

**COMBINED EXERCISE TRAINING IN OLDER ADULTS:
APPLICATION OF A HYDRAULIC RESISTANCE
MACHINE FOR MULTICOMPONENT
FITNESS IMPROVEMENT**

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A thesis submitted in partial fulfilment of the requirements of Teesside
University for the degree of Doctor of Philosophy

June 2017

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ABSTRACT

Ageing is associated with declines in cardiorespiratory *and* muscular fitness; yet for older adults the ability to perform the basic tasks of daily living is partly dependent on upper- and lower-body fitness. Exercise training is an effective approach to counteract these age associated declines, with combined exercise training and high-intensity interval training (HIT) capable of eliciting improvements in cardiorespiratory *and* muscular fitness simultaneously. Recently, a new hydraulic resistance exercise machine (Speedflex) has been developed with potential to be a viable training mode for older adults allowing users to perform high speed movements with upper- and lower-body muscles. Accordingly, the aim of this thesis was to evaluate the potential effectiveness of Speedflex as a training strategy in older adults.

Initially, this work sought to determine the feasibility of performing exercise training using Speedflex in older adults by quantifying the acute training responses to 1) HIT and 2) strength training and comparing these against criterion exercise modes. Here, the observed physiological and perceptual responses demonstrated that Speedflex is a feasible mode of exercise training in older adults, capable of inducing a high-intensity training stimulus. Following this, a systematic review and meta-analysis was performed to quantify the effects of same-session combined exercise training in older adults with results demonstrating possibly small to possibly large beneficial effects on measures of fitness. As muscle power appears to be a critical determinant of physical functioning in older adults, chapter five evaluated the reliability of the Nottingham leg extensor power rig, finding it to be reliable both short- and long-term, thereby confirming its suitability as a primary outcome measure for the final study and providing data for sample size estimation. Finally, chapter six evaluated the effects of a 12-week combined upper- and lower-body HIT intervention using Speedflex on physical fitness in older adults. Clear beneficial improvements were observed for participants in the intervention group compared to those in the control group for maximal oxygen uptake (~8%), muscle power (~10%) and muscle strength (~6%). The findings presented in this thesis demonstrate that both same-session combined training and HIT performed using Speedflex are capable of simultaneously improving cardiorespiratory and muscular fitness in older adults.

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Abbreviations

1RM	one-repetition maximum
6MWT	six-minute walk test
ACSM	American College of Sports Medicine
ADL	activities of daily living
AMPK	5' adenosine monophosphate-activated protein kinase
a-vO ₂ difference	arterio-venous oxygen difference
BMI	body mass index
CHD	coronary heart disease
CI	confidence interval
CK	creatine kinase
CL	confidence limit
CON	concentric
CS	citrate synthase
CVD	cardiovascular disease
DoH	department of health
dRPE	differential rating of perceived exertion
ECC	eccentric
FFM	fat free mass
HIT	high-intensity interval training
HRQL	health related quality of life
HR _{int}	intrinsic heart rate
HR _{max}	maximal heart rate
HR _{peak}	peak heart rate
HRR	heart rate reserve
LDH	lactate dehydrogenase
LVEND	left ventricular end-diastolic volume
LV-HIT	low-volume high-intensity interval training
METs	metabolic equivalents
MICT	moderate intensity continuous training
MPS	muscle protein synthesis
mTORC1	mammalian target of rapamycin complex 1
PGC-1 α	peroxisome proliferator-activated receptor- γ coactivator-1 α
PFK	phosphofructokinase
PPO	peak power output

Q	cardiac output
RPE	rating of perceived exertion
RT	resistance training
SD	standard deviation
SIT	sprint interval training
ST	strength training
SV	stroke volume
TUG	timed up-and-go
$\dot{V}O_2$	oxygen uptake
$\dot{V}O_{2max}$	maximal oxygen uptake
$\dot{V}O_{2peak}$	peak oxygen uptake
WHO	world health organisation
%1RM	percentage of one repetition maximum
%HR _{max}	percentage of maximal heart rate
%HR _{peak}	percentage of heart rate peak
% $\dot{V}O_{2max}$	percentage of maximal oxygen uptake
% $\dot{V}O_{2peak}$	percentage of peak oxygen uptake

Scientific output

Conference Communications

1. **Hurst, C.**, Batterham, A.M., Taylor, K.L. & Weston, M. Acute physiological responses to novel high-intensity interval training in older adults. 20th Annual Congress of the European College of Sports Science (ECSS). Malmo, Sweden. July 2015. Oral presentation.

Publications

1. **Hurst, C.**, Batterham, A.M., Taylor, K.L. & Weston, M. Short- and long-term reliability of leg extensor power measurement in middle-aged and older adults. *Journal of Sports Sciences*. doi:10.1080/02640414.2017.1346820

Acknowledgements

The work presented in this thesis was funded through the sponsorship of a doctoral degree by Speedflex (UK & Ireland) Ltd. It is noted that the funders had no involvement in design, data collection, analysis and interpretation of the work presented in this thesis. Furthermore, Speedflex (UK & Ireland) placed no restrictions on publication of this data and have had no involvement in the preparation of this thesis. This financial support is gratefully acknowledged and particular thanks must go to Graham Wylie and Paul Ferris for their support throughout the process. Thanks also to Matt Portas for his initial introduction to Speedflex (UK & Ireland) Ltd.

I must sincerely thank my Director of Studies, Dr Matthew Weston for all of his time, expertise and most importantly – his patience. His support and friendship throughout has made this process manageable and I am fortunate to have had the opportunity to work with him. Without his support, I doubt I would have reached the end.

I must also express my gratitude to my other supervisors, Dr Kathryn Weston and Professor Alan Batterham for their expert guidance, support and supervision. Particular thanks must go to Dr Kathryn Weston for all of her time and effort given to the meta-analysis presented in this thesis as well as her motivational support throughout.

I also reserve a special thank you for each participant who gave their time to take be involved; without their willingness and enthusiasm, the work presented in this thesis would not have been possible. Thanks also go to Shaun McLaren and Tom Macpherson for their assistance with data collection. Their help is gratefully acknowledged.

Thank you to all of my friends and family for all of their support over the years. Particular thanks must go to my Mam for her unwavering support and endless encouragement, without which I would not be where I am today. Finally, to Rachel and Finlay, thank you for your unending patience, love and encouragement. Without you this work would not have been possible.

Thank you all.

CHAPTER 1: INTRODUCTION

1.1 Introduction

Human ageing is associated with progressive declines across multiple physiological systems, with changes in the cardiorespiratory and neuromuscular systems some of the most pronounced (Fleg et al., 2005; Goodpaster et al., 2006; López-Otín, Blasco, Partridge, Serrano, & Kroemer, 2013). These degenerations are relevant as cardiorespiratory *and* muscular fitness are important determinants of functional fitness, which relates to quality of life in older adults (Hawkins & Wiswell, 2003; Morey, Pieper, & Cornoni-Huntely, 1998; Paterson, Govindasamy, Vidmar, Cunningham, & Koval, 2004; Posner et al., 1995). For older adults, functional performance or functional fitness, is the ability to perform the basic tasks of daily living (e.g., rising from a chair, climbing stairs, simple lifting tasks) (Rikli & Jones, 1997) with effective performance partly dependent on a combination of upper- and lower-body fitness (Landers, Hunter, Wetzstein, Bamman, & Weinsier, 2001; Lundgren-Lindquist & Sperling, 1983). As such, therapeutic strategies that can attenuate age-associated physiological declines could play an important role in maintaining functional capacity and quality of life in older adults (Rejeski & Mihalko, 2001; Witard, McGlory, Hamilton, & Phillips, 2016).

Exercise training is a strategy which has been demonstrated to have positive effects on functional fitness in older adults, largely free of adverse effects (Fiuza-Luces, Garatachea, Berger, & Lucia, 2013; Garatachea et al., 2015; Hunter, McCarthy, & Bamman, 2004; Katula, Rejeski, & Marsh, 2008). Typically, exercise is broadly dichotomised as either, ‘endurance’ or ‘strength’, with these two groupings characterised by dissimilar physiological adaptations (Coffey & Hawley, 2007; Hawley, Hargreaves, Joyner, & Zierath, 2014). Endurance training is characterised by exercises involving large muscle groups performing dynamic activities for sustained periods, resulting in increases in heart rate and energy expenditure primarily impacting the cardiovascular and respiratory systems (Chodzko-Zajko et al., 2009; Howley, 2001; Jones & Carter, 2000). In contrast, strength training involves exercises requiring muscles to work or hold against an applied force or weight with training effects most prominent on the neuromuscular system (Chodzko-Zajko et al., 2009; Folland & Williams, 2007).

Endurance training is an effective approach to improve cardiorespiratory fitness but has limited effect on muscular fitness (Coggan et al., 1992; Makrides, Heigenhauser, & Jones, 1990) and vice versa (Hunter et al., 2004; Liu & Latham, 2009; Ozaki, Loenneke, Thiebaud, & Abe, 2013). The divergent nature of these training adaptations suggests that training programmes consisting of both endurance and strength activities are needed to maximise the potential benefits of exercise in older adults via holistic fitness improvements (Cadore & Izquierdo, 2013a; Cadore, Pinto, Bottaro, & Izquierdo, 2014; Chodzko-Zajko et al., 2009; Nelson et al., 2007).

Combined exercise training (often referred to as concurrent or multicomponent training) – performing discrete activities for cardiorespiratory and strength improvement within the same training programme, often within the same exercise session – is an appealing prospect in older adults (Cadore et al., 2014; Cadore & Izquierdo, 2013a). Previous work has shown this to be a more efficacious approach than either training modality performed in isolation because of its potential to impact cardiorespiratory *and* muscular fitness (Cadore & Izquierdo, 2013b; Wood et al., 2001). Despite this, the requirement to perform separate endurance and strength activities (e.g. Karavirta, Häkkinen, Kauhanen, et al., 2011; Karavirta, Häkkinen, Sillanpää, et al., 2011) places considerable time demands on individuals. This could affect exercise adherence as lack of time remains one of the most commonly cited barriers to exercise even in older adults (Burton et al., 2017; Cohen-Mansfield, Marx, & Guralnik, 2003; Lian, Gan, Pin, Wee, & Ye, 1999; Rasinaho, Hirvensalo, Leinonen, Lintunen, & Rantanen, 2007; Trost, Owen, Bauman, Sallis, & Brown, 2002). Training interventions which can elicit the benefits of combined training (i.e. cardiorespiratory and muscular fitness improvement) within a single exercise session may be an attractive proposition for potential exercisers because of the impact on overall functional performance. However, a thorough quantification of the effects of this training strategy in older adults is yet to be undertaken.

High-intensity interval training (HIT) – alternating bouts of high-intensity exercise with bouts of recovery – is an efficacious means of improving cardiorespiratory and metabolic function simultaneously (Buchheit & Laursen, 2013a; Buckley et al., 2015; Knowles, Herbert, Easton, Sculthorpe, & Grace, 2015; Macinnis & Gibala, 2017; McRae et al., 2012; Sculthorpe, Herbert, & Grace, 2017; Wang et al., 2014) and more effective than traditional endurance training when it comes to improving cardiorespiratory fitness

(Milanovic, Sporiš, & Weston, 2015; Weston, Taylor, Batterham, & Hopkins, 2014). It has long been acknowledged that exercise intensity is a key mediator of training adaptation (Fox et al., 1975; Macinnis & Gibala, 2017; Shephard, 1968), with cellular stress (the stimulus for adaptation) occurring in proportion to exercise stress (Egan & Zierath, 2013). HIT is typically differentiated as either 1) High-intensity interval training (HIT), typically performed as ‘near maximal’ or ‘submaximal’ intensity or 2) sprint interval training (SIT), characterised by efforts performed at ‘all out’ or ‘supramaximal’ intensity (MacInnis & Gibala, 2017). The intense nature of HIT places considerable demands on both the aerobic and anaerobic energy systems as well as the neuromuscular system suggesting its potential for inducing wide-ranging physiological adaptation (Buchheit & Laursen, 2013b; Burgomaster, Hughes, Heigenhauser, Bradwell, & Gibala, 2005; Burgomaster et al., 2008; Gibala, Little, MacDonald, & Hawley, 2012; Rodas, Ventura, Cadefau, Cussó, & Parra, 2000).

Especially relevant in older adults, HIT may be a viable strategy for improving muscular power (Laursen & Jenkins, 2002; Sculthorpe et al., 2017) because of its potential to induce adaptations of the anaerobic energy system (MacDougall et al., 1998; Rodas et al., 2000; Scribbans et al., 2014) leading to enhanced functional fitness and quality of life (Adamson, Lorimer, Cobley, & Babraj, 2014; Knowles et al., 2015). Exemplifying this, Rodas et al. (2000) reported significant increases in the activity of aerobic (citrate synthase, 3-hydroxy-acyl-CoA dehydrogenase) and anaerobic (creatine kinase, phosphofructokinase, lactate dehydrogenase) enzymes in muscle after 2 weeks of daily SIT, a finding corroborated by MacDougall et al. (1998) who also reported concomitant increases in cardiorespiratory fitness and power output. Notably however, improvements in muscular fitness have typically been reported in studies using a SIT protocol, which require high levels of motivation and may not be practical or suitable for the general population (Coyle, 2005; Levinger et al., 2015). As such, alternate HIT protocols which can improve muscular fitness could widen the potential impact of this training approach. Taken together, these factors raise the interesting possibility of HIT being an effective strategy for simultaneous improvement of cardiorespiratory and muscular fitness in older adults.

Despite the positive physiological and performance benefits afforded by exercise training, few older adults currently meet physical activity guidelines (Jefferis et al., 2014;

Strain, Fitzsimons, Kelly, & Mutrie, 2016) with only 20% of men and 17% of women aged 65-74 achieving recommended levels of moderate-vigorous activity (Activity occurring at 3 or more metabolic equivalents (METs)[Ainsworth et al., 2000]), decreasing to 9% and 6% in men and women respectively aged over 75 years (Townsend et al., 2012). For older adults, considerable barriers to exercise uptake remain including poor health, a lack of motivation, appropriate knowledge of exercise training and the aforementioned lack of time (Burton et al., 2017; Cohen-Mansfield et al., 2003; Schutzer & Graves, 2004). These figures suggest that alternative exercise strategies to those traditionally employed are needed to engage a greater number of older adults.

Recently, a new hydraulic resistance exercise machine (Speedflex; Figure 1.1) has been developed and this mode of exercise provides variable resistance via a double-concentric movement. Although this exercise machine is new, the application of hydraulic-resistance training is not, with previous work suggesting it to be an effective training method across a range of populations (Ballor, Becque, & Katch, 1987; Falcone et al., 2015; Haennel, Teo, Quinney, & Kappagoda, 1989; Katch, Freedson, & Jones, 1985; Lee et al., 2011). Hydraulic-resistance machines provide no external eccentric load directly, which is appealing for older adults because of older adults increased susceptibility to exercise-induced muscle damage (Evans & Cannon, 1991) and impaired post-exercise recovery (Close, Kayani, Vasilaki, & McArdle, 2005).



Figure 1.1 Speedflex machine

Traditional resistance exercise machines require the application of force in one direction, followed by a controlled movement back to the starting position. The Speedflex machine requires users to apply force throughout the entire exercise as the resistance is set in both directions; thereby allowing users to train more than one muscle group per exercise by performing a double-concentric movement. For example, a shoulder press (concentric contraction) using traditional resistance training equipment requires users to push the weight and then resist (eccentric contraction) the weight back to the starting position. Contrastingly, the same exercise using a Speedflex machine requires users to push the weight (shoulder muscles) and then pull the weight back down (back muscles). Consequently, the Speedflex machine allows for training of more muscle groups per exercise compared to traditional resistance machines; thereby engaging more active muscle mass which may provide a stimulus for (cardiorespiratory) fitness improvement (Lewis et al., 1983; Lewis et al., 1985; Lind & McNicol, 1967). Additionally, as the user applies increased force (by pushing or pulling harder), the level of resistance increases relative to speed of movement with users able to safely terminate the movement at any point. Reduced eccentric loading, combined with the ability of the user to perform higher velocity movements represents a potent strategy for improving muscle power (Earles, Judge, & Gunnarsson, 2001; Fielding et al., 2002; Marsh, Miller, Rejeski, Hutton, & Kritchevsky, 2009), thereby make this mode of training appealing in an older population.

Despite this, there is currently no objective understanding of the acute training responses to exercise performed using Speedflex in older adults – an important precursor to effective training application and prescription.

In contrast to cycling (lower body only), running (predominantly lower body) and strength training (usually one muscle group per exercise) the nature of the Speedflex machine means that exercise sessions can be delivered which target both the upper- and lower-body musculature simultaneously. For older adults, this is significant because of the need to maintain upper- and lower-body fitness to perform the activities of daily living (Landers et al., 2001; Rikli & Jones, 1997). While Speedflex appears to have potential to provide a HIT stimulus in healthy adults (Taylor, Weston, Hurst & Batterham, 2014), it remains to be determined if the training stimulus is appropriate for improving fitness in older adults.

1.2 Aims and objectives

Collectively, the chapters of this thesis aim to provide an understanding of a new exercise training mode which could have potential health and fitness benefits for older adults, evaluating it in context of a more traditional combined training approach. Following this introduction, the thesis begins with a review of literature to provide a theoretical framework for the following chapters. Experimental studies are presented in chapters three, five and six with a systematic review and meta-analysis presented in chapter four. The thesis concludes with a synthesis of all presented findings while also discussing training, practical and research implications. The individual aims and objectives of the thesis are presented in Table 1.1.

Table 1.1 Aims and objectives of the thesis

<i>Aim 1</i>	Establish the viability of the Speedflex machine as a mode of HIT and strength training in older adults.	Chapter 3
<i>Objective 1</i>	Measure the acute physiological and perceptual responses to both HIT and strength training undertaken by older adults using Speedflex.	
<i>Aim 2</i>	Synthesise and evaluate the current literature on combined training in older adults	Chapter 4
<i>Objective 2</i>	Undertake a systematic review and meta-analysis of the effects of same-session combined endurance and strength training on the fitness of older adults	
<i>Aim 3</i>	Establish the reliability of a commonly used method of leg power assessment	Chapter 5
<i>Objective 3</i>	Evaluate the short- and long-term reliability of the Nottingham leg extensor power rig as a method for assessing lower body muscular power in older adults.	
<i>Aim 4</i>	Determine the effectiveness of Speedflex training for improving fitness in older adults	Chapter 6
<i>Objective 4</i>	Implement a 12-week combined upper- and lower-body high-intensity interval training (HIT) intervention performed using Speedflex on measures of cardiorespiratory and muscular fitness in older adults.	

CHAPTER 2: REVIEW OF LITERATURE

2.1 Overview

Human ageing is a complex, multidimensional process characterised by a progressive decline in physiological functioning leading to reduced levels of physical performance and functional capacity (Aagaard, Suetta, Caserotti, Magnusson, & Kjær, 2010; Janssen, Heymsfield, & Ross, 2002; Skelton, Greig, Davies, & Young, 1994). This reduction in ‘functional fitness’ – maintaining sufficient levels of cardiorespiratory fitness as well as upper- and lower-body muscle strength and power (Rikli & Jones, 1997; Rikli & Jones, 2013) – ultimately affects the ability of older adults to effectively perform the basic tasks of daily living and maintain physical independence (Aagaard et al., 2010; Janssen et al., 2002; Mistic, Rosengren, Woods, & Evans, 2007; Skelton et al. 1994). Although the etiology of the age associated decline in physical performance is multifaceted, structural and functional changes in the cardiorespiratory (Fleg et al., 2005; Hawkins & Wiswell, 2003) and neuromuscular systems (Baumgartner et al., 1998; Foldvari et al., 2000; Skelton et al., 1994) appear to be of prime importance. As both cardiorespiratory and muscular fitness play a fundamental role in the maintenance of physical capacity with ageing (Clark & Manini, 2008; Paterson et al., 2004), and the fact this thesis is focused on the application of exercise training and not ageing per se, the following literature review will focus primarily on these systems. Nevertheless, it is acknowledged that successful ageing is a complex construct involving an interplay of biological, psychological, social and physical factors (Anton et al., 2015). The overall aim of this chapter is to provide a comprehensive theoretical background to the issues that will be explored in the following chapters.

2.2 Defining older adults

In the United Kingdom, there are now over 23 million people aged 50 or above, equating to over a third of the total population (ONS, 2016). By the year 2040, nearly one in four people (24%) will be aged 65 or over, while the number of people aged over 85 is predicted to more than double in the next 23 years to 3.4 million (Age UK, 2016).

Advances in medical treatment, infrastructure and lifestyle have helped to increase life expectancy; however, the unintended consequences of this mean many people are living longer with no concomitant increase in the period of life that is spent in good health (Rechel et al., 2013). The disproportionate use of healthcare services by older adults emphasises the economic impact of population ageing (Witard et al., 2016), with the need to reduce the burden on healthcare systems an important goal for influential bodies such as Public Health England and the World Health Organisation. This is highlighted through publications such as the World Report on Ageing and Health (WHO, 2015), which provides a framework for improving population level and individual health outcomes for older adults. Despite this need however, there remains no consensus on what constitutes an ‘older adult’ or when ‘old age’ begins.

Typically, older adults are defined based on chronological age alone. For example, the United Nations (2012) categorises older adults as aged 60 and above, while the WHO have accepted an age of 65 years as a definition of older adults in developed countries; however, in developing regions (e.g. Africa), old age is defined as 50 years and above (WHO, 2002). While changes in biological and physical systems appear to be an unavoidable consequence of ageing, these changes do not occur in a linear fashion and are only loosely associated with chronological age (Steves, Spector & Jackson, 2012). As such, socially constructed meanings of age, such as the roles assigned to older people and the loss of roles also contribute to defining old age (WHO, 2002). For example, the age of retirement, typically 60 or 65 in most developed countries, is often said to be the beginning of old age (WHO, 2015). It should be noted however, that biological and social factors are inextricably linked. For example, physical changes can impact levels of social participation with functional decline limiting involvement in social and leisure activities (James, Wilson, Barnes & Bennett, 2011). In reality, ageing represents the complex interplay between biological and social factors (Anton et al., 2015) meaning that the definition of older adults requires broader consideration than chronological age alone.

As the ageing population has continued to grow, older adults have often been sub-classified as being either ‘young-old’ (e.g. 60-73 years [Toraman, 2005], 56-65 years [Sculthorpe et al., 2017], 60-69 years [Verrusio et al., 2017]) or ‘old’ (e.g. Toraman, 2005). However, despite the application of these more focused sub-divisions of older age, there remains considerable heterogeneity between the health status of individuals

(Lowsky, Olshansky, Bhattacharya, & Goldman, 2013). Moreover, the use of any chronological age threshold to demarcate old age is limited by the assumption that chronological and biological age are synonymous. Accordingly, any arbitrary definition of older adults is likely to be imperfect.

While it is evident that physiological and functional changes in the cardiorespiratory and muscular systems begin to manifest by the fourth decade of life (Fleg et al., 2005; Lexell, 1988), it is also well documented that these declines begin to accelerate beyond the age of 50 years (Deschenes, 2004; Lynch et al., 1999; Metter et al., 1997). Worryingly, the onset of physical limitations typically manifests between the ages of 40-55 years for 50% of adults (National Center for Health Statistics, 1997) while data from the National Health Interview Survey indicates significant increases in difficulty performing mobility-related physical functions among adults aged 50-64 years (Martin et al., 2010). In the UK, the British Birth Cohort Study (Cooper, Strand, Hardy, Patel, & Kuh, 2014) reported lower levels of physical capability at age 53 and inability to perform capability tests were associated with higher rates of mortality. Even at this relatively young age these measures identified individuals who are less likely than others to achieve a long and healthy life. Taken together these findings suggest that early intervention (i.e. from ~50 years of age onwards) with evidence-based strategies may play a critical role in preventing physical disability in later adulthood. Accordingly, for the purposes of this thesis older adults will be considered as those aged 50 years and above.

2.3 Cardiorespiratory fitness in older adults

2.3.1 Definition

Cardiorespiratory fitness reflects the ability of the cardiovascular and respiratory systems to supply oxygen to the working muscles and is typically defined in terms of maximal oxygen uptake ($\dot{V}O_{2max}$) – the highest rate at which oxygen can be taken up and utilised by the body during exercise (Bassett & Howley, 2000; Howley, 2001). This is generally accepted as being the best method for quantifying the functional capacity of the cardiorespiratory system and is widely used within clinical practice as a gauge of

cardiorespiratory fitness (Howley et al., 1995). Practically, $\dot{V}O_{2max}$ is a product of maximal cardiac output (Q, delivery of oxygen to the working muscle); itself the product of stroke volume (SV, the amount of blood pumped per heart beat) and maximal heart rate (HR_{max} , the maximal number of times the heart beats/min), and arterio-venous oxygen difference (a-vO₂ difference, i.e. oxygen extraction at muscle tissue level) (Bassett & Howley, 2000). Although the terms $\dot{V}O_{2max}$ and peak oxygen uptake ($\dot{V}O_{2peak}$) are often used interchangeably, $\dot{V}O_{2peak}$ typically represents the highest measured value of oxygen uptake on a specific test, often limited by local muscular factors and participant motivation rather than circulatory factors, while $\dot{V}O_{2max}$ provides a more thorough qualification of a 'true' maximal value (Poole & Jones, 2017).

While there are clear associations between endurance exercise performance and $\dot{V}O_{2max}$ in the sports performance domain (Jones & Carter, 2000), in older adults, cardiorespiratory fitness is related to health status, functional capacity and the odds of dependent living (Bachmann et al., 2015; Morey et al., 1998; Paterson et al., 2004). Moreover, low cardiorespiratory fitness is a strong independent predictor of mortality (Blair et al., 1995; Blair et al., 1996; Kodama et al., 2009) with each 1-MET (3.5 mL·kg⁻¹·min⁻¹) increase in cardiorespiratory fitness associated with a 12% relative risk reduction in all-cause mortality (Myers et al., 2002). Although $\dot{V}O_{2max}$ has little impact on daily living in most healthy individuals, the age-related decline in cardiorespiratory fitness means that the ability of older adults to perform everyday tasks becomes greatly dependent on $\dot{V}O_{2max}$ (i.e. activities require a high % of $\dot{V}O_{2max}$ [Paterson et al., 2004]) with previous authors suggesting that a minimum $\dot{V}O_{2peak}$ of 15-18 mL·kg⁻¹·min⁻¹ is necessary to maintain independent functioning (Paterson, Cunningham, Koval, & St Croix, 1999).

2.3.2 Effects of ageing

A reduction in cardiorespiratory fitness with advancing age is well documented (Fleg et al., 2005; Hollenberg, Yang, Haight, & Tager, 2006; Pimentel, Gentile, Tanaka, Seals., & Gates, 2003; Stathokostas, Jacob-Johnson, Petrella, & Paterson, 2004), with $\dot{V}O_{2max}$ progressively declining from ~25-30 years of age in sedentary adults (Fleg et al., 2005; Hawkins & Wiswell, 2003) at a rate approximating 10% per decade (Astrand, Astrand,

Hallbäck, & Kilbom, 1973; Fleg & Lakatta, 1988; Pimentel et al., 2003). However, this decline in $\dot{V}O_{2\max}$ is not linear, occurring at an increased rate in later years as demonstrated by Fleg et al. (2005) who reported declines of over 20% per decade at age 70 and beyond. Declines in cardiorespiratory fitness are associated with an age-related decrease in functional capacity and have been linked to reduced quality of life and loss of independence, thereby emphasising that maintaining $\dot{V}O_{2\max}$ is an important component of successful ageing (Morey et al., 1998; Paterson et al., 2004). Observational data has shown that $\dot{V}O_{2\max}$ in distance runners aged 60-80 years is 30-40% higher than non-trained peers of the same age, yet similar rates of decline are observed compared with sedentary adults suggesting that decreased $\dot{V}O_{2\max}$ is an unavoidable consequence of ageing (Fleg, Schulman, O'Connor, Gerstenblith, et al., 1994).

