT can enhance the various aspects of gait in older adults.

Regarding balance, 11 studies analyzed at least one balance variable and all of them reported that RT had a significant effect on improving balance; only 1 of the studies analyzed advised concern regarding the improvements from the RT group. That study, by Alfieri et al., could not determine which of the programs included in their research (a multisensory or RT intervention) was more suitable for improving balance control [31]. They further state that although there was no significant between-group difference, the multisensory group showed better improvements in the dorsiflexor and plantar flexor muscles of the ankle which have been demonstrated to be important for the maintenance of static balance. In any case, RT did induce a significant change in measures such as TUG, BBS, and the body's center of oscillation.

Numerous variables need to be controlled and/or modified to achieve the desired objectives of improving balance. For that very reason, RT can be difficult to program and prescribe to such a diverse population base [40,41]. Considering that there are many variables requiring attention to develop an effective RT program, it is promising to report that all studies included in this review obtained significant improvements in balance across a wide variety of RT programs.

The duration of the interventions varied widely from 6 to 32 weeks, with 12 weeks being the most common. It is important to highlight that Gonzalez et al., obtained improvements in balance with a basic RT program consisting of 2 days/week for 6 weeks. This indicates that an RT program with a specific objective (in this case, improved balance) can achieve significant improvements in a relatively short intervention time. This reduction in intervention time could prevent the abandonment of the program by participants, since lack of adherence due to interest is one of the main reasons why subjects cease training [42,43]. This short training time could allow the exercise specialist to include well-deserved breaks for the participants within the macro/mesocycle, as well as changing the program accordingly to make it more desirable for the participants.

Regarding the number of sets used (2–3) and the number of repetitions (between 8–15), 11 of the articles analyzed used a methodology following the American College of Sports Medicine Position Stand on Progression Models in Resistance Training for Healthy Adults in order to increase muscle mass through hypertrophy [44]. Five of the twelve studies used the 1-repetition maximum (1-RM) method to prescribe training loads [21,22,26–28]. Despite its widespread use, this method has some disadvantages that must be considered. Among others, this can be unsafe and harmful for the performer when the subject does not have prior training and/or their performance technique is not correct [45]. The intense efforts of a 1-RM may produce unnecessary musculoskeletal loading that may not be recommended for certain populations such as the elderly. For this population, an alternative method would be to include one of the many 1-RM prediction equations which have been shown to be a good predictor of an individual's true 1-RM [46].

Several studies analyzed in this review included a variety of rest times between sets from 1 min, 2 min, and 3 min. However, many of the studies analyzed did not report the rest time between sets. The rest time between sets is an important variable to consider when planning an RT program and, surprisingly, more studies did not plan or at least

report their rest times appropriately [47]. In this regard, a shorter rest time between sets implies a reduction in the total training time, and therefore the perception of fatigue could also be perceived as less. Common knowledge amongst the scientific literature suggests that the rest time between sets should range between 180–300 s when the objective is to increase maximum strength, 1–2 min for muscle gain through hypertrophy, and 30–60 s for improving muscular endurance [48]. However, a recent study by Villanueva et al. in older adult males concluded that a 60-s rest between sets was optimal for hypertrophic muscular gains, which appear to compensate for the effects produced by age [49]. The difference in rest time between sets, as well as the absence of it in several studies analyzed in this review, makes it difficult to determine to what extent this variable may have influenced the improvement of balance and/or gait variables. Further studies need to be very clear in not only the number of repetitions and sets but further into the rest time between sets as well as total exercise time.

Due to the differences in the training programs, evaluation methods, and the subject population used in the studies of the current review, it has not been possible for the authors to determine to what extent the variables in these programs has had a greater influence on improving balance and gait. However, it is noteworthy to report that a recent systematic review looking at the effects of supervised vs. unsupervised training programs on balance and muscle strength in older adults suggests that supervised training improved measures of balance and muscle strength/power to a greater extent than that of unsupervised programs [50]. Therefore, the authors of the current review suggest that future studies need to be carried out to focus on the RT variable/s that allow for superior improvements in gait and balance.

This review also helps identify the feasibility and safety of implementing an RT program in an aging population. Remember that many of the participants from the studies included in this review were over 70 years of age, and although there were a significant number of dropouts reported, the authors did not relate those dropouts to the RT program. Only half of the studies reported adverse events in their respective studies. When adverse events were reported, most of those events (13 of 14) were related to musculoskeletal aches and pains. This is not out of the ordinary at any age, but may be the leading cause of adverse events in an aging population, as stated in a systematic review by Lui and Latham (2010). However, in that same review they report that many adverse events may go undocumented because there is no consensus on reporting, nor the definition of an adverse event. They further state that reporting adverse events in an aging population needs to become part of the standard research protocol to further guide practitioners and further develop research [42]. We would like to echo that opinion and encourage researchers to become more prudent in reporting participants' adverse events; which could be a simple comment or complaint of simple aches and pains that may arise in day to day conversation with the participants.

Considering the results provided by the different studies analyzed in this review, RT is an adequate method to improve balance in people over 65 years of age. Even in the study in which improvements in balance were questioned, there were still significant improvements in lower body strength in the participants. These improvements in strength can, in turn, lead to greater independence and autonomy to carry out the activities of daily living [51,52].

5. Conclusions

This work aimed to review the general impact that an RT program has on key measures relating to gait and balance in older adults. With the studies included in this review, RT has a positive influence on both gait and balance in an aging population. RT enhances gait parameters, but specifically straight-line walking speed, in older adults. It appears that the improvement can be highly attributed to the significant improvements in lower body strength. Nonetheless, it appears that RT is an adequate and safe method to improve balance and gait parameters in people over 65 years of age. However, more research is

needed to determine if RT can improve the various and complex aspects of gait in older adults. Furthermore, adverse events often go unreported and should become part of the standard research protocol when partaking in studies on older adults.

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References

1. Colombo, P.J.; Crawley, M.E.; East, B.S.; Hill, A.R. Aging and the Brain. *Encycl. Hum. Behav. Second Ed.* **2012**, 53–59. [CrossRef]
2. Kanasi, E.; Ayilavarapu, S.; Jones, J. The aging population: Demographics and the biology of aging. *Periodontol. 2000* **2016**, *72*, 13–18. [CrossRef]
3. Álvarez-García, J.; Durán-Sánchez, A.; Río-Rama, D.; de la Cruz, M.; García-Vélez, D.F. Active ageing: Mapping of scientific coverage. *Int. J. Environ. Res. Public Health* **2018**, *15*, 2727. [CrossRef] [PubMed]
4. Bauman, A.; Merom, D.; Bull, F.C.; Buchner, D.M.; Fiatarone Singh, M.A. Updating the Evidence for Physical Activity: Summative Reviews of the Epidemiological Evidence, Prevalence, and Interventions to Promote "active Aging. " *Gerontologist* **2016**, *56*, S268–S280. [CrossRef] [PubMed]
5. De Labra, C.; Guimaraes-Pinheiro, C.; Maseda, A.; Lorenzo, T.; Millán-Calenti, J.C. Effects of physical exercise interventions in frail older adults: A systematic review of randomized controlled trials Physical functioning, physical health and activity. *BMC Geriatr.* **2015**, *15*, 154. [CrossRef]
6. Khanuja, K.; Joki, J.; Bachmann, G.; Cuccurullo, S. Gait and balance in the aging population: Fall prevention using innovation and technology. *Maturitas* **2018**, *110*, 51–56. [CrossRef]
7. Wales, N.S.; Health, P. Exercise for reducing fear of falling in older people living in the community: Cochrane systematic review and meta-analysis. *Age Ageing* **2016**, *38*, 345–352. [CrossRef]
8. Sherrington, C.; Fairhall, N.; Wallbank, G.; Tiedemann, A.; Michaleff, Z.A.; Howard, K.; Clemson, L.; Hopewell, S.; Lamb, S. Exercise for preventing falls in older people living in the community: An abridged Cochrane systematic Review. *Br. J. Sports Med.* **2020**, *54*, 885–891. [CrossRef]
9. Papa, E.V.; Dong, X.; Hassan, M. Resistance training for activity limitations in older adults with skeletal muscle function deficits: A systematic review. *Clin. Interv. Aging* **2017**, *12*, 955–961. [CrossRef] [PubMed]
10. Schaap, L.A.; Van Schoor, N.M.; Lips, P.; Visser, M. Associations of sarcopenia definitions, and their components, with the incidence of recurrent falling and fractures: The longitudinal aging study Amsterdam. *J. Gerontol. Ser. A Biol. Sci. Med. Sci.* **2018**, *73*, 1199–1204. [CrossRef]
11. Clark, B.C.; Manini, T.M. What is dynapenia? *Nutrition* **2012**, *28*, 495–503. [CrossRef] [PubMed]
12. Sgaravatti, A.; Santos, D.; Bermúdez, G.; Barboza, A. Velocidad de marcha del adulto mayor funcionalmente saludable Gait Speed in Functionally and Healthy Elder People Velocidade da marcha do idoso funcionalmente saudável. In *Anales de la Facultad de Medicina*; Universidad de la República: Montevideo, Uruguay, 2018; Volume 5, pp. 93–101.
13. Gomeñuka, N.A.; Oliveira, H.B.; Silva, E.S.; Costa, R.R.; Kanitz, A.C.; Liedtke, G.V.; Schuch, F.B.; Peyré-Tartaruga, L.A. Effects of Nordic walking training on quality of life, balance and functional mobility in elderly: A randomized clinical trial. *PLoS ONE* **2019**, *14*, e0211472. [CrossRef] [PubMed]
14. Bouaziz, W.; Vogel, T.; Schmitt, E.; Kaltenbach, G.; Geny, B.; Olivier, P. Health bene fi ts of aerobic training programs in adults aged 70 and over: A systematic review. *Arch. Gerontol. Geriatr.* **2017**, *69*, 110–127. [CrossRef] [PubMed]
15. Fragala, M.S.; Cadore, E.L.; Dorgo, S.; Izquierdo, M.; Kraemer, W.J.; Peterson, M.D.; Ryan, E.D. Resistance Training for Older Adults: Position Statement From the National Strength and Conditioning Association. *J. Strength Cond. Res.* **2019**, *33*, 2019–2052. [CrossRef]
16. Hassan, B.H.; Hewitt, J.; Keogh, J.W.L.; Bermeo, S.; Duque, G.; Henwood, T.R. Impact of resistance training on sarcopenia in nursing care facilities: A pilot study. *Geriatr. Nurs.* **2016**, *37*, 116–121. [CrossRef]
17. Woolford, S.J.; Sohan, O.; Dennison, E.M.; Cooper, C.; Patel, H.P. Approaches to the diagnosis and prevention of frailty. *Aging Clin. Exp. Res.* **2020**, *32*, 1629–1637. [CrossRef]

18. Jadczak, A.D.; Makwana, N.; Luscombe-Marsh, N.; Visvanathan, R.; Schultz, T.J. Effectiveness of exercise interventions on physical function in community-dwelling frail older people: An umbrella review of systematic reviews. *JBI Evid. Synth.* **2018**, *16*, 752–775. [CrossRef]
19. Lopez, P.; Silveira, R.; Regis, P.; Rech, A.; Grazioli, R.; Izquierdo, M.; Cadore, E.L. Benefits of resistance training in physically frail elderly: A systematic review. *Aging Clin. Exp. Res.* **2018**, *30*, 889–899. [CrossRef]
20. Latham, N.K.; Bennett, D.A.; Stretton, C.M.; Anderson, C.S. Systematic Review of Progressive Resistance Strength Training in Older Adults. *J. Gerontol. Ser. A Biol. Sci. Med. Sci.* **2004**, *59*, 48–61. [CrossRef]
21. Steib, S.; Schoene, D.; Pfeifer, K. Dose-response relationship of resistance training in older adults: A meta-analysis. *Med. Sci. Sports Exerc.* **2010**, *42*, 902–914. [CrossRef] [PubMed]
22. Moher, D.; Liberati, A.; Tetzlaff, J.; Altman, D.G. Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *J. Clin. Epidemiol.* **2009**, *7*, 889–896. [CrossRef]
23. Maher, C.G.; Sherrington, C.; Herbert, R.D.; Moseley, A.M.; Elkins, M. Reliability of the PEDro Scale for Rating Quality of Randomized Controlled Trials. *Phys. Ther.* **2003**, *83*, 713–721. [CrossRef] [PubMed]
24. Fahlman, M.M.; McNevin, N.; Boardley, D.; Morgan, A.; Topp, R. Effects of resistance training on functional ability in elderly individuals. *Am. J. Heal. Promot.* **2011**, *25*, 237–243. [CrossRef]
25. Gonzalez, A.M.; Mangine, G.T.; Fragala, M.S.; Stout, J.R.; Beyer, K.S.; Bohner, J.D.; Emerson, N.S.; Hoffman, J.R. Resistance training improves single leg stance performance in older adults. *Aging Clin. Exp. Res.* **2014**, *26*, 89–92. [CrossRef] [PubMed]
26. Sparrow, D.; Gottlieb, D.J.; Demolles, D.; Fielding, R.A. Increases in muscle strength and balance using a resistance training program administered via a telecommunications system in older adults. *J. Gerontol. Ser. A Biol. Sci. Med. Sci.* **2011**, *66*, 1251–1257. [CrossRef] [PubMed]
27. Nicklas, B.J.; Chmelo, E.; Delbono, O.; Carr, J.J.; Lyles, M.F.; Marsh, A.P. Effects of resistance training with and without caloric restriction on physical function and mobility in overweight and obese older adults: A randomized controlled trial. *Am. J. Clin. Nutr.* **2015**, *101*, 991–999. [CrossRef]
28. Marques, E.A.; Wanderley, F.; Machado, L.; Sousa, F.; Viana, J.L.; Moreira-Gonçalves, D.; Moreira, P.; Mota, J.; Carvalho, J. Effects of resistance and aerobic exercise on physical function, bone mineral density, OPG and RANKL in older women. *Exp. Gerontol.* **2011**, *46*, 524–532. [CrossRef] [PubMed]
29. Martins, R.; Coelho, E.; Silva, M.; Pindus, D.; Cumming, S.; Teixeira, A.; Veríssimo, M. Effects of strength and aerobic-based training on functional fitness, mood and the relationship between fatness and mood in older adults. *J. Sports Med. Phys. Fitness* **2011**, *51*, 489–496.
30. Hewitt, J.; Goodall, S.; Clemson, L.; Henwood, T.; Refshauge, K. Progressive Resistance and Balance Training for Falls Prevention in Long-Term Residential Aged Care: A Cluster Randomized Trial of the Sunbeam Program. *J. Am. Med. Dir. Assoc.* **2018**, *19*, 361–369. [CrossRef]
31. Alfieri, F.M.; Riberto, M.; Gatz, L.S.; Ribeiro, C.P.C.; Lopes, J.A.F.; Battistella, L.R. Comparison of multisensory and strength training for postural control in the elderly. *Clin. Interv. Aging* **2012**, *7*, 119–125. [CrossRef] [PubMed]
32. Ramirez-Campillo, R.; Diaz, D.; Martinez-Salazar, C.; Valdés-Badilla, P.; Delgado-Floody, P.; Méndez-Rebolledo, G.; Cañas-Jamet, R.; Cristi-Montero, C.; García-Hermoso, A.; Celis-Morales, C.; et al. Effects of different doses of high-speed resistance training on physical performance and quality of life in older women: A randomized controlled trial. *Clin. Interv. Aging* **2016**, *11*, 1797–1804. [CrossRef] [PubMed]
33. Shiotsu, Y.; Yanagita, M. Comparisons of low-intensity versus moderate-intensity combined aerobic and resistance training on body composition, muscle strength, and functional performance in older women. *Menopause* **2018**, *25*, 668–675. [CrossRef] [PubMed]
34. Sylliaas, H.; Brovold, T.; Wyller, T.B.; Bergland, A. Progressive strength training in older patients after hip fracture: A randomised controlled trial. *Age Ageing* **2011**, *40*, 221–227. [CrossRef] [PubMed]
35. Cancela Carral, J.M.; Rodríguez, A.L.; Cardalda, I.M.; Gonçalves Bezerra, J.P.A. Muscle strength training program in nonagenarians—A randomized controlled trial. *Rev. Assoc. Med. Bras.* **2019**, *65*, 851–856. [CrossRef]
36. Ribeiro, P.A.B.; Boidin, M.; Juneau, M.; Nigam, A.; Gayda, M. High-intensity interval training in patients with coronary heart disease: Prescription models and perspectives. *Ann. Phys. Rehabil. Med.* **2017**, *60*, 50–57. [CrossRef]
37. Guralnik, J.M.; Ferrucci, L.; Pieper, C.F.; Leveille, S.G.; Markides, K.S.; Ostir, G.V.; Studenski, S.; Berkman, L.F.; Wallace, R.B. Lower extremity function and subsequent disability: Consistency across studies, predictive models, and value of gait speed alone compared with the short physical performance battery. *J. Gerontol. Ser. A Biol. Sci. Med. Sci.* **2000**, *55*, 221–231. [CrossRef]
38. Whittle, M.W. Chapter 5—Applications of gait analysis. In *Gait Analysis*, 4th ed.; Whittle, M.W., Ed.; Butterworth-Heinemann: Edinburgh, Scotland, 2007; pp. 177–193. ISBN 978-0-7506-8883-3.
39. Latorre Román, P.Á.; Muñoz Jiménez, M.; Salas Sánchez, J.; Consuegra González, P.; Moreno Del Castillo, R.; Herrador Sánchez, J.A.; López Ivanco, M.D.A.; Linares Jiménez, C.; Navas Morales, J.F.; Párraga Montilla, J.A. Complex gait is related to cognitive functioning in older people: A cross-sectional study providing an innovative test. *Gerontology* **2020**, *66*, 401–408. [CrossRef]
40. Bird, S.P.; Tarpenning, K.M.; Marino, F.E. Designing resistance training programmes to enhance muscular fitness: A review of the acute programme variables. *Sport Med.* **2005**, *35*, 841–851. [CrossRef]
41. Kraemer, W.J.; Ratamess, N.A. Fundamentals of Resistance Training: Progression and Exercise Prescription. *Med. Sci. Sports Exerc.* **2004**, *36*, 674–688. [CrossRef]

42. Schwenk, M.; Jordan, E.D.H.; Honarvararaghi, B.; Mohler, J.; Armstrong, D.G.; Najafi, B. Effectiveness of foot and ankle exercise programs on reducing the risk of falling in older adults: A systematic review and meta-analysis of randomized controlled trials. *J. Am. Podiatr. Med. Assoc.* **2013**, *103*, 534–547. [CrossRef]
43. Simek, E.M.; McPhate, L.; Haines, T.P. Adherence to and efficacy of home exercise programs to prevent falls: A systematic review and meta-analysis of the impact of exercise program characteristics. *Prev. Med.* **2012**, *55*, 262–275. [CrossRef]
44. Kraemer, W.J.; Adams, K.; Cafarelli, E.; Dudley, G.A.; Dooly, C.; Feigenbaum, M.S.; Fleck, S.J.; Franklin, B.; Fry, A.C.; Hoffman, J.R.; et al. Progression models in resistance training for healthy adults. *Med. Sci. Sports Exerc.* **2002**, *34*, 364–380. [CrossRef]
45. González-Badillo, J.J.; Marques, M.C.; Sánchez-Medina, L. The Importance of Movement Velocity as a Measure to Control Resistance Training Intensity. *J. Hum. Kinet. Spec. Issue* **2011**, *29*, 15–19. [CrossRef]
46. Knutzen, K.M.; Brilla, L.R.; Caine, D. Validity of 1RM Prediction Equations for Older Adults. *J. Strength Cond. Res.* **1999**, *13*, 242–246. [CrossRef]
47. Willardson, J.M. A brief review: How much rest between sets? *Strength Cond. J.* **2008**, *30*, 44–50. [CrossRef]
48. Borde, R.; Hortobágyi, T.; Granacher, U. Dose–Response Relationships of Resistance Training in Healthy Old Adults: A Systematic Review and Meta-Analysis. *Sport Med.* **2015**, *45*, 1693–1720. [CrossRef] [PubMed]
49. Villanueva, M.G.; Lane, C.J.; Schroeder, E.T. Short rest interval lengths between sets optimally enhance body composition and performance with 8 weeks of strength resistance training in older men. *Eur. J. Appl. Physiol.* **2015**, *115*, 295–308. [CrossRef] [PubMed]
50. Lacroix, A.; Hortobágyi, T.; Beurskens, R.; Granacher, U. Effects of Supervised vs. Unsupervised Training Programs on Balance and Muscle Strength in Older Adults: A Systematic Review and Meta-Analysis. *Sport Med.* **2017**, *47*, 2341–2361. [CrossRef] [PubMed]
51. Haraldstad, K.; Rohde, G.; Stea, T.H.; Lohne-Seiler, H.; Hetlelid, K.; Paulsen, G.; Berntsen, S. Changes in health-related quality of life in elderly men after 12 weeks of strength training. *Eur. Rev. Aging Phys. Act.* **2017**, *14*, 10–15. [CrossRef]
52. Krist, L.; Dimeo, F.; Keil, T. Can progressive resistance training twice a week improve mobility, muscle strength, and quality of life in very elderly nursing-home residents with impaired mobility? A pilot study. *Clin. Interv. Aging* **2013**, *8*, 443–448. [CrossRef]

III. Utilizing Heart Rate and RPE to prescribe Cycle Ergometer HIIT in Older Adults: A Feasibility Study

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Original Research

Utilizing Age-Predicted Heart Rate Maximum to Prescribe a Minimally Invasive Cycle Ergometer HIIT Protocol in Older Adults: A Feasibility Study

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ABSTRACT

International Journal of Exercise Science 15(4): 896-909, 2022. Previous research has provided evidence that aerobic HIIT exercise can induce important physiological adaptations and elicit improvements in health and fitness parameters. However, most of the research has taken place in a laboratory setting with specialized equipment and monitoring devices. It begs the question, is HIIT accessible to the general aging population? The objective of the current research was to employ an age-predicted HRmax to prescribe a minimally invasive 4x4 cycle ergometer HIIT protocol. Ten participants (age: 64.2 ± 6.1) completed a non-weight-bearing cycle ergometer protocol for 6 weeks. Significant Pearson correlations were found between %HRmax and W/kg in seven of the ten participants. Two participants showed significant correlations between RPE and W/kg. Half of the participants exhibited a significant correlation between %HRmax and RPE. Pre- to post-intervention measures demonstrated a significant increase in lower limb strength by the 10-repetition chair sit-to-stand (p = 0.004) and 30-second sit-to-stand (p = 0.021). Increased functional capacity demonstrated by TUG (p = 0.001) and SB (p = 0.034) also presented significant differences pre- to post-intervention. There was a 96% participant session completion rate. These data imply that a simple 4x4 cycle ergometer HIIT protocol prescribed using a %HRmax is effective at increasing lower-limb power/strength and can be used in the general older adult population without excessive oversight. Our intervention protocol demonstrates that 6 weeks of cycle ergometer HIIT is an adequate amount of time to result in lower limb strength and functional capacity improvements in active older adults.