2.3.3 Etiology of age associated changes

Ageing induces structural and functional changes in the cardiorespiratory system, with the age-associated decline in $\dot{V}O_{2\max}$ largely related to the observed reduction in cardiac output (Lakatta & Levy, 2003; Ogawa et al., 1992). An inevitable consequence of ageing, maximal heart rate (HR_{\max}) progressively declines at approximately one beat per year from around the age of twenty, independent of sex and habitual physical activity (Christou & Seals, 2008; Hawkins, Marcell, Victoria, & Wiswell, 2001). Reductions in intrinsic heart rate (HR_{int} [i.e. the HR observed in the absence of autonomic influences]) and chronotropic responsiveness to β -adrenergic stimulation as well as attenuated electrophysiology of the sinoatrial node have been proposed as mechanisms explaining the decrease in HR_{\max} with ageing (Christou & Seals, 2008; Fleg, Schulman, O'Connor, Becker, et al., 1994; Tanaka & Seals, 2008). As well as reduced HR_{\max} , decreased maximal stroke volume (SV) (Hagberg et al., 1985) contributes to the age-related difference in $\dot{V}O_{2\max}$ (Ogawa et al., 1992). Peripheral changes with ageing have also been implicated, with reductions in maximal a-v O_2 difference (Ogawa et al., 1992) and reduced skeletal muscle oxidative capacity (Russ & Kent-Braun, 2004) contributing to the age-associated decline. Changes in body composition, specifically a decline in lean body mass and a simultaneous increase in body fat also appear to play an important role (Fleg & Lakatta, 1998; Hawkins et al., 2001). Illustrating this, Proctor & Joyner (1997) found that almost half of the age-associated decline in $\dot{V}O_{2\max}$ in highly trained subjects was due to

age-associated changes in body composition, with Rosen, Sorkin, Goldberg, Hagberg, & Katznel (1999) reporting that the age-related reduction in fat free mass accounts for ~35% of the decline in $\dot{V}O_{2\max}$ in athletic and sedentary men. Taken together, these findings show that the age-related decline in cardiorespiratory fitness is complex, and determined by multiple central and peripheral factors.

2.3.4 Training guidelines

Despite the age-associated declines in cardiorespiratory fitness and functional performance, disability and a loss of independence need not be inevitable consequences of ageing (Cadore, Rodríguez-Mañas, Sinclair, & Izquierdo, 2013). Higher cardiorespiratory fitness is related to the ability to perform the basic tasks of daily living (Morey et al., 1998; Paterson & Warburton, 2010) and increased quality of life (Sloan, Sawada, Martin, Church, & Blair, 2009), while lifelong trained older adults show higher levels of fitness compared to sedentary age matched peers (Tanaka & Seals, 2003). Taken together, these factors demonstrate the potential effectiveness of exercise training as a therapeutic strategy for counteracting the deleterious effects of ageing (den Ouden, Schuurmans, Arts, & van der Schouw, 2011; Paterson et al., 2004). As such, guidelines in the UK and around the world have aimed to provide clear recommendations to encourage older adults to engage in physical activity.

In the United Kingdom, the Department of Health (DOH, 2011) advocate that older adults should aim to be active daily and that over a week an individual should perform a minimum of 150 minutes of moderate-intensity aerobic physical activity (3-6 metabolic equivalents (METs) [Ainsworth et al., 2000]) or 75 minutes of vigorous intensity activity (>6 METs [Ainsworth et al., 2000]) per week. These guidelines are similar to those endorsed by the American College of Sports Medicine (Haskell et al., 2007; Nelson et al., 2007) and the World Health Organisation (WHO, 2010) who suggest that adults aged >65 years should aim to perform 30 minutes of physical activity, in bouts of ten minutes or more at least 5 days per week. Despite the clear beneficial effects of exercise training in older adults, many older adults remain insufficiently active (Jefferis et al., 2014). In England, only 57% of men and 52% of women (aged 65-74) achieve the target of 150 minutes of moderate intensity exercise per week, while for those aged 75-84 years this reduces to 43% of men and only 21% of women (Health Survey for England, 2012).

The time demands of meeting these recommended guidelines for physical activity are considerable and the recommended high frequency of training might discourage older adults from participating in a training programme. This is compounded by the fact that lack of time remains one of the key barriers to participation in regular exercise for older adults (Troost et al., 2002; Rasinaho et al., 2007), a factor which needs to be considered when designing training programmes for older adults. Programme-related factors influencing participation for older people include the format, intensity, convenience, time, location, structure and affordability of the programme (King, 2001; Tak, Van Uffelen, Paw, van Mechelen, & Hopman-Rock, 2012), with group- or facility-based programmes showing higher attendance rates compared to individual- or home-based exercise programmes (Hong, Hughes, & Prohaska, 2008).

Ultimately, the role of exercise training is to elicit improvements in physical performance with training induced changes primarily determined by the physiological load imposed during training (Impellizzeri, Rampinini, & Marcora, 2005). Information on the frequency (i.e. how often; e.g., the number of training sessions per week) and the volume (i.e. how much; e.g. 4 x 30 s sprints or 3 sets of 12 repetitions) of training is needed to facilitate a clear understanding of the exercise prescribed, and performed by participants. The training process (Figure 2.1) is often characterised by the external training load (i.e. the training activities prescribed) but the stimulus for adaptation to training is the physiological stress imposed on the individual (internal training load) (Impellizzeri, Rampinini, Coutts, Sassi, & Marcora, 2004; Impellizzeri et al., 2005). As such, valid and reliable measures of internal load are crucial for practitioners and clinicians to prescribe and evaluate the training dose-response relationship (Weston, 2013).

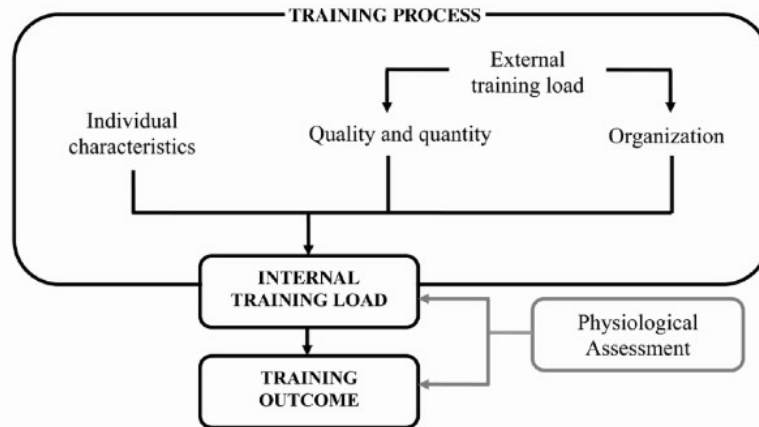


Figure 2.1 The training process (Impellizzeri et al., 2005)

Often exercise training studies have classified intensity based on the absolute energy demands of the activity (e.g. caloric expenditure [$\text{kcal}\cdot\text{min}^{-1}$], absolute oxygen uptake [$\text{L}\cdot\text{min}^{-1}$] or metabolic equivalents (METs) (Garber et al., 2011). However, these absolute measures can lead to incorrect classification of intensity (e.g. moderate, vigorous) as they do not consider fitness level – a considerable determinant of the individual response to exercise (Weston, Weston, Prentis, & Snowden, 2016). Accordingly, a relative measure of intensity (i.e., the energy cost of the activity relative to an individual’s maximal capacity) is more appropriate (Garber et al., 2011).

The most commonly used objective measures of intensity during endurance training are percentage of maximal oxygen uptake ($\%\dot{V}O_{2\text{max}}$) and heart rate (percentage of maximal heart rate [$\%\text{HR}_{\text{max}}$], heart rate reserve [HRR]). Assessment of an individual’s perception of effort using Borg’s rating of perceived exertion (RPE) scales (Borg, 1982) can provide subjective quantification of exercise intensity. A combination of objective and subjective measures represents best practice for prescribing and evaluating exercise intensity (Weston et al., 2016).

Percentage of maximal oxygen uptake ($\%\dot{V}O_{2\text{max}}$) is a commonly used method for normalising exercise intensity (Garber et al., 2011; Howley et al., 2001), yet Swain and colleagues (Swain, Abernathy, Smith, Lee, & Bunn, 1994; Swain & Leutholtz, 1997) have suggested that $\%\dot{V}O_{2\text{max}}$ does not account for individual differences in resting metabolic rate which may limit its meaningfulness. As $\dot{V}O_{2\text{max}}$ is most effectively determined by performance of a maximal exercise test, failure of participants to provide

a maximal effort results in an underestimation of $\dot{V}O_{2\max}$ (Mann, Lamberts, & Lambert, 2013). This approach is further constrained by the need for laboratory testing facilities and equipment, potentially limiting its usability in the applied setting.

In contrast, heart rate monitoring provides a simple and reliable measure of exercise intensity and is one of the most popular ways for prescribing and monitoring exercise intensity both in, and out of the laboratory (Achten & Jeukendrup, 2003; Impellizzeri et al., 2004; Weston, Helsen, MacMahon, & Kirkendall, 2004). The use of heart rate to determine exercise intensity is based on the linear relationship between heart rate and $\dot{V}O_2$ over a wide range of steady-state sub-maximal workloads (Astrand & Rodahl, 1986). Typically, intensity is quantified based on an individual's maximal heart rate (HR_{\max}) value and expressed as a percentage of maximal heart rate ($\%HR_{\max}$). Caution is warranted when using heart rate with older adults as medication (e.g. beta blockers) can reduce the reliability of exercise heart rate data (Weston et al., 2016). Maximal heart rate is usually obtained from a maximal exercise test, yet in the clinical environment the performance of a maximal fitness test is often contraindicated or infeasible due to time or resources. As such, prediction equations for determining maximal heart rate can provide a practical alternative (Gellish et al., 2007; Tanaka, Monahan, & Seals, 2001).

Ratings of perceived exertion (RPE) offer a practical, non-invasive and valid method for monitoring exercise intensity, with concurrent validity demonstrated through strong relationships with other indicators of exercise intensity (Foster, 1998; Foster et al., 2001). Typically, RPE refers to an overall gestalt perception of exertion, dependent on a number of factors with scores representative of the internal load imposed (Foster, 1998; Impellizzeri et al., 2004). Although RPE is easy to use, reliable and consistent with objective measures, the use of an overall gestalt measure may lack sensitivity (McLaren, Graham, Spears, & Weston, 2016). As such, differential ratings of perceived exertion (dRPE) could overcome this by discriminating between discrete sensory inputs, such as central and peripheral exertion signals (McLaren et al., 2016; Weston, Siegler, Bahnert, McBrien, & Lovell, 2015). Differences between peripheral and central exertion have been reported following training (Borg, Borg, Larsson, Letzter, & Sundblad, 2010; McLaren et al., 2016; Weston et al., 2017) demonstrating that dRPE provides additional

information about the exercise training load compared to an overall assessment of RPE in isolation.

Thorough quantification of exercise training intensity permits an evaluation of intervention fidelity. Intervention fidelity – the extent to which an experimental manipulation has been implemented as intended, in a comparable manner to all participants (Dumas, Lynch, Laughlin, Smith, & Prinz, 2001) – is receiving increased attention in the exercise science domain (Taylor, Weston & Batterham, 2015; Weston et al., 2017). Intervention fidelity is integral to the internal validity of intervention-based trials (Bellg et al., 2004) and provides information allowing the reader to make an informed interpretation of the results presented. Taylor et al. (2015) evaluated the effect of HIT on fitness in adolescents, appraising intervention fidelity using HR measures reporting that 58% of repetitions met their prespecified criterion, while Weston et al. (2017) delivered a HIT intervention in abdominal aortic aneurysm (AAA) patients reporting that ~23% of repetitions met their RPE criteria for high-intensity. These studies provide support for HR and RPE as methods which lend themselves readily to the concept of intervention fidelity as they can be easily evaluated against prespecified criteria (e.g. $HR > 80\%HR_{max}$) and reported simply as the proportion of exercise training sessions that were performed at the prescribed intensity.

2.3.5 Trainability and adaptations

Despite the considerable physiological changes associated with ageing, the cardiorespiratory system remains highly trainable even into advanced age with improvements of >20% in $\dot{V}O_{2max}$ following endurance training not uncommon (Makrides et al., 1990; Seals, Hagberg, Hurley, Ehsani, & Holloszy, 1984; Stratton, Levy, Cerqueira, Schwartz, & Abrass 1994). Moreover, studies have consistently reported improvements in older adults of a similar relative magnitude compared to younger counterparts (Grimby et al., 1992; Hagberg et al., 1989; Jubrias, Esselman, Price, Cress, & Conley, 2001, Makrides et al., 1990). These findings are encouraging and suggest that effective exercise prescription can elicit positive cardiorespiratory adaptations in older adults.

Characteristically, endurance training elicits physiological adaptations that are associated with an improved ability to generate energy via oxidative metabolism leading to increased $\dot{V}O_{2\max}$ (Egan & Zierath, 2013; Holloszy & Coyle, 1984). These changes are typically demarcated as being either central (i.e. related to the delivery of oxygen to the working muscles), or peripheral (i.e. related to extraction and utilisation of oxygen) (Vigorito & Giallauria, 2014). As maximal heart rate does not increase, and may even decrease, in response to endurance training, increased stroke volume (SV), as a result of increased left ventricular end-diastolic volume (LVEND), is responsible for the increased cardiac output observed after endurance training (Levine, 2008; Spina et al., 1993). Increased blood volume (Hagberg et al., 1998) and improved cardiac chamber compliance (Levine, Lane, Buckey, Friedman, & Blomqvist, 1991) contribute to increased LVEND. Peripheral adaptations to endurance training are characterised by increased size and number of mitochondria (mitochondrial biogenesis) in skeletal muscle as evidenced by increased activity of oxidative enzymes (e.g. citrate synthase; CS), increased capillary density and widening of the a-vO₂ difference (Beere et al., 1999; Hawley, 2002; Holloszy, 1967; Seals et al., 1984; Holloszy & Coyle, 1984). Endurance training increases peroxisome proliferator-activated receptor- γ coactivator-1 α (PGC-1 α) activity (Hawley, 2009) with increases in muscle mitochondrial content and oxidative capacity mediated by increases in PGC-1 α (Baar et al., 2002) suggesting it to be a critical contributor to the adaptive response to endurance training (Gibala & McGee, 2008). Ultimately, these adaptations lead to reduced utilisation of muscle glycogen and blood glucose and an increased capacity to oxidise fats during exercise at a given workload (Holloszy & Booth, 1976; Holloszy, 1967; Holloszy & Coyle, 1984).

Early investigations into the effects of endurance training on cardiorespiratory fitness in older adults failed to demonstrate an increase in $\dot{V}O_{2\max}$ (Benestad, 1965; Niinimaa & Shephard, 1978) – with the lack of training response likely due to the inadequate training stimulus employed in these studies (Montero & Lundby, 2017). Based on these findings the authors wrongly concluded that older adults lose the ability to adapt to exercise training (Benestad, 1965; Niinimaa & Shephard, 1978). However, more recent studies have shown that older adults can significantly improve cardiorespiratory fitness in a relatively short time with increases of ~15-38% in $\dot{V}O_{2\max}$ in response to endurance training (Kohrt et al., 1991; Makrides et al., 1990; Stratton et al., 1994) – a similar relative

magnitude to those observed in younger adults (Coggan et al., 1992; Hepple, Mackinnon, Goodman, Thomas, & Plyley, 1997; Makrides et al., 1990; Seals et al., 1984). While this work has shown that significant increases in $\dot{V}O_{2max}$ are achievable, there exists considerable between- and within-study variability in the magnitude of these improvements. Differences between exercise volume and intensity as well as training programme duration likely affect observed fitness improvements. For example, the study from Coggan and colleagues (Coggan et al., 1992) demonstrated a 23% increase in $\dot{V}O_{2max}$ following a training programme of 9-12 months in duration (45 minutes per day, 4 days per week of walking at 80% HR_{max}) In contrast, Hepple et al. (1997) reported a 16% improvement in $\dot{V}O_{2peak}$ following 18 weeks of aerobic training (30 minutes, 3 times per week at 60-70% HRR). It may be that the difference in training programme duration contributed to the between study difference in fitness improvement. The study reporting the greatest improvement in $\dot{V}O_{2peak}$ (38% increase) was that of Makrides et al. (1990). This observed improvement may be related to a higher exercise training stimulus compared to the other studies, while the authors also suggested that baseline assessment of $\dot{V}O_{2peak}$ may have been artificially low because of the use of a cycle ergometer or a lack of participant motivation. It is important to acknowledge that participant characteristics such as baseline fitness (Sisson et al., 2009) play an important role in determining training response – although the impact of baseline fitness as a determinant of adaptation has been questioned (Timmons et al., 2010) – while the trainability of $\dot{V}O_{2max}$ also includes a significant genetic component (Bouchard et al., 1999). Despite these factors, it appears that provision of a minimum training stimulus is a prerequisite for inducing positive gains in fitness (Sisson et al., 2009).

Supporting these encouraging experimental findings, meta-analyses evaluating endurance training in adults aged over 60 have reported improvements in $\dot{V}O_{2max}$ of 16% (Huang, Gibson, Tran, & Osness, 2005) and 14% (Green & Crouse, 1995) with increases related to duration of exercise bouts, pre-training $\dot{V}O_{2max}$ and training programme duration (Chodzko-Zajko et al., 2009). In older men, it has been estimated that two thirds of the training induced increase in $\dot{V}O_{2max}$ is determined by central factors (Murias, Kowalchuk, & Paterson, 2010a; Spina, 1999) with peripheral adaptation responsible for the final third (Murias et al., 2010a; Spina, 1999). In older women, the physiological adaptations responsible for the increase in $\dot{V}O_{2max}$ have been reported to be central

(Dogra, Spencer, & Paterson, 2012), peripheral (Murias, Kowalchuk, & Paterson, 2010b; Spina et al., 1993) or a combination of both (Ogawa et al., 1992). This inconsistency between findings may be related to differences in training volume and intensity or length of training programme as well as participant characteristics (e.g. training history and baseline fitness). Further research, with larger sample sizes is needed to elucidate the mechanisms responsible for training induced improvements in $\dot{V}O_{2\max}$.

It is widely assumed that endurance training leads to small or no increases in muscle strength or hypertrophy (Izquierdo, Häkkinen, Ibáñez, Kraemer, & Gorostiaga, 2005). This idea has been perpetuated as researchers have not typically sought to evaluate muscular fitness outcomes after endurance training. Despite this, limited evidence has suggested a potential role for endurance training as a method for improving muscular fitness (Harber et al., 2009; Konopka & Harber, 2014). For example, endurance training may provide a stimulus for improved muscular strength as reported by Holviala et al. (2012) (8% improvement in bilateral 1RM leg press strength after 21 weeks of endurance training in healthy ageing men) which may be mediated through muscular hypertrophy and remodelling of the contractile properties of myofibers (Coggan et al., 1992; Harber et al., 2009; Konopka, Trappe, Jemiolo, Trappe, & Harber, 2011). These findings contrast with previous investigations reporting that aerobic training does not increase muscle size in older adults (Jubrias et al., 2001; Short, Vittone, Bigelow, Proctor, & Nair, 2004; Sipilä & Suominen, 1995). This discrepancy in observed findings is likely related to differences in exercise programme design and participant characteristics. For example, the study of Jubrias et al. (2001) utilised an exercise training stimulus that consisted of either single-leg or upper-body based exercise. As the authors used the cross-sectional area and volume of the quadriceps muscle to evaluate changes in muscular size, the lack of training induced increase may be related to the low-volume of lower-body exercise stimulus. Despite the effectiveness of endurance training for improving cardiorespiratory fitness in older adults and its potential for improving muscular fitness, evidence for the effectiveness of endurance training to enhance muscular fitness remains unclear (Bean, Vora, & Frontera, 2004).

Effective training prescription is crucial to promote a positive adaptive response, yet assessment of training outcomes is also a key part of the training process (Winter et al., 2007). Fitness testing aims to provide specific information about the strengths and

weaknesses of a subject, allowing practitioners to design, deliver and evaluate training interventions (Rikli & Jones, 1999; Winter et al., 2007). Training programmes devised to improve cardiorespiratory and muscular fitness should be evaluated with specific tests that can detect changes in these discrete components of fitness (Weston et al., 2016).

The gold standard assessment of cardiorespiratory fitness remains laboratory-based incremental exercise testing, where individuals are required to exercise until volitional exhaustion while expired air is collected and then analysed to give a $\dot{V}O_{2\max}$ value – representing the integration of the cardiovascular and respiratory systems (Bentley, Newell, & Bishop, 2007). Maximal incremental testing provides the most accurate and reproducible assessment of $\dot{V}O_{2\max}$ and is typically performed on a treadmill or cycle ergometer (Fleg et al., 2000). Nevertheless, this method is time consuming, expensive and requires trained personnel to administer while also inducing high physical stress which may not be feasible or safe in some populations (Bennett, Parfitt, Davison, & Eston, 2016; Noonan & Dean, 2000). Moreover, the equipment needed for performing maximal incremental testing typically confines this approach to the laboratory.

As such, considerable effort has been expended by researchers seeking to predict $\dot{V}O_{2\max}$ from submaximal exercise (Bennett et al., 2016; Noonan & Dean, 2000) with a considerable number of protocols in use (e.g. Astrand and Ryhming cycle ergometer test [Astrand & Ryhming, 1954], Modified Bruce treadmill test [Bruce, Kusumi, & Hosmer, 1973]). Submaximal step tests offer a method of estimating $\dot{V}O_{2\max}$ in adults (Bennett et al., 2016) and typically rely on extrapolation of maximal aerobic capacity from work-rate achieved at a given submaximal heart rate (Fleg et al., 2000). These tests are simple to perform; allowing time-efficient assessment of large numbers of participants with limited personnel (Fleg et al., 2000) as well as being an ecologically valid method for estimating $\dot{V}O_{2\max}$ (Benett et al., 2016; Sykes & Roberts, 2004).

One of the more commonly used submaximal step tests for predicting $\dot{V}O_{2\max}$ is the Chester Step test (Sykes & Roberts, 2004). This protocol was originally developed as a tool for assessing aerobic fitness in fire fighters across the world. The test utilises exercise HR at various intensities to predict $\dot{V}O_{2\max}$, thereby providing an effective estimation of aerobic capacity (Sykes & Roberts, 2004). The test is performed using a step height of

between 15-25cm – similar to that of a household step (22 cm rise) – and represents a movement that constitutes an important activity of daily living for older adults (i.e. stair climbing). As well as this, the test is also appealing from a practical perspective as it requires only minimal equipment and space meaning it can be performed easily in a wide-range of environments. The test is time-efficient with testing duration ranging from 4-10 minutes and is easy to administer and score using the associated software. As with the majority of submaximal tests, the Chester Step test is non-invasive which may be appealing to older adults unfamiliar with this type of activity – an important consideration as tests should be acceptable to the participant to promote optimum motivation (Rikli & Jones, 1997). The small error of measurement (high test-retest reliability [inter trial bias $-0.8 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$; 95% Limits of agreement $\pm 3.7 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) associated with this test also demonstrates its suitability for tracking changes in cardiorespiratory fitness (Bennett et al., 2016; Buckley, Sim, Eston, Hession, & Fox, 2004). While the Chester Step test provides a reliable estimate of $\dot{V}O_{2\text{max}}$, more research is needed to fully evaluate the validity of this test as a measure of aerobic fitness.

Another approach to submaximal exercise testing is the use of time-constant tests (e.g. 6-minute walk test, 2-minute step test) which allow for assessment of a wide-range of participants regardless of ability (Rikli & Jones, 1998). Such tests have been widely used in the clinical setting and are also appealing because of their simplicity, safety and applicability to the performance of everyday activities (Fleg et al., 2000). For example, the 6-minute walk test (6MWT), which measures the total distance walked at a self-paced intensity over a 6-minute period, is a valid and reliable (test-retest ICC 0.88) measure of physical endurance that is sensitive to change (Rikli & Jones, 1998) with a large relationship ($r=0.61-0.71$) with self-reported functional ability (assessed via a composite physical function scale) (Rikli & Jones, 1998).

2.4 Muscular fitness in older adults

2.4.1 Definition

Muscular fitness encompasses several interrelated components of physical performance and is considered to consist of muscular strength, muscular power and muscular

endurance (Deschenes, 2004; Garber et al., 2011; Ratamess et al., 2009). Muscular strength refers to the capacity of skeletal muscle to generate force (Knuttgen & Komi, 2003) and is determined by structural and functional components of the neuromuscular system including the muscle cross sectional area (CSA), neural activation and muscle architecture (Aagaard et al., 2010). Muscle strength is inversely associated with mortality risk with participants over the age of 60 classified in the lowest strength category being 50% more likely to die of all-causes than individuals in the upper third (Ruiz et al., 2008). In comparison to muscle strength, muscular power reflects the ability to generate muscular work per unit of time and is defined as the product of the force of muscular contraction and the velocity at which the contraction occurs (Power [watts] = Force [newtons] x Velocity [ms^{-1}]) (Harridge, Pearson & Young, 1999). Muscle power, although related to strength is a discrete physical attribute (Bean et al., 2003; Reid & Fielding, 2012). Muscular endurance involves the ability to resist muscular fatigue when performing repeated contractions, usually when the resistance is submaximal (Deschenes, 2004). Impaired muscular endurance contributes to the incidence of falls in elderly adults (Schwendner, Mikesky, Holt, Peacock, & Burr, 1997) placing considerable economic burden on healthcare systems (Scuffham, Chaplin, & Legood, 2003; Stevens, Corso, Finkelstein, & Miller, 2006).

While muscular strength is an important physical attribute in older adults (Clark & Manini, 2008), muscular power may be a more important determinant of effective physical functioning (Foldvari et al., 2000; Reid & Fielding, 2012). For example, muscular power is more important than strength for performance of basic daily activities which depend on the ability to produce force at high velocity, such as chair rising and stair climbing (Basseby et al., 1992; Katula et al., 2008). Additionally, muscle power is related to clinically important improvements in gait speed (i.e. walking velocity measured over a set distance) (Bean et al., 2010; Suzuki, Bean, & Fielding, 2001; Tiggemann et al., 2016) and plays a role in fall prevention (Skelton, Kennedy, & Rutherford, 2002; Landers et al., 2001). Improvements in leg muscle power, independent of strength, could make an important contribution to clinically meaningful improvements in mobility in older adults (Bean et al., 2010). Taken together, considerable evidence exists to support the supposition that muscular fitness is an important determinant of physical functioning in older adults (Manini & Clark, 2012).

2.4.2 Effects of ageing

In sedentary adults, the reduction in muscle strength – termed ‘dynapenia’ (Clark & Manini, 2008) – begins in middle-age and accelerates beyond the onset of the sixth decade (Deschenes, 2004; Frontera et al., 1991). Annual declines in muscular strength of up to 3-4% and 2.5-3% have been reported in longitudinal investigations of men and women, respectively (Delmonico et al., 2009; Frontera et al., 2000; Goodpaster et al., 2006) with cross-sectional investigations reporting a rate of decline of approximately 0.8-1% per year (Lindle et al., 1997) progressing to about 1.2 to 1.4% per year after the age of about 50 years (Lindle et al., 1997; Lynch et al., 1999; Metter et al., 1997). Discordance in findings may be explained by methodological inconsistencies. Longitudinal studies (Delmonico et al., 2009; Goodpaster et al., 2006) eliminate much of the survival effect bias that is likely to occur in cross-sectional studies (Lindle et al., 1997; Lynch et al., 1999) whereby stronger individuals may have had a better chance to survive until old age and be included in baseline cross-sectional comparisons (Goodpaster et al., 2006). Typically, the few longitudinal studies that exist report a more rapid decline in strength than suggested by cross-sectional studies (Delmonico et al., 2009; Frontera et al., 2000; Goodpaster et al., 2006). Despite the variability in reported findings; it is clear that there is a precipitous decline in muscle strength with ageing (Deschenes, 2004).

Compared with strength, muscular power has been shown to decline earlier and more rapidly (Reid & Fielding, 2012) at a rate of up to 6% per year (Clark et al., 2013; Skelton et al., 1994). These age-related reductions in muscular strength and power have severe functional consequences, such as an increased risk of falls (Basseby et al., 1992; Suzuki et al., 2001) and can affect the ability of older adults to perform the functional tasks of daily living (Basseby et al., 1992; Foldvari et al., 2000; Puthoff, Janz, & Nielsen, 2008; Skelton et al., 1994), ultimately increasing the risk of dependence in later years (Christensen, McGue, Petersen, Jeune, & Vaupel, 2008). Accordingly, intervention strategies which are able to improve muscular fitness are in demand.

2.4.3 Etiology of age associated changes

The age-associated decrease in muscular strength is commonly attributed to the age-related reduction in skeletal muscle mass, termed ‘sarcopenia’ (Cruz-Jentoft et al., 2010;

Deschenes, 2004; Frontera et al., 1991; Frontera et al., 2000). Muscle mass typically peaks between the ages of 20-30 years (Janssen, Heymsfield, Wang, & Ross, 2000; Lexell, Taylor, & Sjöström, 1988) before starting to decline around the fifth decade of life (Janssen et al., 2000; Metter, Conwit, Tobin, & Fozard, 1997). This decline occurs at a rate of approximately 0.5-1% per year after the age of 50 (Mitchell et al., 2012) with an increase in severity after the age of 65 (Baumgartner et al., 1998). The exact mechanistic basis of sarcopenia is still to be elucidated yet the most consistent findings have demonstrated a decline in the total number of muscle fibres as well as a reduction in CSA, particularly of type II fibres (Lexell, 1995; Nilwik et al., 2013). This preferential reduction in type II fibre CSA may contribute to the greater age-related reductions in muscle strength and power (Macaluso & De Vito, 2004) as type II (fast-twitch) fibres can generate four times the power output of type I fibres (Lexell, 1995).

Despite the decline in muscle mass, numerous studies have demonstrated a clear disassociation between loss of muscle mass and reduced muscle strength, with strength reducing at a rate 2-5 times faster than muscle mass (Delmonico et al., 2009). These data would imply that other physiological changes are mediators of the age-associated loss of strength (Clark & Manini, 2008). Impairments in neural activation, via decreased maximal voluntary activation and changes in agonist-antagonist co-activation and suboptimal motor unit recruitment contribute to reductions in muscle strength (Clark & Manini, 2010; Häkkinen, Kallinen et al., 1998; Häkkinen, Newton et al., 1998). Additionally, 'muscle quality', i.e. strength/power per unit of muscle mass, (Goodpaster et al., 2006) and contractile quality also decrease with ageing (Clark & Manini, 2010), with muscle quality being a strong predictor of lower-extremity physical function (Straight, Brady, & Evans, 2015a; Straight, Brady, & Evans, 2015b). Despite original investigations identifying a strong association between low muscle mass and prevalence of disabilities in activities of daily living (Baumgartner et al., 1998), more recent investigations have found no association between physical function and muscle mass (Lauretani et al., 2003) suggesting that overall neuromuscular function, rather than muscle mass, is a critical determinant of health in older adults (Clark & Manini, 2010).

2.4.4 Training guidelines

Exercise recommendations for older adults consistently advocate the performance of strength training – exercises that causes muscles to work against, move or overcome an applied force or weight (Garber et al., 2011; Howley, 2001) – with substantial health benefits to be attained from chronic training programmes (Garber et al., 2011; Ratamess et al., 2009). For older adults, muscle strengthening activities involving major muscle groups should be performed at least twice per week (Chodzko-Zajko et al., 2009; DOH, 2011; Nelson et al., 2007) with the American College of Sports Medicine (ACSM) stressing that a combination of endurance and strength training activities is more effective than either form of training in isolation (Chodzko-Zajko et al., 2009).

Strength training has been shown to be one of the most effective methods for improving physical function in older adults (Chodzko-Zajko et al., 2009; Liu & Latham, 2004; Steib, Schoene, & Pfeifer, 2010) yet only a small number of older adults regularly engage. For example, in Scotland only 19% of males and 16% of females aged 55-64 perform ≥ 2 sessions of muscle strengthening activities per week, decreasing to 14 and 12% for males and females aged 65-74, and to 9 and 4% for males and females aged over 75 (Strain et al., 2016). Worryingly, population data from around the world corroborate these findings, (National Center for Health Statistics, 2015; Humphries, Duncan, & Mummery, 2010) highlighting the need for alternate training strategies for muscular fitness improvements (Burton et al., 2017).

As with endurance training, effective prescription and monitoring of strength training is needed to maximise potential benefits. Typically, intensity during strength training refers to the amount of ‘resistance’, while ‘repetitions’ describes the number of times a weight is lifted or a resistance is moved and ‘set’ describes the number of repetitions performed (Howley, 2001). The one repetition maximum (1RM) is the highest amount of weight lifted once using correct form and is the most commonly used descriptor of resistance training intensity (Hass, Feigenbaum, & Franklin, 2001). The intensity of resistance training exercise, or the amount of resistance used, is often estimated based on repetition maximum (RM) or as the percentage of the 1 repetition maximum (%1RM) (Haas et al., 2001). As there is considerable variability in the number of repetitions that can be

performed at the same %1RM for different muscle groups, and between trained and untrained participants, these estimates are best viewed as guidelines rather than hard and fast rules (Howley, 2001). Ratings of perceived exertion (RPE) have also been shown to be an effective approach for prescribing resistance training (Day, McGuigan, Brice, & Foster, 2004; McGuigan & Foster, 2004) with several studies demonstrating that RPE is an effective method for quantifying intensity during resistance training (Day et al., 2004; McGuigan & Foster, 2004; Sweet, Foster, McGuigan, & Brice, 2004). RPE can differentiate between different types of resistance exercise with higher-load training (i.e. strength and hypertrophy) perceived to be more difficult than lower-load training (i.e. power) (Singh, Foster, Tod, & McGuigan, 2007) and is positively related to intensity (%1RM) when total load and rest duration is kept constant (Day et al., 2004).

2.4.5 Trainability and adaptations

As with cardiorespiratory fitness, skeletal muscle remains highly malleable even into advanced age with exercise training a powerful intervention for improving muscle function and health in older adults (Robinson et al., 2017; Wyckelsma et al., 2017). The American College of Sports Medicine suggest that several different types of equipment can be used to improve muscular fitness, including free weights, machines and resistance bands (Garber et al., 2011; Ratamess et al., 2009). In older adults, strength training has been consistently shown to have potential as a strategy to mitigate age-related structural (Häkkinen, Kraemer, Newton, & Alen, 2001; Häkkinen, Newton et al., 1998; Kryger & Andersen, 2007), and functional changes in muscular fitness (Fiatarone et al., 1994; Holviala, Sallinen, Kraemer, Alen, & Häkkinen, 2006). Reviews from Hunter et al. (2004) and Peterson, Rhea, Sen, & Gordon (2010) as well as meta-analytical reviews (Latham, Bennett, Stretton, & Anderson, 2004; Liu & Latham, 2009; Steib et al., 2010; Straight, Lindheimer, Brady, Dishman, & Evans, 2016) have provided robust evidence for the effectiveness of strength training to promote improvements in muscle hypertrophy, strength, power and functional performance in older adults. As many of the activities of daily living require muscular fitness (e.g. carrying shopping, gardening or housework), strength training is an appealing, and effective strategy for improving function and maintaining independence in older adults.

Improvements in muscular strength and power may primarily result from neural adaptations in the first few weeks of a training programme, with increases in maximal electromyographic (EMG) activity of trained muscles reported (Häkkinen, Newton et al., 1998; Moritani & Devries, 1980). As well as increased activation of the agonist muscles, reduced coactivation of the antagonist muscles has been observed (Häkkinen, Kallinen et al., 1998) along with an enhanced maximal motor unit firing rate (Kamen & Knight, 2004) following training. Morphological adaptations to strength training include an increase in the cross-sectional area (CSA) of whole muscle as well as individual muscle fibres (Folland & Williams, 2007) with significant increases in both type I and type II fibres reported (Pyka, Lindenberger, Charette, & Marcus, 1994).

Numerous experimental studies have reported considerable improvements in muscular fitness following strength training interventions in older adults. Fiatarone and colleagues (Fiatarone et al., 1990) evaluated 10 frail institutionalised adults aged 90 ± 1 yr reporting average muscle strength increases of 174% after 8 weeks of high-intensity resistance training. These increases in muscle strength were accompanied by a 9% increase in mid-thigh muscle area as well as 48% improvement in tandem gait speed. Additionally, Serra-Rexach et al. (2011) found that nonagenarians (age 90-97) improved leg press strength by 17% after 8 weeks of lower body strength training while a recent meta-analysis has suggested that resistance training has the potential to elicit muscular hypertrophy (mean difference 2.31 cm^2 , 95% confidence interval [CI] 0.62 to 4.00 cm^2) and increase muscle strength (standardised mean difference 1.04, 95% CI 0.65 to 1.43) in elderly muscle (>75 years) (Stewart, Saunders, & Greig, 2014). Despite large heterogeneity in response to resistance training (Davidsen et al., 2011; Hubal et al., 2005), Churchward-Venne et al. (2015) concluded that there are no non-responders to resistance-type exercise training in adults aged over 65 years as every participant in their investigation demonstrated a positive adaptive response for at least one training outcome (lean body mass, muscle fibre size, muscle strength or function). However, in this study the authors defined a responder based on an observed absolute increase from baseline for each outcome measure. This approach is limited as it does not consider the random variability due to technical and biological variation and will identify a greater number of participants as responders than actually exist (Atkinson & Batterham, 2015). Available data suggest that older adults can adapt to strength training at the same relative magnitude as their younger counterparts

(Fielding, 1995) and men and women appear to increase their maximal strength to a similar extent when considered in relative terms (Lemmer et al., 2000; Lemmer et al., 2001). In addition to increases in muscle mass and strength, resistance training has been shown to contribute to improved mobility and balance as well as enhanced quality of life and overall health in older adults (Rejeski & Mihalko, 2001; Symons, Vandervoort, Rice, Overend, & Marsh, 2005).

Though traditional strength training is effective at improving a range of physiological outcomes, the moderate velocity of movement may not substantially improve muscular power or functional performance (Earles et al., 2001), a key aim of training interventions in older adults (Bassegy et al., 1992; Evans, 2000; Porter, 2006). In contrast to strength training, power training typically involves moving a lighter resistance at higher velocity (Miszko et al., 2003) with high-velocity movements able to improve the motor-unit firing rate and levels of muscle activation more than strength training (Sale, 1988). The inclusion of explosive muscular contractions leads to beneficial increases in maximal power, rate of force development, maximal dynamic strength, rapid muscle activation, functional outcomes and quality of life compared with traditional (i.e. slow contractions) strength training (Bottaro, Machado, Nogueira, Scales, & Veloso, 2007; Henwood, Riek, & Taaffe, 2008; Miszko et al., 2003; Pereira et al., 2012). In contrast to these studies, Sayers et al. (2003) compared high-velocity (Concentric phase performed as fast as possible) against low-velocity resistance training (2s concentric phase) at 70% of 1RM finding no difference in the magnitude of improvements – although substantial improvements were reported in both groups – in chair rise time, stair climbing and gait velocity it may be that between study differences in training programmes (e.g. external resistance, training volume, muscle groups trained) and participant characteristics (e.g. baseline muscular fitness, training history) are responsible for the discordance in findings. Evidence has also suggested that external resistance may not be needed when performing high velocity resistance training as similar improvements in functional fitness have been shown when comparing unloaded high-velocity resistance training (no external load) against loaded training (70% of 1RM) (Glenn, Gray, & Binns, 2015); suggesting that speed of movement rather than external resistance may be a more important determinant of adaptation.

As well as inducing changes in muscular strength and power, resistance training may also have the capacity to improve aerobic capacity in older adults with previous work reporting improvements in $\dot{V}O_{2\max}$ following strength training (Frontera, Meredith, O'Reilly, & Evans, 1990; Ozaki et al., 2013). Strength training can increase capillarisation (Frontera et al., 1990; Hepple et al., 1997) while also being an efficient method to improve mitochondrial proteins related to aerobic capacity (Frank et al., 2016). Despite these encouraging findings, potential adaptations in cardiorespiratory fitness from strength training are of a considerably lower magnitude than those from endurance training (Cadore & Izquierdo, 2013a).

In addition to traditional resistance training modes, hydraulic resistance training offers a viable approach for performing strength training across a range of populations (Ballor et al., 1987; Blimkie et al., 1996; Cooney & Walker, 1986; Haennel et al., 1989; Katch et al., 1985). The nature of hydraulic resistance means that users work against resistance in both parts of the movement (i.e. up/down or push/pull), thereby allowing users to train more than one muscle group per exercise by performing a double-concentric movement. Additionally, hydraulic resistance machines provide no external eccentric load directly, which is appealing for older adults because of older adults increased susceptibility to exercise-induced muscle damage and impaired post-exercise recovery (Close et al., 2005). Furthermore, external resistance is determined by speed of movement (i.e. increased speed of movement = greater external resistance) allowing participants to terminate exercise safely when necessary. Practically, hydraulic resistance training is appealing as weights cannot be dropped and the movements can be easily and quickly learned (Taaffe, 2006).

Intuitively, Speedflex is an exercise mode which may be capable of inducing improvements in multiple components of fitness for a number of reasons. In terms of muscular fitness, Lee et al. (2011) have shown increases in muscle strength and power following 12-weeks of hydraulic resistance exercise in older adults corroborating the findings of Takeshima et al. (2004) who reported increases of muscle strength of 6% - 92% following 12-weeks of combined aerobic and hydraulic resistance exercise in older volunteers.

While hydraulic resistance training appears to be a viable method of improving muscular

fitness, hydraulic resistance training may also be capable of inducing a substantial cardiorespiratory stimulus (Falcone et al., 2015) suggesting it's potential as a tool for cardiorespiratory fitness improvement (Katch et al., 1985). As resistance is set in both directions during movement, the user is required to perform two exercises within each double-concentric movement. This allows users to train more muscle groups per exercise, thereby potentially engaging greater muscle mass. As recruitment of greater muscle mass increases cardiovascular demand (Joyner & Casey, 2015), and concentric actions have a higher energetic demand than eccentric actions (Ryschon, Fowler, Wysong, Anthony, & Balaban, 1997), together this results in increased cardiovascular strain (Overend, Versteegh, Thompson, Birmingham, & Vandervoort, 2000) which may provide a stimulus for (cardiorespiratory) fitness improvement (Lewis et al., 1983; Lewis et al., 1985; Lind et al., 1967; Katch et al., 1985). Supporting this, Cooney & Walker (1986) reported that $\dot{V}O_{2max}$ improved by 28% after 9 weeks of training in patients with spinal cord injury while Selig et al. (2004) noted a 10% improvement in $\dot{V}O_{2peak}$ in patients with chronic heart failure following 3 months of moderate intensity hydraulic resistance training. As well as this, Falcone et al. (2015) have reported that HR and RPE was higher when using a concentric-only hydraulic based HIT protocol compared with running, cycling or strength training with the authors suggesting that this may allow individuals to gain the benefits of endurance and strength training within the same exercise session.

In addition to any potential cardiorespiratory fitness benefits, Speedflex also provides an opportunity to train the upper- and lower-body simultaneously, a limitation of cycle ergometer or treadmill based training approaches. This may have important implications for older adults who require upper-body fitness to perform the activities of daily living (Landers et al., 2001). From a practical perspective, the structure of the Speedflex machine provides extra stability as users are able to hold the machine throughout the movement while performing predominantly closed kinetic chain exercises. Moreover, users are able to terminate the movement when they choose with resistance remaining proportional to force produced.

Although double concentric exercise (e.g. hydraulic resistance training) offers an appealing approach to resistance training in older adults, it is not without limitation. Firstly, it is important to consider that eccentric muscle contractions, and therefore

eccentric muscle strength, are of central importance for the performance of many activities of daily living (Dickinson et al., 2000). For example, muscles must contract eccentrically to decelerate movement (LaStayo, Ewy, Pierotti, Johns, & Lindstedt, 2003) and it has been suggested that maximal eccentric knee and ankle strength play an important role in the safe descent of stairs (Startzell, Owens, Mulfinger, & Cavanagh, 2001). As most falls (~75%) on stairs occur during descent (Tinetti, Speechley, & Ginter, 1988), increases in eccentric strength could help to reduce fall risk in older adults (LaStayo et al., 2003). Furthermore, the lower energetic demands of eccentric training when compared to concentric training, results in less stress on the cardiovascular system (Gluchowski, Harris, Dulson & Cronin, 2015), thereby making eccentric training a powerful and appealing tool for increasing muscle strength in older adults who may have a limited capacity to train at high intensities (Hortobágyi and De Vita, 2006).

Recently, the application of eccentric training has begun to receive greater attention as a training approach for muscular fitness improvement (LaStayo, Marcus, Dibble, Frajaco & Lindstedt, 2014). There remains however, a lack of consensus as to which training mode (i.e. eccentric or concentric movements) offers the most effective approach. For example, strength improvements following eccentric training may be greater (Raj, Bird, Westfold, & Shield, 2012) or similar to those observed following concentric training (Franchi et al., 2014; Reeves, Maganaris, Longo, & Narici, 2009). The investigation from Franchi and colleagues (Franchi et al., 2014) reported similar increases in maximal voluntary isometric contraction following 10 weeks of training (+9% CON and +11% ECC), while Blazeovich et al. (Blazeovich, Cannavan, Coleman, & Horne, 2007) have suggested that resistance training induced muscular architectural adaptations are influenced by factors other than contraction mode. It remains equivocal which training mode leads to greater long-term muscle growth (Franchi, Reeves & Narici, 2017) with Franchi et al. (2014) reporting similar increases in muscle volume (+8% CON and +6% ECC) following training.

Despite the limitations associated with concentric only training, it may be that its potential for eliciting positive adaptation (Franchi et al., 2014), combined with the advantage of reduced muscle damage (e.g. DOMS) and potential for cardiorespiratory fitness improvement (Falcone et al., 2015) makes this approach an appealing strategy for older adults. Further research is needed to establish superiority of either training method in this

population. As with most exercise training strategies, there are both advantages and disadvantages associated with concentric and eccentric resistance training that should be considered when designing training programmes for older adults.

Assessment of muscle strength is typically performed via a one-repetition maximum (1RM) test – the maximal amount of weight that can be lifted or moved in a single repetition (Haas et al., 2001). As the 1RM is a specific skill, improving most when training closely reflects the 1RM assessment, motor learning can lead to artificially high results of up to 200% (Gentil, 2017). As such multiple methods are needed to capture holistic strength adaptation (Buckner et al., 2017). In contrast to 1RM, which is typically confined to the laboratory or the gym, the measurement of handgrip strength is an easy, portable test of upper-body muscle strength that can provide an approximation of total body muscle strength and has been shown to be a robust predictor of mortality and disability (Kuh, Bassey, Butterworth, Hardy, & Wadsworth, 2005; Rantanen et al., 1994; Rantanen et al., 1999; Rantanen, 2003). In terms of muscular power, isokinetic dynamometers allow assessment of single muscle groups from the torque measured when a limb rotates at constant angular velocity (Macaluso & De Vito, 2004). This method however, does not reflect the reality of day to day activity where older adults must work against resistance at varying speeds (Harridge et al., 1999). In older adults, muscle power has previously been assessed using a vertical jump (Ditroilo, Forte, McKeown, Boreham, & De Vito, 2011), often performed on a force platform (De Vito et al., 1998). However, this method is confined to the laboratory and forces older adults to lift their own body weight, representing a higher proportion of their maximum strength forcing the individual to work in a less favourable area of the force/velocity curve (Macaluso & De Vito, 2004). Moreover, the validity of older adults performing vertical jumps appears questionable in terms of real-world relevance. To overcome these problems Bassey & Short (1990) developed the Nottingham leg extensor power rig which measures power generated by the lower limb muscles during a single leg extension. The leg extensor power rig provides an isolated assessment of lower body muscular power – a predictor of physical function in older adults (Straight et al., 2015a; Straight et al., 2015b) – where the angles of the hip, knee and ankle during the movement are similar to those occurring during rising from a chair or stepping.

Over the past two decades considerable effort has been expended to develop and validate several tests designed specifically for the assessment of functional fitness in older adults (Jones & Rikli, 2002). As such, the use of functional fitness tests can provide a more relevant evaluation of training induced changes by considering the impact of training on the ability to perform the tasks of daily living (Weston et al., 2016). Functional measurements may be more sensitive than capacity measures for detecting change after an exercise intervention, because physical function is the submaximal integration of physiological systems (Cress, Buchner, Questad, Esselman, & Schwartz, 1996). Although many functional fitness tests are in use, sit-to-stand tests, of which there are several derivatives, and the timed up-and-go test (TUG) are often used as measures of lower limb strength or power (Cheng et al. 2014; McCarthy, Horvat, Holtsberg, & Wisenbaker, 2004; Podsiadlo & Richardson, 1991). While evidence suggests that these are reliable tests in older populations (Jones, Rikli, & Beam, 1999; Rikli and Jones 1999), sit-to-stand performance is influenced by a number of physiological and psychological processes (Lord, Murray, Chapman, Munro, & Tiedemann, 2002) thus suggesting it may be a composite measure of several components of performance. Although there are a wide range of assessment tools available for monitoring lower body muscular fitness, there remains no consensus on the most appropriate method. Accordingly, practitioners and researchers selecting tests must base their decisions on practical and logistical issues (e.g. time and equipment requirements, space needs) and if they want to assess isolated fitness components (e.g. leg power measured via leg extensor power rig) or composite measures of performance (e.g. chair stand test). It is likely that a combination of outcome measures is most effective.

In summary, despite some recent encouraging findings, current available data would suggest that neither traditional endurance nor strength training alone can significantly improve all aspects of physical performance in older adults. As such, it would appear that a combination of both training modalities (i.e. combined exercise training) may be a more effective training strategy in this population (Chodzko-Zajko et al., 2009).

2.5 Combined training in older adults

Combined (or concurrent) training programmes, where individuals perform discrete activities for endurance and strength development within the same training programme – often within the same training session – have become a popular approach to exercise training in older adults because of their potential to improve multiple components of fitness (Cadore & Izquierdo, 2013a; Cadore & Izquierdo, 2013b; Cadore et al., 2014; Häkkinen et al., 2003; McCarthy et al., 1995). The American College of Sports Medicine (ACSM) recommend three or more endurance training sessions per week for older adults (Chodzko-Zajko et al., 2009; Haskell et al., 2007; Nelson et al., 2007) in combination with 2-3 strength training sessions per week (Ratamess et al. (2009). As endurance training and strength training provide different physiological challenges to the cardiorespiratory and neuromuscular systems (i.e. differences in motor unit recruitment and energetic demand) (Hawley et al., 2014; Nader, 2006), combined training aims to induce improvements across several physiological systems with the ultimate aim of improving functional performance (Cadore et al., 2014).

Investigations evaluating cardiorespiratory adaptations to combined training have reported increases of ~10-22% in $\dot{V}O_{2\max}$ from training programmes of 12-21 weeks in duration with a training frequency of between 1-3 sessions per week (Cadore et al., 2010; Holviala et al., 2010; Izquierdo et al., 2005; Sillanpää, Häkkinen, Punnonen, Häkkinen, & Laaksonen, 2009; Wood et al., 2001). Considerable variation exists between these studies in terms of the volume and intensity of the endurance training performed. For example, the study reporting the greatest improvement in $\dot{V}O_{2\max}$ (Cadore et al., 2010) involved 20 minutes of endurance training per session at an intensity equivalent to 80% $\dot{V}O_{2\max}$, while the study of Wood et al. (2001) involved 21-30 minutes of endurance training performed at 60-70% HR_{\max} . These differences in programming related factors likely contribute to the observed differences in cardiorespiratory fitness improvement. As would be expected – based on the principle of training specificity (Astrand & Rodahl, 1986; Holloszy & Coyle, 1984;) – evidence has shown that combined strength and endurance training is more effective than strength training alone for improving cardiorespiratory fitness (Cadore et al., 2014), while combining endurance and strength training does not appear to impair adaptations usually induced by endurance training

alone (Burich, Teljigović, Boyle, & Sjøgaard, 2015; Cadore et al., 2011; Wood et al., 2001). From a programming perspective, intrasession exercise sequence appears to have limited impact on the magnitude of $\dot{V}O_{2peak}$ improvement (8% vs. 9%) following 12 weeks of combined training (Cadore et al., 2012). Combined training has also been shown to be a robust approach for improving muscle mitochondrial outcomes and characteristics independent of age (Irving et al., 2015); an important finding as declines in mitochondrial content with ageing are closely related to reduced cardiorespiratory fitness (Short et al., 2005).

Combined training is also an effective strategy for improving muscular fitness in older adults with training induced improvements in muscular strength, power and functional performance reported across several studies (Cadore et al., 2014; Holviala et al., 2010; Holviala et al., 2012; Sillanpää et al., 2008). These improvements can be substantial, for example, Cadore et al. (2014) reported improvements of 144% in lower body 1RM and 96-116% in maximal power output following 12-weeks of twice-weekly combined training. These improvements should be interpreted with caution though as this investigation involved institutionalised older adults (mean age 93 ± 4 years) with very low baseline fitness (lower body 1RM of 16.4 ± 9.6 kg) who are likely to demonstrate considerable training induced improvements. Compared with strength training alone, combined training can induce adaptations of a similar magnitude with 21-weeks of training eliciting improvements in 1RM leg strength of 20-22% (strength training only) vs 21-23% (combined training) (Holviala et al., 2010; Holviala et al., 2012; Sillanpää et al., 2008). Furthermore, Ferrari et al. (2013) have demonstrated that performing three training sessions per week does not induce greater strength gains when compared with twice weekly combined training (22% vs 20%).

In terms of muscular power, Karavirta, Häkkinen, Sillanpää, et al. (2011) observed comparable improvements in maximal concentric power of the lower body in men aged 40-67 years after 21 weeks of training involving similar training volumes in both the strength training and combined training groups. In contrast to cardiorespiratory outcomes, intra-session exercise order may influence the magnitude of strength adaptation (Cadore et al., 2012; Cadore et al., 2013) with strength prior to endurance suggested as the optimal sequence to optimise neuromuscular adaptation (Cadore & Izquierdo, 2013a). Currently only limited data exist to support this assertion and further

investigation is needed to quantify the effects of manipulating exercise order. As well as improvements in muscular performance, Izquierdo et al. (2005) reported increased cross-sectional area of the quadriceps following both strength training only (14%) and combined training (12%) with no significant difference between groups following 16 weeks of training, while Ferrari et al. (2013) reported similar hypertrophy of the quadriceps (~5%) comparing both three times per week and twice-weekly combined training. In addition to these fitness benefits, combined training has also been shown to improve lipid profiles of older adults (Carvalho et al., 2010) and reduce the risk of falls and related fractures in older women (Marques et al., 2011).