KEYWORDS: High-intensity interval training, HR, rate of perceived exertion, RPE

INTRODUCTION

High-Intensity Interval Training (HIIT) is an exercise regimen that has been shown to induce important physiological adaptations and therefore elicit significant improvements in fitness and health (11). A typical session of HIIT consists of relatively brief bursts of vigorous physical activity (i.e. greater than 80% of aerobic capacity), interspersed with short rest periods of low-intensity physical activity (i.e. 50-60% of aerobic capacity) between intervals (9). A primary

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objective of HIIT is to maximize the efficiency of the exercise while minimizing the time investment (32). Therefore, HIIT can be considered a time-efficient training program since previous research has shown that the participants spend approximately 40% less time training than they would have in other types of exercise regimens (37). In addition, HIIT induces a greater adherence since many participants find it to be more enjoyable than other training methods (3). For that reason, HIIT avoids one of the greatest barriers to engaging in an exercise program: the "lack of time" (30).

HIIT has also been recognized as a suitable exercise regimen for patients diagnosed with chronic conditions such as cardiovascular diseases and diabetes due to its increased effect on cardiorespiratory fitness and metabolic function (13, 34). Some studies have reported that when compared with Moderate-Intensity Continues Training (MICT), HIIT has been shown to elicit superior improvements in indices of cardiorespiratory fitness (1, 13, 15, 29, 38). In addition, HIIT has improved memory in older adults and possibly avoided some age-related memory decline (20). Research has also determined that HIIT may be beneficial at reducing systolic blood pressure, improve body composition, decrease fall risk, and improve metabolic parameters (10, 14, 26, 38). A recently published systematic review by the authors of the current study found that HIIT was well-tolerated in an older population with significant, divergent comorbidities as well as being effective at increasing cardiorespiratory fitness (19). With that in mind, a study by Lee et al. found that cardiorespiratory fitness was more strongly associated with all-cause mortality than physical activity alone (22); therefore, although HIIT may elicit varying health benefits, improving cardiorespiratory fitness should be encouraged to reduce the risk of all-cause mortality and the current body of research is demonstrating that HIIT is beneficial at doing just that.

Additionally, while previous research suggests that HIIT is beneficial for older adults, much of that research has taken place in a clinical and/or laboratory setting with specialized equipment, monitoring devices (i.e., metabolic cart, graded exercise test, heart rate monitors, etc.), and substantial staff oversight. It begs the question, is HIIT accessible to the greater aging population outside of the research setting and without specialized equipment? Is HIIT a practical exercise protocol that can be utilized in the general older adult population without access to or adequate resources to pay for the appropriate supervision? An influential systematic review and meta-analysis by Weston, Wisloff, and Coombes (2014) indicate that more research needs to access the sustainability of an unsupervised HIIT program, one that would be encountered in a "real-world" setting, outside the clinical atmosphere (36). The current research builds upon a recently published systematic review and looks to explore the practicality and effectiveness of adding a minimally invasive HIIT protocol (2 days/week) to the weekly exercise regimen of active older adults.

Therefore, this research aimed to determine the feasibility of utilizing a cycle ergometer HIIT protocol prescribed solely with a percentage of age-predicted heart rate maximum (HRmax) in a community-based, minimally invasive exercise program. A secondary aim was to determine what effects this cycle ergometer HIIT protocol may have on strength, balance, and gait

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parameters in an active, older adult population. The researchers hypothesize that there will be strength, balance, and gait benefits of a minimally invasive, HRmax controlled, cycle ergometer HIIT protocol, without aggressive staff oversight or need for specialized equipment. The program's feasibility will be considered successful if the participants can complete the HIIT protocol with ≥ 80% completion rate and improvements are noted in any of the outcome variables observed in the research.

METHODS

Participants
A randomized control design including a HIIT intervention group, and a non-intervention control group were originally enrolled in the study. Due to the unexpected state of emergency enacted by the Spanish government regarding the Covid-19 pandemic, the authors could collect data from only a limited number of HIIT intervention participants that had already been scheduled for post-intervention measurements prior to the state of emergency and consequently the closure of the facilities. Therefore, the authors consider that these data serve as a feasibility study for enacting a minimally invasive HIIT intervention in an active aging population without aggressive oversight or equipment requirements.

Participants were recruited and screened according to the study inclusion/exclusion criteria. Randomization was based on a random number generator as well as the availability of the participants to complete the two additional HIIT interventions per week. Participants were instructed not to alter their diet, or their normal physical activity habits except for the scheduled exercise sessions of this study. Outcome assessments were performed at baseline and after the 6-week intervention. The same researchers performed the assessments at baseline and post-intervention while strictly adhering to the established standard operating procedures. Individual participant's data was coded to ensure blinding during data analysis.
The ethical recommendation approved in the Declaration of Helsinki (2013) was observed. In addition, we followed the instructions of the European Union on Good Clinical Practice (111/3976/88 of July 1990), as specified in a National legal framework for human clinical research (Royal Decree 561/1993 on clinical essays). The study was approved by the University Ethics Committee (Reference: NOV.19/5.TES).

Measurements: Study procedures and exercise training were performed at the local university's sports center. Baseline and post-intervention testing were performed as follows.

Anthropometrics: Participants wore light, exercise-type clothing and were assessed barefoot during this test; they were asked to wear the same or similar clothing for both the pre-and post-tests. Height was measured to the nearest millimeter using a stadiometer and an average of three measures was used. Bodyweight was measured to the nearest 0.1 kg using the InBody 270 bio-impedance analysis scale (InBody Co. Ltd. InBody Bldg., 625, Eonju-ro, Gangnam-gu, Seoul, 06106 Korea). Body mass index was calculated by taking the weight in kilograms divided by height in meters squared (kg/m^2).

Resting Blood Pressure (BP): BP and Heart Rate (HR) were measured over the brachial artery using an automated oscillometric device (Omron M2 - HHEM-7121-E, OMRON Healthcare Europe B.V. Scorpius 33, 2132 LR Hoofddorp, The Netherlands) while the participant was seated with both feet placed on the ground. For this study, the lowest of two measurements was used.

Lipids & Glucose: Fasting serum blood samples were analyzed by using a handheld device using standard procedures; total cholesterol levels were analyzed with the Accutrend® Plus System (Roche Diagnostics International AG, Forrenstrasse 26343, Rotkreuz, Switzerland) and glucose was analyzed with the Accu-Check® Aviva (Roche Diabetes Care Spain, S.L. Avda. de la Generalitat, 171-173. 08174 Sant Cugat del Vallès, Barcelona).

Upper body strength: We used a handgrip dynamometer to measure isometric grip force. Both the right- and left-hand grip forces were measured. Two measures were performed for each hand, and the highest value was used for statistical analysis. Complete recovery was allowed between attempts (16). We used the TKK.5101 adaptive manual pressure dynamometer, with a precision of 0.1 Kg, as used in previous studies (27).

Lower body strength was assessed through the different tests: 30-second Chair sit-to-stand (S-t-S): To conduct the test, we used a standard 42 cm chair without arms. The chair was situated against a wall to avoid any movement during the test. To start the test, the participant was seated on the chair, back straight, feet approximately shoulder-width apart, and placed on the floor at an angle slightly back from the knees. The test started at the signal of "ready, set, go", then the participant would rise to a full stand (body erect and straight) and then return to the seated position. They were encouraged verbally to complete as many full stands as possible in 30 seconds. The evaluator silently counted each correct stand. Before the participant began the test, the evaluator conducted a demonstration and a practical trial of 1-2 repetitions was allowed. The total number of repetitions executed properly was recorded per previous research (18).

10-repetition Chair S-t-S: Similarly, the 10-repetition chair S-t-S was conducted in the same way as the 30-second chair S-t-S. We recorded the time required to complete 10 full stands from the sitting position. We allowed one practice trial before starting the test to learn the task and perform it properly. The participants were encouraged to complete the test as quickly as possible (8).

Lower limb power was calculated using the method presented by Baltazar et al. (2). Using both the 30-second S-t-S and the 10 repetition S-t-S, we calculated power (watts). Mechanical Power (W) = Force x Velocity (see equation below)

$$\textbf{Estimated Power} = (BM \times 0.9 \times g) \times \frac{([Body\ h \times 0.5] - Chair\ h)}{\left(\frac{Total\ STS\ t}{n\ STS\ reps}\right) \times 0.5}$$

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To measure gait, we used the OptoGait device (Microgate, Bolzano, Italy). It is an optical data acquisition system, composed of a transmitter and a receiver optical bar. Each bar contains 96 Infrared LEDs (1,041 cm resolution). These LEDs are located on the transmitter bar and communicate continuously with the LEDs located on the receiver bar. The system detects the eventual interruptions and their duration. It is a valid measurement device for the assessment of spatiotemporal gait parameters (23). The protocol used to carry out the test was 5 meters in which they had to walk within the walkway formed by the OptoGait. They made 6 roundtrip passes in which they had to walk comfortably at a normal pace, like that used in their everyday life. Participants started walking 2.5 meters before the start of the OptoGait system and turned around 2.5 meters from the end of the Optogait system. The total travel in each pass was 10 m, as the Optogait covers the 5 m in the center, where the measurement takes place. The variables that were considered in this research were step length (cm), coefficient of variation of step (%), and gait speed (m/s)

Static balance (SB): Measured in time (seconds). To perform the test, the participants must stand unassisted on one leg (dominant leg) with their arms folded across the chest. Time was recorded with a stopwatch and time started when the participant lifted one foot off the ground and stopped when that same foot touched the ground again or when the participant reached 60 seconds. The test was performed with eyes open and with tennis shoes. Before testing, the evaluator demonstrated the position to assume during the test (17).

Timed up & go (TUG): Measured in time (seconds) and reflects agility and dynamic balance. To complete this test, the participant started sitting and stood from a 42cm chair. After a countdown (ready, set, go), a timer was initiated, and the participant started the test. They were asked to rise from the seated position, walk at a self-selected pace toward a marker on the floor 3 meters away from the chair, turn around the marker, return to the chair and sit down again. Timing stopped when the participant sat back down in the chair (28).

Cardiorespiratory fitness: 6 Minute walk test measured in distance (m) was used to assess aerobic endurance. The original version of this test is included in the Senior Fitness Test which has exhibited high reliability (31). To complete the test, the participants walk for 6 minutes in a flat rectangular course (30 x 5 m) which is marked with a red line every 5 meters. Bright-colored cones were used to mark the four corners of the course which indicated to the participant the point at which they turn left. We assessed the participants in groups (between 3 to 6 participants) on the course at a given time, using staggered starting and stopping times to promote individual pacing and avoid walking together in groups or pairs. The participants were instructed to cover the maximum distance possible walking as fast as they comfortably could without running, and without overexerting or pushing themselves beyond their limits. Furthermore, the evaluators used encouragement phrases (e.g., You are doing well, keep up the good work, you can do it...) each time that the participants passed the starting point. We announced to the participants the time left approximately halfway through the test (3 min), 2 min left, and 1 min left respectively. When the time was complete, the evaluators announced the name of the participant and the

word "stop". At this moment, the evaluator recorded the total distance completed by each participant to the nearest 5 meters.

Exercise Intervention: Subjects participated in a non-weight-bearing cycle ergometer (KOR M-9540 by Salter, Arias Montano 28, 28007 Madrid, Spain) HIIT exercise regimen 2 days/week for 6 weeks, under the supervision of an onsite exercise specialist who tracked the participant's heart rate (HR), rate of perceived exertion (RPE) and watt production during every interval of each exercise session. The objective of the onsite exercise specialist was notating outcome measures (HR, RPE, and watts) and help the participants in the case of an adverse event or specific questions regarding equipment and/or malfunctions. The intervention consisted of 4×4-minute intervals interspersed by 3×3-minute active recovery periods. The participants were given 85% of their heart rate maximum (HRmax) and were instructed to attain their respective values in the 4-minute HIIT intervals. A 5-minute warm-up at 60% of HRmax was included in each exercise session which amassed a total of 32 minutes of cycling.

HRmax was predicted applying the Tanaka method using 208 – 0.7 x age (33). Exercise HR was displayed and recorded during each exercise session using the cycle ergometers respective handheld heart rate telemetry system. Participants were instructed to reach target HR by modifying their cadence (increased cadence = increased HR, decreased cadence = decreased HR), if the adjustment of cadence was not adequate to elicit a rise or fall in HR the participants were advised to adjust the level of resistance accordingly. Due to the possibility that participants may have been unfamiliar with exercising on a cycle ergometer, a pre-conditioning period was completed before the 6-week intervention. The preconditioning sessions increased the individual's tolerated duration of exercise until the participants could perform 35 minutes of cycling at 70% of HRmax and they were familiar with the exercise equipment, at which point the participants started the 6-week HIIT intervention.

Statistical Analysis

Power analysis was performed with G*Power Version 3.1.9.4 using lower limb functional capacity (TUG and S-t-S) as the primary outcome measures. The sample size was calculated with $\alpha = 0.05$ and power = 0.70 with values between pre-and post-tests based on previous research (5, 24, 26). All variables are expressed as a mean and standard deviation (M ± SD) and were analyzed using the statistical package SPSS v. 27 (SPSS Inc., Chicago, IL, USA). Normality assumption by Shapiro–Wilks was identified for each variable of the paired samples. A paired sample's t-test was used to compare the pre- to post-intervention measures. Post hoc analysis was corrected using the Bonferroni adjustment. Significant differences were established at a p-value of < 0.05. Cohen's D was used to assess the magnitude of mean differences. A recent review of effect size in gerontology suggested the interpretation of effect sizes is small = 0.15, medium = 0.40, and large = 0.75 (4). Post analysis of % HRmax, RPE, and watts per kilogram of body mass (W/kg) for the average of all exercise sessions for each of the four intervals were analyzed using a general linear model within-subjects repeated measures. Individual participants' Pearson correlations were analyzed between %HRmax, RPE, and W/kg respectively.

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RESULTS

The estimated marginal means for all exercise sessions of W/kg, %HRmax, and RPE by gender and total are presented in Table 1. W/kg remained consistent throughout the intervals although there was a slight rise from interval 1 to 4. Similarly, there was a documented rise of %HRmax alongside the increased effort of W/kg from intervals 1 to 4 from approximately 80% to 85%. Likewise, RPE showed a trivial yet progressive rise alongside W/kg from interval 1 to 4 as noted in Table 1.

Table 1. Estimated Marginal Means per Interval (mean ± standard deviation).

		Total (N = 10)	Males (N = 3)	Females (N = 7)
Interval 1	W/kg	1.14 ± 0.38	1.51 ± 0.35	0.98 ± 0.28
	%HRmax	79.70 ± 6.57	78.79 ± 6.96	80.09 ± 6.93
	RPE	12.11 ± 0.57	12.00 ± 0.34	12.16 ± 0.66
Interval 2	W/kg	1.18 ± 0.41	1.53 ± 0.47	1.02 ± 0.29
	%HRmax	82.75 ± 7.03	82.48 ± 8.00	82.87 ± 7.26
	RPE	12.67 ± 0.63	12.37 ± 0.77	12.80 ± 0.58
Interval 3	W/kg	1.20 ± 0.39	1.53 ± 0.41	1.06 ± 0.30
	%HRmax	82.96 ± 6.65	82.08 ± 7.90	83.34 ± 6.70
	RPE	12.67 ± 0.63	12.85 ± 0.79	12.59 ± 0.61
Interval 4	W/kg	1.24 ± 0.39	1.59 ± 0.41	1.09 ± 0.28
	%HRmax	84.82 ± 6.63	83.85 ± 7.15	85.23 ± 6.94
	RPE	13.11 ± 0.74	12.94 ± 0.92	13.19 ± 0.72

The individual participants' Pearson correlations of W/kg, %HRmax, and RPE throughout the intervention are presented in Table 2. Significant Pearson correlations were found between %HRmax and W/kg in seven of the ten participants. Only two participants had significant correlations between RPE and W/kg. Five of the ten participants demonstrated a significant correlation between %HRmax and RPE. The observation of all exercise sessions reveals a significant correlation between RPE and W/kg (r = 0.144) and %HRmax and RPE (r=0.155). Pearson correlation was not significant between %HRmax and W/kg when compared across all exercise sessions.

The participants lower limb strength demonstrated by the 10 repetition Sit-to-Stand (p = 0.004, Cohen's D = 0.660) and 30 second Sit-to-Stand (p = 0.021, Cohen's D = 0.635) displayed significant differences pre- to post-intervention. Likewise, the estimated calculated power of the 10 repetitions Sit-to-Stand (p = 0.005, Cohen's D = 0.494) exhibited a significant difference whereas the 30-second Sit-to-Stand bordered significance but not definitively (p = 0.05, Cohen's D = -0.662). Increased functional capacity demonstrated by TUG (p=0.001, Cohen's D = 0.940) and SB (p = 0.034, Cohen's D = 0.292) also presented significant differences pre- to post-intervention. No significant differences pre- to post-intervention were assessed for the other outcome measures reported in this study. Paired samples T-tests, effect size, and p-values in Table 3.

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Table 2. Pearson Correlation for Individual Participants & Group Combined.

Participant		%HRmax – W/kg	RPE – W/kg	%HRmax - RPE
1	*r*	**0.523***	0.143	0.264
2	*r*	0.007	0.255	**0.396***
3	*r*	0.257	-0.010	0.322
4	*r*	**0.684***	-0.247	-0.029
5	*r*	**0.382***	0.144	**0.659****
6	*r*	**0.581****	**0.573****	**0.645****
7	*r*	0.183	-0.263	-0.283
8	*r*	**0.849****	0.250	**0.539****
9	*r*	**0.521***	0.358	0.147
10	*r*	**0.808****	**0.563****	**0.693****
ALL	*r*	0.065	**0.144***	**0.155***

** Correlation is significant at the 0.01 level (2-tailed)
* Correlation is significant at the 0.05 level (2-tailed)

Table 3. Paired Samples T-Test (mean ± standard deviation).

Variable	Pre-test	Post-test	Effect size†	*p*-value
Systolic BP (mmHg)	141.5 ± 12.8	137.6 ± 20.8	0.20	0.435
Diastolic BP (mmHg)	90.3 ± 5.3	87.6 ± 7.9	0.34	0.092
Resting Heart Rate (bpm)	78.2 ± 11.4	75.7 ± 10.7	0.23	0.296
Body Mass (kg)	77.3 ± 11.2	76.5 ± 10.3	0.05	0.099
Body Mass Index (kg/m^2)	29.2 ± 4.1	28.9 ± 3.9	0.06	0.106
Total Cholesterol (mg/dl)	211.4 ± 39.2	226.9 ± 33.7	0.42	0.169
Fasting Glucose (mg/dl)	99.22 ± 9.1	99.78 ± 6.2	0.07	0.855
Hand Grip (right) (kg)	28.1 ± 9.4	29.0 ± 11.2	0.08	0.463
Hand Grip (left) (kg)	26.0 ± 9.0	26.8 ± 10.3	0.07	0.405
10 rep S-t-S(s)	13.9 ± 3.0	11.9 ± 3.1	0.66	**0.004**
Power S-t-S (w)	206.2 ± 61.7	236.5 ± 51.3	0.49	**0.005**
30 sec. S-t-S(Rep)	18.0 ± 3.3	20.3 ± 3.9	0.64	**0.021**
Power 30 sec. S-t-S (w)	158.4 ± 27.0	177.0 ± 29.1	0.66	0.050
Timed Up and Go (s)	5.1± 0.5	4.5 ± 0.7	0.94	**0.001**
Complex Gait Test (s)	14.0 ± 2.4	14.1 ± 1.8	0.03	0.891
Static Balance (s)	30.4 ± 21.0	36.6 ± 21.5	0.29	**0.034**
6-Minute Walk (m)	624 ± 53.2	641 ± 62.8	0.28	0.121
Gait Velocity (m/s)	1.69 ± 0.17	1.64 ± 0.20	0.25	0.273
Step Length (cm)	75.83 ± 4.8	73.34 ± 5.3	0.49	0.124

† Cohen's D; S-t-S: Sit to Stand; bpm: beats per minute; W: watts: Rep: repetition.