Despite the range of physiological and performance benefits elicited by combined training, this approach is not without limitation. A consequence of combined training can be the 'interference effect', which refers to impaired training adaptation in comparison to that observed after similar endurance or strength training alone (Cadore & Izquierdo, 2013b). The seminal investigation of Dr Robert Hickson in 1980 (Hickson, 1980) into the effects of combining aerobic and resistance exercise within the same training programme reported that performing combined training interfered with improvements in leg strength relative to strength training alone. It is likely that the interference effect is largely determined by the variables of training programming including exercise mode, intensity, order, training volume and training frequency (Fyfe, Bishop, & Stepto, 2014). When the volume, frequency and duration of combined training are moderate, simultaneous development of cardiorespiratory and muscular fitness does not appear to be compromised in both younger (Häkkinen et al., 2003; McCarthy, Agre, Graf, Pozniak, & Vailas, 1995) and older adults (Wood et al., 2001). Contrastingly, an extended training period and high training volume has been shown to attenuate strength gains and muscle hypertrophy compared with strength training alone (Bell, Syrotuik, Socha, Maclean, & Quinney, 1997; Hickson, 1980; Kraemer et al., 1995).

Training volume appears to be the most important variable to manipulate to prevent the interference effect (Fyfe et al., 2014). Studies involving twice weekly sessions of each modality (i.e. endurance and strength) have reported similar adaptations in strength when compared with strength training alone (Holviala et al., 2010; Sillanpää et al., 2008). The study from Häkkinen and colleagues (Häkkinen et al., 2003) compared strength training only against concurrent training consisting of two endurance and two strength sessions

per week for 21-weeks. The authors found large gains of a similar magnitude across both groups for maximal strength (strength training 21%, concurrent training 22%), with significant increases in muscle CSA (6%, 9%) and increased size of individual muscle fibres. In contrast, concurrent training programs involving three weekly sessions of strength and endurance training have produced equivocal findings with some evidencing no interference in strength development (Haykowsky et al., 2005; McCarthy et al., 1995; McCarthy, Pozniak, & Agre, 2002) and others reporting strength impairments (Bell, Syrotuik, Martin, Burnham, & Quinney, 2000; Cadore et al., 2010; Dolezal & Potteiger, 1998). It may be that differences in exercise programming variables, for example exercise intensity and volume contribute to the discordance between findings.

While the mechanistic basis of the interference effect is likely multifactorial (Fyfe et al., 2014), it is suggested that endurance exercise either interferes with the quality of strength training via an accumulation of residual fatigue or substrate depletion (e.g. muscle glycogen) (Leveritt, Abernethy, Barry, & Logan, 1999) and/or compromises acute molecular responses activated by resistance exercise that mediate muscular hypertrophy (Baar, 2006; Hawley, 2009). From a practical perspective, as training volume is typically higher in combined programmes compared with endurance or strength training alone, short-term fatigue following an initial exercise bout (e.g. endurance training) may limit the quality of the following bout (e.g. strength training) (Leveritt et al., 1999). At the molecular level, the mammalian target of rapamycin (mTOR) signalling is a key mediator of strength training induced increases in protein synthesis and muscle growth (Bodine, 2006), while the activity of adenosine monophosphate-activated protein kinase (AMPK) is increased during endurance exercise and converges on peroxisome proliferator-activated receptor- γ coactivator-1 (PGC-1 α) to coordinate mitochondrial biogenesis (Fyfe et al., 2014; Baar, 2006). Various signalling responses activated by endurance exercise appear to inhibit those that regulate muscle hypertrophy (Fyfe et al., 2014; Fyfe, Bartlett, Hanson, Stepto, & Bishop, 2016) including the activation of AMPK during endurance training which may inhibit mTOR signalling, thereby inhibiting protein synthesis (Baar et al., 2006; Fyfe et al., 2014). However, the mechanistic basis of the interference effect remains incompletely resolved with only limited evidence to support this acute molecular interference mechanism in humans (Fyfe et al., 2014).

As well as potential diminished training adaptation resulting from the interference effect, the practical delivery of combined training may also be problematic. In training programmes where endurance and strength training is delivered within the same training session, combined sessions are typically ~60-90 minutes in duration, meaning a considerable time commitment for individuals. Training programmes which don't include endurance and strength within the same session typically include a minimum of four training sessions per week (as per Holviala et al., 2010; Karavirta, Häkkinen, Sillanpää, et al., 2011) again placing considerable time demands on potential exercisers. As such, exercise training programmes which are capable of elucidating the benefits of combined training with a reduced training volume could be an attractive proposition for potential exercisers. A viable alternative for achieving these benefits may be high-intensity interval training (HIT).

2.6 High-intensity interval training in older adults

High-intensity interval training (HIT) involves repeated bouts of intense exercise interspersed with periods of rest or lower intensity active recovery (Fox et al., 1973). Although HIT has long been utilised as a training approach in elite athletes (Billat, 2001), only more recently has it been popularised as a training approach in the general population (Gibala et al., 2012; MacInnis & Gibala, 2017). In comparison to traditional endurance training, HIT can induce similar or even superior adaptations of the cardiorespiratory and neuromuscular systems in both healthy and clinical populations (Bacon, Carter, Ogle, & Joyner, 2013; Burgomaster et al., 2008; Gibala et al., 2006; Gibala et al., 2012; MacDougall et al., 1998; MacInnis & Gibala, 2017; Milanovic et al., 2015; Tjønnå et al., 2008; Wisløff et al., 2007). Typically, HIT is associated with exercise modes such as cycling or treadmill running / walking; however creative approaches to the delivery of HIT are becoming more widespread both in and outside of the laboratory in an attempt to engage a greater number of individuals (Lunt et al., 2014; Shepherd et al., 2015). These alternative approaches to performing HIT have included body-weight resistance exercise (McRae et al., 2012), combined upper- and lower-body ergometers (Osawa et al., 2014), non-weight bearing all-extremity ergometers (Hwang et al., 2016) and a combination of strength and endurance exercises (Buckley et al., 2015). Not only is HIT a safe and effective approach for inducing physiological remodelling (Gibala et

al., 2012; Rognmo et al., 2012; Weston et al., 2017), it is an enjoyable training strategy with participants often preferring HIT over moderate intensity continuous exercise (Bartlett et al., 2011; Jung, Bourne, & Little, 2014). This may add to the appeal of HIT in older adults as enjoyment is a key mediator of exercise adherence in older adults (Dacey, Baltzell, & Zaichkowsky, 2008).

Despite the prescription of HIT being infinitely variable (Gibala et al., 2012), it can be broadly dichotomised into two distinct groupings; 1) high-intensity interval training (HIT), defined as ‘near-maximal’ or ‘submaximal’ efforts performed at an intensity eliciting $\geq 80\%$ (but often 85-95%) of HR_{max} with intervals typically $>60s$ in duration and 2) sprint interval training (SIT) often described as low-volume HIT (LV-HIT) characterised by efforts performed at an intensity equal or greater to $\dot{V}O_{2max}$ with efforts prescribed as ‘all-out’ or ‘supramaximal’, typically 30-60s duration but often $<30s$ (MacInnis & Gibala, 2017; Weston, Wisløff et al., 2014). The most commonly used HIT protocol consists of four, 4-minute intervals performed at an intensity of 85-95% of maximal heart rate, interspersed with 3-minutes recovery (Rognmo, Hetland, Helgerud, Hoff, & Slørdahl, 2004; Tjønnå et al., 2008; Wang et al., 2014; Wisløff et al., 2007). In contrast, SIT protocols have tended to be based around repeat performance of 30s Wingate tests (Burgomaster et al. 2005; Burgomaster et al., 2008; Gibala et al., 2006). Despite broadly classifying training as either HIT or SIT, it is important to note that acute training responses, and ultimately training induced adaptations, are determined by a combination of several programming variables including exercise duration, exercise intensity, rest duration, exercise mode and training frequency (Buchheit & Laursen, 2013a; Buchheit & Laursen, 2013b; Gibala et al., 2012; Wood et al., 2016). Consideration of these specific training variables is needed to provide a more thorough characterisation of the prescribed training stimulus with considerable effort expended by researchers attempting to delineate the relationship between acute programming variables and subsequent physiological adaptation (Buchheit & Laursen, 2013a; Buchheit & Laursen, 2013b).

In comparison to traditional endurance training, HIT was originally perceived to have less of an impact on oxidative energy metabolism and endurance capacity (Gibala & McGee, 2008). However, considerable research has demonstrated that HIT can induce substantial improvements in $\dot{V}O_{2max}$ in both healthy young (Bacon et al., 2013; Milanovic

et al., 2015; Weston, Taylor, et al., 2014) and older adults (Østerås, Hoff, & Helgerud, 2005; Wang et al., 2014) as well as a range of clinical populations (Helgerud et al., 2011; Liou, Ho, Fildes, & Ooi, 2016; Weston, Wisløff et al., 2014; Wisløff et al., 2007). The intermittent nature of HIT allows participants to maintain intense exercise for longer in comparison to continuous exercise (Guiraud et al., 2012); an important consideration as adaptations to exercise training are intensity dependent with higher intensities conferring greater benefit (Shephard, 1968; Egan & Zierath, 2013). Accordingly, HIT may be more effective than traditional endurance training for improving cardiorespiratory fitness (Milanovic et al., 2015; Wang et al., 2014) with greater improvements possible for older adults (Milanovic et al., 2015) and those with lower baseline fitness (Weston, Taylor, et al., 2014). From a programming perspective, intervals of 3-5 minutes in duration have been proposed as being especially effective for inducing improvements in $\dot{V}O_{2max}$ (Helgerud et al., 2007; Wisløff et al., 2007; Wisløff, Ellingsen, & Kemi, 2009) – a supposition supported by Bacon et al. (2013) and Milanovic et al. (2015) who reported that longer intervals induce greater increases in $\dot{V}O_{2max}$ compared with shorter bouts. However, the duration and frequency of interval training appears to only have a relatively small effect on $\dot{V}O_{2max}$ in comparison to that of exercise intensity (MacInnis & Gibala, 2017).

As HIT has transitioned from the exclusivity of the sports performance domain and been widely applied in healthy and clinical populations, further attention has been given to the application of HIT in healthy older adults. Importantly, HIT appears to be capable of eliciting cardiorespiratory fitness improvements of a similar relative magnitude regardless of age with participants from 20 to 70+ years of age improving $\dot{V}O_{2max}$ by 9-13% after 8 weeks of training with three sessions per week (4 x 4 min at 90-95% HR_{max}) (Støren et al., 2017). Caution is warranted when interpreting these findings due to the small sample size of older adults. Interestingly however, Støren et al., 2017 did observe that participants who were more sedentary and had lower baseline fitness exhibited the greatest training response. Further evidence for the effectiveness of HIT in older adults can be found in the study of Robinson et al. (2017) who reported a 17% improvement in $\dot{V}O_{2peak}$ following a 12-week training intervention in older adults (71 ± 5 years), although the three weekly HIT sessions (4 x 4 min; $>90\% \dot{V}O_{2peak}$) were supplemented with 2 days per week of treadmill walking (45 min; $70\% \dot{V}O_{2peak}$). Further studies (see table 2.1)

evaluating HIT in healthy older adults have shown improvements in $\dot{V}O_{2\max}$ of 6-15% following training programmes of 8-10 weeks (Hwang et al., 2016; Østerås et al., 2005; Støren et al., 2017; Wang et al., 2014;). The study of Wang et al. (2014), which reported the smallest increase in $\dot{V}O_{2\max}$ (6%), involved participants with baseline fitness of $47.9 \pm 3.9 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ providing further indirect evidence that greater improvements in fitness are possible for those with lower baseline fitness (Milanovic et al., 2015). As a caveat, it should be acknowledged that these studies utilised training protocols with recovery periods performed at $\sim 70\% \text{ HR}_{\max}$. According to ACSM classification (Garber et al., 2011), these recovery periods would be categorised as moderate intensity exercise which may provide a training stimulus for fitness improvement. As such, it is difficult to draw firm conclusions on the efficacy of HIT in older adults based on these studies alone.

Table 2.1 Summary of HIT studies involving healthy participants aged >50 yr

Study	Group	Duration (weeks)	Total sessions	Exercise mode	Exercise protocol	$\dot{V}O_{2max}$	$\dot{V}O_{2max}$	$\Delta\dot{V}O_{2max}$ (%)	Other outcomes assessed
						(mL·kg ⁻¹ ·min ⁻¹) (Pre)	(mL·kg ⁻¹ ·min ⁻¹) (Post)		
Østerås et al. (2005)	HIT	10	30	Outdoor running	4 x 4 min (85-95% HR _{max});	24.2 ± 2.5	27.8 ± 2.3*	15	Walking economy; maximal walking speed
	CON				3-min recovery (60-70% HR _{max})	26.7 ± 6.4	26.2 ± 6.2	-2	
Wang et al. (2014)	Old	8	24	Cycle ergometry	4 x 4 min (90-95% HR _{max});	47.9 ± 3.9	50.9 ± 4.2**	6	Maximal power output; cardiac parameters; maximal strength (leg press)
	Young				3-min recovery (~70% HR _{max})	50.5 ± 7.0	56.1 ± 5.5**	13	
Støren et al., 2017	50-59 yr	8	24	Cycling or uphill	4 x 4 min (90-95% HR _{max});	41.3 ± 10.8	45.4 ± 10.3**	12	N/A
	60-69 yr			treadmill	3-min active recovery	33.3 ± 10.5	37.2 ± 9.7**	13	
	70+ yr			walking	(70% HR _{max})	33.3 ± 8.9	36.0 ± 8.3**	9	
Hwang et al. (2016)	HIT	8	32	Combined arm	4 x 4 min (90% HR _{peak}); 3	23.1 ± 2.7	25.7 ± 3.1**	11	Cardiac function; Body composition; Lipids, glucose & insulin; blood pressure
	MICT			and leg	min active recovery (70% HR _{peak})	25.9 ± 6.4	26.0 ± 6.0	0	
	CON			ergometry		24.1 ± 5.6	24.5 ± 5.2	2	

Δ = change; CON = non-exercise control group; HIT = high-intensity interval training; MICT = moderate intensity continuous training

* = significantly different from baseline (p<0.05); ** significantly different from baseline (p<0.01)

While the mechanisms responsible for HIT induced improvements in cardiorespiratory fitness remain to be fully elucidated, peripheral adaptations of a similar nature to traditional endurance training are frequently implicated as being responsible for improvements in $\dot{V}O_{2\max}$ (Jacobs et al., 2013; MacInnis & Gibala, 2017). Rapid increases in skeletal muscle oxidative capacity (Gillen & Gibala, 2014; Jacobs et al., 2013), reflected by increased mitochondrial density (i.e. mitochondrial biogenesis) and function have been reported following HIT (Robinson et al., 2017; Wyklesema et al., 2017). These adaptations are potentially mediated by increases in PGC-1 α (Tjønnå et al., 2008; Wu et al., 1999) with it being suggested that fluctuations in ATP turnover during interval training could activate pathways leading to an increase in PGC-1 α (Daussin et al., 2008). The content and activity of mitochondrial enzymes are often used as a measure of oxidative potential, with increases in maximal citrate synthase (CS) of ~11-40% reported after training (Burgomaster et al., 2005; Burgomaster, Heigenhauser, & Gibala, 2006; Macdougall et al., 1998).

Despite the well documented peripheral changes, there is increasing evidence that HIT can also induce positive central adaptation. Several investigations have reported increased cardiac output (Astorino et al., 2017; Daussin et al., 2008; Wang et al., 2014; Warburton et al., 2004) and stroke volume (Tjønnå et al., 2008) following HIT with increases in plasma volume, and therefore blood volume, mediating observed increases in SV (Warburton et al., 2004). In the study of Astorino et al. (2017), the authors reported increased $\dot{V}O_{2\max}$ (8.9-12.3%) accompanied by a concomitant increase in cardiac output (8-11%) and suggested that participants with higher baseline fitness may require higher training volume or intensity to significantly increase stroke volume in cardiac output. Supporting this, Wang et al. (2014) reported that maximal cardiac output ($11 \pm 12\%$) and maximal stroke volume ($11 \pm 11\%$) increased following 8 weeks of three HIT sessions per week, while there was no change in a- vO_2 difference. Contrastingly, both Jacobs et al. (2013) and Macpherson, Hazell, Olver, Paterson, & Lemon (2011) have reported increased $\dot{V}O_{2\max}$ (8% and 12%, respectively) following HIT with no concomitant improvement in cardiac output. However, the study of Jacobs et al. (2013) consisted of only 6 exercise sessions and was only 2 weeks in duration, while the training programme of Macpherson et al. (2011) involved work bouts of 30-s in duration, which the authors postulated may be too short to improve cardiac output. It may be that differences in

baseline fitness and training programming variables (e.g. intensity, frequency, duration) are responsible for the conflicting findings between studies. It has been suggested that either HIT, or a combination of endurance training and SIT is needed to maximise both central and peripheral adaptations (Macpherson et al., 2011).

As well as improvements in cardiorespiratory fitness, HIT may also be a potent method for inducing positive adaptations in muscular fitness (Adamson et al., 2014; Buckley et al., 2015; Cantrell, Schilling, Paquette, & Murlasits, 2014; Rodas et al., 2000; Sculthorpe et al., 2017; Zelt et al., 2014). Previous work from Rodas et al. (2000) and MacDougall et al. (1998) has reported significant increases in the activity of anaerobic enzymes (creatine kinase [CK], phosphofructokinase [PFK], lactate dehydrogenase [LDH]) following SIT. Interestingly, in contrast to the findings of MacDougall et al. (1998) who reported a significant increase in peak power output (PPO), Rodas et al. (2000) reported no increase in PPO following training, implying that factors other than energy provision were responsible for the lack of performance improvement. However, this discrepancy between studies may be attributable to neuromuscular fatigue following the 14 consecutive days of SIT as post-intervention testing was performed 1-day after the conclusion of the training programme (Rodas et al., 2000). Despite these conflicting findings, several investigations have reported increases in muscular power of 9-17% following HIT (Astorino et al., 2011; Astorino, Allen, Roberson, & Jurancich, 2012; Buckley et al., 2015; Burgomaster et al., 2008). It may be that these improvements are related to exercise intensity, as training was performed 'all out' or supramaximally, with participants' typically performing bouts of 30-60 s duration. It should be noted however, that these studies (Astorino et al., 2011; Astorino et al., 2012; Buckley et al., 2015; Burgomaster et al., 2008) all assessed muscular power using the Wingate test – a 30 s 'all out' sprint test – where performance is largely determined by metabolic factors (Smith & Hill, 1991), thereby making it difficult to determine the impact of this type of training on isolated expressions of muscular power (e.g. in a single movement). As well as performance related improvements, HIT may also be capable of inducing morphological adaptation with Osawa et al. (2014) reporting that a combined upper- and lower-body HIT programme promoted hypertrophy of quadriceps and trunk muscles in healthy men aged 28-48.

Considering older adults specifically, HIT offers an effective method for improving several aspects of muscular fitness. Firstly, Robinson et al. (2017) have reported increased fat-free mass following HIT, thereby demonstrating potential for muscular hypertrophy and suggesting that morphological changes may contribute to increased strength or power following HIT in older adults. Using a protocol consisting of 6 x 30s sprints performed every 5 days for 6 weeks, Sculthorpe et al. (2017) evaluated thirty-three lifelong sedentary men (mean age 62 years) reporting an improvement in peak power output of 26.5% compared to control. Using a HIT protocol rather than SIT, Wang et al. (2014) reported that healthy older adults (60 ± 3 years) improved peak power output by $10 \pm 6\%$ following 8 weeks of three times per week cycle-based HIT (4 x 4 min, 90-95% HR_{max}). Typically, these studies have assessed muscular power via a 6s or 30s peak power test rather than as a single explosive movement – potentially a more relevant assessment in older adults as it more closely resembles activity such as rising from a chair or preventing a fall (Bassey et al., 1992; Skelton et al., 1994). Future work needs to assess the effects of HIT on explosive power. Despite not assessing muscular power output, Adamson et al. (2014) reported a 14% improvement in sit-to-stand performance following 6 weeks of SIT (6-10 6s ‘all-out’ sprints) suggesting that HIT has potential to improve functional measures of muscular fitness.

In addition to functional improvements in muscular fitness, limited evidence also exists showing that HIT is capable of inducing improvements in muscle protein synthesis (MPS) comparable to those of resistance based exercise (Bell, Séguin, Parise, Baker, & Phillips, 2015; Di Donato et al., 2014). This may be of particular relevance for older adults who are postulated to exhibit anabolic resistance – defined as a reduced muscle protein synthetic response to protein intake (Burd, Gorissen, & van Loon, 2013) – which over time contributes to the decrease in muscle mass observed with ageing. However, this evidence is drawn from short-duration, acute training studies, meaning it is difficult to draw firm conclusions without further investigation.

As well as any potential morphological adaptations (Osawa et al., 2014; Robinson et al., 2017), changes in muscular fitness following HIT may be related to altered neuromuscular characteristics (Scribbans et al., 2014). Increases in exercise intensity lead to increased muscle fibre recruitment (Henneman, Somjen, & Carpenter, 1965) with

exercise intensities ($>80-85\% \dot{V}O_{2\max}$) requiring recruitment of fast-twitch muscle fibres (Buchheit & Laursen, 2013b). Compared with continuous exercise, training induced adaptations following HIT may be fibre type specific (Wyckelsma et al., 2017) with larger recruitment of type II fibres during interval exercise compared with continuous training (Kristensen et al., 2015). This may have important implications for older adults who display specific atrophy of type II fibres (Lexell, 1995). From a programming perspective, longer duration HIT bouts (>60 s) as well as SIT are effective approaches for inducing acute neuromuscular load (Buchheit & Laursen, 2013b) although it is likely to be greater following short intervals as exercise intensity is usually higher (Buchheit & Laursen, 2013b). Indeed, it follows that activation of the greatest amount of muscle fibres would presumably result in the greatest degree of adaptation (Scribbans et al., 2014). Short-sprint training may induce morphological changes in muscle fibre type and contractile properties (Ross & Leveritt, 2001) while SIT increases motor unit activation (Creer, Ricard, Conlee, Hoyt, & Parcell, 2004) and HIT based running improves neuromuscular characteristics in triathlon athletes (García-Pinillos, Cámara-Pérez, Soto-Hermoso, & Latorre-Román, 2017). Further research is needed to determine the mechanisms responsible for muscular fitness improvements following HIT in older adults.

Collectively, the data presented in this section has demonstrated that HIT is an appealing and potent method for improving cardiorespiratory and muscular fitness across a range of populations. In older adults specifically, only limited work currently exists evaluating the impact of HIT on cardiorespiratory and muscular fitness. Despite this, preliminary findings suggest substantial improvements in fitness can be made following short-term training programmes, thereby making HIT a viable training approach in older adults especially given that early safety concerns remain unsubstantiated (Wisløff et al., 2007; Weston et al., 2017). Further research should seek to understand the effects of manipulating training programming variables on measures of fitness in older adults.

2.7 Summary

Structural and functional changes in the cardiorespiratory and neuromuscular systems with ageing lead to declines in cardiorespiratory and muscular fitness, ultimately limiting functional capacity in older adults. Both endurance and strength training are potent methods for enhancing cardiorespiratory and muscular fitness respectively, yet neither mode appears to be appropriate for inducing significant improvements across all aspects of physical performance in older adults. Combined exercise training programmes may be an effective approach to improve both cardiorespiratory *and* muscular fitness in older adults but typically require a considerable weekly training volume. This is problematic as lack of time remains one of a myriad of barriers to exercise participation in older adults, an issue reinforced by considerable evidence demonstrating that few older adults currently meet physical activity guidelines. Collectively, these factors reinforce the need for alternative exercise strategies for older adults. High-intensity interval training has potential to improve multiple components of fitness simultaneously but is typically confined to cycle ergometry or treadmill running, which may not be the most appropriate training approach in older adults. Accordingly, alternative approaches to the delivery of HIT have potential to be a viable and effective strategy to counteract age-associated physical declines in older adults.

CHAPTER 3: ACUTE PHYSIOLOGICAL AND PERCEPTUAL RESPONSES TO SPEEDFLEX TRAINING IN OLDER ADULTS: A CONCURRENT VALIDITY STUDY

3.1 Introduction

Declines in cardiorespiratory and muscular fitness are an unavoidable consequence of the ageing process (Fleg, Schulman, O'Connor, Gerstenblith, et al., 1994; Goodpaster et al., 2006). Nevertheless, this age-related decline in physical functioning is modifiable, with exercise training having potential to ameliorate age-associated changes in physical functioning (Jubrias et al., 2001; Makrides et al., 1990; McCartney, Hicks, Martin, & Webber, 1995).

Endurance training is an effective strategy for maintaining and improving cardiorespiratory fitness (Garber et al., 2011), though more recently, HIT has been proposed as an alternative, and possibly more effective approach in older and less fit adults (Adamson et al., 2014; Buckley et al., 2015; Hwang et al., 2016; Milanovic et al., 2015; Sculthorpe et al., 2017; Weston, Taylor, et al., 2014). However, HIT has traditionally been confined to laboratory-based equipment such as cycle ergometry and treadmill walking/running, where age-related mobility and balance limitations can preclude older adults (Daley and Spinks, 2000); thereby highlighting a need for alternative exercise modes for performing HIT. In contrast, strength training is a potent strategy for maintaining physical functioning in older adults – increasing muscle mass, strength and power as well as quality of life and functional independence (Hunter et al., 2004; Latham et al., 2004; Liu & Latham, 2009; Steib et al., 2010; Straight et al., 2016). Despite this, only a small number of older adults regularly engage and considerable barriers to uptake remain suggesting alternate modes are welcomed (Burton et al., 2017; Humphries et al., 2010; Strain et al., 2016).

Speedflex has the potential to be a feasible exercise mode (Taylor et al., 2014) for improving fitness in older adults, but practitioners and researchers must develop an understanding of acute training responses prior to future longitudinal investigations to make an informed decision about potential use and training prescription (Billat, 2001).

Currently, no study has examined the usefulness of Speedflex for performing HIT or strength training in older adults. As such, the aim of the present investigation was to establish the concurrent validity of the Speedflex machine as an exercise mode for performing HIT and strength training in older adults by assessing and comparing the acute physiological (e.g. heart rate, $\dot{V}O_2$, blood lactate) and perceptual responses (e.g. RPE, enjoyment) to HIT and strength training sessions.

3.2 Methods

3.2.1 Experimental approach

To meet the dual aims of this investigation, the study was conducted in two parts. Part one assessed the acute physiological and perceptual responses to performing high-intensity interval training (HIT) using Speedflex, while Part two evaluated the acute responses to strength training (ST) using Speedflex. To evaluate the feasibility of using the equipment in these ways (i.e. HIT and ST), a randomised crossover design was used for each part, to compare the acute physiological and perceptual responses between Speedflex and a criterion mode of exercise.

In Part one, the HIT criterion exercise mode was cycle ergometry, which has been previously demonstrated to be an appropriate method for performing HIT (Little et al., 2011); whereas in Part two, elastic resistance bands were the ST criterion exercise mode (Martins et al., 2013). In both study parts, all testing and experimental sessions were completed 4-7 days apart, with subjects avoiding vigorous physical activity 24 h prior to each session and maintaining usual dietary habits. Participants completed all sessions at the same time of day to minimise the impact of circadian variation (Atkinson & Reilly, 1996).

3.2.2 Participants

While there remains little consensus on when old age begins (see section 2.2), it is well documented that physiological and physical declines accelerate beyond the age of 50 years (Lexell, 1988; Fleg et al., 2005). Moreover, low levels of physical performance at

age 53 are associated with higher rates of mortality and identify those less likely to achieve a long and healthy life (Cooper et al., 2014). As such, early intervention (i.e. from ~50 years of age onwards) with evidence-based exercise strategies may play a critical role in preventing physical disability in later adulthood. Accordingly, a total of 39 healthy community-dwelling adults aged 55-83 were recruited and took part in this investigation. Participants were physically active, but were not currently, and had not in the previous year, engaged in structured exercise more than twice per week. Participants were recruited via word of mouth and advertisement at local fitness clubs, community groups and local offices in Newcastle-Upon-Tyne, UK and the surrounding area. All participants had no previous experience of exercise training using Speedflex. Prior to enrolment, all participants completed a medical screening questionnaire to identify any health issues which could affect their ability to perform the required exercise. Participants with pre-existing, musculoskeletal disorders or systemic disease (e.g. diabetes mellitus, cancer, heart disease) were excluded. Following a comprehensive explanation and demonstration of the benefits and risks, all individual subjects provided written, informed consent to participate in the study, which conformed to the requirements of The Declaration of Helsinki and was approved by Teesside University Research and Ethics Committee (Appendix A). Participant characteristics are presented in Table 3.1.

Table 3.1 Participant characteristics

	Part one (n = 20)	Part two (n = 19)
Age (yr)	62.7 ± 6.1	66.7 ± 6.1
Sex (male/female)	10/10	10/9
Height (cm)	169.8 ± 8.5	168.6 ± 9.0
Body Mass (kg)	77.2 ± 15.1	79.4 ± 13.9
Body Mass Index (kg/m ²)	26.5 ± 3.4	27.9 ± 4.0
$\dot{V}O_{2peak}$ (ml·kg ⁻¹ ·min ⁻¹)	24.5 ± 3.7	-

Data presented as mean ± SD

3.2.3 Experimental Procedures

Part One

Familiarisation and baseline assessment

In Part one, subjects visited the laboratory on four separate occasions (Figure 3.1). The first visit acted as an information and familiarisation session where subjects were instructed on correct exercise form and participation requirements. In session two, subjects performed a continuous, graded maximal exercise test to determine peak oxygen uptake ($\dot{V}O_{2\text{peak}}$), peak heart rate (HR_{peak}) and power output at $\dot{V}O_{2\text{peak}}$ using an electromagnetically braked cycle ergometer (Excalibur Sport, Lode BV, Groningen, The Netherlands). The test began at 30 W and increased by 15 W/min⁻¹ until volitional exhaustion. Strong, standardised verbal encouragement was given throughout the test. Heart rate (Polar RS400, Polar, Kempele, Finland) and oxygen uptake (K4b², Cosmed s.r.l, Rome, Italy) were recorded throughout. $\dot{V}O_{2\text{peak}}$ was defined as the highest $\dot{V}O_2$ obtained over a 30-s period during the test (McRae et al., 2012).

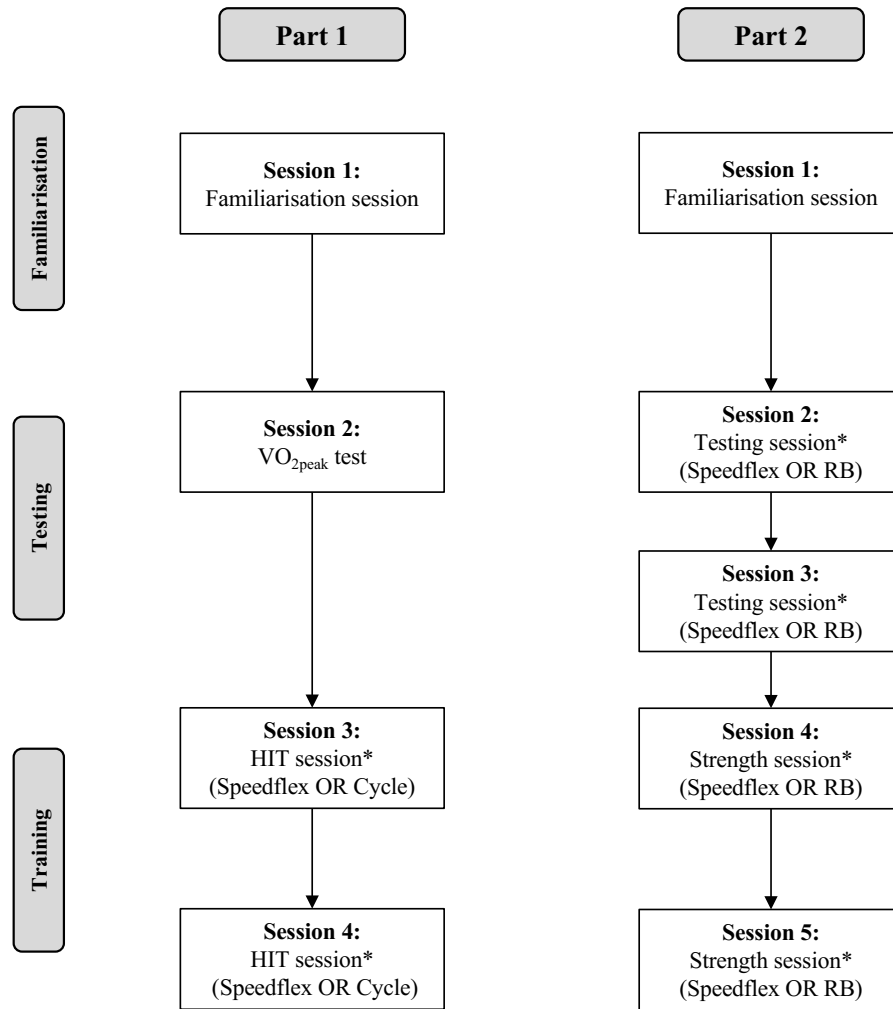


Figure 3.1 Schematic of study design

*Performed in counterbalanced order; RB, Resistance bands

Experimental sessions

In sessions three and four, participants completed two experimental HIT sessions (Speedflex and cycle) in a counterbalanced order with the exercise protocol based upon work by Weston et al. (2004) who demonstrated this approach to be effective at inducing a high-intensity training stimulus. Both experimental sessions followed an identical format with the exercise consisting of three sets with a cumulative total of 10.5 minutes of high-intensity exercise (see Figure 3.2). Following completion of each set, subjects had two minutes of passive rest during which blood lactate was sampled (YSI 2300, Yellow Springs, Ohio) and subjects were asked to provide a differential rating of

perceived exertion (dRPE) of “how heavy and strenuous the physical task felt” using the CR100[®] scale (Appendix B) (Borg & Borg, 2002) for: 1) the sense of breathlessness (RPE-B), 2) upper-body exertion (RPE-U) and 3) leg exertion (RPE-L). Due to the ability to discriminate between discrete sensory inputs, such as central (e.g., breathlessness / oxygen uptake) and peripheral factors (e.g., neuromuscular and musculoskeletal characteristics), the use of dRPE enables a more sensitive assessment of perceived exercise intensity when compared to traditional ratings of perceived exertion (RPE) (Weston et al., 2015).

During the cycle HIT session (Excalibur Sport, Lode BV, Groningen, The Netherlands), resistance was set at 80% of power output at $\dot{V}O_{2peak}$ observed during the incremental exercise test with pedalling cadence ~80-90 revolutions per minute. During the Speedflex HIT session (Speedflex, AlphaTech Inc, Nelson, NC), the Speedflex machine was set at resistance setting 5 (1-10) and subjects were encouraged to work at high-intensity (RPE = ‘very hard’). Subjects completed four full-body exercises per set: 1) Power clean and press (combined upper- and lower-body), 2) Squat (lower-body), 3) Step and press (combined upper- and lower-body) and 4) Pulldown to squat (combined upper- and lower-body). Full descriptions and diagrammatic representation of exercises can be found in Appendix C. Heart rate was recorded at 5-s intervals throughout the entire duration of the exercise sessions (Polar RS400, Polar, Kempele, Finland) and is presented as percentage points of maximal heart rate with maximal heart rate considered to be the highest 5-s peak obtained during exercise or test sessions (Weston et al., 2004). At the completion of the exercise protocol and 24 h post exercise, subjects provided a rating of perceived enjoyment using the physical activity enjoyment scale (Kendzierski & DeCarlo, 1991).

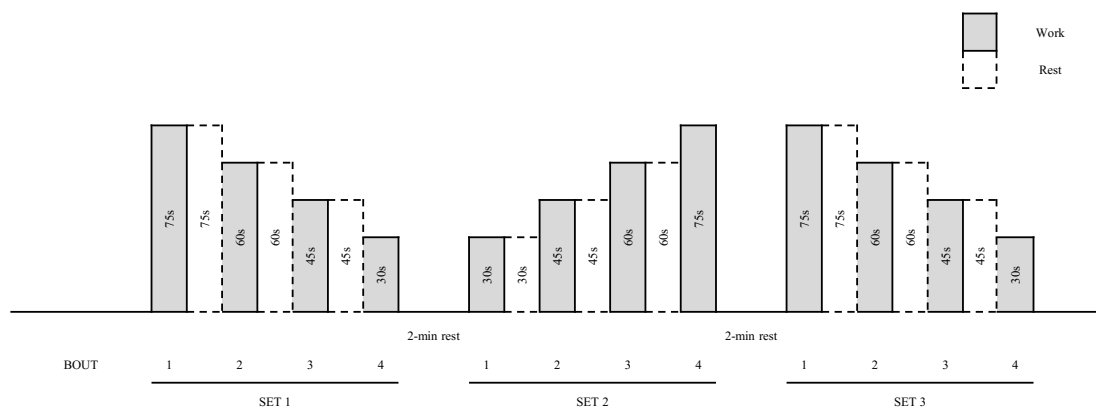


Figure 3.2 Structure of HIT session.

Part Two

Familiarisation and baseline assessment

In Part two, participants visited the laboratory on five separate occasions (Figure 3.1). The first visit acted as an information and familiarisation session where participants were instructed on correct exercise form and participation requirements. For each exercise mode (resistance bands [Bodylastics, Bodylastics International Inc, Boca Raton, FL] and Speedflex) participants completed six exercises; two chest exercises, two shoulder exercises and two back exercises. The resistance band exercises were: 1) supine bench press (chest), 2) supine flat row (back), 3) shoulder press (shoulder), 4) seated pull down (back), 5) upright row (shoulder) and 6) press down (chest). In contrast, the nature of the Speedflex machine requires participants to perform a double concentric movement as resistance is set in both directions thereby enabling participants to perform two separate exercises within the same complete movement. To this extent, and to allow for suitable comparison and equivalence between exercise modes, the exercise combinations during the Speedflex session were: 1) supine bench press with flat row (chest and back); 2) shoulder press with pull down (shoulder and back) and 3) upright row with press down (shoulder and chest). Diagrammatic representation of resistance band and Speedflex exercises can be found in Appendix C.

Sessions two and three estimated strength in both exercise modes with the greatest resistance that the participant could lift using correct technique for one complete

repetition (One repetition maximum; 1RM), at the correct tempo (1 s:1 s) determined. In the resistance band session, participants' strength was evaluated in each of the six exercises. These bands allow for multiple bands of differing tension to be attached to the handles, thereby providing flexibility in increasing and decreasing resistance easily. Participants performed a light warm up, with an estimated resistance of ~50% 1RM for 10 repetitions and ~70% 1RM for 5 repetitions, separated by 2-min rest prior to completing their 1RM trial (Hiscock, Dawson, Donnelly, & Peeling, 2015). If a participant was not successful in attaining a 1RM they rested for ~3 minutes, prior to a second attempt with a lower load. Loads were adjusted based on participant feedback, with the goal of identifying 1RM within three to five attempts. A period of ~5-minute rest was given between exercises. For Speedflex, resistance was determined by changing the resistance setting of the machine; the Speedflex machine has ten resistance settings, moving from level 1 (very low resistance) to level 10 (very high resistance). Although the settings of the Speedflex machine can be changed, resistance is also determined by the speed of movement with faster movement resulting in greater resistance as is usual with hydraulic resistance exercise machines. As such, speed of movement was standardised so that each movement was completed in 1 s. As resistance can be set in both directions using the Speedflex machine, each exercise was assessed in isolation (i.e. bench press then flat row) allowing resistance to be manipulated for each element of the complete movement. Strength was then determined using the same protocol as previously described.

Experimental sessions

In sessions four and five participants completed two strength training sessions (Speedflex and resistance bands) performed in a counterbalanced order with each session involving the same exercises as described above (Table 3.2). Based on previous resistance training prescription in older adults, intensity was set at 70% of the subjects 1RM with the concentric phase of each movement completed in 1 s (Fielding et al., 2002). The double concentric nature of Speedflex meant that each complete repetition was completed in 2 s (1 s per concentric movement). To ensure equivalence across exercise modes, this meant that a complete repetition performed using resistance bands was also performed in 2 s (1 s concentric: 1 s eccentric). Speed of movement was controlled using a custom-made metronome (Garageband, Apple Inc, California) using the specific movement commands

relative to the exercise (e.g. push, pull). Total between-set and between-exercise rest periods were matched across exercise modes. The author was present for all exercise sessions to ensure correct exercise form throughout and that complete range of motion was maintained.

Participants provided ratings of perceived exertion for the active muscle group (RPE_{chest} , RPE_{back} , RPE_{shoulder}) at the completion of each set using the CR-100 scale (Borg & Borg, 2002) as well as session RPE (sRPE) at the conclusion of each training session. Participants were habituated with the RPE scale during familiarisation and testing sessions in an attempt to anchor RPE across a range of exercise intensities and were provided with an annotated diagram identifying the location of the relevant muscle groups. Heart rate was recorded at 5 s intervals throughout the entire duration of the exercise sessions (Polar RS400, Polar, Kempele, Finland) with the equation of Gellish et al. (Gellish et al., 2007) used to estimate maximal heart rate. Rating of perceived enjoyment was assessed as in Part one.

Table 3.2 Structure of strength training sessions

		Exercise	Sets	Reps	Total reps	Between-set rest (s)	Between- exercise rest (s)	Total time (s)
Resistance bands	1	Bench press	3	12	36	60	120	240
	2	Flat row	3	12	36	60	120	240
	3	Shoulder press	3	12	36	60	120	240
	4	Pull down	3	12	36	60	120	240
	5	Upright row	3	12	36	60	120	240
	6	Press down	3	12	36	60	120	240
		Total	18	72	216	360	720	1440
Speedflex	1	Bench press with flat row	3	24	72	120	240	480
	2	Shoulder press with pull down	3	24	72	120	240	480
	3	Upright row with press down	3	24	72	120	240	480
		Total	9	72	216	360	720	1440

3.2.4 Statistical analysis

Descriptive data are presented as mean \pm standard deviation (SD). Prior to analyses, plots of the residuals versus the predicted values revealed no evidence of non-uniformity of error and therefore analysis was performed on the raw, untransformed data with the uncertainty of estimates expressed as 90% confidence limits (CL). For both study parts, data were analysed using mixed linear modelling (SPSS v.22, Armonk, NY: IBM Corp) with both, fixed (i.e. exercise mode) and random effects (i.e. within-participant) specified. Following this, standardised thresholds for small, moderate and large differences of 0.2, 0.6 and 1.2, respectively of the pooled between-subject standard deviations were used to assess the magnitude of all differences (Hopkins, Marshall, Batterham, & Hanin, 2009). While classifying the magnitude of differences based on the observed effect (i.e. the point estimate of the mean) and standardised thresholds provides a useful quantification of the size of the effect, this method represents a crude approach as there is no distinction between outcomes with confidence intervals that span a single magnitude level and those that overlap into another level. As such, quantifying clear outcomes with a qualitative descriptor that represents the likelihood that the true value will have the observed magnitude is a more informative approach (Batterham & Hopkins, 2006). This likelihood was calculated via the spreadsheet of Hopkins (2007) using the observed effect, the p-value, degrees of freedom, t-distribution and the confidence interval of the observed effect. This spreadsheet gives the chances (expressed as probabilities) that the true value is either substantial (positive or negative) or trivial. As such, inferences were based on the disposition of the confidence interval for the mean difference in relation to the standardised thresholds described previously. Differences between exercise modes were evaluated non-clinically (classified as unclear when the confidence limits overlapped both substantially positive and negative thresholds by $>5\%$). The chance of the difference being substantial or trivial was interpreted using the following scale of qualitative descriptors: 25-75%, possibly; 75-95%, likely; 95-99.5%, very likely; $>99.5\%$, most likely (Batterham & Hopkins, 2006).

3.3 Results

Part One

Descriptive data and between-mode differences for physiological measures, differential ratings of perceived exertion and enjoyment for Part one are presented in Table 3.3. Between-mode differences were trivial for all physiological measures and RPE-B. RPE-U was rated higher (a most likely large difference) for Speedflex and RPE-L was rated higher (possibly small) for cycle ergometer. Enjoyment was higher (possibly small) for Speedflex at 24 h post exercise, with an unclear difference immediately post exercise.

Table 3.3 Acute responses to HIT (Part one; Cycle ergometer versus Speedflex)

	Raw data (Mean \pm SD)		Between-mode difference	
	Cycle ergometer	Speedflex	Mean difference; $\pm 90\%$ CL*	Qualitative inference
<i>Physiological measures</i>				
HR _{mean} (% of max)	81.7 \pm 8.2	82.5 \pm 7.2	-0.8; ± 0.9	Trivial ^b
HR _{peak} (% of max)	89.7 \pm 7.2	90.1 \pm 6.7	-0.5; ± 0.9	Trivial ^c
$\dot{V}O_{2peak}$ (% of max)	84.5 \pm 10.6	82.8 \pm 11.2	1.7; ± 1.5	Trivial ^a
Blood lactate (mmol \cdot l ⁻¹)	5.5 \pm 1.7	5.3 \pm 1.7	0.2; ± 0.4	Trivial ^a
<i>Differential ratings of perceived exertion</i>				
RPE-U (AU)	25.5 \pm 13.6	57.6 \pm 21.7	-32.1; ± 4.2	Large ^d
RPE-L (AU)	64.4 \pm 20.3	58.9 \pm 22.2	5.5; ± 3.8	Small ^a
RPE-B (AU)	57.9 \pm 22.3	61.5 \pm 21.9	-3.6; ± 4.5	Trivial ^a
<i>Enjoyment</i>				
Enjoyment (AU)	99.3 \pm 15.6	97.8 \pm 15.6	1.6; ± 6.3	Unclear
Enjoyment 24h post (AU)	96.1 \pm 17.3	99.4 \pm 15.8	-3.3; ± 5.0	Small ^a

*Cycle ergometer minus Speedflex. ^a Possibly, 25-75%; ^b Likely, 75-95%; ^c Very likely, 95-99.5%; ^d Most likely, >99.5%

SD, standard deviation; CL, confidence limits; % of max, percentage of maximal; AU, arbitrary units. RPE-U, ratings of perceived upper-body muscle exertion; RPE-L, ratings of perceived leg muscle exertion; RPE-B, ratings of perceived breathlessness

Part Two

Descriptive data and between-mode differences for heart rate, ratings of perceived exertion and enjoyment for Part two are presented in Table 3.4. HR_{mean} was higher during Speedflex (a most likely small difference) with RPE_{chest} (most likely small) and sRPE (likely small) higher for resistance bands. Between-mode differences for RPE_{back} and RPE_{shoulder} were likely trivial and possibly trivial, respectively. Enjoyment was rated higher for Speedflex immediately post exercise (possibly small), while at 24h post exercise the difference was possibly trivial.

Table 3.4 Acute responses to strength training (Part two; Resistance bands versus Speedflex)

	Raw data (Mean \pm SD)		Between-mode difference	
	Resistance Bands	Speedflex	Mean difference; \pm 90% CL*	Qualitative inference
<i>Physiological measures</i>				
HR_{mean} (% of max)	61.1 \pm 7.2	64.2 \pm 8.9	-3.1; \pm 0.7	Small ^d
<i>Differential ratings of perceived exertion</i>				
RPE_{chest} (AU)	28.3 \pm 12.4	22.9 \pm 11.4	5.4; \pm 1.6	Small ^d
RPE_{back} (AU)	24.1 \pm 11.4	23.4 \pm 11.9	0.8; \pm 1.6	Trivial ^b
RPE_{shoulder} (AU)	32.5 \pm 14.6	29.9 \pm 12.2	2.6; \pm 1.9	Trivial ^a
sRPE (AU)	31.9 \pm 14.4	27.3 \pm 10.7	4.6; \pm 3.4	Small ^b
<i>Enjoyment</i>				
Enjoyment (AU)	110.1 \pm 14.7	113.1 \pm 12.3	-3.0; \pm 4.4	Small ^a
Enjoyment 24h post (AU)	109.2 \pm 16.5	111.4 \pm 13.1	-2.2; \pm 3.8	Trivial ^a

*Resistance bands minus Speedflex. ^a Possibly, 25-75%; ^b Likely, 75-95%; ^c Very likely, 95-99.5%; ^d Most likely, >99.5%

SD, standard deviation; CL, confidence limits; % of max, percentage of maximal heart rate; AU, arbitrary units; sRPE, session RPE; RPE_{chest} , ratings of perceived chest muscle exertion; RPE_{back} , ratings of perceived back muscle exertion; RPE_{shoulder} , ratings of perceived shoulder muscle exertion

3.4 Discussion

Novel training modes for the delivery of HIT and ST may help to increase exercise adherence and ultimately improve health outcomes in older adults. Prior to the implementation of newly-developed exercise modes, practitioners and researchers should first develop an understanding of acute responses that can be elicited when training with the apparatus. As such, this investigation sought to compare training responses from a novel exercise mode (Speedflex) against more traditional exercise modes. The findings presented here demonstrate that Speedflex induces similar HIT physiological and perceptual responses to cycle ergometry, with at most small differences compared with elastic resistance bands when performing ST.

Within Part one, no substantial differences in the physiological response to HIT across both exercise modes were observed. This suggests Speedflex to be a viable alternative for performing HIT using the protocol in this investigation. Furthermore, the findings demonstrate that the exercise protocol employed in this investigation is suitable for inducing a HIT stimulus. For example, the heart rate and $\dot{V}O_2$ responses observed in this investigation classify the exercise as 'vigorous' according to ACSM guidelines (Garber et al., 2011) and the HR_{peak} values are comparable to previous HIT work reported by Little and colleagues (Little et al., 2011) and the more general recommendations for HIT prescription (Weston, Wisløff et al., 2014). Trivial differences observed for $\dot{V}O_2$ and blood lactate provide further confirmation of both exercise modes placing similar, yet substantial demand on both the aerobic and anaerobic energy systems during exercise. The observed blood lactate values are similar to those previously reported (Wisløff et al., 2007) of $\sim 5.0 \text{ mmol l}^{-1}$ from HIT but higher than those reported by others (Gosselin, Kozlowski, DeVinney-Boymel, & Hambridge, 2012). As blood lactate production is related to exercise intensity and duration (Stallknecht, Vissing, & Galbo, 1998), the amount of active muscle mass employed (e.g. lower-body exercise vs. whole-body exercise) (Borresen & Lambert, 2009) as well as participant training status (Hurley et al., 1984), reconciling between-study differences is challenging.

The RPE values observed in Part one demonstrate clear differences in the demands placed on the upper- and lower-body musculature between exercise modes. This finding is not

unexpected as despite both exercise modes being physiologically demanding – evidenced by the observed physiological and perceptual responses in this investigation – cycling is largely performed by the muscles of the lower limbs while Speedflex places demands on both upper- and lower-body musculature, thereby eliciting dissimilar dimensions of peripheral exertion (McLaren et al., 2016; Millet, Vleck, & Bentley, 2009). There was a large difference in RPE-U (‘hard’ to ‘very hard’ vs ‘moderate’), showing the demand on the muscles of the upper-body to be greater during the Speedflex session. Differences in substrate metabolism, fibre type composition as well as increased peripheral fatigue during upper-body exercise may affect perceptual responses in comparison to lower-body exercise (Sawka, 1986). By contrast, the cycle HIT session was rated higher for RPE-L, although both exercise modes elicited ratings of ‘hard’ to ‘very hard’. Collectively, these findings provide further evidence that dRPE provides a more comprehensive quantification of internal load by differentiating between upper- and lower-body muscular demands (Weston et al., 2015). The inclusion of an overall session RPE (sRPE) could have supported this assertion and its absence is acknowledged as a limitation of the present investigation. The magnitude of the between-mode difference was lower for RPE-L when compared with RPE-U, suggesting that Speedflex can provide a whole-body exercise stimulus during HIT – a supposition supported by the trivial between-mode difference in RPE-B. Previously, HIT has been performed at an intensity classified as ‘hard’ to ‘very hard’ (Ciolac et al., 2015; Falcone et al., 2015; Little et al., 2011) and although these investigations used different RPE scales, the verbal descriptors of intensity are comparable to the present findings thereby providing further validation of Speedflex being able to induce a HIT stimulus.

In Part two, there were trivial to small between-mode differences for physiological and perceptual measures. The most likely small difference between-modes for mean heart rate may be attributable to the double concentric nature of the movement performed for each exercise and the increased energetic demand of such a movement (Thompson, Versteegh, Overend, Birmingham, & Vandervoort, 1999). Interestingly, the higher mean heart rate observed during Speedflex (64.2%) falls into the moderate intensity range as defined by the ACSM (Garber et al., 2011) suggesting that it could provide a stimulus to promote adaptations in cardiorespiratory fitness, as per previous work (Ozaki et al., 2013). Although speculative, it is possible that the higher observed values for RPE_{chest} and sRPE during the resistance bands session are attributable to greater levels of muscle

activity or increased blood lactate concentration when compared to Speedflex (Lagally et al., 2002). However, the absence of blood lactate measurement, acknowledged as a limitation of this investigation, means this possibility cannot be validated and the mechanisms explaining the difference remain unknown.

Training interventions delivered using elastic resistance bands can be effective at improving muscle quality (Hofmann et al., 2016) and functional performance (Oesen et al., 2015) in elderly participants signifying that this training mode is an appropriate criterion in this population. The use of differential RPE of active muscle groups and overall session RPE provides an effective assessment of exertion during ST (Lagally et al., 2002). In this investigation, between-mode differences in dRPE and sRPE ranged from trivial to small with consistent ratings of ‘moderate’ to ‘somewhat hard’ for both exercise modes. The nature of Speedflex means that it is not possible to accurately quantify the external load, as is usually the case when performing ST because of the hydraulic nature of the equipment, whereby increased speed of movement induces increased resistance. However, the similarity in physiological and perceptual responses, with at most small differences observed between exercise modes in this investigation suggests that it may be a useful training approach in this population. Intervention studies are needed to elucidate this fully.

Higher RPE values observed in Part one (‘hard’ to ‘very hard’), in comparison to Part two (‘moderate’ to ‘somewhat hard’), suggest that a considerable demand is placed on the upper- and lower-body muscular system, as well as the cardiovascular system when performing HIT using Speedflex. This raises the interesting possibility of HIT performed using Speedflex as a training tool to impact on both cardiorespiratory and muscular fitness simultaneously within the same exercise session. Previous work has demonstrated that combined whole-body aerobic-resistance programs can induce cardiorespiratory and muscular adaptations in a time efficient manner in younger participants (Buckley et al., 2015; McRae et al., 2012), while HIT has also been shown to improve multiple components of fitness in older adults (Adamson et al., 2014). Furthermore, full-body HIT has been shown to be safe and feasible, as well as effective at improving cardiometabolic status in older adults with an 11% improvement in $\dot{V}O_{2max}$ after 8 weeks (Hwang et al., 2016). The ability to deliver an upper- and lower-body exercise stimulus, as offered by Speedflex, is appealing in this population because of their need to maintain upper- and

lower-body muscle strength to perform activities of daily living (Landers et al., 2001; Skelton et al., 1994).

In both Part one and Part two of this investigation, similar ratings of perceived enjoyment were observed suggesting that either exercise mode could be an appealing strategy in this population. This finding is encouraging as enjoyment is a motivator for exercise participation in older adults (Dacey et al., 2008) with enjoyment of exercise having potential to increase long-term adherence (Bartlett et al., 2011). In comparison to previous work, the present enjoyment scores were considerably higher than those reported by Bartlett and colleagues who evaluated recreationally active men (mean age 25 ± 5 years) performing treadmill running reporting an enjoyment rating of (88 ± 6 AU) (Bartlett et al., 2011) and those of Stork, Kwan, Gibala, & Martin Ginis, 2015) evaluating SIT in moderately active young adults (>80 AU). In both Part one and Part two of the present investigation, between-mode differences in enjoyment demonstrated a latency effect. Currently, no further data exists to corroborate this finding, although Stork et al. (2015) did report an increase in perceived enjoyment over time and at follow up following SIT. Further research is needed to understand this latency effect.