DISCUSSION

This research aimed to determine the feasibility of prescribing a minimally invasive cycle ergometer HIIT protocol using a percentage of age-predicted HRmax to improve functional capacities. Although the target HR of 85% HRmax was not achieved, improvements in lower limb strength and balance were nevertheless significant. When examining the group means of W/kg, %HRmax, and RPE all data points demonstrated a steady rise from interval 1 to interval 4 with a small plateau between interval 2 and 3. Although these changes are small, they do reveal

that when examined as a group mean all three variables incrementally change together which contributes to the idea that HR is a good indicator of work rate. This is demonstrated in Table 2 where the individual correlation between %HRmax and W/kg are correlated in seven of the ten participants.

Therefore, the authors believe that HR can be used to prescribe an unsupervised or minimally supervised cycle ergometer HIIT protocol in an older adult population. Using HR to prescribe HIIT can become even more practical when used in combination with RPE. However, it is necessary to caution that not every individual response is equivalent (i.e., 85% of HRmax is not always equal to an RPE of 13). At a given work rate, individual participants can demonstrate a higher %HRmax although their respective RPE is much lower or vice versa. This idea is supported by a study by Jabbour & Majed (2018) which determined that RPE alone may misclassify exercise intensity for sedentary older adults but that is nevertheless useful when used in combination with other commonly used methods such as %HRmax (18). When examining group data combined it appears that RPE is more closely correlated with W/kg. However, once again, it is necessary to use caution as the authors believe this is an erroneous approach to reviewing the data because it does not consider the individual's capacity for work (peak watts, functional threshold power, etc.). If the study had accounted for the maximum aerobic capacity of each participant, we could have then examined the correlation between %HRmax and a percentage of maximum aerobic capacity, which is a more valid comparison. Thus, while %HRmax was not correlated with W/kg in the grouped data of this study, it appears to be a more appropriate means to prescribe cycle ergometer exercise on an individual level. As mentioned earlier, the current data revealed that at the individual level, an increase in W/kg correlated with an increase in %HRmax in seven of the ten participants.

The authors believe that the feasibility of implementing a HIIT protocol in older adults using a simple calculation of %HRmax is justified, and further research can use this method of prescribing exercise in older adults. Although the prescribed intensity of 85% of HRmax was not met in all the intervals, they were not far below the mark and when examining the mean of all intervals combined it is equal to approximately 83% of HRmax. To put that into context, the average target HR (85% of maximum) for the current participants was 138 bpm, 135 bpm was the average recorded HR to equal the approximation of 83% of HRmax. A percentage of 82% of HRmax is still well within the range of what would be considered HIIT and/or vigorous exercise (6,36).

Though it is not comfortable to engage in HIIT exercise, once a participant understands their respective aerobic capacity (in this case, %HRmax) they often self-regulate their interval intensities without the need of an exercise specialist or other onsite observer. The current study maintained one exercise specialist per three HIIT participants; the authors consider this to be an appropriate 1:3 working ratio to maintain suitable oversight in the beginning stages of a HIIT protocol when the exercise specialist is needed the most to resolve any problems that may arise or questions that may need to be addressed. No specialized equipment was used in the current study and a simple, commercially available, cycle ergometer with power (watts), cadence (rpm),

and a handheld heart rate sensor (bpm) was all that was needed to complete the 4x4 HIIT protocol. The authors of the current research trust that appropriately informed older adults can easily participate in cycle ergometer HIIT with minimum oversight from an exercise specialist and minimal amounts of specialized equipment. The authors would like to reiterate that the exercise specialist was not present to control the exercise intensities of the individual participants but rather track/report the intensities, encourage, and help participants in the case of an adverse event.

A secondary aim was to determine the effects that cycle ergometer HIIT training may have on parameters such as strength, balance, and gait in an already active, older adult population. The researchers hypothesized that there would be an added benefit to including minimally invasive HIIT to the exercise regimen of these active older adults. This research demonstrates that the authors' hypothesis was correct in that 6 weeks of cycle ergometer HIIT is an adequate amount of time to result in lower limb functional capacity and strength improvements in an active, non-clinical population of older/aging adults. This data is corroborated by research from Herrod, Lund, & Phillips (2021) which demonstrated positive health adaptations with just 6-weeks of cycle ergometer HIIT exercise (14). Therefore, the authors believe that these data are aligned with the literature in that 6-weeks of cycle ergometer HIIT is an adequate time to see significant improvements in health parameters such as balance, strength, and functional capacity.

Perhaps the most notable change witnessed in the participants was their lower limb power measures in both the 10 repetition sit-to-stand and the 30-second sit-to-stand. As noted in previous studies, loss of muscle mass and strength is common among older adults, which in turn decreases lower-limb function and therefore autonomy (7, 12, 21). The authors would like to repeat that one inclusion criteria for participation in the study was to be active in the multi-component group exercise class for longer than 6 months and many of the participants had been active for much longer (2-3 years on average). Therefore, the authors strongly believe that the lower limb strength was due to the adaptation from the HIIT training rather than the multi-component group exercise class. To the best of our knowledge, to date, there is no aerobic HIIT intervention that has demonstrated this type of positive increase in the S-t-S measurements and calculated power in watts. However, recently published research by Marzuca-Nassr et al. (2020) found that 12-weeks of cycle ergometer HIIT increased 1 repetition maximum for dominant leg strength (26). Likewise, Research by Vogel et al. indicated that with 9 weeks of aerobic cycling HIIT, participants had a greater maximum tolerance of power from baseline measures; suggesting that there may have been some muscular adaptation to allow for this increased tolerance (35). The authors of the current research highly recommend that future aerobic HIIT investigations in older adults report lower-limb power measures such as the chair sit-to-stand and TUG as they are easy to include, accessible to most research scenarios, and require minimal equipment.

Of the 115 total training sessions completed by the participants, not one resulted in an adverse event. The biggest complaint from the participants was related to the comfort of the seat on the cycle ergometer. As mentioned above, 115 total training sessions were completed out of a

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possible 120 which resulted in a 96% session completion rate. The training sessions not completed were reported as an unrelated illness or scheduling conflict.

The current research is just another study demonstrating that HIIT is a safe and effective means of participating in cardiovascular exercise, as not one participant presented an adverse event throughout the intervention. Our claim that HIIT is safe, is aligned with recent data reported in systematic reviews, a meta-analysis, as well as other previously published research (1, 10, 13, 19, 25). Not only does HIIT seem to be safe but also effective at engaging participants that would otherwise drop out of moderate-intensity continuous training (MICT) exercise routines. The participants of the current research often reported to the onsite exercise specialists that they enjoyed the challenge of the HIIT intervals and that the change in pace often made the exercise session time feel shorter than it actually was. These types of reports (although anecdotal), as well as other factors, may be contributing to the high completion rates that are seen with aerobic HIIT interventions. More research should assess the completion rates of various exercise interventions for longer periods and determine if there is a statistically significant difference amongst varying exercise interventions.

Limitations: The authors acknowledge that the current research has its limitations that need to be addressed. The central limitation of this data is the lack of a control group. The current research, like others, was affected by the Covid-19 pandemic and after a government-enforced shutdown, we could no longer access the control (nor the remaining HIIT) participants, thus no comparison group. However, due to the significant increase in lower limb strength and the large effect sizes, the authors believe the data merit further research. A secondary limitation is the small sample size of only 10 individuals, which in turn, limits our statistical power and increases the chance of type II error. Future research should examine larger samples of older adults from a variety of populations to determine the effectiveness of utilizing a %HRmax prescribed cycle ergometer exercise program without aggressive oversight to determine if HIIT is a practical exercise protocol to recommend in the general population.

Practical applications: The value of this research is that it indicates two practical applications for an aerobic cycle ergometer HIIT protocol. The first and most exciting for the authors is that aerobic HIIT can be applied outside of a clinical setting with little need for special equipment or oversight from an exercise specialist. The current research used a common cycle ergometer that can be found in most fitness centers/workout facilities, and we used a simple maximum heart rate calculation to determine the prescribed interval intensities. Once the participant established an understanding of the protocol they could and would often be self-sufficient; at times even reminding the onsite exercise specialist when their intervals were beginning and/or ending to log the participant's data.

A secondary application is the usefulness of an aerobic cycle ergometer HIIT protocol to not only have cardiorespiratory benefits, as noted in the current body of evidence but also appears to improve lower limb strength and functional capacity in older adults. The current study helps fill some gaps in the research regarding the effect that cycle ergometer HIIT may have on lower

limb strength, gait, and balance parameters. The authors believe that although this data has its limitations and more research is needed, it also strengthens the idea that aerobic cycling HIIT improves functional capacities that may be capable of preventing falls and improving quality of life in older adults.

Conclusion: Although it is not possible to draw definitive conclusions from this data due to the lack of a control and/or comparison group, these data imply that a simple 4x4 cycle ergometer HIIT protocol can be prescribed to a broader, non-clinical population of older adults by using HRmax and using RPE as a guide in an unsupervised fashion. This study also demonstrates that 6 weeks of cycle ergometer HIIT is an adequate amount of time to result in lower limb strength and functional capacity improvements in active older adults. More research is warranted to determine the effects that cycle ergometer HIIT has on strength, balance, and gait parameters in older adults.

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REFERENCES

1. Angadi SS, Mookadam F, Lee CD, Tucker WJ, Haykowsky MJ, Gaesser GA. High-intensity interval training vs. moderate-intensity continuous exercise training in heart failure with preserved ejection fraction: A pilot study. J Appl Physiol 119(6): 753–8, 2015.
2. Baltasar-Fernandez I, Alcazar J, Rodriguez-Lopez C, Losa-Reyna J, Alonso-Seco M, Ara I, et al. Sit-to-stand muscle power test: Comparison between estimated and force plate-derived mechanical power and their association with physical function in older adults. Exp Gerontol 145: 111213, 2021.
3. Bartlett JD, Close GL, Maclaren DPM, Gregson W, Drust B, Morton JP. High-intensity interval running is perceived to be more enjoyable than moderate-intensity continuous exercise: Implications for exercise adherence. J Sports Sci 29(6): 547–53, 2011.
4. Brydges CR. Effect size guidelines, sample size calculations, and statistical power in gerontology. Innov Aging 3(4): igz036, 2019.
5. Buckinx F, Gouspillou G, Carvalho LP, Marcangeli V, El G, Boutros H, et al. Effect of high-intensity interval training combined with L-citrulline supplementation on functional capacities and muscle function in dynapenic-obese older adults. J Clin Med 7(12): 561, 2018.
6. Bushman BA. Physical activity guidelines for Americans. ACSM Health Fit J 23(3): 5–9, 2019.
7. Candow DG, Chilibeck PD. Differences in size, strength, and power of upper and lower body muscle groups in young and older men. J Gerontol A Biol Sci Med Sci 60(2): 148–56, 2005.
8. Csuka M, McCarty DJ. Simple method for measurement of lower extremity muscle strength. Am J Med 78(1): 77–81, 1985.
9. Eddolls WTB, McNarry MA, Stratton G, Winn CON, Mackintosh KA. High-intensity interval training

interventions in children and adolescents: A systematic review. Sports Med 47(11): 2363–74, 2017.

10. Elboim-Gabyzon M, Buxbaum R, Klein R. The effects of high-intensity interval training (HIIT) on fall risk factors in healthy older adults: A systematic review. Int J Environ Res Public Health 18(22): 11809, 2021.
11. Gillen JB, Gibala MJ. Is high-intensity interval training a time-efficient exercise strategy to improve health and fitness? Appl Physiol Nutr Metab 39(3): 409–12, 2014.
12. Guralnik JM, Ferrucci L, Pieper CF, Leveille SG, Markides KS, Ostir G V., et al. Lower extremity function and subsequent disability: Consistency across studies, predictive models, and value of gait speed alone compared with the short physical performance battery. J Gerontol A Biol Sci Med Sci 55(4): 221–31, 2000.
13. Hannan A, Hing W, Simas V, Climstein M, Coombes J, Jayasinghe R, et al. High-intensity interval training versus moderate-intensity continuous training within cardiac rehabilitation: A systematic review and meta-analysis. Open Access J Sports Med 9: 1–17, 2018.
14. Herrod PJJ, Lund JN, Phillips BE. Time-efficient physical activity interventions to reduce blood pressure in older adults: A randomised controlled trial. Age Ageing 50: 980–4, 2021.
15. Hwang CL, Yoo JK, Kim HK, Hwang MH, Handberg EM, Petersen JW, et al. Novel all-extremity high-intensity interval training improves aerobic fitness, cardiac function and insulin resistance in healthy older adults. Exp Gerontol 82: 112–9, 2016.
16. Innes E. Handgrip strength testing: A review of the literature. Aust Occup Ther J 46(3): 120–40, 1999.
17. Iverson BD, Gossman MR, Shaddeau SA, Turner ME. Balance performance, force production, and activity levels in noninstitutionalized men 60 to 90 years of age. Phys Ther 70(6): 348–55, 1990.
18. Jones CJ, Rikli RE, Beam WC. A 30-s chair-stand test as a measure of lower body strength in community-residing older adults. Res Q Exerc Sport 70(2): 113–9, 1999.
19. Keating CJ, Párraga Montilla JÁ, Latorre Román PÁ, Moreno del Castillo R. Comparison of high-intensity interval training to moderate-intensity continuous training in older adults: A systematic review. J Aging Phys Act 28(5): 798–807, 2020.
20. Kovacevic A, Fenesi B, Paolucci E, Heisz JJ. The effects of aerobic exercise intensity on memory in older adults. Appl Physiol Nutr Metab 45(6): 591–600, 2020.
21. Lauretani F, Russo CR, Bandinelli S, Bartali B, Cavazzini C, Di Iorio A, et al. Age-associated changes in skeletal muscles and their effect on mobility: An operational diagnosis of sarcopenia. J Appl Physiol 95(5): 1851–60, 2003.
22. Lee DC, Sui X, Ortega FB, Kim YS, Church TS, Winett RA, et al. Comparisons of leisure-time physical activity and cardiorespiratory fitness as predictors of all-cause mortality in men and women. Br J Sports Med 45(6): 504–10, 2011.
23. Lienhard K, Schneider D, Maffiuletti NA. Validity of the Optogait photoelectric system for the assessment of spatiotemporal gait parameters. Med Eng Phys 35(4): 500–4, 2013.
24. Losa-Reyna J, Baltasar-Fernandez I, Alcazar J, Navarro-Cruz R, Garcia-Garcia FJ, Alegre LM, et al. Effect of a short multicomponent exercise intervention focused on muscle power in frail and pre frail elderly: A pilot trial. Exp Gerontol 115(October 2018): 114–21, 2019.
25. Martland R, Mondelli V, Gaughran F, Stubbs B. Can high-intensity interval training improve physical and mental health outcomes? A meta-review of 33 systematic reviews across the lifespan. J Sports Sci 38(4): 430–69, 2020.
26. Marzuca-Nassr GN, Artigas-Arias M, Olea MA, SanMartín-Calísto Y, Huard N, Durán-Vejar F, et al. High-intensity interval training on body composition, functional capacity and biochemical markers in healthy young versus older people. Exp Gerontol 141: 111096, 2020.

27. Pedrero-Chamizo R, Albers U, Tobaruela JL, Meléndez A, Castillo MJ, González-Gross M. Physical strength is associated with Mini-Mental State Examination scores in Spanish institutionalized elderly. Geriatr Gerontol Int 13(4): 1026–34, 2013.

28. Podsiadlo D, Richarson S. The timed up and go: A test of basic functional mobility for frail elderly persons. J Am Geriatr Soc 39(2): 142–8, 1991.

29. Ramos JS, Dalleck LC, Tjonna AE, Beetham KS, Coombes JS. The impact of high-intensity interval training versus moderate-intensity continuous training on vascular function: A systematic review and meta-analysis. Sports Med 45(5): 679–92, 2015.

30. Reichert FF, Barros AJD, Domingues MR, Hallal PC. The role of perceived personal barriers to engagement in leisure-time physical activity. Am J Public Health 97(3): 515–9, 2007.

31. Rikli RE, Jones CJ. The reliability and validity of a 6-minute walk test as a measure of physical endurance in older adults. J Aging Phys Act 6(4): 363–75, 1998.

32. Rynecki ND, Siracuse BL, Ippolito JA, Beebe KS. Injuries sustained during high intensity interval training: Are modern fitness trends contributing to increased injury rates? J Sports Med Phys Fitness 59(7): 1206–12, 2019.

33. Tanaka H, Monahan KD, Seals DR. Age-predicted maximal heart rate revisited. J Am Coll Cardiol 37(1): 153–6, 2001.

34. Tjønna AE, Lee SJ, Rognmo Ø, Stølen TO, Bye A, Haram PM, et al. Aerobic interval training versus continuous moderate exercise as a treatment for the metabolic syndrome: A pilot study. Circulation 118(4): 346–54, 2008.

35. Vogel T, Leprêtre PM, Brechat PH, Lonsdorfer E, Benetos A, Kaltenbach G, et al. Effects of a short-term personalized intermittent work exercise program (IWEP) on maximal cardio-respiratory function and endurance parameters among healthy young and older seniors. J Nutr Heal Aging 15(10): 905–11, 2011.

36. Weston KS, Wisløff U, Coombes JS. High-intensity interval training in patients with lifestyle-induced cardiometabolic disease: A systematic review and meta-analysis. Br J Sport Med 48: 1227–34, 2014.

37. Wewege M, van den Berg R, Ward RE, Keech A. The effects of high-intensity interval training vs. moderate-intensity continuous training on body composition in overweight and obese adults: A systematic review and meta-analysis. Obes Rev 18(6): 635–46, 2017.

38. Wu Z-J, Wang Z-Y, Gao H-E, Zhou X-F, Li F-H. Impact of high-intensity interval training on cardiorespiratory fitness, body composition, physical fitness, and metabolic parameters in older adults: A meta-analysis of randomized controlled trials. Exp Gerontol 150: 111345, 2021.

IV. A Single Session of Cycle Ergometer High-Intensity Interval Training (HIIT) Does Not Produce an Elevated Fall Risk in Adults 50 – 70 Years of Age

Submitted

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Research Article

A Single Session of Cycle Ergometer High-Intensity Interval Training Does Not Produce a Transient Elevated Risk of Falling in Older Adults 50 – 70 Years of Age

Submitted

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Short Title: A Single Session of Cycle Ergometer High-Intensity Interval Training

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Abstract

Background: High-intensity interval training (HIIT) is an exercise routine that has been shown to induce physiological adaptations that improve varying aspects of fitness and health in a time-efficient manner. Yet, an often-cited study indicates that a single session of HIIT can elicit an elevated transient risk of falling in older adults and the time efficiency of HIIT could be debated. Other studies suggest that there may only be an exercise-induced fatigue fall risk in those 70 + years of age. ***Objective:*** To determine if a single session of cycle ergometer HIIT produces a negative, transient effect on balance and gait parameters in older adults 50 – 70 years of age and if so, is the effect significantly different from that of a metabolically matched moderate-intensity continuous training (MICT) protocol? ***Methods:*** Twenty healthy, older adults 50-70 years of age were enrolled. Subjects participated in a non-weight-bearing electronically braked cycle ergometer on two separate days; one day they participated in HIIT and the other day in MICT. The HIIT protocol consisted of 4×4-minute intervals at 85-95% of age-predicted heart rate max (HRmax) proceeded by 4×3-minute active recovery periods at 60% of HRmax. The MICT protocol consisted of a continuous intensity of 60-70% of HRmax. Before both exercise interventions baseline measures of center-of-pressure (COP), gait, and dynamic balance were acquired. The same measures were then captured at 4 different time points post-exercise (immediately, 10-, 20-, and 30-minutes post). COP data were collected for double-leg eyes closed (EC) and single-leg eyes opened (SL) scenarios in two directions (anterior-posterior [AP] and medial-lateral [ML]). ***Results:*** No significant difference for condition (HIIT vs MICT) or condition x time (pre, post, 10 post, 20 post, and 30 post) effects were observed. Significant time effects for sway velocity in the AP-SL (F [4] = 4.78, p = 0.002, $\eta_p^2 = 0.23$) and ML-SL (F [2.69] = 3.65, p = 0.023, $\eta_p^2 = 0.186$) positions and significant difference for time in sway range in the ML-EC (F [4] = 4.52, p = 0.003, $\eta_p^2 = 0.21$) position were observed. There was a significant effect for time in gait velocity (F [1.86] = 4.66, p = 0.018, $\eta_p^2 = 0.197$). ***Conclusion:*** A single session of cycle ergometer HIIT does not produce an acute transient effect on postural control or gait parameters in adults 50 – 70 years of age. The current data demonstrate that when compared to a metabolically matched MICT protocol, HIIT is just as safe and more time-efficient. Cycle ergometer HIIT should not be singled out as a hazardous exercise to participate in for the youngest of the older adults when the world's aging population is growing ever faster and needs more time-efficient and effective exercise regimens like cycle ergometer HIIT.

Introduction

The world's population is aging at an exceptionally fast pace. According to the United Nations (UN), by 2050 the world's population ≥ 65 years of age is projected to double from 703 million to 1.5 billion. This trend is no longer a concern that only affects developed countries but rather is now a global phenomenon affecting all countries (United Nations Department of Economic and Social Affairs Population Division, 2019). The rise of the aging population brings with it an increased cost to society because the number of working-age individuals (approximately 25 to 59 years of age) declines relative to the total number of consumers (United Nations, 2013). Therefore, we must focus on emerging efforts to age well and to reverse the impact of chronic disease and disability in older age (Hawkins, 2005).