Limitations

Despite the promising findings of the present investigation, it is not without limitation. Firstly, the comparator exercise modes used (i.e. cycle ergometer and resistance bands) in this study limit the ability to draw firm conclusions about the exercise stimulus provided by Speedflex. While cycle ergometry offers a viable and effective approach for performing HIT in older adults (Sculthorpe et al., 2017), comparing a lower-body only exercise stimulus with the full-body stimulus of Speedflex may influence observed between-mode differences. For example, the full-body exercise stimulus provided by Speedflex may result in a higher observed $\dot{V}O_2$ due to greater muscle activation (Joyner & Casey, 2015) in comparison with cycle ergometry. It may be that comparison of Speedflex with treadmill exercise may have been a more valid approach. However, treadmill based exercise is also constrained by the same limitations as cycle ergometry (i.e. predominantly lower-body exercise stimulus) while also placing considerable loading on the joints of the lower body which may be contraindicated for a number of older adults. In reality, differences are likely to exist between most exercise training

modes when considering factors such as muscle recruitment and cardiovascular demand but to date, cycle ergometry appears to be the ‘gold standard’ exercise mode for performing HIT in older adults (Little et al., 2011; Sculthorpe et al., 2017).

The choice of comparator exercise mode in part two was primarily determined by logistical factors. As the Speedflex facility is located on a single site in Newcastle Upon Tyne, UK the comparator exercise mode had to be portable so that all testing and training sessions could be completed in the same training facility. Resistance machines are the most widely used approach to strength training in this population (Liu & Latham, 2009) while resistance bands – although effective at improving muscular strength (Martins et al., 2013) – are more effective in older adults with lower levels of muscular fitness (e.g. frail or institutionalised older adults [Hofmann et al., 2016]) with only limited work evaluating their effectiveness in a healthy population (Martins et al., 2013). Additionally, tension force values for resistance bands provided by the manufacturer can be overestimated, which may limit correct prescription of exercise intensity (Uchida, Nishida, Sampaio, Moritani & Arai, 2016). Comparison of Speedflex with alternative methods of strength training (e.g. resistance machines) offers an avenue for future investigation. It should also be acknowledged that in part two, strength assessment performed using Speedflex may have been limited by a ceiling effect. As resistance on the Speedflex machine is limited to levels 1-10 (10 representing the highest resistance possible) there may have been a number of participants who were capable of performing the movements against greater resistance in some exercises, thereby underestimating participants’ strength.

As previously discussed, quantification of sRPE in Part one could have provided further validation of the usefulness of dRPE in this population, while blood lactate measurement in Part 2 could have provided additional information on the physiological demands during resistance training. It is also noted that the HIT protocol used in Part one of this chapter may not be conducive to a small-group environment because of the session structure (i.e. differing duration of exercise bouts) while anecdotal feedback from participants suggested they found the 30s repetitions “too short to get going” and that “by the time you started exercising it was time to rest”. More broadly, Speedflex is limited during resistance training by the variable nature of the hydraulic resistance whereby greater speed of movement increases resistance. Although this is one of the reasons why

Speedflex is an appealing training strategy in older adults, for controlled resistance training, being able to manipulate external resistance more closely could be advantageous. If the Speedflex machine were able to provide a quantification of force production during movement this could help to quantify the external training load, which in turn, would be useful for programming resistance training.

3.5 Conclusion

Creative approaches to training intervention design are important for translation into the ‘real world’ and the application of new training modes can help to broaden the appeal and adherence to exercise training. However, prior to implementing new training strategies, practitioners and researchers need to develop an understanding of the acute training responses resulting from new exercise training modes to allow them to make an informed decision about potential use within a training programme. The physiological and perceptual responses observed in this investigation show potential for Speedflex as a viable alternative exercise mode for older adults performing HIT and ST. Additionally, the dRPE scores provided for Speedflex in part one illustrate a considerable muscular and cardiovascular demand, raising potential for this equipment to be used for the simultaneous training of cardiorespiratory and muscular fitness in older adults. This assertion, will be tested in the main experimental study of this thesis presented in chapter six.

CHAPTER 4: THE EFFECTS OF SAME-SESSION COMBINED EXERCISE TRAINING ON FITNESS IN OLDER ADULTS. A SYSTEMATIC REVIEW AND META-ANALYSIS OF CONTROLLED TRIALS

Chapter three demonstrated that Speedflex is a feasible approach for performing HIT and strength training in older adults. Chapter four systematically reviews and meta-analyses the effects of same-session combined strength and endurance training in adults aged over 50 years.

4.1 Introduction

Age-associated changes in physical fitness limit the capacity of older adults to perform the basic tasks of daily living (Aagaard et al., 2010; Fleg et al., 2005; Foldvari et al., 2000; Posner et al., 1995). Despite this, older adults remain highly trainable even into advanced age with exercise training an effective therapeutic strategy (Frontera, Meredith, O'Reilly, Knuttgen, & Evans, 1988; Jubrias et al., 2001; Makrides et al., 1990). As higher levels of both cardiorespiratory and muscular fitness are related to improved functional performance, these fitness components are key targets for intervention (Hazell, Kenno, & Jakobi, 2007; Latham et al., 2004; Miszko et al., 2003; Seals et al., 1984).

As neither endurance or strength training performed in isolation promotes holistic fitness improvement, exercise guidelines for older adults typically recommend training programmes consisting of a combination of endurance and strength training activities (Chodzko-Zajko et al., 2009; DoH, 2011; Nelson et al., 2007). As a result, 'combined' or 'concurrent' training programmes, involving endurance and strength training performed either within the same, or separate exercise sessions of a training programme are commonly prescribed for both healthy and clinical populations (Cadore et al., 2014; Ferrari et al., 2013; Galvao, Taaffe, Spry, Joseph, & Newton, 2009; Karavirta, Häkkinen, Kauhanen, et al., 2011). Combined training has been suggested as a more effective approach than either endurance or strength training alone because of the potential to impact upon multiple components of fitness simultaneously (Cadore & Izquierdo, 2013a; Cadore & Izquierdo, 2013b; Chodzko-Zajko et al., 2009). Despite the well documented and wide-ranging benefits of exercise training, few older adults currently meet physical

activity recommendations (Jefferis et al., 2014; Strain et al., 2016) with lack of time remaining one of the most commonly cited barriers to exercise in older adults (Lian et al., 1999; Rasinaho et al., 2006; Trost et al., 2002). Consequently, training programmes which require a reduced time commitment, via delivery of endurance and strength training within the same training session may be a more time-efficient, and thereby, attractive proposition for potential exercisers.

Although previous work has reviewed strategies and provided recommendations for prescription of combined exercise training (Cadore & Izquierdo, 2013a; Cadore & Izquierdo, 2013b), there is currently no systematic review examining the effect of same-session combined exercise training on measures of fitness in older adults. Accordingly, the aim here was to systematically review and meta-analyse the effects of same-session combined exercise training on measures of fitness in adults aged over 50 years, while also exploring the modifying effects of study and subject characteristics.

4.2 Methods

This review was undertaken in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher et al., 2009) and was prospectively registered on the International Prospective Register of Systematic Reviews (PROSPERO; Registration no. CRD42015019577 [Appendix D]).

4.2.1 Search strategy

Electronic searching of five databases (PubMed, MEDLINE, Scopus, BIOSIS and Web of Science) was performed from the earliest date available up to July 2016. Independent variable search terms were ‘multicomponent training’, ‘multicomponent exercise’, ‘circuit training’, ‘circuit resistance training’, ‘combined exercise training’, ‘combined training’, ‘multi-modal exercise training’, ‘same-session exercise’, ‘concurrent training’ and ‘concurrent exercise’. Dependent variable search terms were ‘functional fitness’, ‘functional performance’, ‘physical performance’, ‘quality of life’, ‘functional decline’, ‘aerobic fitness’, ‘strength’ and ‘power’. Independent variable search terms were

combined with dependent variable search terms, giving a total of 80 search combinations. Reference lists from retrieved studies were also examined for potentially eligible papers.

4.2.2 Inclusion criteria

Study design

This review considered only original research articles, published in English. Randomised and non-randomised controlled trials were included while uncontrolled, cross-sectional and single-group, pre-post studies were excluded.

Participants

Only studies involving healthy, community-dwelling participants aged >50 years were included. An age of 50 years was defined as the cut-off point for inclusion as per Straight et al. (Straight et al., 2016) as there are clear physical and physiological declines beyond this age in adults (Deschenes, 2004; Lynch et al., 1999; Metter et al., 1997). Additionally, evidence suggests that physical capability in midlife is predictive of physical performance in later life (Cooper et al., 2014) implying that earlier intervention ~50 years of age can have positive long-term implications. It is acknowledged however, that the use of an arbitrary threshold implies that chronological and biological age are synonymous; yet there remains no consensus on when old age begins suggesting that any arbitrary definition is likely to be imperfect (Tinkler, 1993).

Studies involving participants with non-communicable disease (e.g. cardiovascular disease, type 2 diabetes mellitus, cancers and chronic obstructive pulmonary disease) or who were being prescribed a specific pharmacological treatment were excluded. Studies were not excluded if participants were labelled as an alternative population group (e.g. obese) as these were considered an extension of a healthy population rather than a specific clinical group. For example, the study of Stewart et al. (2005) categorised their participants as having ‘untreated milder forms of hypertension’ so were suitable for inclusion. Often labelling of participant groups by authors included assessment of physical functioning with pre-determined cut-off values used to assess eligibility (e.g. King et al., 2002). As reduced levels of physical performance are a natural consequence

of ageing (Bassey et al., 1992; Morey et al., 1998) dichotomising the classification of 'healthy' or 'clinical' based on measures of physical functioning alone may be limited.

Training Interventions

To be considered for inclusion in this meta-analysis, studies were required to include at least one combined exercise training group and a comparator group of either 1) no-exercise control; 2) endurance training only; or 3) strength training only. To be considered 'combined training' each training session within the intervention had to contain discrete, standalone activities of 1) endurance training and 2) strength training. Endurance training was defined as exercise involving large muscle groups in dynamic activities that result in substantial increases in heart rate and energy expenditure and was not limited to any specific modes of exercise (Howley, 2001). Strength training was defined as any muscle strengthening activities where participants worked against or moved an external resistance (e.g. free weights, weight machines, elastic resistance bands, body weight exercises) (Garber et al., 2011; Howley, 2001). Interventions where training sessions contained further training elements targeting improvement in other components of fitness (i.e. balance, flexibility, coordination) were not excluded if endurance and strength training activities were present in each session. Activities prescribed as 'warm up' or 'recovery' were not considered. Training interventions were required to be a minimum of 2-week duration with all training sessions supervised to ensure the fidelity of the intervention as previous work has suggested that exercise adherence is generally higher in supervised programmes (Picorelli, Pereira, Pereira, Felício, & Sherrington, 2014). Studies involving nutritional interventions were only included if there was a combined training and a comparator group (described previously) which were not exposed to these interventions. Interventions labelled as 'circuit training' typically involving subjects performing resistance exercises interspersed with aerobic exercises (Ozaki, Kitada, Nakagata, & Naito, 2017) were not included as circuit training and combined training are two discrete training modes (Gettman, Ayres, Pollock, & Jackson, 1978; Gotshalk, Berger, & Kraemer, 2004).

Outcome measures

A range of outcome measures were selected to evaluate the effects of combined training

on the fitness components most relevant for maintaining functional capacity in older adults (e.g. cardiorespiratory fitness, lower body muscular power, balance and mobility [Morey et al., 1998; Paterson et al., 2004; Posner et al., 1995; Reid & Fielding, 2012]). Assessment of functional fitness (e.g. 30s chair stand, 8ft timed up-and-go) provides a composite measure of physical capability as successful performance on these tests is determined by several components of fitness (Lord et al., 2002; Mun-San Kwan, Lin, Chen, Close, & Lord, 2011), thereby providing a more functionally relevant and ecologically valid assessment of fitness (Weston et al., 2016). Accordingly, studies were required to contain at least one of the following outcome measures to be included in this meta-analysis: 1) Peak oxygen uptake ($\dot{V}O_{2peak}$) assessed via maximal incremental test – associated with the ability to maintain independent function and prevent disability (Fleg et al., 2005; Morey et al., 1998); 2) Six-minute walk test (6MWT) – a valid and reliable measure of physical endurance associated with self-reported functional ability with performance determined by leg strength and power (Bean et al., 2002; Rikli & Jones, 1998); 3) 8-ft Timed Up-and-go (TUG) – a composite measure of performance related to dynamic balance and mobility (Rikli & Jones, 1999) correlated with functional measures (e.g. stair climbing) (Bohannon, 2006); 4) 30-s chair stand – a valid measure of lower-body muscle functioning (Jones et al., 1999) capable of detecting change in functional capacity in older adults (Francis et al., 2017); 5) isometric handgrip strength – a measure of upper-body strength, important for maintaining the ability to perform basic tasks of daily living (Wennie Huang, Perera, VanSwearingen, & Studenski, 2010).

4.2.3 Study selection

To identify relevant studies, all records were screened independently for eligibility by the author and one other reviewer with any disagreements resolved by a third reviewer. Papers that were clearly not relevant were removed from the database list before assessing all other titles and abstracts using the pre-determined inclusion and exclusion criteria. Following this, full-text papers, including reviews, were then collected for evaluation. When full-texts were not available, the corresponding author was contacted. After removal of duplicates and elimination of papers based on title and abstract screening there were 351 studies remaining. After evaluation of full texts, there were 25 papers that met the inclusion criteria and were therefore included in the meta-analysis (Figure 4.1).

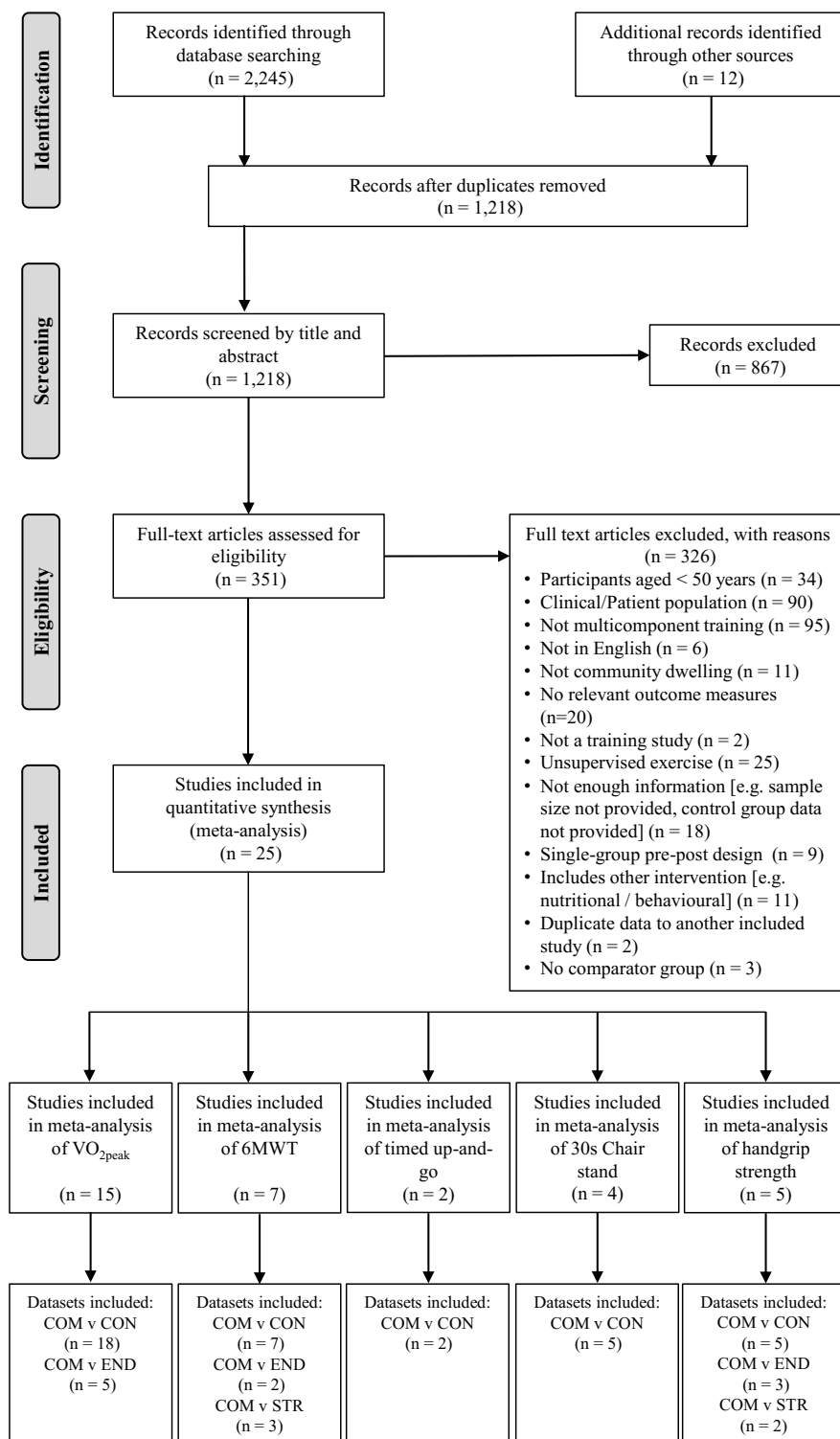


Figure 4.1 PRISMA flow diagram of the study selection process

COM, combined training; END, endurance training only, STR, strength training only; CON, no-exercise control

4.2.4 Data extraction

Data were extracted from eligible studies into a custom-made spreadsheet by the author with a second investigator checking the extracted data for accuracy. Mean and standard deviation of pre-training and post-training values along with sample size from combined and comparator groups were extracted for each outcome measure. In studies where standard deviations were not reported, they were calculated using the standard errors or confidence intervals provided (Higgins & Green, 2011). Data for potential moderator variables that could reasonably influence the overall effect of training on changes in fitness were also extracted. This included both participant (mean age, proportion of males, baseline fitness) and intervention characteristics (intervention duration [weeks], training frequency [sessions per week], exercise order [endurance or strength first]). Where intervention duration was expressed as months, this value was converted to weeks based on 1 month being equal to 4.3 weeks. Attempts were made to contact corresponding authors via email to obtain further information or clarity when needed.

As a number of included studies consisted of multiple arms (e.g. combined training vs no-exercise control, combined training vs endurance only), in order to avoid double counting in analysis – whereby individual participants are included twice, therefore affecting observed estimates – sample size was halved where necessary (Senn, 2009). Several studies (Carvalho et al., 2009; Douuda et al., 2015; King et al., 2002; Wang et al., 2015) reported data at several time points or after a period of detraining during an investigation, in all instances pre- and post-intervention data only was analysed. Details of included studies can be found at the end of this chapter (Table 4.2).

4.2.5 Risk of bias in individual studies

Study level risk of bias was assessed according to the Cochrane collaboration's tool for assessing risk of bias (Higgins & Green, 2011). Risk of bias was classified as being 'high', 'low' or 'unclear' across the following domains: randomisation, allocation concealment, blinding of participants and personnel, blinding of outcome assessors, incomplete outcome data, selective reporting and any other risk of bias.

4.2.6 Data analysis

Meta-analysis

All data analyses were performed using Comprehensive Meta-Analysis software, version 3 (Biostat Inc., Englewood, NJ, USA). Separate random effects meta-analyses were performed to determine the pooled effect of change in each outcome measure for 1) combined training compared with no-exercise control, 2) combined training compared with endurance training only and 3) combined training compared to strength training only. Uncertainty in the pooled effect was expressed as 95% confidence limits (CL) and also as probabilities that the true value of the effect was trivial, beneficial or harmful in relation to threshold values for benefit and harm (Batterham & Hopkins, 2006). These probabilities were then used to make a qualitative probabilistic inference about the overall effect (Hopkins et al., 2009). As enhanced physical functioning has clear clinical application (Cooper et al., 2014; Weston, Taylor, et al., 2014), meta-analysed effects were assessed using clinical inferences. Inferences were based on standardised thresholds for small, moderate and large changes of 0.2, 0.6 and 1.2 SDs respectively (Hopkins et al., 2009) and were derived by averaging appropriate between-subject variances. Magnitude thresholds for small, moderate and large effects, respectively were: $\dot{V}O_{2peak}$, 0.6, 1.8 and 3.7 mL·kg⁻¹·min⁻¹; 6MWT, 11.5, 34.6 and 69.2 m; TUG, 0.2, 0.6 and 1.2 s; 30s-sit-to-stand, 1, 3 and 6 repetitions (expressed as an integer as partial repetitions are not possible); handgrip strength, 0.8, 2.4 and 4.7 kg. Effects were considered unclear if the chance of benefit (improved performance) was high enough to warrant use of the intervention but with an unacceptable risk of harm (reduced performance). An odds ratio of benefit to harm of <66 was used to identify such unclear effects. The chance of the true effect being trivial, beneficial or harmful was then interpreted using the following scale: <0.5% most unlikely; 0.5-5% very unlikely; 5-25% unlikely; 25-75% possibly; 75-95% likely; 95-99.5% very likely; >99.5% most likely (Hopkins et al., 2009). Between-study heterogeneity (Tau [τ]) was expressed as an SD (Higgins, 2008), with the SD doubled to interpret its magnitude (Smith & Hopkins 2011).

Meta-regression

Meta-regression was performed to explore the effect of six putative moderator variables which could reasonably influence the effect of training on fitness. These were baseline fitness, intervention duration, weekly training frequency, exercise order (i.e. endurance or strength training performed first within a session), age and maleness (i.e. the proportion of males in the study sample). The modifying effects of these variables were calculated as the effect of two SDs (i.e. the difference between a typically low and a typically high value) (Hopkins et al., 2009). Meta-regression was performed only when there were >10 datasets (Higgins & Green, 2011).

Publication bias

Publication bias (Appendix E) was assessed using Egger's test to evaluate asymmetry of funnel plots (Egger, Smith, Schneider, & Minder, 1997). However, caution in interpreting these results is warranted when there are less than 10 studies in the meta-analysis as the power of the test is too low to distinguish chance from real asymmetry (Higgins & Green, 2011).

4.3 Results

4.3.1 Risk of bias

Risk of bias assessment is presented in figure 4.2. In all of the included studies it was not possible to blind participants to the treatment (i.e. exercise training). The majority of studies did not describe the process of sequence generation and allocation concealment in enough detail, meaning an ‘unclear’ risk of bias was reported.

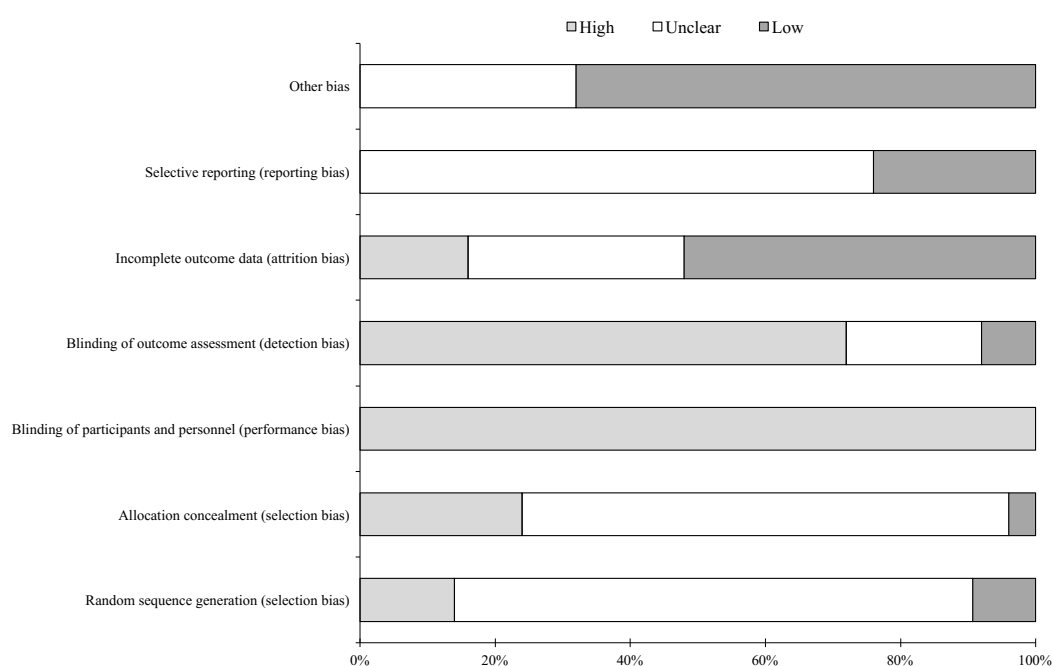


Figure 4.2 Risk of bias assessment

4.3.2 $\dot{V}O_{2peak}$

The meta-analysed effect of combined training, when compared to no-exercise controls (Figure 4.3a), was a possibly large (most likely moderate) beneficial effect on $\dot{V}O_{2peak}$ ($3.6 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$; $\pm 95\%$ confidence limits $0.8 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$). Between-study heterogeneity (τ) was $0.8 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ (magnitude small). Egger’s coefficient was -1.79 (95% CI -2.83 to -0.56 ; $p = 0.006$). Of the six moderator variables selected, meta-regression analysis revealed a possibly moderate influence for studies with a greater proportion of female participants ($2.4 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$; $\pm 2.4 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) and a likely

small influence of typically shorter training programmes ($1.3 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$; $\pm 1.2 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$). The combination of these two variables in the meta-regression reduced τ to 0. The effect of all other putative modifiers was unclear. When compared against endurance training only (Figure 4.3b), the meta-analysed effect of combined training was a possibly small beneficial effect on $\dot{V}O_{2\text{peak}}$ ($0.8 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$; $\pm 1.0 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$). Between-study variability was trivial ($\tau = 0 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) and Egger's coefficient was -0.41 (-1.62 to 0.80 ; $p = 0.36$).