There is a growing body of data confirming that more physically active persons have lower rates of non-communicable chronic disease (Chodzko-Zajko et al., 2009; Lee et al., 2011; Nes et al., 2014). In addition, physical activity in an aging population is associated with increased functional health, a lower risk of falling, and better cognitive function (Chodzko-Zajko et al., 2009). The 2008 Physical Activity Guidelines for Americans asserts that regular physical activity reduces the risk of many adverse health outcomes, stating that adults should avoid sedentary behavior, some activity is better than no activity, and that adults who participate in any amount of physical activity gain health benefits (Bushman, 2019). A recent study found that compared to a sedentary lifestyle, physical activity is associated with a lower risk of mortality for all causes in older adults after controlling for the effect of several other covariates and that health policies for old age care should include exercise as one of the main targets (Llamas-Velasco et al., 2016).

High-Intensity Interval Training (HIIT) is an exercise protocol that has been shown to induce physiological adaptations that improve varying aspects of fitness and health (Gillen & Gibala, 2014). The advantage of HIIT is that it maximizes the efficiency of the exercise while minimizing the time investment (Rynecki et al., 2019). Therefore, HIIT can be considered a time-efficient training program since previous research has shown that the participants spend approximately 40% less time training than they would have in other types of exercise regimens (Wewege et al., 2017). HIIT has also been recognized as a suitable exercise regimen for patients diagnosed with chronic conditions due to its increased effect on cardiorespiratory fitness and metabolic function (Hannan et al., 2018; Tjønna et al., 2008). Studies have reported that when compared with Moderate-Intensity Continues Training (MICT), HIIT can elicit superior improvements in indices of cardiorespiratory fitness. A systematic review by

Keating et al. found that HIIT was well-tolerated in an older population with significant, divergent comorbidities as well as being effective at increasing cardiorespiratory fitness (Keating et al., 2020). That review did not find a single study that had reported adverse events related to falling and/or tripping due to the HIIT intervention. Also, a more recent review concluded that HIIT is safe and effective at improving lower limb strength and dynamic balance in older adults (Elboim-Gabyzon et al., 2021).

Yet, research by Donath et al. suggests that a single session of HIIT can elicit an elevated transient risk of falling and the time efficiency of HIIT could be debated if indeed a HIIT-induced fall window is present and taken into consideration (Donath & Roth, 2014). A systematic review by Helbostad et al. found that balance is impaired due to resistance exercise-induced fatigue but that the rate of fatigue and recovery from that fatigue varied greatly amongst the studies (Helbostad et al., 2010). Various other studies suggest that exercise-induced fatigue is present and can generate acute impairments of balance and gait parameters (Helbostad et al., 2007; Morrison et al., 2016; Nagano et al., 2014; Parijat & Lockhart, 2008). However, all these studies included an older adult population 70+ years of age, and most of those studies focused on resistance exercise fatigue. Aside from the research by Donath et al., few studies have examined the acute effect that HIIT may have on balance and gait parameters and to our knowledge, none have compared the effects of cycle ergometer HIIT to that of a metabolically matched cycle ergometer MICT exercise session.

Therefore, the purpose of this research is to determine if a single session of cycle ergometer HIIT produces a negative, transient effect on balance and gait parameters in older adults 50 – 70 years of age and if so, is the effect significantly different from that of a metabolically matched MICT protocol? The authors hypothesize that there will be no significant difference in balance or gait parameters if the two exercises are metabolically matched.

Methods

Study Design

The present study was designed as a within-subjects repeated measure (2x5) randomized cross-over study. The order of the two exercise conditions (HIIT and MICT) was randomly assigned for each participant. The repeated measure for time (pre, post, 10 minutes post, 20 minutes post, and 30 minutes post) remained constant for both conditions and all participants. The two exercise assessment days were separated with a recovery period of at least 48 hours but no more than 7 days. All measurements were performed at the same or similar time of day for each participant.

The study was approved by the local ethics committee (University of Southern Mississippi Institutional Review Board, #IRB-20-519 - Acute Effects of High-Intensity Interval Training on Gait & Balance) and complied with the 2013 Declaration of Helsinki. All participants signed informed written consent prior to the start of the study.

Participants

Twenty healthy, older adults 50-70 years of age (58.2 ± 6.93; 10 males, 10 females) were enrolled in the study. No participant reported the use of prescribed medication or other health impairments that may have adversely affected gait and balance parameters. Individuals who reported diabetes, untreated hypertension (>180/110 mm Hg), glaucoma, endoprosthesis, arthritis and arthrosis, heart failure, coronary heart disease, stroke, obstructive diseases, eczema, and β-blocker users were not included in the study. All participants were asked to refrain from strenuous exercise 48 hours prior to testing and to maintain consistency between the two testing days.

After signing the informed consent but before the first exercise intervention, participants resting heart rate (RHR), height, weight, and body composition were assessed. RHR was evaluated after 5 minutes in the seated position by a MEDQUIP-CMS50D1 non-invasive fingertip pulse oximeter. Height was measured in centimeters by a SECA 274 (Mount Pleasant, SC, USA) freestanding stadiometer with a digital display. Weight and body composition were determined using a TANITA MC-780U (Arlington, IL, USA) multifrequency bioimpedance analysis (BIA) device.

Interventions

Subjects participated in a non-weight-bearing electronically braked cycle ergometer (Velotron, RacerMate/SRAM, Chicago, IL) exercise regimen under the supervision of one onsite exercise specialist who was present for both sessions for all participants. The exercise specialist observed the heart rate response of the individual throughout the protocol and adjusted the power output accordingly to stay within the heart rate ranges as close as possible. The exercise specialist also manually logged the participants' heart rate (HR), rate of perceived exertion (RPE), and watt production in the last minute of each interval (both high and low-intensity intervals). The participants' bike position (saddle height, handlebar height, reach, and saddle fore & aft) and was set and recorded in the first session and remained the same for the second session. The participants were instructed by the exercise specialist to maintain the revolutions per minute (RPM) at a constant rate throughout the intervention. The Veletron Coaching Software (RacerMate/SRAM, Chicago, IL) recorded the exercise

intervention data collection in real-time for posterior analysis and data collection confirmation (Watts, HR, RPM, kilocalories).

High-Intensity Interval Training (HIIT)

The HIIT intervention used was the 4 x 4 method most often used in older cardiovascular disease (CVD) patients (Dun et al., 2019). The intervention consists of 4×4-minute intervals at 85-95% of age-predicted heart rate max (HRmax) proceeded by 4×3-minute active recovery periods at 60% of HRmax. A 5-minute warm-up at 50-60% of HRmax was included in the exercise session which accrued a total of 33 minutes of cycling.

Moderate Intensity Continuous Training (MICT)

The intervention consisted of a routine continuous intensity of 60-70% of HRmax for 37 minutes. A 5-minute warm-up at 50-60% of HRmax was included in the exercise session amassing a total of 42 minutes of cycling which was estimated by the researchers to be the amount of exercise time needed to be metabolically matched with the HIIT protocol.

Testing Procedures

Center-of-pressure (COP) data from a single force platform (AMTI, Watertown, MA) were acquired at 120Hz using a fixed, below-ground system. The COP trace was separated into medial/lateral (ML) and anterior/posterior (AP) components. Two postural sway measures were then computed from the exported COP data in the ML and AP directions: 1) sway range and 2) sway velocity. Both postural sway measures were calculated using a customized Excel spreadsheet (Mircosoft, Redmond, WA) using similar equations as those reported previously reported by Bailey et al (Bailey et al., 2021). The sway range is the maximum distance between any two points on the COP path in their respective direction (AP or ML). The sway velocity is the average velocity between each time point within the respective trial. Both velocity and range are reported as the average between the two trials.

The battery of tests consisted of the double-leg eyes closed (EC) and single-leg eyes opened (SL) scenarios and the order of the scenarios for individual participants remained constant. However, the order of the test per participant was assigned on a rotating basis to minimize the possible effect of order bias (i.e., participant 1 started with EC while participant 2 started with SL). Prior to data collection, the investigators determined the participants' dominant foot by rolling a ball to the participant and asking them to kick it back to the investigator multiple times. The foot that dominated the receiving and passing of the ball was identified as the dominant leg and used for the SL scenario. Participants were then shown the proper stance, by always aligning the outside of their dominant foot with right or left side markers on the force

platform. The bilateral stance was then demonstrated by placing the non-dominate foot shoulder-width apart on the force platform, toes facing forward, hands by your side but not touching any part of their body, and eyes fixed on their preferred location on the wall in front of them. Before starting and between conditions, the participants were asked to reposition themselves in the stance they had originally. Participants were then addressed "starting from your original position, eyes looking at the spot on the wall in front of you, ready, 3,2,1… eyes closed/one foot". Each measure was recorded during a 10 second period and the average of two tests was used for data analysis. The participants were accessed with tennis shoes on, and the same pair of shoes was worn for both days.

Gait velocity was measured using the 10-meter walk test. The participant walked along a 10-meter path marked by a starting white line and a finishing white line. The timed section was the intermediate 6 meters to allow for acceleration in the first 2 meters and deceleration in the last 2 meters. The time in the intermediate 6 meters was measured using a wireless electronic timing system (Dashr Systems, Lincoln, NE) with the record time being transmitted via Bluetooth to a handheld device. The participant's comfortable, preferred walking speed was used, and they were instructed as such; "I want you to walk at a comfortable walking speed thru the white line on the opposite side of the walkway "I will say comfortable walking speed thru the white line, ready, set, go! When I say go, walk at your preferred walking speed until you cross the opposite white line". Two measures were taken at each of the five time points and the average of the two measures was used for data analysis. As the participants' time was taken over 6 meters, gait velocity was calculated as displacement over time.

Dynamic balance and agility were assessed using the timed up and go (TUG) test. The participant started by sitting in a standard 42cm chair and was asked to rise from the seated position, walk at a self-selected pace toward a marker on the floor 3 meters from the chair, turn around the marker, return to the chair and sit down again. The participant was cued by a countdown (ready, set, go), a timer was initiated at the word go, and the participant started moving; the time stopped when the participant sat back down into the chair. This test was measured in seconds and rounded to the nearest one-hundredth (i.e., 0.00) (Rikli & Jones, 2013).

Statistical Analysis

All variables are expressed as a mean and standard deviation (M±SD) and were analyzed using the statistical package SPSS v. 27 (SPSS Inc., Chicago, IL, USA). The two exercise modes were compared using a paired samples t-test. Due to two different data file corruptions,

COP data were analyzed for 18 participants, whereas all other data were analyzed with 20 participants. Normality assumption by Shapiro–Wilks was identified for each variable and normality was assumed. COP measures (sway velocity and sway range) for both conditions (EC and SL) were analyzed as a within-subjects 2 (condition: MICT and HIIT) by 5 (repeating factor of time: pre, post, 10 post, 20 post, 30 post) repeated measures analyses of variance (ANOVA). Likewise, gait and agility measures were analyzed as a 2 × 5 repeated-measures ANOVA. When sphericity was not met then the Greenhouse-Geisser correction was observed. Beforoni post hoc tests were calculated in the case there was a significant condition and/or time effect. The effect size of partial eta squared (ηp^2) was calculated for the repeated measures ANOVA to determine the practical importance. A ηp^2 is interpreted at $\geq$ 0.01 small, $\geq$ 0.06 medium, and $\geq$ 0.14 large (Jacob Cohen, 1988). Significant differences were established using an a priori alpha level of $p < 0.05$.

Results

Descriptive demographical and anthropometrical data are displayed in Table 1. There was a total of twenty participants that completed both exercise sessions with an average age of 58.2 years ± 6.93. Exercise mode comparisons are displayed in Table 2. The two exercise modes were metabolically matched as demonstrated in the amount of energy expended in kilocalories (kcal) at 242.95 ± 87.95 for HIIT and 234.41 ± 87.18 for MICT (p = 0.519).

Table 1
Descriptive Statistics

	Total (N=20)	Males (N=10)	Females (N=10)
Age (years)	58.2 ± 6.93	56.7 ± 7.47	59.7 ± 6.38
Height (cm)	171.29 ± 12.37	182.18 ± 5.88	160.40 ± 4.97
Weight (kg)	69.58 ± 14.20	79.19 ± 8.84	59.96 ± 11.92
BMI (kg/m^2)	23.5 ± 3.23	23.8 ± 2.54	23.2 ± 3.91
FM (%)	22.13 ± 8.73	16.31 ± 4.77	27.96 ± 7.93
RHR (bpm)	65.9 ± 8.3	67.3 ± 7.2	64.5 ± 9.46

Expressed as mean ± standard deviation; BMI = body mass index, FM = fat mass, RHR = resting heart rate

Table 2
Exercise intervention comparison

	HIIT (N = 20)	MICT (N = 20)	*p*
Watts	121.77 ± 43.79	92.54 ± 34.41	**< 0.001**
RPM	78.81 ± 7.01	78.88 ± 6.90	0.945
HR	129.48 ± 12.86	116.00 ± 16.72	**0.001**
Kilocalories	242.95 ± 87.48	234.41 ± 87.18	0.519

Statistically significant at a p-value of < 0.05. RPM = revolutions per minute, HR = heart rate.

No significant difference for condition (HIIT vs MICT) or condition x time (pre, post, 10 post, 20 post, and 30 post) effects were found for all outcome variables (shown in Fig. 1). However, significant time effects were found for sway velocity in the AP-SL ($F [4] = 4.78$, $p = 0.002$, $\eta_p^2 = 0.23$) and ML-SL ($F [2.69] = 3.65$, $p = 0.023$, $\eta_p^2 = 0.186$) positions and significant difference for time in sway range in the ML-EC ($F [4] = 4.52$, $p = 0.003$, $\eta_p^2 = 0.21$) position. There was also a significant effect for time in gait velocity ($F [1.86] = 4.66$, $p = 0.018$, $\eta_p^2 = 0.197$).

Post hoc testing revealed that the effect for time in sway velocity for the AP-SL position was significantly different between pre to 30 post (p = 0.013), post to 20 post (p = 0.014), post to 30 post (p = 0.002), and 10 post to 30 post (p = 0.002). Effect for time in sway velocity for the ML-SL position were significantly different between pre to 20 post (p = 0.01), pre to 30 post (p = 0.007), post to 30 post (p = 0.003), and 10 post to 30 post (p = 0.011). Effect for time in sway range for the ML-EC position were significantly different between pre to 20 post (p = 0.016), post to 20 post (p = 0.001), post to 30 post (p = 0.012), 10 post to 20 post (p = 0.029). Effect for time in gait velocity was significantly different between pre to post (p = 0.011), pre to 10 post (p = 0.001), pre to 20 post (p = 0.029), and pre to 30 post (p = 0.026).

Figure 1

COP sway velocity (a = AP, b = ML), sway range (c = AP, d = ML), gait velocity (e), and TUG (f) data for both HIIT and MICT exercises. COP data in the EC and SL conditions are represented on the same graphs (a-d). No significant difference for condition or condition x time interactions were found.

Discussion

The primary objective of the current study was to determine if a cycle ergometer HIIT exercise induced a transient effect on balance and gait parameters in older adults and if so, was that effect different from that of a metabolically matched MICT exercise protocol. According to the current data, metabolically matched cycle ergometer HIIT and MICT protocols do not produce a transient effect on balance or gait parameters in older adults 50-70 years of age.

The authors believe that the current data demonstrate the safety and time effectiveness of a cycle ergometer HIIT protocol. When compared to a metabolically matched MICT protocol there were no differences in the postural control measures. Furthermore, there were no undesirable significant differences to any included variable from pre- to post-intervention. This data suggests that there is no transient fall window for either HIIT or MICT cycle ergometer exercise in the current populations' data set. Although prior research has determined that lower limb muscle fatigue can lead to changes in postural control values (Helbostad et al., 2007, 2010; Morrison et al., 2016), a study by Morrison et al. indicated that the only significant changes arise in participants over the age of 70 years and all of those changes were the result of walking and/or resistance training induced fatigue, not cycling. A study by Hill et al. was conducted in younger adults that determined cycle ergometer HIIT produced a transient postural control change lasting about 10 minutes but that was attenuated with training (Hill et al., 2016). To the best of our knowledge, this is the first study that compares a cycle ergometer HIIT protocol to a metabolically matched MICT protocol to determine if the HIIT exercise is producing the change or if it is merely the exercise-induced fatigue regardless of exercise intensity.

Interestingly, the differences noted in the HIIT protocol tended to improve gait and balance parameters. The effects produced by the HIIT protocol on postural sway in the SL position resulted in decreased sway velocities and ranges. Likewise, gait velocity post HIIT and MICT protocols managed to rise although not statistically significant in the current data. A study by Helbostad et al. noted a similar increase in gait velocity post-exercise in which they attributed the increase in gait velocity to movement pattern changes to cope with fatigue due to walking (Helbostad et al., 2007). However, the current data did not find any differences in the postural control variables post-exercise and thus the authors believe that the rise in gait velocity could be attributed to the higher cadences performed on the bike (average of 78 rpm for both interventions) which led to a higher walking cadence post cycling resulting in an

increased gait velocity. A systematic review found that other studies have found similar results but that the evidence was not conclusive as the research was heterogeneous (Santos et al., 2019). That same review suggests that another explanation for this increased gait velocity post-exercise could be a simple fact that a "warm-up" rather than an interference effect might have occurred. If that were true, the increased gait velocity could be due in part to some form of post-activation potentiation, and the exercises intended to cause fatigue simply created a pre-conditioning phase that increased muscle activation post-exercise. Further research should investigate the source of the increased gait velocity phenomena.

As mentioned earlier, research by Donath et al. (Donath & Roth, 2014) has suggested that there could be an elevated fall risk in older adults due to participation in HIIT training, though it does not come without flaws. Most notably, the Donath study compared two exercise interventions that were neither metabolically nor time matched. Although the study indicates that the HIIT and control intervention were equal in time, the recovery periods for the control group were passive and not active as was so in the HIIT intervention. Furthermore, the speed at which the participants walked was not the same between the two interventions. The HIIT intervention was completed at a "brisk" walking pace while speed and inclination were adjusted to accommodate the target HR of 90% whereas the control intervention simply walked at the participants' "comfortable normal" walking speed below 50% of HRmax. Hence, the two exercise interventions compared in that study demonstrated a greater COP path length due to HIIT but not the control, although the two interventions were not equally demanding and consequently not metabolically matched. Therefore, the authors of the current study believe that the only research to date indicating that HIIT may produce a transient elevated fall risk may be incorrect although it has been cited numerous times as the study of reference to caution against using HIIT as an exercise modality in older adults due to its "possible" negative effect. However, the Donath study does include an older adult population approximately 70 years of age and research has demonstrated that this is the population that seems to be affected most by exercise-induced fatigue (Morrison et al., 2016).

Nevertheless, the current study does not come without its limitations, the authors believe that it has two primary constraints, and they should be addressed. First and foremost, the current population of older adults does not represent an at-risk or fall-prone population. While the current study's participants are not fall prone, their age is aligned with the average age of individuals entering cardiac rehabilitation in various countries as noted by the INTERheart study (Yusuf et al., 2004). This is important because cycle ergometer HIIT protocols are

becoming more and more common in chronic disease populations of similar age in rehabilitation programs across the globe (Currie et al., 2013; Dun et al., 2019; Guiraud et al., 2012; Keating et al., 2020; Tschentscher et al., 2016). However, the current population is representative of the aging population that is needing exercise interventions such as HIIT to help curtail the impact that chronic disease and disability are having in older age.

Second, substantial variations in postural sway procedures and calculations make it challenging for COP data to be compared across various studies and it also increases variance in the individual data sets. The current study followed a strict regimen of procedures; however, it was not until data processing that the authors realized that slight balance corrections by the individual (i.e., toe tap, foot-shift) made for large variations in the average postural sway calculations (particularly in the SL condition). The current study was aiming to complete multiple measures in a short time (10 minutes between each time point) and for that reason elected to use the average of two trials of 10 seconds. If one measure contained an event with a slight balance correction, the velocity and/or range could be affected and exaggerate the true postural sway values. This is a concern not only with the current research but among most studies utilizing postural sway values from COP data (25,26). Future research should use three or more trials to decrease the likelihood of unnecessary variance due to balance correction techniques. Additionally, as the goal of this study was to examine the effects of HIIT on fall risk parameters, the authors believed that it was important to allow as many ecological valid testing procedures as possible. Like the TUG test, where participants were allowed to use their self-selected foot position while rising from the chair, which would be common in their day-to-day life. As postural measures remained constant across time except for the reduction (positive adaptation) at post 20 minutes, we feel that these results allow for further exploration of the utility of HIIT in aging populations without the fear of a fall risk post-exercise.

With that being said, the authors believe that the current research has a very simple yet practical purpose and application; neither cycle ergometer HIIT nor MICT produce an elevated risk of falling in older adults 50- 70 years of age. HIIT exercise has been shown to produce positive physiological changes in older adults and they should not be discouraged from participating in HIIT due to the possibility of acute negative balance parameter changes when much of the population in economically developed countries are suffering from chronic diseases caused by sedentary behavior. When used correctly HIIT has the capability of

improving cardiovascular health and lower limb strength while at the same time being time-efficient.

Conclusion

A single session of cycle ergometer HIIT does not produce an acute transient effect on postural control or gait parameters in adults aged 50 – 70 years. The current data demonstrate that when compared to a metabolically matched MICT protocol, HIIT is just as safe and more time-efficient. Both HIIT and MICT protocols produced a slight, yet not statistically significant, increase in gait velocity post-exercise that the authors believe is due to the increased pedaling cadence that may have bled into the walking cadence immediately post to 10 minutes post-exercise. Cycle ergometer HIIT should not be singled out as a hazardous exercise to participate in for the youngest of the older adults when the world’s aging population is growing ever faster and needs more time-efficient and effective exercise regimens like cycle ergometer HIIT.

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Statement of Ethics

Study approval statement: *The study was approved by the local ethics committee at the University of Southern Mississippi Institutional Review Board, #IRB-20-519 - Acute Effects of High-Intensity Interval Training on Gait & Balance.*

Consent to participate statement: All participants were informed of the study procedure, protocols, and risks involved in participation; participants were allowed to express their concerns and ask any questions. Afterward, the participants signed informed written consent prior to the start of the data collection.

Conflict of Interest Statement

The authors have no conflicts of interest to declare.

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Author Contributions

Conception and design of the study: C.J.K., J.A.P.-M., and P.T.D.; Acquisition of data: C.J.K., P.T.D.; Analysis and/or interpretation of data C.K.J., P.T.D; Drafting the manuscript: C.J.K. Revising the manuscript: C.K.J., J.A.P.-M., P.Á.L.-R., and P.T.D.

Data Availability Statement

The data that support the findings of this study are not publicly available due to the possibility that the information contained within could compromise the privacy of research participants but could be available by contacting the corresponding author directly.

References

[1] United Nations Department of Economic and Social Affairs Population Division, World Population Ageing 2019, 2019. http://www.un.org/esa/population/publications/worldageing19502050/pdf/65executivesummary spanish.pdf%0Ahttp://link.springer.com/chapter/10.1007/978-94-007-5204-7_6.

[2] United Nations, Measuring and Analysing the Generational Economy, 2013. https://www.un.org/en/development/desa/population/publications/pdf/development/Final_March2014.pdf.

[3] E. V. Papa, X. Dong, M. Hassan, Resistance training for activity limitations in older adults with skeletal muscle function deficits: A systematic review, Clin. Interv. Aging. 12 (2017) 955–961. https://doi.org/10.2147/CIA.S104674.

[4] J.M. Cancela Carral, A.L. Rodríguez, I.M. Cardalda, J.P.A. Gonçalves Bezerra, Muscle strength training program in nonagenarians – a randomized controlled trial, Rev. Assoc. Med. Bras. 65 (2019) 851–856. https://doi.org/10.1590/1806-9282.65.6.851.

[5] B.A. Hawkins, Aging well: Toward a way of life for all people, Prev. Chronic Dis. 2 (2005) 3–5.

[6] W.J. Chodzko-Zajko, D.N. Proctor, M.A. Fiatarone Singh, C.T. Minson, C.R. Nigg, G.J. Salem, J.S. Skinner, Exercise and physical activity for older adults, Med. Sci. Sports Exerc. 41 (2009) 1510–1530. https://doi.org/10.1249/MSS.0b013e3181a0c95c.

[7] D.C. Lee, X. Sui, F.B. Ortega, Y.S. Kim, T.S. Church, R.A. Winett, U. Ekelund, P.T. Katzmarzyk, S.N. Blair, Comparisons of leisure-time physical activity and cardiorespiratory fitness as predictors of all-cause mortality in men and women, Br. J. Sports Med. 45 (2011) 504–510. https://doi.org/10.1136/bjsm.2009.066209.

[8] B.M. Nes, L.J. Vatten, J. Nauman, I. Janszky, U. WislØff, A simple nonexercise model of cardiorespiratory fitness predicts long-term mortality, Med. Sci. Sports Exerc. 46 (2014) 1159–1165. https://doi.org/10.1249/MSS.0000000000000219.

[9] S. Llamas-Velasco, A. Villarejo-Galende, I. Contador, D. Lora Pablos, J. Hernández-Gallego, F. Bermejo-Pareja, Physical activity and long-term mortality risk in older adults: A prospective population based study (NEDICES), Prev. Med. Reports. 4 (2016) 546–550. https://doi.org/10.1016/j.pmedr.2016.10.002.

[10] J.B. Gillen, M.J. Gibala, Is high intensity interval training a time efficien exercise strategy to improve health and fitnes ?, Appl. Physiol. Nutr. Metab. 39 (2014) 409–412.

[11] N.D. Rynecki, B.L. Siracuse, J.A. Ippolito, K.S. Beebe, Injuries sustained during high intensity interval training: Are modern fitness trends contributing to increased injury rates?, J. Sports Med. Phys. Fitness. 59 (2019) 1206–1212. https://doi.org/10.23736/S0022-4707.19.09407-6.

[12] M. Wewege, R. van den Berg, R.E. Ward, A. Keech, The effects of high-intensity interval training vs. moderate-intensity continuous training on body composition in overweight and obese adults: a systematic review and meta-analysis, Obes. Rev. 18 (2017) 635–646. https://doi.org/10.1111/obr.12532.

[13] A. Hannan, W. Hing, V. Simas, M. Climstein, J. Coombes, R. Jayasinghe, J. Byrnes, J. Furness, High-intensity interval training versus moderate-intensity continuous training within cardiac rehabilitation: a systematic review and meta-analysis, Open Access J. Sport. Med. Volume 9 (2018) 1–17. https://doi.org/10.2147/oajsm.s150596.

[14] A.E. Tjønna, S.J. Lee, Ø. Rognmo, T.O. Stølen, A. Bye, P.M. Haram, J.P. Loennechen, Q.Y. Al-Share, E. Skogvoll, S.A. Slørdahl, O.J. Kemi, S.M. Najjar, U. Wisløff, Aerobic interval training versus continuous moderate exercise as a treatment for the metabolic syndrome: A pilot study, Circulation. 118 (2008) 346–354. https://doi.org/10.1161/CIRCULATIONAHA.108.772822.

[15] C.J. Keating, J.Á. Párraga Montilla, P.Á. Latorre Román, R. Moreno del Castillo, Comparison of High-Intensity Interval Training to Moderate-Intensity Continuous Training in Older Adults: A Systematic Review, J. Aging Phys. Act. 28 (2020) 798–807. https://doi.org/10.1123/japa.2019-0111.

[16] M. Elboim-Gabyzon, R. Buxbaum, R. Klein, The Effects of High-Intensity Interval Training (HIIT) on Fall Risk Factors in Healthy Older Adults: A Systematic Review, Int. J. Environ. Res. Public Health. 18 (2021) 11809. https://doi.org/10.3390/ijerph182211809.

[17] L. Donath, R. Roth, Does a Single Session of High-Intensity Interval Training Provoke a Transient Elevated Risk of Falling in Seniors and Adults ?, (2014). https://doi.org/10.1159/000363767.

[18] J.L. Helbostad, D.L. Sturnieks, J. Menant, K. Delbaere, S.R. Lord, M. Pijnappels, Consequences of lower extremity and trunk muscle fatigue on balance and functional tasks in older people: A systematic literature review, BMC Geriatr. 10 (2010) 56. https://doi.org/10.1186/1471-2318-10-56.

[19] S. Morrison, S.R. Colberg, H.K. Parson, S. Neumann, R. Handel, E.J. Vinik, J. Paulson, A.I. Vinik, Walking-Induced Fatigue Leads to Increased Falls Risk in Older Adults, J. Am. Med. Dir. Assoc. 17 (2016) 402–409. https://doi.org/10.1016/j.jamda.2015.12.013.

[20] H. Nagano, L. James, W.A. Sparrow, R.K. Begg, Effects of walking-induced fatigue on gait function and tripping risks in older adults, J. Neuroeng. Rehabil. 11 (2014) 1–7. https://doi.org/10.1186/1743-0003-11-155.

[21] J.L. Helbostad, S. Leirfall, R. Moe-Nilssen, O. Sletvold, Physical Fatigue Affects Gait Characteristics in Older Persons, Journals Gerontol. Ser. A Biol. Sci. Med. Sci. 62 (2007) 1010–1015. https://doi.org/10.1093/gerona/62.9.1010.

[22] P. Parijat, T.E. Lockhart, Effects of lower extremity muscle fatigue on the outcomes of slip-induced falls, Ergonomics. 51 (2008) 1873–1884. https://doi.org/10.1080/00140130802567087.

[23] Y. Dun, J.R. Smith, S. Liu, T.P. Olson, High-Intensity Interval Training in Cardiac Rehabilitation, Clin. Geriatr. Med. 35 (2019) 469–487. https://doi.org/10.1016/j.cger.2019.07.011.

[24] C.F. Bailey, G.K. Cagle, C.D. Grozier, K.N. Lehtola, J.F. Weaver, S.J. Wilson, H. Chander, N.K. Rendos, J.D. Simpson, Gathering your ‘sea legs’: Extended durations in an offshore environment increases postural sway excursions, Gait Posture. 86 (2021) 45–50. https://doi.org/10.1016/j.gaitpost.2021.02.014.

[25] R.E. Rikli, C.J. Jones, Development and Validation of Criterion-Referenced Clinically Relevant Fitness Standards for Maintaining Physical Independence in Later Years, Gerontologist. 53 (2013) 255–267. https://doi.org/10.1093/geront/gns071.

[26] Jacob Cohen, Statistical Power Analysis for the Behavioral Sciences, Revised, Academic Press, New York, NY, 1988. https://books.google.com/books?hl=en&lr=&id=rEe0BQAAQBAJ&oi=fnd&pg=PP1&ots=swWXKtOWo6&sig=ZGB-15bQCc34zdFuCwp7WHApU5s#v=onepage&q&f=false.

[27] M.W. Hill, M.F. Higgins, M.J. Price, The effect of high - intensity cycling training on postural sway during standing under rested and fatigued conditions in healthy young adults, Eur. J. Appl. Physiol. 116 (2016) 1965–1974. https://doi.org/10.1007/s00421-016-3448-1.

[28] P.C.R. dos Santos, F.A. Barbieri, I. Zijdewind, L.T.B. Gobbi, C. Lamoth, T. Hortobágyi, Effects of experimentally induced fatigue on healthy older adults’ gait: A systematic review, PLoS One. 14 (2019) e0226939. https://doi.org/10.1371/journal.pone.0226939.

[29] S. Yusuf, S. Hawken, S. Ôunpuu, T. Dans, A. Avezum, F. Lanas, M. McQueen, A. Budaj, P. Pais, J. Varigos, L. Lisheng, Effect of potentially modifiable risk factors associated with myocardial infarction in 52 countries (the INTERHEART study): case-control study, Lancet. 364 (2004) 937–952. https://doi.org/10.1016/S0140-6736(04)17018-9.

[30] M. Tschentscher, J. Eichinger, A. Egger, S.I.L.K.E. Droese, M. Schönfelder, J. Niebauer, High-intensity interval training is not superior to other forms of endurance training during cardiac rehabilitation, Eur. J. Prev. Cardiol. 23 (2016) 14–20. https://doi.org/10.1177/2047487314560100.

[31] K.D. Currie, J.B. Dubberley, R.S. McKelvie, M.J. Macdonald, Low-volume, high-intensity interval training in patients with CAD, Med. Sci. Sports Exerc. 45 (2013) 1436–1442. https://doi.org/10.1249/MSS.0b013e31828bbbd4.

[32] T. Guiraud, A. Nigam, V. Gremeaux, P. Meyer, M. Juneau, L. Bosquet, High-Intensity Interval Training in Cardiac Rehabilitation, Sport. Med. 42 (2012) 587–605. https://doi.org/10.2165/11631910-000000000-00000.

Discussion

The objective of the current Ph.D. thesis was to determine the acute and chronic effects that a cycle ergometer HIIT protocol may have in older adults and how it compares to other exercise interventions commonly used in the same population.

Although not all studies in the scientific literature agree, the most recent and most noted consensus is that HIIT is superior to MICT at improving cardiorespiratory fitness which was also the general conclusion of the first systematic review in the current thesis (Paper I). A recent systematic review and meta-analysis performed by Hannan et al. (2018), concluded that HIIT is a superior exercise model in comparison with MICT in improving cardiorespiratory fitness in cardiac rehabilitation patients (Hannan et al., 2018). A systematic review and meta-analysis by Ramos et al. promote HIIT as a superior exercise modality to improve vascular function but in particular, the 4 × 4 method (Ramos et al., 2015), which was the method used in Paper III & IV of the current thesis. The 4 × 4 method is four high-intensity intervals for 4 minutes, interspersed by three lower intensity intervals for 3 minutes. This implies that the HIIT intervention lasts 28 minutes which is substantially less time consuming when compared to a metabolically matched MICT protocol lasting approximately 37 minutes (without a warmup and/or cool-down included). Therefore, HIIT is not only superior at improving cardiorespiratory fitness, but it is also much more time-efficient as clearly demonstrated in Paper IV.

HIIT interventions can take place in many different forms as long as the work intensity can be adapted, and quantifiably measured. The current thesis opted to focus on a cycle ergometer HIIT intervention as the original systematic review (Paper I) demonstrated that there may be an added benefit of using cycle ergometry as a modality in an aging population. The systematic review from the current thesis (Paper I) is not alone in this finding as another systematic review exploring the health benefits of cycle ergometry in older adults 70 + years of age concluded that cycling may not only be safer but also places less impact on the joints thus leading to a more enjoyable experience for the participants (Bouaziz et al., 2015). The benefit of using a bike is that most gyms and/or fitness centers have a basic cycle ergometer with power (watts), cadence (rpm), and a handheld heart rate sensor (bpm). If an individual cannot find a fitness center or cannot make it to a facility, many different leg ergometers can be purchased for a reasonable price (100 – 500 USD) which often include heart rate monitors/censors. As demonstrated in Paper III, properly informed older adults can easily participate in cycle ergometer HIIT with minimal oversight and/or specialized equipment

which allows the participant to partake in vigorous physical activity and minimize excessive stress on the body that is commonly associated with other exercise modalities such as walking/running.

A study included in the first systematic review of the current thesis (Paper I) by Tschentscher et al. did not report an increased effect of the HIIT intervention in comparison with MICT, yet a comparable and significant effect of the two interventions. However, one conclusion from the authors of that research noted a 99.2% attendance rate among its cycle ergometer participants, indicating "impeccable" compliance in comparison with other modalities (Tschentscher et al., 2016). Evermore evidence suggests that cycle ergometry is a more efficient and effective mode of exercise in an aging population with possible divergent underlying health conditions. HIIT exercise in any form is not easy, though, the participants from Paper III reported that the time spent in the intervention was enjoyable, and time passed more quickly than they would have imagined before the start of the intervention. This more pleasing experience could be attributed to the multiple intervals and change of pace inherent to HIIT protocols. These types of reports by participants may help explain the high compliance rates that are seen with aerobic HIIT interventions. That was demonstrated in Paper III, which had a 96% session completion rate. More research should assess the completion rates of various exercise interventions for longer periods and determine if there is a significant difference amongst varying exercise interventions as well as determine if these completion rates continue over longer durations of time.

When addressing the safety of utilizing HIIT in an aging population, it is important to note that the intensity is relative to the participant's level of fitness, implying that the intensity of exercise is especially individualized. High-intensity exercise for a previously inactive older adult might involve walking at a slightly increased pace from their comfortable walking speed, whereas a regularly active participant might need to run at a fast pace to achieve the same intensity and/or percentage of aerobic capacity. The first systematic review (Paper I) found that only one study documented a total of three adverse events related to the HIIT intervention, those side effects were musculoskeletal, mainly muscle soreness (Ellingsen et al., 2017). The second systematic review (Paper II) examining the influence of RT on gait and balance reported similar musculoskeletal adverse events, although the number of those events were slightly higher per participant than that noted in Paper I. Musculoskeletal events should not be unexpected as it is has been identified as the leading cause of adverse events in an aging population by a systematic review on the effects of RT (Liu & Latham, 2010).

However, it should be highlighted once again that adverse events often go underreported by the participants and researchers alike, thus, more effort should be made to include a systematic method for reporting all adverse events in interventions involving older adults.

Resistance training has traditionally been used to improve strength, balance, and gait parameters in older adults. Although using cycle ergometer HIIT, the most notable change witnessed in Paper III was the participants' lower limb power measures in both the sit-to-stand scenarios. As noted in previous research, loss of muscle mass and strength is common among older adults, which in turn decreases function and therefore autonomy (Candow & Chilibeck, 2005; Guralnik et al., 2000; Lauretani et al., 2003). As indicated in Paper II, RT improves gait parameters in older adults, but more specifically unidirectional walking speed, most often associated with the increased lower limb strength of the participants. However, there are many forms of gait parameter tests that are more complex which can include obstacles and/or directional changes to navigate. Furthermore, a complex gait test like mentioned above would possibly be a more accurate representation of a real-life scenario, and therefore a better predictor of future fall risk. Nonetheless, increased lower limb strength, regardless of exercise modality, has been shown to decrease the risk of falls (Ishigaki et al., 2014).

Yet, to prescribe an effective RT program, numerous variables need to be controlled to achieve the desired objectives. For that reason, RT can be difficult to prescribe to such a diverse population as often encountered in older adults (Bird et al., 2005; Kraemer et al., 2002). Considering that there are so many variables needing attention to develop an effective RT program, HIIT may be a better option. Cycle ergometer HIIT is easy to plan as indicated in Paper III and appears to improve lower limb strength at a comparable level to that of RT programs reported in the second systematic review (Paper II). With that in mind, it would not be out of line to suggest that an individual participant with certain time constraints would be best advised to participate in cycle ergometer HIIT 2-3 days a week and moderate-intensity physical activity another 2-3 days a week to reach the appropriate physical activity minimum requirements outlined in the various exercise guidelines for older adults (Bushman, 2019; Chodzko-Zajko et al., 2009). Cycle ergometer HIIT appears to have multiple advantages (when compared to MICT and RT) in the form of both strength and cardiorespiratory fitness in an aging population and can be completed in a more time-effective manner without the need for complex programming or equipment requirements.

Research, investigating the effects of HIIT in older adults suggests that it is a valuable exercise regimen. However, much of that research has been completed in a clinical or laboratory setting with specialized equipment (i.e., metabolic cart, graded exercise test, heart rate monitors, etc.). The current thesis was intended to help answer the question "Is HIIT accessible to the larger aging population outside of the research setting and without specialized equipment?". Paper III aimed to determine the feasibility of prescribing a cycle ergometer HIIT protocol using a percentage of age-predicted HRmax. The conclusion of Paper III suggested that either HR or RPE can be used to prescribe a cycle ergometer HIIT protocol in an older adult population although RPE should be used with caution and in conjunction with other parameters such as HRmax and/or power numbers (watts). These data corroborate conclusions from a study by Jabbour & Majed (2018) which determined that RPE may misclassify exercise intensity for sedentary older adults but that is nevertheless useful when used in combination with other commonly used methods such as %HRmax (Jabbour & Majed, 2018). The effectiveness of implementing a HIIT protocol in older adults with a simple calculation of %HRmax is justified, and further research should use this method of prescribing HIIT exercise as a fast and simple way to engage older adults. The current thesis has demonstrated that appropriately informed older adults can participate in cycle ergometer HIIT with minimal supervision from an exercise specialist and no specialized equipment.

Research by Donath & Roth suggests that there could be an elevated fall risk in older adults due to participation in HIIT, which would imply that the time effectiveness of HIIT could be questioned (Donath & Roth, 2014). The objective of Paper IV in the current thesis was to determine if a cycle ergometer HIIT exercise induced a transient effect on balance and gait parameters in older adults (50-70 years of age) and if so, was that effect different from that of a metabolically matched MICT exercise protocol. To the best of our knowledge, this was the first study to compare a cycle ergometer HIIT protocol to a metabolically matched MICT protocol to determine if the HIIT exercise is producing the change or if it is merely the exercise-induced fatigue regardless of exercise intensity. The Donath & Roth study did not include a metabolically matched control group and that research was also completed using a treadmill. According to the data from Paper IV, metabolically matched cycle ergometer HIIT and MICT protocols do not produce a transient effect on balance or gait parameters in older adults, meaning that there was no difference in the postural control measures. Although prior research has concluded that lower limb muscle fatigue can lead to changes in postural control values (Helbostad et al., 2007, 2010; Morrison et al., 2016), a study by Morrison et al.

indicated that significant changes only arose in those participants over the age of 70 years. A study by Hill et al. was conducted in younger adults that determined cycle ergometer HIIT produced a transient postural control change lasting about 10 minutes but that was attenuated with just a few weeks of training (Hill et al., 2016). This indicates that no matter the exercise modality, an untrained individual may need time to adapt to an increased training load by having an adaptation/acclimation period. It also suggests that if there is a transient effect, only the older adults (70+ years of age) may see elevated fall risk due to postural instability brought about by a HIIT protocol. Paper IV is just another data set advocating the safety and time effectiveness of a cycle ergometer HIIT protocol.