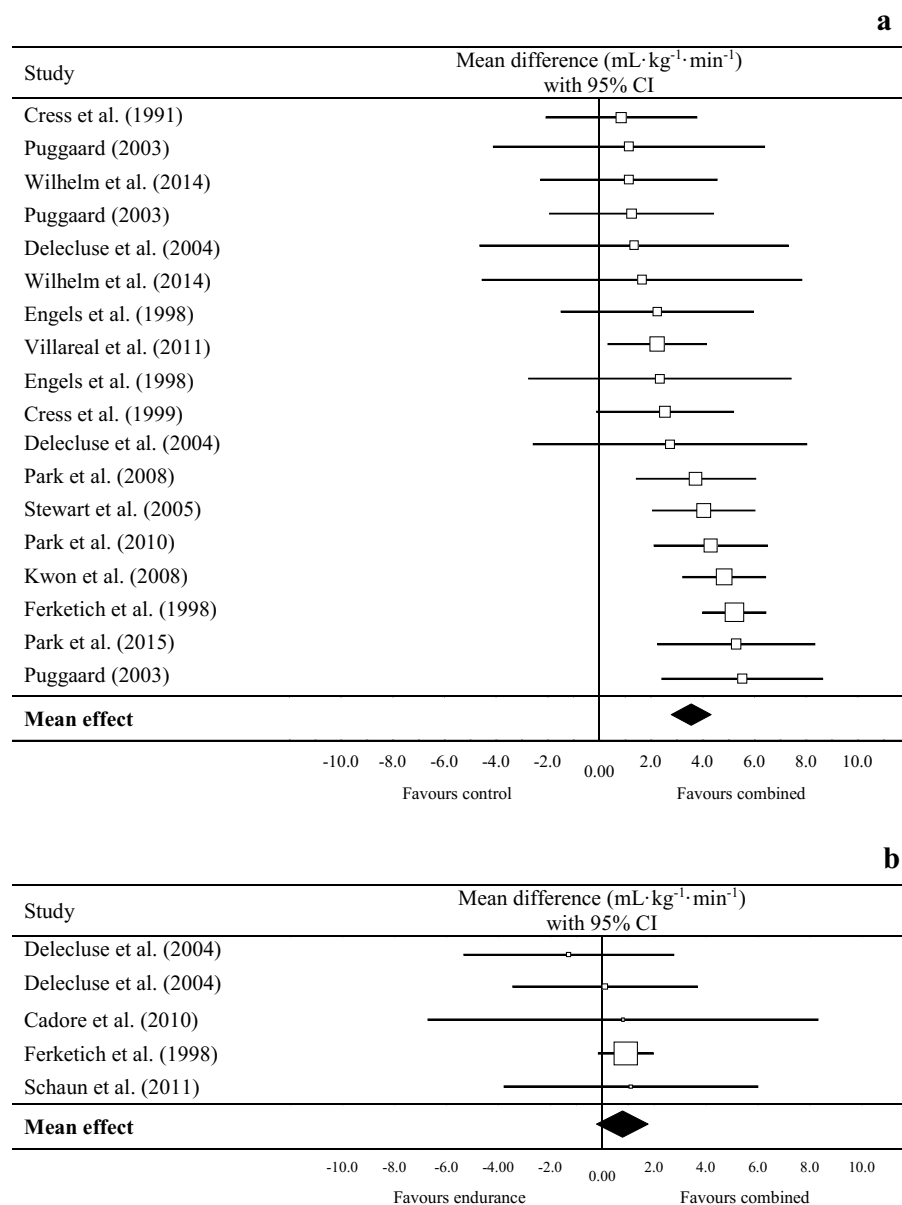


Figure 4.3 Effects of combined training on peak oxygen uptake ($\dot{V}O_{2\text{peak}}$). *CI*, confidence interval A) vs control; B) vs endurance only

4.3.3 6MWT

When compared to no-exercise controls (Figure 4.4a) there was a very likely small beneficial effect for combined training on 6MWT performance (31.5 m; \pm 22.4 m). Between study heterogeneity (τ) was moderate (19.2 m) while Egger's coefficient was 1.03 (-2.50 to 4.57; $p = 0.49$). The meta-analysed effects of combined training compared with endurance training only (25.9 m; \pm 25.9 m) (Figure 4.4b) and strength training only (4.7 m; \pm 22.1 m) (Figure 4.4c) were both unclear. For combined training versus endurance training only there were only two datasets from one study so assessment of publication bias was not possible while for combined training versus strength training only, Egger's coefficient was 0.47 (-3.26 to 4.20; $p = 0.36$).

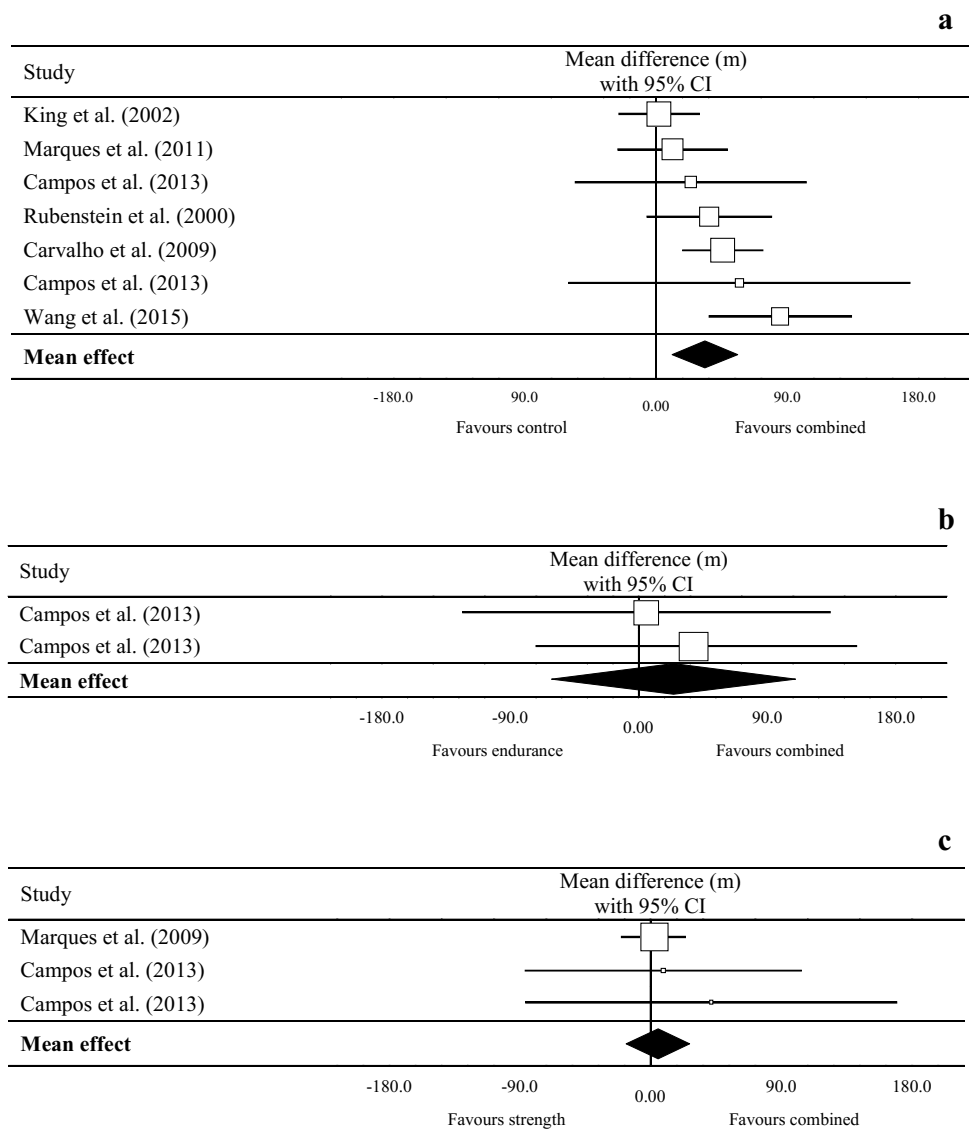


Figure 4.4 Effects of combined training on six-minute walk test performance (6MWT). *CI*, confidence interval A) vs control; B) vs endurance only; C) vs strength only

4.3.4 TUG

The meta-analysed effect of combined training compared with no-exercise controls (Figure 4.5) was a very likely moderate beneficial effect on timed up-and-go performance (0.8 s; ± 0.7 s). Between-study heterogeneity (τ) was moderate (0.4 s).

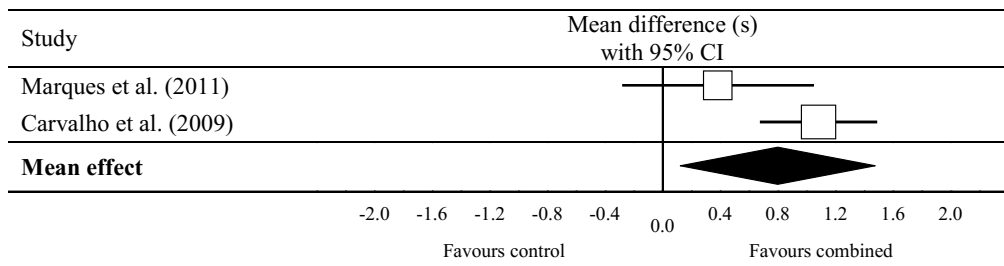


Figure 4.5 Effects of combined training compared to control on Timed Up-and-go performance (TUG). *CI*, confidence interval

4.3.5 30-s chair stand

Compared to no-exercise controls, the meta-analysed effect of combined training (Figure 4.6) was a possibly moderate beneficial effect on 30-s chair stand performance (2.8 repetitions; ± 1.7 repetitions). Between-study heterogeneity was moderate (1.7 repetitions) and Egger's coefficient was -0.58 (-8.78 to 7.63; $p = 0.84$).

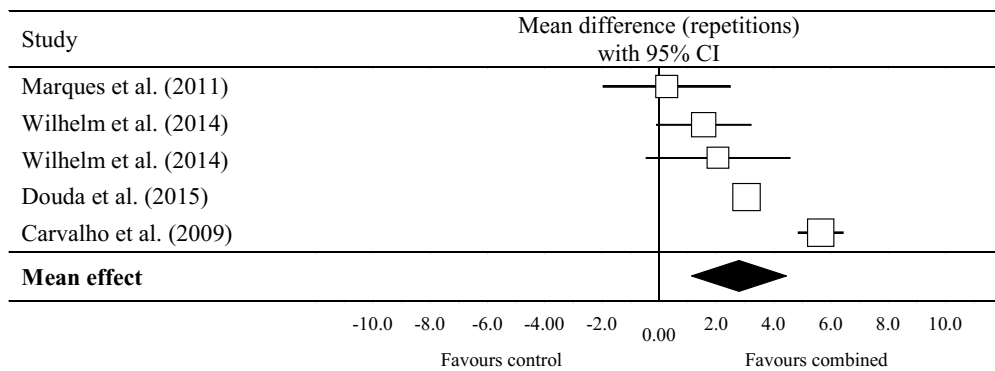


Figure 4.6 Effects of combined training compared to control on 30-s chair stand performance. *CI*, confidence interval

4.3.6 Handgrip strength

When compared with no-exercise controls, the meta-analysed effect of combined training (Figure 4.7a) was a most likely moderate beneficial effect on handgrip strength (2.9 kg; ± 5.3 kg). Between study heterogeneity was trivial (0.0 kg) and Egger's coefficient was 0.004 (-2.44 to 2.45; $p = 1.00$). When compared with endurance training only (0.5 kg; ± 3.7 kg) (Figure 4.7b) and strength training only (1.8 kg ± 5.3 kg) (Figure 4.7c) effects were unclear. For combined training compared to endurance training only Egger's coefficient was 0.46 (-4.75 to 5.66; $p = 0.47$).

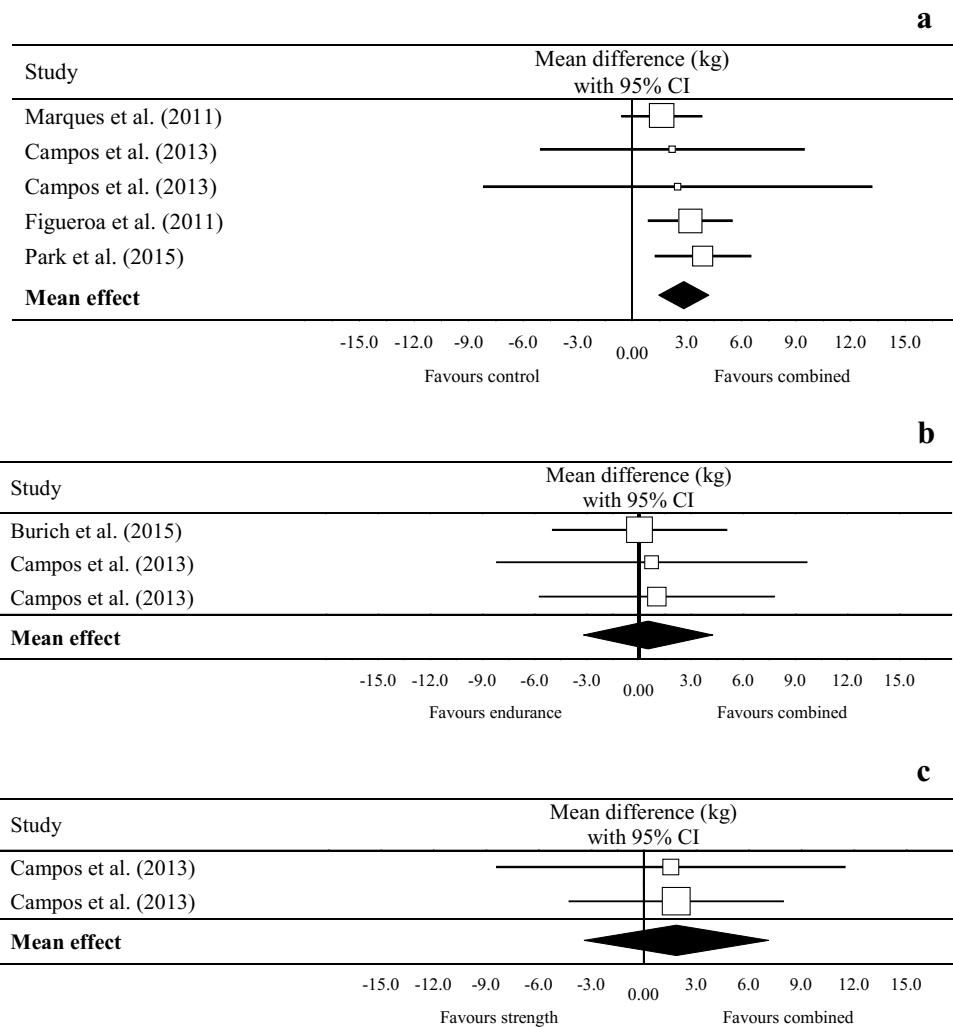


Figure 4.7 Effects of combined training on handgrip strength. *CI*, confidence interval A) vs control; B) vs endurance only; C) vs strength only

4.4 Discussion

The present investigation has systematically reviewed and quantified the effects of same-session combined training on measures of fitness in adults aged over 50 years with results demonstrating clear beneficial effects for combined training on $\dot{V}O_{2\text{peak}}$, 6MWT, Timed Up-and-go, 30-s chair stand and handgrip strength when compared with no-exercise controls. In addition, there was a small beneficial effect for combined training when compared to endurance training only for $\dot{V}O_{2\text{peak}}$.

The data reported in this investigation confirm the findings of previous experimental studies (Cadore et al., 2010; Ferketich et al., 1998; Stewart et al., 2005) demonstrating that combined training – advocated as a method for simultaneously improving cardiorespiratory and muscular fitness (Cadore & Izquierdo, 2013a; Cadore et al., 2014) – is an effective training strategy for improving $\dot{V}O_{2\text{peak}}$. The meta-analysed effect reported here is comparable to previous meta-analyses reporting mean effects of $3.78 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ (Huang et al., 2005) and $3.5 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ (Green & Crouse, 1995) following endurance training in older adults, suggesting that combined training may be as effective for cardiorespiratory fitness improvement as traditional endurance training alone. Supporting these meta-analyses, previous experimental studies evaluating the application of endurance training in older adults have demonstrated its effectiveness as a training strategy, reporting improvements in $\dot{V}O_{2\text{peak}}$ ranging from $\sim 15\text{-}38\%$ (Kohrt et al., 1991; Makrides et al., 1990; Stratton et al., 1994). The mean effect on $\dot{V}O_{2\text{peak}}$ reported in this meta-analysis ($\sim 16\%$ increase from baseline) is comparable to these findings. However, between-study differences in training (e.g. training volume and intensity) and participant characteristics (e.g. baseline $\dot{V}O_{2\text{peak}}$, age, sex) likely contribute to the observed variability in findings.

When compared with endurance training alone, combined training had a possibly small beneficial effect on $\dot{V}O_{2\text{peak}}$. Although the present investigation has not sought to understand the mechanisms of adaptation underlying training induced changes, central and peripheral adaptations to endurance training improving delivery, utilisation and extraction of oxygen may explain increased $\dot{V}O_{2\text{peak}}$ (Bassett & Howley, 2000; Holloszy & Coyle, 1984). In the context of combined training, it may be that the inclusion of

strength training provides an additive benefit with previous investigations reporting improvements in cardiorespiratory fitness following strength training (Ozaki et al., 2013) mediated by increases in capillary density and mitochondrial enzyme activity (Frank et al., 2016; Frontera et al., 1990; Hepple et al., 1997). Furthermore, improvements in lower body strength may lead to increased time to exhaustion on an incremental exercise test, thereby increasing observed $\dot{V}O_{2\text{peak}}$ (Karavirta, Häkkinen, Kauhanen, et al., 2011).

The effect of combined training on $\dot{V}O_{2\text{peak}}$ was greater for female participants, a finding in contrast to that of Weston, Taylor, et al. (2014) who reported an unclear modifying effect for females following HIT ($-2.5 \pm 90\%$ confidence limits $4.1 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$). This finding may be related to lower baseline fitness observed in females compared to males (Fleg & Lakatta, 1988; Fleg et al., 2005). There was also a likely small influence for shorter training programmes, a potentially significant finding with important practical implications as training programmes requiring a reduced time commitment may be more appealing to potential exercisers (Vollaard, Metcalfe, & Williams, 2017; Vollaard & Metcalfe, 2017). Further research is needed to develop an understanding of the sex-specific responses to combined exercise training and the modifying effects of training programming variables.

As well as cardiorespiratory fitness, maintaining muscular fitness is a primary aim of exercise training interventions in older adults (Evans, 2000) because of the role it plays in determining functional capacity with ageing (Foldvari et al., 2000; Manini & Clark, 2012; Reid & Fielding, 2012). Multiple methods of assessment should be used to evaluate training induced changes in muscular fitness (Buckner et al., 2017) with functional fitness tests recommended to evaluate performance in the context of the activities of daily living (Weston et al., 2016). The present investigation reported a very likely small beneficial effect on 6MWT for combined training compared with no-exercise controls, while there were very likely moderate beneficial and most likely large beneficial effects for timed up-and go and 30-s chair stand, respectively. Typically, these measures reflect overall physical functioning (Lord & Menz, 2002; Rikli & Jones, 1998) with muscle strength, power, mobility and balance all contributing to successful performance (Bean et al., 2002; Rikli & Jones, 1998). Previous work has demonstrated that both endurance training (Kalapotharakos et al., 2006) and resistance training (Coetsee & Terblanche, 2015; Stec

et al., 2017) performed in isolation are effective at eliciting positive adaptations in these measures of functional fitness. For example, Kalapotharakos and colleagues (Kalapotharakos et al., 2006) evaluated the effects of 12 weeks of progressive high-intensity endurance training performed three times per week and reported a 17% increase in 6WMT distance. This improvement was greater than the effect reported in this meta-analysis however, the baseline fitness of the participants in the Kalapotharakos et al. (2006) was lower. When considering resistance training only, the study of Stec et al (2017) evaluated changes in 6MWT performance following 35 weeks of high-intensity resistance reporting improvements of 32 m in the group that trained three times per week and 42 m in the group that trained twice weekly. As with $\dot{V}O_{2peak}$, improvements in measures of functional fitness are likely to be related to participant and training characteristics which result in differences in observed effects between studies.

The present meta-analysis also reported a most likely beneficial effect on handgrip strength for combined training, demonstrating that improvements in upper-body fitness are possible using this training approach. This observed improvement is greater than that of Pereira et al. (2012) who reported improvements of 5% (dominant hand) and 6.9% (non-dominant hand) after 12-weeks of high-speed power training. However, between-study differences (e.g. baseline grip strength) make it difficult to draw conclusive inference from this data. Importantly, increases in handgrip strength are functionally significant for older adults, who require upper-body muscular fitness to effectively perform the activities of daily living (Landers et al., 2001), while a 5 kg reduction in handgrip strength is associated with increased odds of difficulty performing activities of daily living (Ensrud et al., 1994).

It is well documented that strength training is an effective approach for improving muscular fitness (Fiatarone et al., 1994; Fielding et al., 2002; Joszi et al., 1999) and functional performance in older adults (Fiatarone et al., 1990; Skelton, Young, Greig, & Malbut, 1995) with training induced changes in muscular strength often translated into improvements in functional performance. For example, lower extremity strength gain is associated with chair rise performance, gait speed and mobility tasks (Chandler, Duncan, Kochersberger, & Studenski, 1998) while strength training can improve muscle power of the lower-body muscle groups relevant for carrying out daily functional tasks (Straight et al., 2016). It seems likely therefore, that performing strength training within a combined

training programme contributes to the observed improvements reported in this investigation with these changes mediated by a range of morphological and neurological adaptations (Folland & Williams, 2007). These findings have important practical implications in older adults as functional fitness is associated with reduced risk of disability and enhanced functional independence in older adults (Guralnik, Ferrucci, Simonsick, Salive, & Wallace, 1995; Misic et al., 2007). In the wider context of exercise training in older adults, the observed findings are largely unsurprising based on the principle of training specificity (Holloosy & Coyle, 1984; Astrand & Rodahl, 1986). Both endurance and strength training are effective approaches for improving cardiorespiratory and muscular fitness respectively, in older adults. Conceptually therefore, it makes sense that the combination of these training modes would elicit fitness improvements across both systems.

The pooled effects presented in this meta-analysis provide an overall quantification of the effects of same-session combined training which can be used for comparison and assessment of superiority with alternative modes of exercise training in subsequent investigations. One potential comparator mode is high-intensity interval training (HIT). Conceptually this comparison makes sense as HIT is also capable of inducing improvements in both cardiorespiratory and muscular fitness with an exercise stimulus delivered within a single exercise session (Adamson et al., 2014; Buckley et al., 2015; Sculthorpe et al., 2017; Wang et al., 2014). While long-term studies evaluating HIT in older adults are limited, current findings are encouraging as previous authors have shown that HIT favours older and less fit individuals (Milanovic et al., 2015; Weston, Taylor, et al., 2014) with significant improvements in fitness possible after a training programme of 6-12 weeks (Grace et al., 2015; Østerås et al., 2005; Sculthorpe et al., 2017; Wang et al., 2014). Within the context of this thesis, the mean effects reported for $\dot{V}O_{2\text{peak}}$ and handgrip strength in this meta-analysis will be used to contextualise any training induced changes observed in the following intervention study (chapter 6).

The findings presented in the current investigation may be interpreted with caution for a number of reasons. Firstly, the inclusion of only healthy community dwelling adults aged over 50 years limits the generalisability of these results as they should not be extrapolated more widely to include frail elderly or adults with chronic long-term conditions. Secondly, several of the analyses presented are limited by the small numbers of eligible

studies, which combined with the between-study heterogeneity may have affected the magnitude of observed effects and the uncertainty of these effects (e.g. the width of the reported CIs). One of the principle factors explaining the small number of included studies is the large variation in outcome measures used by different authors and research groups to evaluate training interventions. This is typified by the timed up-and-go test considered in this meta-analysis which included only studies which used the 8-ft (2.44 m) protocol compared to the original version of this test performed over a 3-m distance (Podsiadlo & Richardson, 1991). The shorter version of the test is preferable as it is simpler and more feasible to perform in the home environment (Rikli & Jones, 1999). This meant that studies were excluded – despite meeting all the other inclusion criteria – because the test was performed over a different distance. Although challenging to implement, standardised recommendations for a battery of physical capacity tests to evaluate training interventions in older adults would aid future attempts at synthesising research findings.

Finally, the practical implications of this work are limited by the wide variability of training programmes and incomplete reporting within the included studies. Exercise volume and intensity are both important mediators of training adaptation for both endurance and strength training (Gormley et al., 2008; Shephard, 1968; Steib et al., 2010), yet the reporting of this data was inconsistent or missing across a number of included studies. As such, it was not possible to extract and evaluate the effects of exercise intensity on outcomes following combined training. While authors of systematic reviews and meta-analyses can attempt to find further information about the study characteristics, this is a time consuming, and often ineffective process (Tew, Brabyn, Cook, & Peckham, 2016). As such, the present meta-analysis is in agreement with Straight et al. (2016) who have called for standardised reporting of exercise training protocols to enable researchers to fully quantify the effects of training in future meta-analyses. This should include the presentation of training programming variables (e.g. training intensity, volume, frequency and duration) as well as information about the fidelity of the intervention (Taylor et al., 2015; Weston, Taylor, et al., 2014).

4.5 Conclusion

The present meta-analysis provides further evidence supporting the effectiveness of combined exercise training in older adults, demonstrating that same-session combined exercise is capable of promoting improvements in cardiorespiratory, muscular and functional fitness when compared with no exercise control in adults aged over 50 years. However, comparison of combined training with either endurance training or strength training performed in isolation is limited because of lack of available data. Where comparisons are possible, between study differences in training related and participant related characteristics likely contribute to the discordance in findings between studies. Future work should seek to understand the modifying effects of exercise programming variables (e.g. volume, intensity) on training outcomes to inform future training prescription. The quantitative mean effects presented in this chapter allow for comparison between same-session combined training and alternative training interventions and this data will be used to contextualise and evaluate changes in fitness from 12-weeks of Speedflex HIT presented in chapter 6.