The differences noted in Paper IV regarding the acute effects of a cycle ergometer HIIT protocol on gait and balance parameters were intriguing and tended to improve those measures rather than cause disfunction. The effects on postural sway in the SL position resulted in decreased sway velocities and ranges. Likewise, gait velocity from pre- to post-intervention in both the HIIT and MICT intervention tended to rise. This doesn't seem to be out of the ordinary as a study by Helbostad et al. noted a similar increase in gait velocity post-exercise. However, that study attributed the increase in gait velocity post-exercise to movement pattern changes to cope with fatigue due to the walking intervention (Helbostad et al., 2007). Though, the current thesis (Paper IV) did not find any differences in the postural control variables post-exercise and therefore the rise in gait velocity could be attributed to the higher cadences performed on the bike (average of 78 rpm for both interventions) which led to a higher walking cadence post cycling resulting in the noted increased gait velocity. A systematic review by Santos et al. stated that other studies have found a similar increase in walking speed post-exercise but that the evidence was not conclusive as the research was heterogeneous (Santos et al., 2019). That same review suggests that another explanation for this increased gait velocity post-exercise could be a simple fact that a "warm-up" rather than an interference effect might have occurred. If that were true, the increased gait velocity could be due in part to some form of post-activation potentiation, and the exercises intended to cause fatigue simply created a pre-conditioning phase that increased muscle activation post-exercise. Further research should investigate the source of the increased gait velocity phenomena.

Cycle ergometer HIIT protocols are becoming more and more common in older adults and chronic disease populations in rehabilitation programs across the globe (Currie et al., 2013; Dun et al., 2019; Guiraud et al., 2012; Tschentscher et al., 2016). The aging population needs

exercise interventions such as HIIT to help curtail the impact that chronic disease and disability are having worldwide. The results from the current thesis demonstrate the utility of cycle ergometer HIIT in this population and further exploration of cycle ergometer HIIT research in an aging population should take place without exorbitant fear of possible injury or fall risk.

Discusión

El objetivo de la actual tesis PhD. fue determinar los efectos agudos y crónicos que un protocolo HIIT en cicloergómetro puede tener en adultos mayores y cómo se compara con otras intervenciones de ejercicio comúnmente utilizadas en la misma población.

Aunque no todos los estudios en la literatura científica están de acuerdo, el consenso más reciente y destacado es que HIIT es superior a MICT para mejorar el estado cardiorrespiratorio, lo que también fue la conclusión general de la primera revisión sistemática de la presente tesis (Articulo I). Una revisión sistemática y un metanálisis reciente, realizados por Hannan et al. (2018), concluyó que HIIT es un modelo de ejercicio superior en comparación con MICT para mejorar la aptitud cardiorrespiratoria en pacientes con rehabilitación cardíaca (Hannan et al., 2018). Una revisión sistemática y metanálisis de Ramos et al. promueve el HIIT como una modalidad de ejercicio superior para mejorar la función vascular, pero en particular, el método 4 × 4 (Ramos et al., 2015), que fue el método utilizado en los Artículos III y IV de la presente tesis. El método 4 × 4 consiste en cuatro intervalos de alta intensidad durante 4 minutos, intercalados con tres intervalos de menor intensidad durante 3 minutos. Esto implica que la intervención HIIT dura 28 minutos, lo que consume mucho menos tiempo en comparación con un protocolo MICT igualado metabólicamente, con una duración aproximada de 37 minutos (sin calentamiento y / o enfriamiento incluidos). Por lo tanto, HIIT no solo es superior para mejorar la aptitud cardiorrespiratoria, sino que también es mucho más eficiente en el tiempo, como se demostró claramente en el Articulo IV.

Las intervenciones HIIT pueden tener lugar de muchas formas diferentes siempre que la intensidad del trabajo se pueda adaptar y medir de forma cuantificable. La tesis actual optó por centrarse en una intervención HIIT en cicloergómetro, ya que la revisión sistemática original (Articulo I) demostró que puede haber un beneficio adicional de utilizar la cicloergometría como modalidad en una población que envejece. La revisión sistemática de la tesis actual (Articulo I) no es la única en este hallazgo, ya que otra revisión sistemática que explora los beneficios para la salud de la cicloergometría en adultos mayores de 70 años o más concluyó que el ciclismo no solo puede ser más seguro, sino que también tiene menos impacto en las articulaciones, lo que conduce a una experiencia más agradable para los participantes (Bouaziz et al., 2015). El beneficio de usar una bicicleta es que la mayoría de los gimnasios y / o centros de fitness tienen un cicloergómetro básico con potencia (vatios), cadencia (rpm) y un sensor de frecuencia cardíaca de mano (bpm). Si una persona no puede

encontrar un gimnasio o no puede ir a una instalación, se pueden comprar diferentes ergómetros de piernas por un precio razonable (100 - 500 USD), que a menudo incluyen monitores / sensores de frecuencia cardíaca. Como se demostró en el Articulo III, los adultos mayores debidamente informados pueden participar fácilmente en el cicloergómetro HIIT con una supervisión mínima y / o equipo especializado que permite la participación del adulto mayor en una AF vigorosa y minimizar el estrés excesivo en el cuerpo que comúnmente se asocia con otras modalidades de ejercicio como caminar / correr.

Un estudio incluido en la primera revisión sistemática de la tesis actual (Artículo I) de Tschentscher et al. no informó un mayor efecto de la intervención HIIT en comparación con MICT, pero un efecto comparable y significativo de las dos intervenciones. Sin embargo, una conclusión de los autores de esa investigación señaló una tasa de asistencia del 99,2% entre sus participantes en cicloergómetro, lo que indica un cumplimiento "impecable" en comparación con otras modalidades (Tschentscher et al., 2016). Cada vez más la evidencia sugiere que la cicloergometría es un modo de ejercicio más eficiente y efectivo en una población que envejece con posibles condiciones de salud subyacentes divergentes. El ejercicio HIIT en cualquier forma no es fácil, sin embargo, los participantes del Articulo III informaron que el tiempo que pasaron en la intervención fue agradable y el tiempo pasó más rápido de lo que hubieran imaginado antes del inicio de la intervención. Esta experiencia más agradable podría atribuirse a los múltiples intervalos y cambios de ritmo inherentes a los protocolos HIIT. Este tipo de informes de los participantes pueden ayudar a explicar las altas tasas de cumplimiento que se observan con las intervenciones HIIT aeróbicas. Eso se demostró en el Articulo III, que tuvo una tasa de finalización de sesión del 96%. Se deben realizar más investigaciones para evaluar las tasas de finalización de varias intervenciones de ejercicio durante períodos más prolongados y determinar si hay una diferencia significativa entre las distintas intervenciones de ejercicio, así como determinar si estas tasas de finalización continúan durante períodos de tiempo más prolongados.

Al abordar la seguridad de utilizar HIIT en una población que envejece, es importante tener en cuenta que la intensidad es relativa al nivel de condición física del participante, lo que implica que la intensidad del ejercicio es especialmente individualizada. El ejercicio de alta intensidad para un adulto mayor previamente inactivo puede implicar caminar a un ritmo ligeramente mayor de su velocidad de caminata cómoda, mientras que un participante activo regularmente puede necesitar correr a un ritmo rápido para lograr la misma intensidad y / o porcentaje de capacidad aeróbica. La primera revisión sistemática (Articulo I) encontró que

solo un estudio documentó un total de tres eventos adversos relacionados con la intervención HIIT, esos efectos secundarios fueron de naturaleza musculoesquelética, principalmente dolor muscular (Ellingsen et al., 2017). La segunda revisión sistemática (Articulo II), que examinó la influencia de la RT en la marcha y el equilibrio, informó eventos adversos musculoesqueléticos similares, aunque el número de esos eventos fue ligeramente mayor por participante que el anotado en el Articulo I. Los eventos musculoesqueléticos no deben ser inesperados, ya que han sido identificados como la principal causa de eventos adversos en una población que envejece mediante una revisión sistemática sobre los efectos de la RT (Liu y Latham, 2010). Sin embargo, debe destacarse una vez más que los participantes y los investigadores a menudo no notifican los eventos adversos por igual, por lo que se deben hacer más esfuerzos para incluir un método sistemático para informar todos los eventos adversos en las intervenciones que involucran a adultos mayores.

El entrenamiento de resistencia se ha utilizado tradicionalmente para mejorar la fuerza, el equilibrio y los parámetros de la marcha en los adultos mayores. Aunque se utilizó HIIT en cicloergómetro, el cambio más notable observado en el Articulo III fueron las medidas de potencia de las extremidades inferiores de los participantes en los dos escenarios sentados y de pie. Como se señaló en investigaciones anteriores, la pérdida de masa muscular y fuerza es común entre los adultos mayores, lo que a su vez disminuye la función y, por lo tanto, la autonomía (Candow y Chilibeck, 2005; Guralnik et al., 2000; Lauretani et al., 2003). Como se indica en el Articulo II, la RT mejora los parámetros de la marcha en los adultos mayores, pero más específicamente la velocidad de la marcha unidireccional, más a menudo asociada con el aumento de la fuerza de las extremidades inferiores de los participantes. Sin embargo, existen muchas formas de pruebas de parámetros de la marcha que son más complejas y que pueden incluir obstáculos y / o cambios de dirección para deambular. Además, una prueba de marcha compleja como la mencionada anteriormente posiblemente sería una representación más precisa de un escenario de la vida real y, por lo tanto, un mejor predictor del riesgo de caídas en el futuro. No obstante, se ha demostrado que el aumento de la fuerza de las extremidades inferiores, independientemente de la modalidad de ejercicio, disminuye el riesgo de caídas (Ishigaki et al., 2014).

Sin embargo, para prescribir un programa de RT eficaz, es necesario controlar numerosas variables para lograr los objetivos deseados. Por esa razón, la RT puede ser difícil de prescribir a una población tan diversa como la que se encuentra a menudo en los adultos mayores (Bird et al., 2005; Kraemer et al., 2002). Teniendo en cuenta que hay tantas

variables que necesitan atención para desarrollar un programa de RT eficaz, HIIT puede ser una mejor opción. El cicloergómetro HIIT es fácil de planificar como se indica en el Articulo III y parece mejorar la fuerza de las extremidades inferiores a un nivel comparable al de los programas de AF informados en la segunda revisión sistemática (Articulo II). Teniendo esto en cuenta, no estaría fuera de lugar sugerir que a un participante individual con ciertas limitaciones de tiempo se le recomendaría que participara en cicloergómetro HIIT 2-3 días a la semana y AF de intensidad moderada otros 2-3 días a la semana, para alcanzar los requisitos mínimos de AF adecuados, descritos en las diversas pautas de ejercicio para adultos mayores (Bushman, 2019; Chodzko-Zajko et al., 2009). El cicloergómetro HIIT parece tener múltiples ventajas (en comparación con MICT y RT) en forma de fuerza y aptitud cardiorrespiratoria en una población que envejece y se puede completar de una manera más eficaz en el tiempo sin la necesidad de una programación compleja o requisitos de equipamiento.

La investigación, que estudia los efectos del HIIT en adultos mayores, sugiere que es un régimen de ejercicio valioso. Sin embargo, gran parte de esa investigación se ha completado en un entorno clínico o de laboratorio con equipo especializado (es decir, carro metabólico, prueba de ejercicio graduada, monitores de frecuencia cardíaca, etc.). La tesis actual estaba destinada a ayudar a responder la pregunta "¿Es HIIT accesible para una población mayor que envejece fuera del ámbito de la investigación y sin equipo especializado?". El artículo III tenía como objetivo determinar la viabilidad de prescribir un protocolo HIIT de cicloergómetro utilizando un porcentaje de la FCmáx predicha por la edad. La conclusión del Articulo III sugirió que tanto la FC como el RPE pueden usarse para prescribir un protocolo de HIIT en cicloergómetro en una población de adultos mayores, aunque el RPE debe usarse con precaución y junto con otros parámetros como la FCmáx y/o los números de potencia (vatios). Estos datos corroboran las conclusiones de un estudio realizado por Jabbour & Majed (2018) que determinó que el RPE puede clasificar erróneamente la intensidad del ejercicio para adultos mayores sedentarios, pero que, sin embargo, es útil cuando se usa en combinación con otros métodos de uso común como el %FCmax (Jabbour & Majed, 2018). La efectividad de implementar un protocolo HIIT en adultos mayores con un simple cálculo de % FCmáx está justificada, y la investigación adicional debería utilizar este método de prescribir ejercicio HIIT como una forma rápida y sencilla de involucrar a los adultos mayores. La tesis actual ha demostrado que los adultos mayores debidamente informados

pueden participar en el cicloergómetro HIIT con la supervisión mínima de un especialista en ejercicio y sin equipo especializado.

La investigación realizada por Donath & Roth sugiere que podría haber un riesgo elevado de caídas en los adultos mayores debido a la participación en el entrenamiento HIIT, lo que implicaría que se podría cuestionar la eficacia temporal de HIIT (Donath & Roth, 2014). El objetivo del Artículo IV de la presente tesis fue determinar si un ejercicio HIIT en cicloergómetro inducía un efecto transitorio en los parámetros de equilibrio y marcha en adultos mayores (50-70 años) y, de ser así, si ese efecto era diferente al de un ejercicio MICT metabólicamente emparejado. Hasta donde sabemos, este fue el primer estudio en comparar un protocolo HIIT de cicloergómetro con un protocolo MICT metabólicamente emparejado para determinar si el ejercicio HIIT está produciendo el cambio o si es simplemente la fatiga inducida por el ejercicio, independientemente de la intensidad del ejercicio. El estudio de Donath & Roth no incluyó un grupo de control metabólicamente emparejado y esa investigación también se completó usando una caminadora. De acuerdo con los datos del Articulo IV, los protocolos HIIT y MICT de cicloergómetro combinados metabólicamente no producen un efecto transitorio en los parámetros de equilibrio o marcha en adultos mayores, lo que significa que no hubo diferencia en las medidas de control postural. Aunque investigaciones anteriores han concluido que la fatiga muscular de las extremidades inferiores puede provocar cambios en los valores de control postural (Helbostad et al., 2007, 2010; Morrison et al., 2016), un estudio de Morrison et al. indicaron que solo se presentaron cambios significativos en aquellos participantes mayores de 70 años. Un estudio de Hill et al. se llevó a cabo en adultos más jóvenes y determinó que el cicloergómetro HIIT producía un cambio transitorio en el control postural que duraba unos 10 minutos, pero que se atenuaba con solo unas pocas semanas de entrenamiento (Hill et al., 2016). Esto indica que, independientemente de la modalidad de ejercicio, una persona no entrenada puede necesitar tiempo para adaptarse a una mayor carga de entrenamiento al tener un período de adaptación/aclimatación. Las diferencias observadas en el Articulo IV, con respecto a los efectos agudos de un protocolo HIIT de cicloergómetro sobre los parámetros de la marcha y el equilibrio, fueron intrigantes y tendieron a mejorar esas medidas en lugar de causar disfunción. Los efectos sobre el balanceo postural en la posición SL dieron como resultado una disminución de las velocidades y rangos del balanceo. Del mismo modo, la velocidad de la marcha antes y después de la intervención en los protocolos HIIT y MICT tendió a aumentar. Esto no parece estar fuera de lo común, ya que un estudio de Helbostad et al. notó

un aumento similar en la velocidad de la marcha después del ejercicio. Sin embargo, ese estudio atribuyó el aumento en la velocidad de la marcha después del ejercicio a cambios en el patrón de movimiento para hacer frente a la fatiga debido a la intervención de la marcha (Helbostad et al., 2007). Sin embargo, la tesis actual (Articulo IV) no encontró diferencias en las variables de control postural post-ejercicio y, por lo tanto, el aumento de la velocidad de la marcha podría atribuirse a las mayores cadencias realizadas en la bicicleta (promedio de 78 rpm para ambas intervenciones) que condujo a una mayor cadencia de la marcha después del ciclismo, lo que resultó en el aumento observado de la velocidad de la marcha. Una revisión sistemática de Santos et al. afirmó que otros estudios han encontrado un aumento similar en la velocidad de la marcha después del ejercicio, pero que la evidencia no fue concluyente ya que la investigación fue heterogénea (Santos et al., 2019). Esa misma revisión sugiere que otra explicación para este aumento de la velocidad de la marcha después del ejercicio podría ser un simple hecho de que podría haber ocurrido un efecto de "calentamiento" en lugar de un efecto de interferencia. Si eso fuera cierto, el aumento de la velocidad de la marcha podría deberse en parte a alguna forma de potenciación posterior a la activación, y los ejercicios destinados a causar fatiga simplemente crearon una fase de preacondicionamiento que aumentó la activación muscular después del ejercicio. La investigación adicional debería investigar la fuente de los fenómenos de aumento de la velocidad de la marcha.

Los protocolos HIIT de cicloergómetro se están volviendo cada vez más comunes en adultos mayores y poblaciones con enfermedades crónicas en programas de rehabilitación en todo el mundo (Currie et al., 2013; Dun et al., 2019; Guiraud et al., 2012; Tschentscher et al., 2016). La población que envejece necesita intervenciones de ejercicio como HIIT para ayudar a reducir el impacto que las enfermedades crónicas y la discapacidad están teniendo en todo el mundo. Los resultados de la tesis actual demuestran la utilidad del cicloergómetro HIIT en esta población y se debe realizar una mayor exploración de la investigación del cicloergómetro HIIT en una población que envejece sin un temor exorbitante de posibles lesiones o riesgo de caídas.

Conclusions

General:

High-Intensity Interval Training is an effective and safe exercise regimen that is well-tolerated in older adults and is known to increase cardiorespiratory fitness. A simple 4 x 4 cycle ergometer HIIT protocol can be prescribed to the broader, non-clinical population of older adults by using a simple HRmax calculation and RPE. 6 weeks of cycle ergometer HIIT has demonstrated that it can improve lower limb strength and functional capacity in an already active older adult population comparable to improvements seen with RT. A single session of cycle ergometer HIIT does not produce an acute risk of falling in the youngest of the older adults (50-70 years of age) and it should not be singled out as a hazardous exercise regimen to participate in as previously published by another research group.

Specifically:

- HIIT is a valuable exercise regimen that can take place in a variety of forms to increase cardiorespiratory fitness in older adults (Paper I).
- HIIT was well-tolerated and appears to be safe and effective in an older population with significant, divergent comorbidities (Paper I & Paper III).
- HIIT may be effective at engaging participants that would otherwise drop out of the traditional MICT exercise routines (Paper III).
- A simple 4x4 cycle ergometer HIIT protocol can be prescribed to a broader, non-clinical population of older adults by using HRmax and using RPE as a secondary guide (Paper III).
- 6 weeks of cycle ergometer HIIT is an adequate amount of time to result in significant lower limb strength and functional capacity improvements in an already active older adult population (Paper III).
- A single session of cycle ergometer HIIT does not produce an acute transient effect on postural control or gait parameters in older adults 50 – 70 years of age (Paper IV).
- When compared to a metabolically matched MICT protocol, HIIT is just as safe and more time-efficient (Paper IV).
- Both HIIT and MICT protocols produced a slight increase in gait velocity post-exercise that lasted for approximately 20 minutes (Paper IV).
- Cycle ergometer HIIT should not be singled out as a hazardous exercise to participate in for the youngest of the older adults when the world's aging population is growing

ever faster and needs more time-efficient and effective exercise regimens like cycle ergometer HIIT (Paper IV).

- RT has a positive influence on both gait and balance in an aging population, but specifically straight-line walking speed, in older adults. The improvements in gait and balance parameters can be highly attributed to the significant increases in lower limb strength (Paper II).
- It is unclear in the increase in lower limb strength due to RT can improve the various and complex aspects of gait in older adults Paper (II).

Conclusiones

Generales:

El entrenamiento en intervalos de alta intensidad es un régimen de ejercicio eficaz y seguro que se tolera bien en los adultos mayores y se sabe que aumenta la capacidad cardiorrespiratoria. Se puede prescribir un protocolo HIIT en ergómetro de ciclo 4 x 4 simple a la población no clínica más amplia de adultos mayores mediante el uso de un cálculo simple de FCmáx y RPE. Seis semanas de cicloergómetro HIIT han demostrado que pueden mejorar la fuerza de las extremidades inferiores y la capacidad funcional en una población adulta mayor ya activa en comparación con las mejoras observadas con la RT. Una sola sesión de HIIT en cicloergómetro no produce un riesgo agudo de caídas en el más joven de los adultos mayores (50-70 años) y no debe ser señalado como un régimen de ejercicio peligroso para participar, según lo publicado previamente por otro grupo de investigación.

Específicas:

- HIIT es un régimen de ejercicio valioso que puede llevarse a cabo en una variedad de formas para aumentar la aptitud cardiorrespiratoria en los adultos mayores (Articulo I).
- El HIIT se toleró bien y parece ser seguro y eficaz en una población mayor con comorbilidades importantes y divergentes (Articulo I y Articulo III).
- El HIIT puede ser eficaz para involucrar a los participantes que, de otro modo, se saldrían de las rutinas tradicionales de ejercicios MICT (Articulo III).
- Se puede prescribir un protocolo HIIT en cicloergómetro 4x4 simple a una población no clínica más amplia de adultos mayores mediante el uso de FCmáx y el uso de RPE como guía secundaria (Articulo III).
- Seis semanas de cicloergómetro HIIT es una cantidad de tiempo adecuada para dar como resultado mejoras significativas en la fuerza de las extremidades inferiores y la capacidad funcional en una población adulta mayor ya activa (Articulo III).
- Una sola sesión de cicloergómetro HIIT no produce un efecto transitorio agudo sobre el control postural o los parámetros de la marcha en adultos mayores de 50 a 70 años (Articulo IV).
- En comparación con un protocolo MICT igualado metabólicamente, HIIT es igual de seguro y más eficiente en el tiempo (Articulo IV).

- Tanto los protocolos HIIT como MICT produjeron un ligero aumento en la velocidad de la marcha después del ejercicio que duró aproximadamente 20 minutos (Articulo IV).
- El cicloergómetro HIIT no debe considerarse un ejercicio peligroso para los adultos mayores más jóvenes cuando la población que envejece en el mundo crece cada vez más rápido y necesita regímenes de ejercicio más eficaces y eficientes en el tiempo, como el cicloergómetro HIIT (Articulo IV).
- La RT tiene una influencia positiva tanto en la marcha como en el equilibrio en una población que envejece, pero específicamente la velocidad de la marcha en línea recta, en los adultos mayores. Las mejoras en los parámetros de la marcha y el equilibrio se pueden atribuir en gran medida a los aumentos significativos en la fuerza de las extremidades inferiores (Articulo II).
- No está claro que el aumento de la fuerza de las extremidades inferiores debido a la RT puede mejorar los diversos y complejos aspectos de la marcha en los adultos mayores (Articulo II).

Future research

The current doctoral thesis had sought out the safety and feasibility of utilizing cycle ergometer HIIT in older adults. Based on the current data, it appears HIIT is just as safe and possibly more effective as comparable exercise interventions. However, more research is warranted in underrepresented populations; First and foremost is the lack of data regarding the older female population that is growing larger as years after year. Furthermore, HIIT has been utilized heavily in clinical populations, long-term research should look at the feasibility of utilizing HIIT in the general aging population outside of the clinical/laboratory setting.

Interestingly, data from the current thesis has found that aerobic cycle ergometer HIIT enhances lower limb strength comparable to that of traditional RT but with an added cardiovascular benefit. This suggests that cycle ergometer HIIT can achieve multiple, positive health-related objectives with a single exercise regimen, yet, in a more time-efficient manner. Therefore, more research should be done to determine if the increased strength gains are linked to improved gait, balance, and/or efficacy of falls in older adults.

Finally, Paper IV has observed that cycling causes a transient increase in gait velocity. The current thesis speculates that the increased velocity is due in part to a high cycling cadence that leads to an increased walking cadence, therefore, causing an acute increase in gait velocity for approximately 10 minutes post-exercise. Further research should examine this outcome to verify if the author's speculation is correct and to determine if long-term participation in cycling chronically affects walking cadence/gait velocity.

Estudios del futuro

La tesis doctoral actual había buscado la seguridad y viabilidad de utilizar cicloergómetro HIIT en adultos mayores. Según los datos actuales, parece que el HIIT es tan seguro y posiblemente más efectivo que las intervenciones de ejercicio comparables. Sin embargo, se justifica más investigación en poblaciones subrepresentadas; Lo primero y más importante es la falta de datos sobre la población femenina de mayor edad que crece año tras año. Además, HIIT se ha utilizado mucho en poblaciones clínicas, la investigación a largo plazo debe analizar la viabilidad de utilizar HIIT en la población general que envejece fuera del entorno clínico/laboratorio.

Curiosamente, los datos de la tesis actual han encontrado que el cicloergómetro aeróbico HIIT mejora la fuerza de las extremidades inferiores comparable a la de la RT tradicional, pero con un beneficio cardiovascular adicional. Esto sugiere que el cicloergómetro HIIT puede lograr múltiples objetivos positivos relacionados con la salud con un solo régimen de ejercicio, pero de una manera más eficiente en el tiempo. Por lo tanto, se debe realizar más investigación para determinar si las mayores ganancias de fuerza están relacionadas con una mejor marcha, equilibrio y/o eficacia de las caídas en adultos mayores.

Finalmente, Artículo IV ha observado que el ciclismo provoca un aumento transitorio en la velocidad de la marcha. La tesis actual especula que el aumento de la velocidad se debe en parte a una alta cadencia de ciclismo que conduce a un aumento de la cadencia de la marcha y, por lo tanto, provoca un aumento agudo en la velocidad de la marcha durante aproximadamente 10 minutos después del ejercicio. La investigación adicional debe examinar este resultado para verificar si la especulación de los autores es correcta y para determinar si la participación a largo plazo en el ciclismo afecta crónicamente la cadencia/velocidad de la marcha.

Curriculum Vitae (Currículum Vitae)

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EDUCATION

2018- pres. Ph.D. Candidate –Physical Activity and Sport Science, University of Jaén, Spain
Dissertation: Effects of High-Intensity Interval Training in Older Adults

2017-2018 M.S. – Gerontology: Longevity and Quality of Life, University of Jaén, Jaén, Spain
Thesis: Comparing Moderate-Intensity Continuous Training to High-Intensity Interval Training in older adults

2007-2009 M.S. – Exercise & Wellness, Health Promotion, Arizona State University, Mesa, AZ
Thesis: A comparison of Total Body Water in High School Wrestlers using two different bio-impedance measures.

2004-2007 B.A. – Physical Education and Health, Northwestern College, Orange City, IA

CERTIFICATION

2006-present Certified Exercise Physiologist, American College of Sports Medicine (ACSM)
2014-present Single Pitch Instructor (SPI), American Mountain Guides Association (AMGA)

EMPLOYMENT

2021-Pres. Assistant Teaching Professor, University of Southern Mississippi, Hattiesburg, MS
2020-2021 Visiting Instructor, University of Southern Mississippi, Hattiesburg, MS
2018-2020 English Language Instructor, SeaHaven – Centros de Inglés, Jaén, Spain
2017-2019 Language/Cultural Assistant, Junta de Andalucía, Andalucía, Spain
2015-2017 Program Coordinator (Physical Ed./Health), San Juan College, Farmington, NM
2014-2015 Instructor/Fitness Coordinator, San Juan College, Farmington, NM
2012-2014 Student Activities Specialist, San Juan College, Farmington, NM
2010-2012 Language/Cultural Assistant, Junta de Andalucía, Martos (Jaén), Spain
2009-2010 Exercise Physiologist, Arizona Heart Institute, Phoenix, AZ
2007-2010 Adjunct Faculty, Chandler Gilbert Community College, Chandler, AZ
2007-2009 Teaching Associate, Arizona State University, Mesa, AZ

TEACHING EXPERIENCE

Instructor, School of Kinesiology and Nutrition, College of Education & Human Science
University of Southern Mississippi, Hattiesburg, Mississippi August 2020 – Present

KIN 308 – Exercise Physiology I Fall, Spring & Online
This course outlines an understanding of how the body, from a functional standpoint, responds, adjusts, and adapts to exercise. Topics include bioenergetics, neuromuscular concepts, cardiorespiratory considerations, physical training, and environmental concerns involving physical activity, athletic performance, and health-related fitness.

KIN 402 L – Exercise Physiology II Lab Fall, Spring
A comprehensive laboratory review of bioenergetic, neuromuscular, neuroendocrine, and cardiovascular aspects of exercise and training with special attention to the effects of the stress of exercise on physiological processes.

KIN 406 – Physiology of Aging & Chronic Disease Fall, Spring & Online
This is an advanced course in the clinical use of exercise therapy in the management of patients with chronic disease. The course is designed to provide a basic understanding of the pathophysiology and exercise response in patients with cardiovascular, pulmonary, metabolic, musculoskeletal, neuromuscular, and immunologic diseases.

KIN 471 – Physiological Principles of Resistance Training Fall 2021
This course is designed to educate students on how the human body adapts to physiological stresses imposed by resistance training and conditioning. This course focuses on the development and practical applications of muscular strength, anaerobic conditioning, joint flexibility, speed, power, and agility programs. Upon completion of this course, the student should attain a greater state of preparedness to sit for the NSCA's Certified Strength and Conditioning Specialist (CSCS) exam.

KIN 302 –Exercise Testing & Prescription Fall 2021
This class prepares the student to be able to choose and administer the appropriate pre-activity screening assessments according to the subject's age, health status, and fitness goals. The student will also be able to design a safe and effective exercise prescription from the test results.

KIN 105 – Concepts of Physical Fitness Fall, Spring & Online
This course is a comprehensive introduction to how physical activity and fitness affect health. Emphasis is placed on how physical activity and fitness reduce and control chronic fatigue. Attention is also given to weight control and weight loss using both physical activity and nutrition. The primary goal of the course is to develop students' knowledge and understanding of the scientific basis of the relationship between physical activity and health and associated topics including obesity.

Instructor, School of Health Sciences, Department of Health & Physical Education
San Juan College, Farmington, New Mexico May 2014 – August 2017

HLTH 118 – Intro to Nutrition Fall, Spring, Summer & Online
This course prepares students to become informed consumers of nutrients and nutrition information so they might make good decisions about personal nutrition, health, and fitness. The course includes the biochemistry of the essential nutrients, nutritional needs within the life cycle, nutritional status assessment of individuals and populations, food policies and regulatory agencies, nutritional aspects of disease, and current nutritional issues.

HLTH 150 – Personal Health and Wellness Fall, Spring, & Online
This course is designed to study the various aspects of personal health and wellness, including the emotional, physical, social, occupational, spiritual, environmental, and intellectual components. The class looks at the nature, scope, and function of major health considerations.

PHED 113 – Intro to Personal Training Fall & Spring
The purpose of this course is to instruct and improve student's knowledge on how to develop the skills and knowledge necessary to be a Personal Trainer; begin preparation to take and pass a Personal Trainers Certification; develop the ability to critically think through and apply information acquired to make rational decisions associated to fitness training.

PHED 137 – Weight Training Fall, Spring & Summer
This course covers the basic skills of muscular strength and endurance development, theories of strength training, equipment, and safety in weight training. This course covers how to safely use weight training in an exercise program, which muscles are being utilized in which exercises, weight training terminology, and how to design an exercise program.

Instructor, School of Health Sciences, Department of Outdoor Leadership
San Juan College, Farmington, New Mexico August 2014 – August 2017

OLER 155 – Intro to Gym Climbing Fall & Spring
This course is designed for the climber who wishes to gain a review of the basics of climbing in an indoor climbing gym setting. The course covers the topics and skills necessary to safely Boulder, Top Rope, and Lead climbing in a climbing facility.

OLER 156 – Rock Climbing Fall
This course covers the fundamentals of rock climbing. Students will experience climbing in an indoor climbing facility as well as outdoor locations. The course covers the topics and skills necessary to safely climb by learning equipment selection and usage, belay techniques, anchor systems, and climbing skills. Topics covered include safety, knots, different belay techniques, proper climbing gear selection, and rope management systems.

OLER 157 – Sport Climbing Spring
Designed for the experienced climber who wishes to gain the knowledge and skills for lead climbing in an indoor and outdoor setting. This course will cover the topics and skills necessary to safely lead climb. Other topics will include a review of the basics, lead-climbing safety, belaying the leader, lead climbing technique, falling, and advanced climbing technique.

OLER 260 – Advanced Rock Climbing Summer
The course introduces students to the concepts of planning and execution of a climbing expedition. Students learn expedition behavior and planning, crag safety, LNT, philosophies of ethics in leadership, navigation, and adventure climbing techniques. This course is a step-up preparing the student to take the next step in becoming AMGA Single Pitch Instructors.

Teaching Associate, College of Nursing & Health Innovation Department of Exercise & Wellness
Arizona State University, Mesa, Arizona August 2007 – May 2009

EXW 105 – Weight Training Fall 2007-Spring 2009
This course is designed to introduce the student to weight training through a variety of modalities involved with effective weight training. This course covers how to safely use weight training in an exercise program, which muscles are being utilized in which exercises, weight training terminology, and how to design an exercise program.

EXW 105 – Physical Conditioning Spring 2009
This course is designed to introduce the student to various exercises and physical activities. The course covers how to safely participate in an exercise program including proper warm-up and cool-down techniques, stretching modalities, basic exercise program development, and elementary muscular function and structure.

Adjunct Faculty, Departments of Physical Education, Health Science, and Exercise Science
Chandler-Gilbert Community College, Chandler, Arizona August 2007 – Summer 2010

PED 117 – Weight Training Fall 2007 – Summer 2010
Fitness activity and wellness study to help develop a lifetime of regular exercise, stress management, and proper nutrition. Workout includes a warm-up, aerobic exercise, selected strength exercises, and cool down.

PED 115 – Lifetime Fitness Fall 2008 – Spring 2009
Fitness activity and wellness study to help develop a lifetime of regular exercise, stress management, and proper nutrition. Workout includes a warm-up, aerobic exercise, selected

strength exercises, and cool down.

EXS 125 – Intro to Exercise Physiology Spring 2010

This course studies human movement with an emphasis on the physiological function of the body in response to physical activity and exercise and its application to teaching fitness/aerobics. Emphases were focused upon the basic human anatomy/ physiology, exercise physiology, and biomechanics.

EXS 212C – Instructional Competency Lab: Cardio Fall 2009 – Spring 2010

This hands-on course was designed to help the student learn various safe and effective teaching methods and modalities that are appropriate for individuals as well as various age groups and physical abilities. This course provided the student with a basic understanding of the effects of cardiorespiratory exercises and general scientific principles relative to improving cardiorespiratory fitness.

RESEARCH

The purpose of my research is to distinguish the key differences between varying exercise interventions in older adults. Specifically, to determine which exercise interventions are best at preventing and/or treating various aspects of health. Health outcomes such as cardiorespiratory fitness, muscular strength, cognition, health quality of life, and self-efficacy of falls. Most of my current and future research plans are focused on the following areas:

- High-Intensity Interval Training
- Prevention of age-related functional decline
- Gait analysis and falls in older adults

PUBLICATIONS

Keating, C.J.; Cabrera-Linares, J.C..; Párraga-Montilla, J.A..; Latorre-Román, P.L.; Moreno del Castillo, R..; García-Pinillos, F. (2021) Influence of Resistance Training on Gait & Balance Parameters in Older Adults: A Systematic Review. *International Journal of Environmental Research and Public Health*,18 (4), 1759. https://doi.org/10.3390/ijerph18041759

Keating, C. J., Párraga Montilla, J. Á., Latorre Román, P. Á., & Moreno del Castillo, R. (2020). Comparison of High-Intensity Interval Training to Moderate-Intensity Continuous Training in Older Adults: A Systematic Review. *Journal of Aging and Physical Activity*, *28*(5), 798–807. https://doi.org/10.1123/japa.2019-0111

Latorre-Román, P. A., Martínez-Redondo, M., Párraga-Montilla, J. A., Lucena-Zurita, M., Manjón-Pozas, D., González, P. J. C., Robles-Fuentes, A., Cardona-Linares, A. J., **Keating, C. J.**, & Salas-Sánchez, J. (2021). Analysis of dynamic balance in preschool children through the balance beam test: A cross-sectional study providing reference values. *Gait & Posture*, *83*, 294–299. https://doi.org/10.1016/j.gaitpost.2020.11.004

Warr, B. J., Alvar, B. A., Dodd, D. J., Heumann, K. J., Mitros, M. R., **Keating, C. J.**, & Swa, P. D. (2011). How do they compare?: An assessment of predeployment fitness in the arizona national guard. *Journal of Strength and Conditioning Research*, *25*(11), 2955–2962. https://doi.org/10.1519/JSC.0b013e31822dfba8

Keating, C.J., Párraga-Montilla, J.A., Cabrera-Linares, J.C., De la Casa Pérez, A., Latorre-Román, P.A. Utilizing heart rate and RPE to prescribe cycle ergometer HIIT in older adults: A feasibility study. *Submitted*

Keating, C.J., Párraga Montilla, J.A., Latorre Román, P.A., Donahue, P.T. A Single Session of Cycle Ergometer High-Intensity Interval Training (HIIT) Does Not Produce a Transient Elevated Fall Risk in Adults 50 – 70 Years of Age. *Submitted*

Keating, C. J., Swan, P., & Heumann, K. J. (2010). Comparison Of Total Body Water In High School Wrestlers Using Bio-impedance Measures. *Medicine & Science in Sports & Exercise*. https://doi.org/10.1249/01.mss.0000385718.57488.52

PRESENTATIONS

Keating, C.J., Párraga Montilla, J. Á., Cabrera Linares, J.C., De la Casa Pérez, A., Latorre Román, P. Á., (July 2020) Can we detect cognitive deterioration through simple gait parameters in older adults? Poster presented virtually at the British Society of Gerontology Annual Meeting 2020, Online

Keating, C.J., Párraga Montilla, J. Á., Latorre Román, P. Á., (July 2020) Age-related physical decline is independent of physical activity level in older adults. Poster presented virtually at the British Society of Gerontology Annual Meeting 2020, Online

Warr, B.J., Alvar, B., Dodd, D., Heumann, K.J., Mitros, M., **Keating, C.**, Swan, P.D. (June 2011). How does combat effect fitness? An evaluation of deployed Arizona National Guardsmen. Presented orally at the 58th Annual American College of Sports Medicine Meeting, Denver, Colorado.

Keating, C.J., Swan, P., Heumann, K.J. (June 2010). Comparison of total body water in high school wrestlers using bio-impedance measures. Poster presented at the 57th Annual American College of Sports Medicine Meeting, Baltimore, Maryland.

Keating, C.J., Swan, P., Heumann, K.J. (October, 2009). Comparison of total body water in high school wrestlers using bio-impedance measures. Poster presented at the Southwest Chapter of theAmerican College of Sports Medicine Annual Meeting, San Diego, California.

SERVICE

2021-pres. Volunteer route setter, University of Southern Mississippi Payne Center, Hattiesburg, MS
2019-2021 Doctoral Student Advisor, Department Advisory Committee, UJA, Jaén, Spain
2014-2017 San Juan College Outdoor Adventure Club/Rock Climbing Club Advisor
2008-2009 President: ASU Polytechnic Cycle & Tri Club, Mesa, AZ
2008-2009 Secretary: ASU Exercise and Wellness Graduate Club, Mesa, AZ
2004-2006 Treasurer: Kinesiology Club, Orange City, IA

AWARDS

2020 Inductee – New Mexico Wrestling Hall of Fame
2015 New Mexico State Wrestling Official of the Year Award
2009 Outstanding Masters Graduate Award, EXW, Arizona State University, Mesa, AZ
2008 Graduate and Professional Student Association Grant Competition Award for Masters Research, Arizona State University, Tempe, AZ - $2000
2007 Physical Education Major of the Year Award, Northwestern College, Orange City, IA

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I would like to express my sincere gratitude to the best mom in the world… **LaVern Loretta (Duran) Keating-McDaniel**; Without you, I would not strive to be the person I am today. Thank you for being my inspiration and guiding light in everything that I do. Words will never be able to describe the love and appreciation I have for you and everything you have done to make us boys the most productive members of society that we can be. I love you!

To my beloved grandparents, **Willa Nadine Keating, Frank Duran (Rucker) & Leonor (Valdez) Duran**. I would especially like to thank my grandfather **Frank** for believing in me before I ever knew what I wanted to do or who I wanted to be "Doctor Chris…". What I would give to have one last conversation with you and show you the impact you have on my life and your influence on the choices that I make day in and day out.

To my wife; **Mercedes (Leles) Llavero Quiros**, I would not be writing this doctoral thesis right now without you and your support over the last four years. Like all relationships, we have our ups and downs, but we are better together, and we bring out the best in one another. Most would not tolerate the distance and struggles that we face as an international couple; you have not only overcome it, but you have insisted it will only be better for us and our future together. Thank you for supporting me with all your heart and inspiring me to be a better person.

To my brothers; **Vince Keating and John Keating**. Vince, I have always looked up to you and you have challenged me to be the best at what I do. We have been through a lot together and nobody can ever take that bond away from us. John, I have always admired your work ethic and you challenge me to think differently and outside the box. Sometimes that involves going outside my comfort zone and pushing the limits of my capabilities, thank you for keeping me on my toes. You guys have shaped me to be the best version of myself.

To my father; **James William Keating**. If only you could see your boys now… we have changed immensely since your last day on this earth, and I am sure you would be even more proud of us now than you ever were then. Thank you for always telling me to listen to and respect the authority of that wonderful mother of mine... you were not wrong; she is amazing. You taught me the most valuable lesson of them all… life is short, enjoy every minute of it, and share what's on your mind with those that you love, you never know if it is the last conversation you will have with them. I love and miss you dearly!

To my best friend and cousin **Daniel (Frankenstein) Diswood**. Without you, I would possibly not be here today. You have kept me honest and loyal to who I am and to what I believe in… I couldn't imagine a childhood without you by my side and adulthood without your conversations to help shape and guide me.

To my family, to which there are way too many to list them all by name. But, to all my aunties, my uncles, my cousins, my nephews, my stepfather, my in-laws, my half-sister. You have all made such a great impact on my life and I can only hope there is so much more to come. You all have provided me with such a strong family unit to rely on, to laugh with, to cry with, and to fall back on when times are tough.

To my friends, all that have been with me along the way and those who I have discovered (or you have discovered me 😊) along the way. You guys have all been supportive in your own right, and I appreciate it greatly.

To the University of Jaen, particularly to the department of didactics, music, art, and bodily expression. Thank you for taking me in and providing me with the space and time to take on this task of completing a lifelong dream. To **Rafael Moreno** for providing me with guidance and support during my master's program in Gerontology. To **Jose Carlos** and **Ana** for your help with the 12-week intervention that was cut short to 6-weeks due to some crazy virus that ravaged the world order and all our plans that would not be what we planned for them to be.

To the School of Kinesiology and Nutrition at the University of Southern Mississippi for providing me with a platform to continue my research during a global pandemic. Particularly to **Scott Piland** for believing in me wholeheartedly and allowing me to have great autonomy at a time when most universities were restricting and not expanding their horizons. Thank you for being a mock advisor in the absence of my Ph.D. advisors.

Last but least to my advisors; **Juan Párraga** and **Pedro Latorre**. Thank you both for giving me the encouragement and support to apply for the Ph.D. program when I was in the master's program. Juan, I appreciate all the time you spent with me and struggling to understand my crazy guidi accent. Pedro, thank you for allowing me to take part in some substantial document preparation early on in my Ph.D. and providing me with considerable experience in doing so. I greatly appreciate all your patients and consideration for my strange circumstance; you both have been great!

Me gustaría expresar mi más sincero agradecimiento a la mejor mamá del mundo… LaVern Loretta (Duran) Keating-McDaniel; Sin ti, no me esforzaría por ser la persona que soy hoy. Gracias por ser mi inspiración y luz de guía en todo lo que hago. Las palabras nunca podrán describir el amor y el aprecio que tengo por ti y todo lo que has hecho para convertirnos en las personas más productivas de la sociedad que podemos ser. ¡Te quiero!

A mis amados abuelos, Willa Nadine Keating, Frank Duran (Rucker) y Leonor (Valdez) Duran. Me gustaría agradecer especialmente a mi abuelo Frank por creer en mí antes de que supiera lo que quería hacer o quién quería ser "Doctor Chris...". Lo que daría por tener una última conversación contigo y mostrarte el impacto que tienes en mi vida y tu influencia en las decisiones que tomo día tras día.

Para mi esposa; Mercedes (Leles) Llavero Quirós, no estaría escribiendo esta tesis doctoral en este momento sin ti y tu apoyo durante los últimos cuatro años. Como todas las relaciones, tenemos nuestros altibajos, pero somos mejores juntos y sacamos lo mejor de cada uno. La mayoría no toleraría la distancia y las luchas que enfrentamos como pareja internacional; no solo lo has superado, sino que has insistido en que solo será mejor para nosotros y nuestro futuro juntos. Gracias por apoyarme con todo tu corazón e inspirarme a ser una mejor persona.

A mis hermanos; Vince Keating y John Keating. Vince, siempre te he admirado y me has desafiado a ser el mejor en lo que hago. Hemos pasado por muchas cosas juntos y nadie podrá quitarnos ese vínculo. John, siempre he admirado tu ética en el trabajo y me desafías a pensar diferente y fuera de la caja. A veces eso implica salir de mi zona de confort y empujar los límites de mis capacidades, gracias por mantenerme alerta. Vosotros me habéis formado para ser la mejor versión de mí mismo.

Para mi padre; James William Keating. Si tan solo pudieras ver a tus hijos ahora... hemos cambiado inmensamente desde tu último día en esta tierra, y estoy seguro de que estarías aún más orgulloso de nosotros ahora que nunca. Gracias por haberme dicho siempre que escuche y respete la autoridad de mi maravillosa madre... no te equivocaste; ella es asombrosa. Me enseñaste la lección más valiosa de todas... la vida es corta, disfruta cada minuto y comparte lo que piensas con tus seres queridos, nunca sabes si es la última conversación que tendrás con ellos. ¡Te amo y te extraño mucho!

A mi mejor amigo y primo Daniel (Frankenstein) Diswood. Sin ti, posiblemente no estaría aquí hoy. Me has mantenido honesto y leal a lo que soy y a lo que creo… No podría imaginar

una niñez sin ti a mi lado y una adultez sin tus conversaciones para ayudarme a moldearme y guiarme.

A mi familia, hay demasiados para enumerarlos todos por su nombre, pero a todas mis tías, mis tíos, mis primo/as, mis sobrino/as, mi padrastro, mi familia política y mi media hermana. Todos vosotros habéis tenido un gran impacto en mi vida y solo puedo esperar que haya mucho más por venir. Todos me habéis brindado una unidad familiar tan fuerte en la que confiar, con la que reír, llorar y en la que apoyarme cuando los tiempos son difíciles.

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Bibliography (Bibliografía)

Angadi, S. S., Mookadam, F., Lee, C. D., Tucker, W. J., Haykowsky, M. J., & Gaesser, G. A. (2015). High-intensity interval training vs. moderate-intensity continuous exercise training in heart failure with preserved ejection fraction: A pilot study. *Journal of Applied Physiology*, *119*(6), 753–758. https://doi.org/10.1152/japplphysiol.00518.2014

Bailey, C. F., Cagle, G. K., Grozier, C. D., Lehtola, K. N., Weaver, J. F., Wilson, S. J., Chander, H., Rendos, N. K., & Simpson, J. D. (2021). Gathering your 'sea legs': Extended durations in an offshore environment increases postural sway excursions. *Gait and Posture*, *86*, 45–50. https://doi.org/10.1016/j.gaitpost.2021.02.014

Baltasar-Fernandez, I., Alcazar, J., Rodriguez-Lopez, C., Losa-Reyna, J., Alonso-Seco, M., Ara, I., & Alegre, L. M. (2021). Sit-to-stand muscle power test: Comparison between estimated and force plate-derived mechanical power and their association with physical function in older adults. *Experimental Gerontology*, *145*(September 2020). https://doi.org/10.1016/j.exger.2020.111213

Bird, S. P., Tarpenning, K. M., & Marino, F. E. (2005). Designing resistance training programmes to enhance muscular fitness: A review of the acute programme variables. *Sports Medicine*, *35*(10), 841–851. https://doi.org/10.2165/00007256-200535100-00002

Bouaziz, W., Schmitt, E., Kaltenbach, G., Geny, B., & Vogel, T. (2015). Health benefits of cycle ergometer training for older adults over 70: A review. *European Review of Aging and Physical Activity*, *12*(1). https://doi.org/10.1186/s11556-015-0152-9

Bushman, B. A. (2019). Physical Activity Guidelines for Americans. *ACSM'S Health & Fitness Journal*, *23*(3), 5–9. https://doi.org/10.1249/FIT.0000000000000472

Centre for Economics and Business Research. (2015). *The economic cost of physical inactivity in Europe Foreword and introduction from Mogens Kirkeby President, International Sport and Culture Association (ISCA). June*. http://inactivity-time-bomb.nowwemove.com/download-report/The Economic Costs of Physical Inactivity in Europe (June 2015).pdf

Chodzko-Zajko, W. J., Proctor, D. N., Fiatarone Singh, M. A., Minson, C. T., Nigg, C. R., Salem, G. J., & Skinner, J. S. (2009). Exercise and physical activity for older adults. *Medicine and Science in Sports and Exercise*, *41*(7), 1510–1530. https://doi.org/10.1249/MSS.0b013e3181a0c95c

Csuka, M., & McCarty, D. J. (1985). Simple method for measurement of lower extremity muscle strength. *The American Journal of Medicine*, *78*(1), 77–81. https://doi.org/10.1016/0002-9343(85)90465-6

Currie, K. D., Dubberley, J. B., McKelvie, R. S., & Macdonald, M. J. (2013). Low-volume, high-intensity interval training in patients with CAD. *Medicine and Science in Sports and Exercise*, *45*(8), 1436–1442. https://doi.org/10.1249/MSS.0b013e31828bbbd4

D'antona, G., Pellegrino, M. A., Carlizzi, C. N., & Bottinelli, R. (2007). Deterioration of contractile properties of muscle Wbres in elderly subjects is modulated by the level of physical activity. *Eur J Appl Physiol*, *100*, 603–611. https://doi.org/10.1007/s00421-007-0402-2

Donath, L., & Roth, R. (2014). *Does a Single Session of High-Intensity Interval Training Provoke a Transient Elevated Risk of Falling in Seniors and Adults ?* https://doi.org/10.1159/000363767

Dun, Y., Smith, J. R., Liu, S., & Olson, T. P. (2019). High-Intensity Interval Training in Cardiac Rehabilitation. *Clinics in Geriatric Medicine*, *35*(4), 469–487. https://doi.org/10.1016/j.cger.2019.07.011

Ellingsen, Ø., Halle, M., Conraads, V., Støylen, A., Dalen, H., Delagardelle, C., Larsen, A. I., Hole, T., Mezzani, A., Van Craenenbroeck, E. M., Videm, V., Beckers, P., Christle, J. W., Winzer, E., Mangner, N., Woitek, F., Höllriegel, R., Pressler, A., Monk-Hansen, T., … Linke, A. (2017). High-Intensity Interval Training in Patients with Heart Failure with Reduced Ejection Fraction. *Circulation*, *135*(9), 839–849. https://doi.org/10.1161/CIRCULATIONAHA.116.022924

Elliott, M. L., Caspi, A., Houts, R. M., Ambler, A., Broadbent, J. M., Hancox, R. J., Harrington, H., Hogan, S., Keenan, R., Knodt, A., Leung, J. H., Melzer, T. R., Purdy, S. C., Ramrakha, S., Richmond-Rakerd, L. S., Righarts, A., Sugden, K., Thomson, W. M., Thorne, P. R., … Moffitt, T. E. (2021). Disparities in the pace of biological aging among midlife adults of the same chronological age have implications for future frailty risk and policy. *Nature Aging*, *1*(3), 295–308. https://doi.org/10.1038/s43587-021-00044-4

Fragala, M. S., Cadore, E. L., Dorgo, S., Izquierdo, M., Kraemer, W. J., Peterson, M. D., & Ryan, E. D. (2019). Resistance Training for Older Adults: Position Statement From the National Strength and Conditioning Association. *Journal of Strength and Conditioning Research*, *33*(8), 2019–2052. https://doi.org/10.1519/JSC.0000000000003230

Gibala, M. J., & McGee, S. L. (2008). Metabolic Adaptations to Short-term High-Intensity Interval Training. *Exercise and Sport Sciences Reviews*, *36*(2), 58–63. https://doi.org/10.1097/JES.0b013e318168ec1f

Gillen, J. B., & Gibala, M. J. (2018, October). Interval training: A time-efficient exercise strategy to improve cardiometabolic health. *Applied Physiology, Nutrition and Metabolism*, *43*(10), iii–iv. https://doi.org/10.1139/apnm-2018-0453

Guiraud, T., Nigam, A., Gremeaux, V., Meyer, P., Juneau, M., & Bosquet, L. (2012). High-Intensity Interval Training in Cardiac Rehabilitation. *Sports Medicine*, *42*(7), 587–605. https://doi.org/10.2165/11631910-000000000-00000

Hannan, A., Hing, W., Simas, V., Climstein, M., Coombes, J., Jayasinghe, R., Byrnes, J., & Furness, J. (2018). High-intensity interval training versus moderate-intensity continuous training within

cardiac rehabilitation: a systematic review and meta-analysis. *Open Access Journal of Sports Medicine*, *Volume 9*, 1–17. https://doi.org/10.2147/oajsm.s150596

Heidenreich, P. A., Trogdon, J. G., Khavjou, O. A., Javed Butler, M. ;, Dracup, K., Ezekowitz, M. D., Eric, F. ;, Finkelstein, A., Hong, Y., Johnston, ; S Claiborne, Khera, A., Lloyd-Jones, D. M., Nelson, S. A., Nichol, G., Orenstein, D., Peter, ;, Wilson, W. F., & Woo, ; Y Joseph. (2011). *AHA Policy Statement Forecasting the Future of Cardiovascular Disease in the United States A Policy Statement From the American Heart Association Council on Cardiopulmonary, Critical Care, Perioperative and Resuscitation, Council on Cardiovascular Nursing, Council on the Kidney in Cardiovascular Disease, Council on Cardiovascular Surgery and Anesthesia, and Interdisciplinary Council on Quality of Care and Outcomes Research*. https://doi.org/10.1161/CIR.0b013e31820a55f5

Helbostad, J. L., Leirfall, S., Moe-Nilssen, R., & Sletvold, O. (2007). Physical Fatigue Affects Gait Characteristics in Older Persons. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, *62*(9), 1010–1015. https://doi.org/10.1093/gerona/62.9.1010

Helbostad, J. L., Sturnieks, D. L., Menant, J., Delbaere, K., Lord, S. R., & Pijnappels, M. (2010). Consequences of lower extremity and trunk muscle fatigue on balance and functional tasks in older people: A systematic literature review. *BMC Geriatrics*, *10*(1), 56. https://doi.org/10.1186/1471-2318-10-56

Hill, M. W., Higgins, M. F., & Price, M. J. (2016). The effect of high - intensity cycling training on postural sway during standing under rested and fatigued conditions in healthy young adults. *European Journal of Applied Physiology*, *116*(10), 1965–1974. https://doi.org/10.1007/s00421-016-3448-1

Hood, M. S., Little, J. P., Tarnopolsky, M. A., Myslik, F., & Gibala, M. J. (2011). Low-volume interval training improves muscle oxidative capacity in sedentary adults. *Medicine and Science in Sports and Exercise*, *43*(10), 1849–1856. https://doi.org/10.1249/MSS.0b013e3182199834

Hwang, C. L., Lim, J., Yoo, J. K., Kim, H. K., Hwang, M. H., Handberg, E. M., Petersen, J. W., Holmer, B. J., Leey Casella, J. A., Cusi, K., & Christou, D. D. (2019). Effect of all-extremity high-intensity interval training vs. moderate-intensity continuous training on aerobic fitness in middle-aged and older adults with type 2 diabetes: A randomized controlled trial. *Experimental Gerontology*, *116*, 46–53. https://doi.org/10.1016/j.exger.2018.12.013

Hwang, C. L., Yoo, J. K., Kim, H. K., Hwang, M. H., Handberg, E. M., Petersen, J. W., & Christou, D. D. (2016). Novel all-extremity high-intensity interval training improves aerobic fitness, cardiac function and insulin resistance in healthy older adults. *Experimental Gerontology*, *82*, 112–119. https://doi.org/10.1016/j.exger.2016.06.009

Ishigaki, E. Y., Ramos, L. G., Carvalho, E. S., & Lunardi, A. C. (2014). Effectiveness of muscle strengthening and description of protocols for preventing falls in the elderly: a systematic review. *Brazilian Journal of Physical Therapy*, *18*(2), 111–118. https://doi.org/10.1590/S1413-35552012005000148

Iverson, B. D., Gossman, M. R., Shaddeau, S. A., & Turner, M. E. (1990). Balance performance, force production, and activity levels in noninstitutionalized men 60 to 90 years of age. *Physical Therapy*, *70*(6), 348–355. https://doi.org/10.1093/ptj/70.6.348

Jabbour, G., & Majed, L. (2018). Ratings of perceived exertion misclassify intensities for sedentary older adults during graded cycling test: Effect of supramaximal high-intensity interval training. *Frontiers in Physiology*, *9*(OCT), 1–9. https://doi.org/10.3389/fphys.2018.01505

Jones, C. J., Rikli, R. E., & Beam, W. C. (1999). A 30-s chair-stand test as a measure of lower body strength in community-residing older adults. *Research Quarterly for Exercise and Sport*, *70*(2), 113–119. https://doi.org/10.1080/02701367.1999.10608028

Kraemer, W. J., Adams, K., Cafarelli, E., Dudley, G. A., Dooly, C., Feigenbaum, M. S., Fleck, S. J., Franklin, B., Fry, A. C., Hoffman, J. R., Newton, R. U., Potteiger, J., Stone, M. H., Ratamess, N. A., & Triplett-McBride, T. (2002). Progression models in resistance training for healthy adults. *Medicine and Science in Sports and Exercise*, *34*(2), 364–380. https://doi.org/10.1097/00005768-200202000-00027

Lee, D. C., Sui, X., Ortega, F. B., Kim, Y. S., Church, T. S., Winett, R. A., Ekelund, U., Katzmarzyk, P. T., & Blair, S. N. (2011). Comparisons of leisure-time physical activity and cardiorespiratory fitness as predictors of all-cause mortality in men and women. *British Journal of Sports Medicine*, *45*(6), 504–510. https://doi.org/10.1136/bjsm.2009.066209

Lienhard, K., Schneider, D., & Maffiuletti, N. A. (2013). Validity of the Optogait photoelectric system for the assessment of spatiotemporal gait parameters. *Medical Engineering and Physics*, *35*(4), 500–504. https://doi.org/10.1016/j.medengphy.2012.06.015

Liu, C. J., & Latham, N. (2010). Adverse events reported in progressive resistance strength training trials in older adults: 2 sides of a coin. *Archives of Physical Medicine and Rehabilitation*, *91*(9), 1471–1473. https://doi.org/10.1016/j.apmr.2010.06.001

Llamas-Velasco, S., Villarejo-Galende, A., Contador, I., Lora Pablos, D., Hernández-Gallego, J., & Bermejo-Pareja, F. (2016). Physical activity and long-term mortality risk in older adults: A prospective population based study (NEDICES). *Preventive Medicine Reports*, *4*, 546–550. https://doi.org/10.1016/j.pmedr.2016.10.002

Morrison, S., Colberg, S. R., Parson, H. K., Neumann, S., Handel, R., Vinik, E. J., Paulson, J., & Vinik, A. I. (2016). Walking-Induced Fatigue Leads to Increased Falls Risk in Older Adults. *Journal of the American Medical Directors Association*, *17*(5), 402–409. https://doi.org/10.1016/j.jamda.2015.12.013

Nagano, H., James, L., Sparrow, W. A., & Begg, R. K. (2014). Effects of walking-induced fatigue on gait function and tripping risks in older adults. *Journal of NeuroEngineering and Rehabilitation*, *11*(1), 1–7. https://doi.org/10.1186/1743-0003-11-155

Nes, B. M., Vatten, L. J., Nauman, J., Janszky, I., & WislØff, U. (2014). A simple nonexercise model of cardiorespiratory fitness predicts long-term mortality. *Medicine and Science in Sports and Exercise*, *46*(6), 1159–1165. https://doi.org/10.1249/MSS.0000000000000219

Podsiadlo, D., & Richarson, S. (1991). The Timed Up and Go: A Test of Basic Functional Mobility for Frail Elderly Persons. *Journal of the American Geriatrics Society*, *39*(2), 142–148.

Pollock, R. D., Carter, S., Velloso, C. P., Duggal, N. A., Lord, J. M., Lazarus, N. R., & Harridge, S. D. R. (2014). 3 (2015) pp 657-680 The Journal of Physiology C 2014 The Authors. *The Physiological Society J Physiol*, *593*(3). https://doi.org/10.1113/jphysiol.2014.282863

Ramos, J. S., Dalleck, L. C., Tjonna, A. E., Beetham, K. S., & Coombes, J. S. (2015). The Impact of High-Intensity Interval Training Versus Moderate-Intensity Continuous Training on Vascular Function: a Systematic Review and Meta-Analysis. In *Sports Medicine* (Vol. 45, Issue 5, pp. 679–692). Springer International Publishing. https://doi.org/10.1007/s40279-015-0321-z

Rikli, R. E., & Jones, C. J. (1998). The reliability and validity of a 6-minute walk test as a measure of physical endurance in older adults. *Journal of Aging and Physical Activity*, *6*(4), 363–375. https://doi.org/10.1123/japa.6.4.363

Santos, P. C. R. dos, Barbieri, F. A., Zijdewind, I., Gobbi, L. T. B., Lamoth, C., & Hortobágyi, T. (2019). Effects of experimentally induced fatigue on healthy older adults' gait: A systematic review. *PLOS ONE*, *14*(12), e0226939. https://doi.org/10.1371/journal.pone.0226939

Soriano, J. B., Rojas-Rueda, D., Alonso, J., Antó, J. M., Cardona, P.-J., Fernández, E., Garcia-Basteiro, A. L., Benavides, F. G., Glenn, S. D., Krish, V., Lazarus, J. V., Martínez-Raga, J., Masana, M. F., Nieuwenhuijsen, M. J., Ortiz, A., Sánchez-Niño, M. D., Serrano-Blanco, A., Tortajada-Girbés, M., Tyrovolas, S., … Murray, C. J. L. (2018). The burden of disease in Spain: Results from the Global Burden of Disease 2016. *Medicina Clínica (English Edition)*, *151*(5), 171–190. https://doi.org/10.1016/j.medcle.2018.05.043

Talbot, J., & Maves, L. (2016). Skeletal muscle fiber type: using insights from muscle developmental biology to dissect targets for susceptibility and resistance to muscle disease. *WIREs Developmental Biology*, *5*(4), 518–534. https://doi.org/10.1002/wdev.230

Thomson, J. A., Green, H. J., & Houston, M. E. (1979). Muscle glycogen depletion patterns in fast twitch fibre subgroups of man during submaximal and supramaximal exercise. *Pflügers Archiv*, *379*(1), 105–108. https://doi.org/10.1007/BF00622912

Tjønna, A. E., Lee, S. J., Rognmo, Ø., Stølen, T. O., Bye, A., Haram, P. M., Loennechen, J. P., Al-Share, Q. Y., Skogvoll, E., Slørdahl, S. A., Kemi, O. J., Najjar, S. M., & Wisløff, U. (2008). Aerobic interval training versus continuous moderate exercise as a treatment for the metabolic syndrome: A pilot study. *Circulation*, *118*(4), 346–354. https://doi.org/10.1161/CIRCULATIONAHA.108.772822

Tschentscher, M., Eichinger, J., Egger, A., Droese, S. I. L. K. E., Schönfelder, M., & Niebauer, J. (2016). High-intensity interval training is not superior to other forms of endurance training during cardiac rehabilitation. *European Journal of Preventive Cardiology*, *23*(1), 14–20. https://doi.org/10.1177/2047487314560100

VØLLESTAD, N. K., & BLOM, P. C. S. (1985). Effect of varying exercise intensity on glycogen depletion in human muscle fibres. *Acta Physiologica Scandinavica*, *125*(3), 395–405. https://doi.org/10.1111/j.1748-1716.1985.tb07735.x

Warburton, D. E. R., Nicol, C. W., & Bredin, S. S. D. (2006). Health benefits of physical activity: the evidence Review. *CMAJ*, *174*(6), 801. https://doi.org/10.1503/cmaj.051351

WHO | World Health Organization. (2019). WHO; World Health Organization. https://www.who.int/gho/ncd/en/