Table 4.1 Study characteristics for the meta-analysed studies (in alphabetical order)

Study	Group	Sample size	Mean age, y	Proportion of males	Intervention duration (weeks)	Training frequency (per week)	Exercise mode		Exercise order (END or STR)	Outcome measures
							END	STR		
Burich et al. (2015)	COM	16	62.7	0.19	12	3	Cycle	RM	END	Handgrip
Burich et al. (2015)	END	17	63.6	0.18	-	-	-	-	-	Handgrip
Cadore et al. (2010)	COM	8	66.8	1.00	12	3	Cycle	RM	END	$\dot{V}O_{2peak}$
Cadore et al. (2010)	STR	8	64.0	1.00	-	-	-	-	-	$\dot{V}O_{2peak}$
Cadore et al. (2010)	END	7	64.4	1.00	-	-	-	-	-	$\dot{V}O_{2peak}$
Campos et al. (2013)	COM	5	62.0	0.00	12	3	Treadmill walking	RM	END	6MWT, handgrip
Campos et al. (2013)	COM	5	66.0	0.00	12	3	Treadmill walking	RM	STR	6MWT, handgrip
Campos et al. (2013)	END	5	63.6	0.00	-	-	-	-	-	6MWT, handgrip
Campos et al. (2013)	STR	4	70.0	0.00	-	-	-	-	-	6MWT, handgrip
Campos et al. (2013)	CON	3	74.0	0.00	-	-	-	-	-	6MWT, handgrip
Carvalho et al. (2009)	COM	32	68.4	0.00	35	2	Walking, Dance, Aerobics, Jogging	Elastic bands, FW	END	6MWT, TUG, Sit-to-stand
Carvalho et al. (2009)	CON	25	69.6	0.00	-	-	-	-	-	6MWT, TUG, Sit-to-stand
Cress et al. (1991)	COM	17	71.1	0.00	50	3	Stair climbing	BW, Elastic bands	STR	$\dot{V}O_{2peak}$
Cress et al. (1991)	CON	10	73.3	0.00	-	-	-	-	-	$\dot{V}O_{2peak}$
Cress et al. (1999)	COM	23	75.6	?	26	3	Stairmaster	RM, FW	?	$\dot{V}O_{2peak}$

Cress et al. (1999)	CON	26	76.0	?	-	-	-	-	-	$\dot{V}O_{2peak}$
Delecluse et al. (2004)	COM	20	63.8	1.00	20	2.5	Cycling, walking	RM	END	$\dot{V}O_{2peak}$
Delecluse et al. (2004)	COM	21	63.7	1.00	20	2.5	Cycling, walking	RM	END	$\dot{V}O_{2peak}$
Delecluse et al. (2004)	END	21	64.5	1.00	-	-	-	-	-	$\dot{V}O_{2peak}$
Delecluse et al. (2004)	CON	13	61.5	1.00	-	-	-	-	-	$\dot{V}O_{2peak}$
Douda et al. (2015)	COM	10	65.6	0.00	39	3	Aerobic dance, stepping	BW, elastic bands, FW	END	Sit-to-stand
Douda et al. (2015)	END	12	63.8	0.00	-	-	-	-	-	Sit-to-stand
Douda et al. (2015)	STR	10	62.1	0.00	-	-	-	-	-	Sit-to-stand
Douda et al. (2015)	CON	10	66.2	0.00	-	-	-	-	-	Sit-to-stand
Engels et al. (1998)	COM	10	68.6	0.00	10	3	Dance aerobics	BW, elastic bands	END	$\dot{V}O_{2peak}$
Engels et al. (1998)	COM	10	68.6	0.20	10	3	Dance aerobics	BW, elastic bands	END	$\dot{V}O_{2peak}$
Engels et al. (1998)	CON	11	68.6	0.18	-	-	-	-	-	$\dot{V}O_{2peak}$
Ferketich et al. (1998)	COM	7	67.2	0.00	12	3	Cycle	RM	END	$\dot{V}O_{2peak}$
Ferketich et al. (1998)	END	8	69.2	0.00	-	-	-	-	-	$\dot{V}O_{2peak}$
Ferketich et al. (1998)	CON	6	69.8	0.00	-	-	-	-	-	$\dot{V}O_{2peak}$
Figueroa et al. (2011)	COM	12	54.0	0.00	12	3	Treadmill walking	RM	STR	Handgrip
Figueroa et al. (2011)	CON	12	54.0	0.00	-	-	-	-	-	Handgrip
King et al. (2002)	COM	80	77.0	0.23	13	3	Walking	BW, Velcro closure weights	END	6MWT

King et al. (2002)	CON	75	77.9	0.20	-	-	-	-	-	6MWT
Kwon et al. (2008)	COM	20	77.4	0.00	24	3	Low impact aerobics exercises	BW	END	$\dot{V}O_{2peak}$
Kwon et al. (2008)	CON	20	77.0	0.00	-	-	-	-	-	$\dot{V}O_{2peak}$
Marques et al. (2009)	COM	36	68.6	0.00	35	2	Walking, Jogging, Dance, Aerobics	Elastic bands, FW	END	6MWT
Marques et al. (2009)	STR	38	68.1	0.00	-	-	-	-	-	6MWT
Marques et al. (2011)	COM	30	70.1	0.00	32	2	Marching, stepping	Elastic bands, FW, weighted vests	END	6MWT, TUG, Sit-to- stand, handgrip
Marques et al. (2011)	CON	30	68.2	0.00	-	-	-	-	-	6MWT, TUG, Sit-to- stand, handgrip
Park et al. (2008)	COM	25	68.3	0.00	48	3	?	?	STR	$\dot{V}O_{2peak}$
Park et al. (2008)	CON	25	68.4	0.00	-	-	-	-	-	$\dot{V}O_{2peak}$
Park et al. (2010)	COM	10	66.1	0.00	12	3	Walking	Elastic bands	END	$\dot{V}O_{2peak}$
Park et al. (2010)	CON	10	67.7	0.00	-	-	-	-	-	$\dot{V}O_{2peak}$
Park et al. (2015)	COM	10	57.2	0.00	12	3	Treadmill	RM	END	$\dot{V}O_{2peak}$, handgrip
Park et al. (2015)	CON	10	57.2	0.00	-	-	-	-	-	$\dot{V}O_{2peak}$, handgrip
Puggaard (2003)	COM	12	65.0	0.00	35	1	Walking	Elastic bands, BW	END	$\dot{V}O_{2peak}$
Puggaard (2003)	COM	12	75.0	0.00	35	2	Walking	Elastic bands, BW	END	$\dot{V}O_{2peak}$

Puggaard (2003)	COM	17	85.0	0.00	35	1	Walking	Elastic bands, BW	END	$\dot{V}O_{2peak}$
Puggaard (2003)	CON	2	65.0	0.00	-	-	-	-	-	$\dot{V}O_{2peak}$
Puggaard (2003)	CON	23	75.0	0.00	-	-	-	-	-	$\dot{V}O_{2peak}$
Puggaard (2003)	CON	16	85.0	0.00	-	-	-	-	-	$\dot{V}O_{2peak}$
Rubenstein et al. (2000)	COM	31	76.4	1.00	12	3	Cycle, treadmill, indoor walking	Ankle bands, elastic bands, wrist weights	STR	6MWT
Rubenstein et al. (2000)	CON	28	74.4	1.00	-	-	-	-	-	6MWT
Schaun et al. (2011)	COM	10	54.0	1.00	12	3	Cycle	RM	END	$\dot{V}O_{2peak}$
Schaun et al. (2011)	END	10	54.0	1.00	-	-	-	-	-	$\dot{V}O_{2peak}$
Stewart et al. (2005)	COM	51	63.0	0.49	26	3	Treadmill, cycle, stepper	RM	STR	$\dot{V}O_{2peak}$
Stewart et al. (2005)	CON	53	64.1	0.49	-	-	-	-	-	$\dot{V}O_{2peak}$
Villareal et al. (2011)	COM	26	70.0	0.38	52	3	Walking, cycling, stair climbing	RM	END	$\dot{V}O_{2peak}$
Villareal et al. (2011)	CON	27	69.0	0.33	-	-	-	-	-	$\dot{V}O_{2peak}$
Wang et al. (2015)	COM	17	70.3	0.24	12	3	Stepping, marching, walking	?	STR	6MWT
Wang et al. (2015)	CON	12	70.5	0.33	-	-	-	-	-	6MWT
Wilhelm et al. (2014)	COM	12	67.1	1.00	12	2	Cycle	RM, FW	STR	$\dot{V}O_{2peak}$, Sit-to-stand
Wilhelm et al. (2014)	COM	11	63.2	1.00	12	2	Cycle	RM, FW	END	$\dot{V}O_{2peak}$, Sit-to-stand
Wilhelm et al. (2014)	CON	13	65.8	1.00	-	-	-	-	-	$\dot{V}O_{2peak}$, Sit-to-stand

Abbreviations: COM, combined training; END, endurance training only; STR, strength training only; CON, Non-exercise control group; R, randomised; NR, Non-randomised, $\dot{V}O_{2peak}$, peak oxygen uptake; 6MWT, 6-minute walk test; TUG, Timed-up-and-go; -, indicates not applicable; ?, indicates data not available; FW, free weights; BW, body weight exercises; RM, resistance machines; Cycle, cycle ergometer

CHAPTER 5: SHORT- AND LONG-TERM RELIABILITY OF LEG EXTENSOR POWER MEASUREMENT IN OLDER ADULTS ¹

Chapter four quantified the effects of same-session combined training in older adults, observing clear beneficial effects for combined training compared with no-exercise control for $\dot{V}O_{2peak}$, 6MWT, Timed up-and-go, 30s chair stand and handgrip strength. Chapter five evaluates the short- and long-term reliability of leg extensor power measurement in older adults.

5.1 Introduction

Given the importance of lower body muscular power as a determinant of physical functioning in older adults (Bassey et al., 1992; Harridge et al., 1999; Puthoff et al., 2008; Reid & Fielding, 2012; Skelton et al., 1994; Suzuki et al., 2001), its assessment is an important tool for practitioners wishing to monitor and evaluate functional capacity, as well as for researchers intending to quantify training intervention outcomes. One device used for evaluating functional lower body muscle power in older adults is the leg extensor power rig (Medical Engineering Unit, University of Nottingham, Nottingham, UK) (Figure 5.1). This equipment provides a functional method for the assessment of leg extensor power (Bassey and Short, 1990; Bassey et al. 1992) employing similar muscle groups and joint angles to those used in activities such as stair climbing and rising from a chair (Bassey and Short, 1990). Lower-body muscle power measured using the leg extensor power rig has been shown to be a predictor of physical function in older adults (Straight et al., 2015a; Straight et al., 2015b), while the non-impact nature of the movement and simplicity of the test itself make it an appealing measurement tool.

To enable informed decision making about the appropriateness of a test, as well as future sample-size estimation, practitioners and researchers require an understanding of its reliability (Atkinson and Nevill, 1998), as high test re-test reliability facilitates the quantification of changes that are small, yet could be practically important (Hopkins, 2015). The reliability of test performance refers to the consistency or reproducibility of

¹ The work presented in this chapter has been accepted for publication in the Journal of Sports Sciences. doi:10.1080/02640414.2017.1346820

performance when the test is performed repeatedly (Hopkins, Schabert, & Hawley, 2001) and a statistic which captures the variability in repeated testing is the typical error (Hopkins, 2000). For many measurements in sports science and medicine, the typical error increases as the value of the measure increases (Nevill & Atkinson, 1997). As such, typical error is best expressed as a percentage of the mean (Coefficient of variation; CV) (Hopkins, 2000), which as a dimensionless measure also enables comparison of reliability between equipment, tests and subject populations.

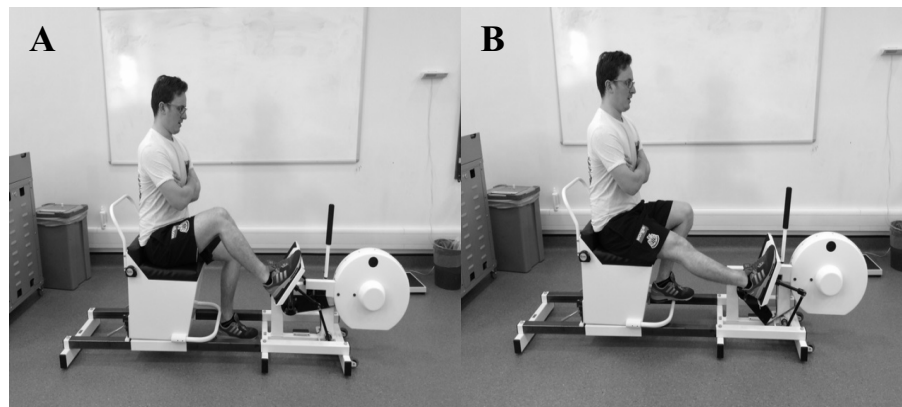


Figure 5.1 Nottingham leg extensor power rig

A, body position at commencement of movement; B, body position at completion of movement

In the original investigation of the leg extensor power rig, a CV of 9.4% in 46 participants (age range: 20-86 years) across two trials (a test-retest design) was reported (Bassey & Short, 1990). More recent investigations into the leg extensor power rig in older men ($n=55$, mean age 73 years [Blackwell, Cawthon, Marshall, & Brand, 2009]; $n=73$ men, age range 60-87 years [Schroeder et al., 2007]) and older women ($n=35$, aged >65 years [Skelton et al., 2002]), have reported test-retest CVs, calculated using different methods, ranging from <8% to 15.5%. A limitation of these reliability studies is that they provide information relating only to short-term reliability as CVs were calculated over two trials, usually performed one week apart. These data are of limited use within this programme of work as the Nottingham leg rig is to be used as the primary outcome measure in a 12-week intervention study (chapter 6). This means that for sample-size estimation, reliability over the same duration as the planned intervention is needed (Hopkins, 2000). As such, the primary aim of this study was to rigorously evaluate the short- and long-term reliability (i.e. mean change, typical error and test re-test correlation) of the leg extensor power rig in a large sample of older adults tested on multiple occasions to assess

usefulness as an outcome measure for the final experimental study of this thesis. The secondary aim of this investigation was to perform sample-size estimation for the final experimental study of this thesis (chapter 6) using the data collected.

5.2 Methods

5.2.1 Experimental approach

To examine the reliability of the leg extensor power rig, all participants completed five trials. As at least four trials are typically needed to properly assess habituation effects in laboratory tests (Hopkins, 2015), to evaluate short-term reliability participants were tested on four occasions with ~72h apart (Trials 1-4). After these four trials, all participants returned 12 weeks later to complete a fifth trial (Trial 5), thus enabling the evaluation of long-term reliability (Figure 5.2).

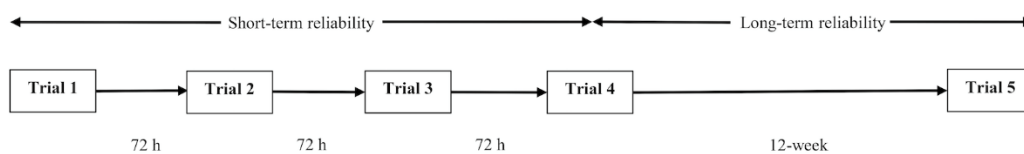


Figure 5.2 Schematic of study design

5.2.2 Participants

A total of 72 community dwelling adults aged 50-83 years took part in this investigation. Participants were physically active but were not currently, and had not in the previous year, engaged in structured exercise more than twice per week. Participants were recruited via word of mouth and advertisement at local fitness clubs, community groups and local offices. Prior to enrolment, all participants completed a medical screening questionnaire to identify any medical issues that could affect their ability to perform the required exercise. Participants with pre-existing, lower-body musculoskeletal complaints or systemic disease (e.g. diabetes mellitus, cancer, heart disease) were excluded. Following initial screening participants were excluded because of pre-existing

musculoskeletal problems (n = 8) and engaging in structured exercise training (n=3). Six participants withdrew citing lack of time while one participant withdrew during the investigation because of an injury unrelated to the study. The final sample consisted of 38 males and 34 females. All individual subjects provided written, informed consent to participate in the study, which conformed to the requirements of The Declaration of Helsinki and was approved by Teesside University Research and Ethics Committee (Appendix F). Participant characteristics are presented in Table 5.1.

Table 5.1 Participant characteristics (n = 72)

	Male	Female
Sample size	38	34
Age (yr)	62.5 ± 8.2	62.8 ± 9.2
Height (cm)	175.0 ± 5.6	162.5 ± 6.0
Body mass (kg)	88.4 ± 13.8	73.1 ± 15.9
Body Mass Index (kg/m ²)	28.8 ± 3.8	27.6 ± 5.0

Data presented as mean ± SD

5.2.3 Experimental procedures

Participants were assessed on dominant and non-dominant legs separately, with the dominant leg determined via a modified version of the lateral preference inventory (Coren, 1993). Testing was performed in a randomised, counterbalanced order with participants performing all testing sessions in the same order (e.g. always dominant leg first or always non-dominant leg first based on initial randomisation). All testing was performed at the same time of the day to minimise the impact of circadian variation on leg extensor power (Atkinson & Reilly, 1996) and participants were asked to avoid strenuous physical activity and alcohol in the 24 h prior to each testing session. During the intervening 12-week period, participants were instructed to maintain their habitual physical activity and not engage in any additional structured exercise.

For body and seat positioning on the power rig, we followed the testing procedures previously described by Bassey & Short (1990). Briefly, participants were seated with a

flexed knee in an upright position with arms folded across the chest. Participants performed a unilateral leg extension until the footplate was fully depressed while the free foot rested on the floor. Seat position was determined so that the leg reached full extension at the end of the footplate movement (0.165 m). Seat position was recorded to ensure standardisation across all trials. Participants were asked to wear flat, comfortable lace-up shoes and to wear the same footwear during each trial. Participants completed a standardised warm-up prior to the testing protocol, which consisted of three warm-up leg extensions at increasing submaximal intensity (~50, ~75 and ~90% of self-perceived maximal effort). Following completion of the warm-up, participants performed the first leg extension within 45 s. Ten maximal effort leg extensions, each separated by 30 s of passive rest were performed with participants asked to extend their leg “as hard and as fast as possible” each time. After assessment of the first leg, participants then performed the same standardised warm up as previously described, followed by the testing protocol on the second leg. The highest value recorded over the ten leg extensions was taken as the subject’s peak power output for data analysis. Strong verbal encouragement was provided throughout and the first author supervised all testing sessions.

5.3.4 Statistical analysis

Analyses were stratified by sex and lateral preference (dominant/ non-dominant leg). Descriptive statistics were calculated for peak power and reported as mean \pm SD. All analyses were performed on log-transformed data to reduce the effect of non-uniformity of error. The custom-made reliability spreadsheet of Hopkins (2015) was used, as this spreadsheet provides pairwise analyses of consecutive trials (Trial 1 v Trial 2, Trial 2 v Trial 3, Trial 3 v Trial 4, Trial 4 v Trial 5) to properly assess habituation and measurement reliability. Inferences for the between-trial changes in percentage peak power output were subsequently based on standardised thresholds for trivial, small and moderate differences of <0.2, 0.2 and 0.6 of the pooled between-subject standard deviations (Hopkins et al. 2009). Here, the range of thresholds for small and moderate were 5.5% to 6.8% and 17.4 to 21.7%, respectively. Typical errors were calculated via the same reliability spreadsheet (Hopkins, 2015) using the formula:

$$\text{Typical error} = \frac{\text{SD of change score}}{\sqrt{2}}$$

and are expressed as a percentage. To assess the magnitude of the typical errors, the previously described thresholds for assessing standardised mean changes were halved (<0.1, 0.1 and 0.3) (Atkinson & Batterham, 2015; Smith & Hopkins, 2011). Here, the range of thresholds for small and moderate were 2.8% to 3.4% and 8.7% to 10.9%, respectively. Between-trial reductions in typical error were considered meaningful when they crossed a magnitude threshold (e.g. 'moderate' to 'small'). The intraclass correlation coefficient (ICC_{3,1}; Shrout & Fleiss, 1979) was calculated (SPSS v.21, Armonk, NY: IBM Corp) with qualitative inference based on the following thresholds: >0.99, extremely high; 0.99-0.90, very high; 0.75-0.90, high; 0.50-0.75, moderate; 0.20-0.50, low; <0.20, very low (Malcata, Vandenbergaeerde & Hopkins, 2014). Uncertainty in estimates is shown as 90% confidence intervals throughout.

Following the above analysis, data were used to perform sample-size estimation for the final experimental study presented in this thesis (chapter 6). This was performed using a magnitude based inference approach, via a custom-made spreadsheet (Hopkins, 2006), by specifying the two type II error rates for the true positive (25%) and true negative (0.5%) effects without defining and specifying a type I error rate (Hopkins & Batterham, 2016). This was then combined with the observed smallest worthwhile effect, corresponding to 0.2 of the between-subject standard deviation and the observed typical error (Hopkins, 2006).

5.3 Results

5.3.1 Descriptive data

Descriptive data for peak power across all five trials are presented in Figure 5.3 and Appendix G.

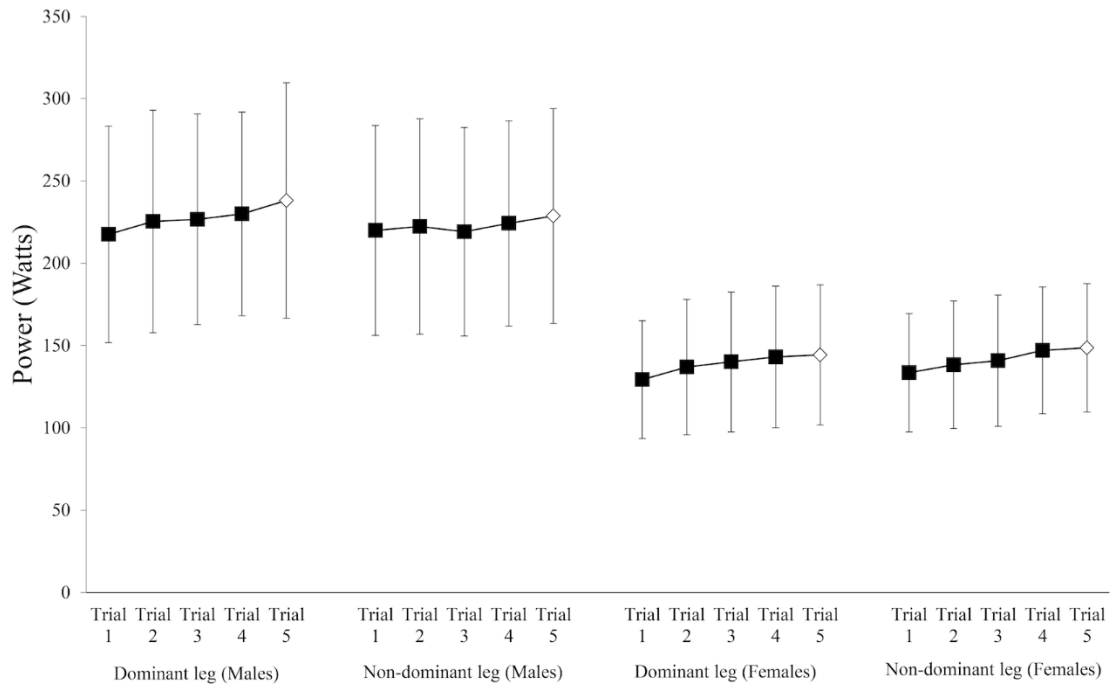


Figure 5.3 Peak power output (watts) from each trial. Closed squares represent short-term trials (1-4) and open diamonds represent long-term trials (5). Error bars represent SD.

5.3.2 Short-term reliability

Between-trial pairwise analyses and intraclass correlation coefficients are presented in Table 5.2. The mean change in peak power output for the dominant and non-dominant leg of males and females was trivial (1.2-4.8%) after two trials (Trial 1 and Trial 2) and remained trivial (1.9-5.3%) after a further two trials (Trial 3 and Trial 4). Intraclass correlation coefficients were very high for all comparisons (0.88-0.96). Between-trial typical errors derived from the pairwise analyses of consecutive trials are presented in Figure 5.4. Here, the magnitude of the typical errors reduced from moderate to small following four trials in the dominant leg of males (5.8%) (Figure 5.4a) and following

three trials in the non-dominant leg of males (6.2%) (Figure 5.4b) and the dominant leg in females (9.6%) (Figure 5.4c). The typical error was small after only two trials in the non-dominant leg of females (8.3%) (Figure 5.4d).

Table 5.2 Pairwise comparisons of the short- and long-term reliability for the leg extensor power rig

		Short-term reliability			Long-term reliability
		Trial 1 v Trial 2	Trial 2 v Trial 3	Trial 3 v Trial 4	Trial 4 v Trial 5
<i>Males (n=38)</i>					
Dominant leg	Mean change (%)	4.0	0.9	1.9	2.5
	90% CI	0 to 8.3	-2.9 to 4.9	-0.3 to 4.2	0 to 5.1
	Qualitative inference	<i>Trivial</i>	<i>Trivial</i>	<i>Trivial</i>	<i>Trivial</i>
	ICC	0.88	0.88	0.96	0.95
	90% CI	0.81 to 0.93	0.80 to 0.93	0.93 to 0.98	0.92 to 0.97
	Qualitative inference	<i>Very High</i>	<i>Very High</i>	<i>Very high</i>	<i>Very high</i>
Non-dominant leg	Mean change (%)	1.2	-1.4	2.7	1.7
	90% CI	-2.4 to 4.9	-3.6 to 1.0	0.5 to 5.0	-0.8 to 4.3
	Qualitative inference	<i>Trivial</i>	<i>Trivial</i>	<i>Trivial</i>	<i>Trivial</i>
	ICC	0.91	0.96	0.96	0.95
	90% CI	0.84 to 0.94	0.93 to 0.98	0.94 to 0.98	0.92 to 0.97
	Qualitative inference	<i>Very high</i>	<i>Very high</i>	<i>Very high</i>	<i>Very high</i>
<i>Females (n=34)</i>					
Dominant leg	Mean change (%)	4.8	2.4	2.1	1.2
	90% CI	0.8 to 9.0	-1.4 to 6.3	-0.6 to 4.8	-2.2 to 4.7
	Qualitative inference	<i>Trivial</i>	<i>Trivial</i>	<i>Trivial</i>	<i>Trivial</i>
	ICC	0.91	0.92	0.96	0.94
	90% CI	0.84 to 0.95	0.87 to 0.96	0.93 to 0.98	0.89 to 0.96
	Qualitative inference	<i>Very high</i>	<i>Very high</i>	<i>Very high</i>	<i>Very high</i>
Non-dominant leg	Mean change (%)	3.4	1.3	5.3	1.0
	90% CI	0.1 to 6.9	-1.6 to 4.2	2.2 to 8.5	-1.4 to 3.3
	Qualitative inference	<i>Trivial</i>	<i>Trivial</i>	<i>Trivial</i>	<i>Trivial</i>
	ICC	0.92	0.95	0.94	0.96
	90% CI	0.87 to 0.96	0.91 to 0.97	0.90 to 0.97	0.93 to 0.98
	Qualitative inference	<i>Very high</i>	<i>Very high</i>	<i>Very high</i>	<i>Very high</i>

ICC = Intraclass correlation coefficient; CI = confidence intervals

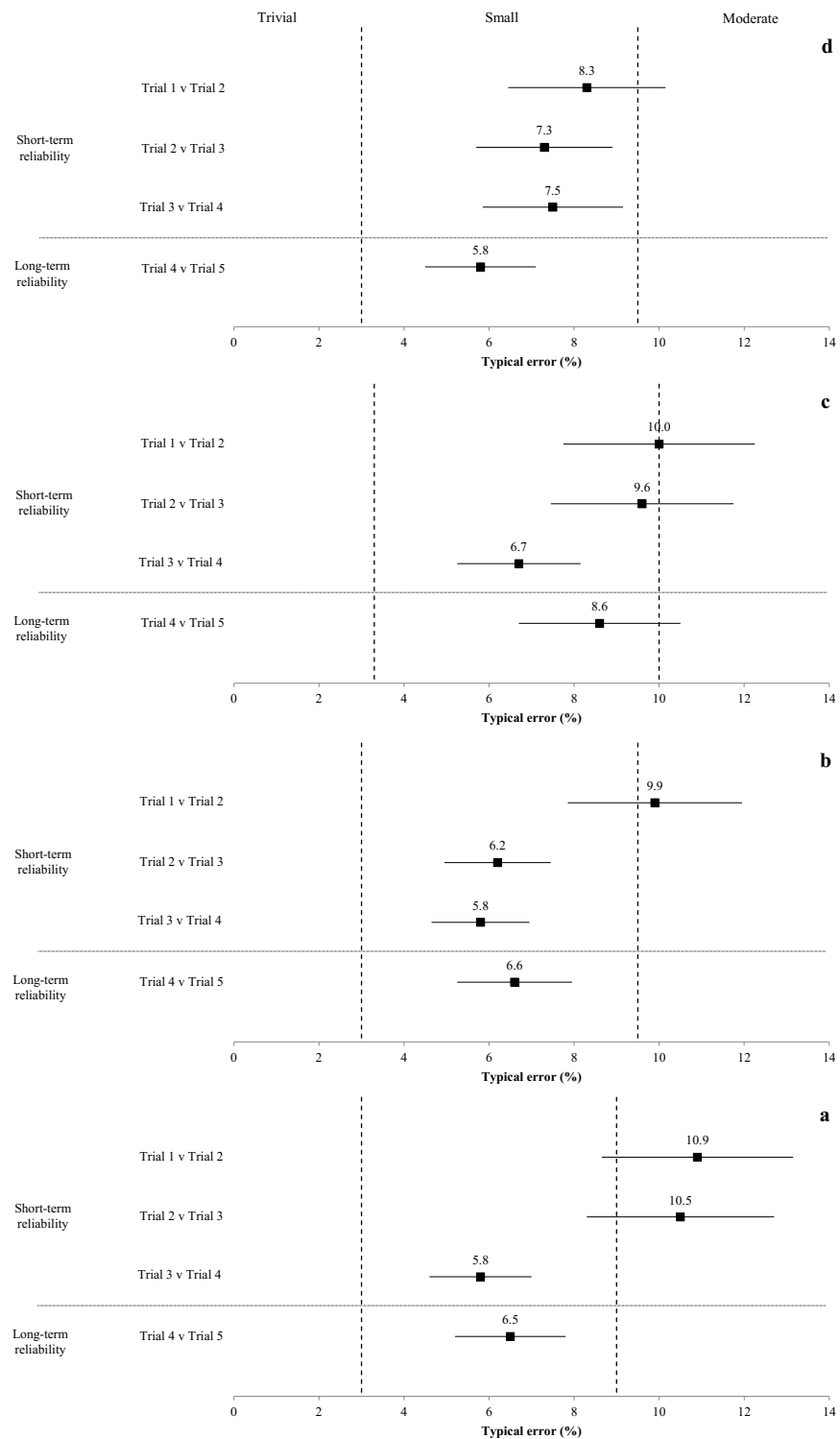


Figure 5.4 Short- and long-term between-trial typical errors (coefficient of variation, %) for the leg extensor power rig. (a = male, dominant leg; b = male, non-dominant leg; c = female, dominant leg; d = female, non-dominant leg). Solid horizontal lines represent 90% confidence intervals. Dotted vertical lines represent thresholds for small and moderate effect sizes for the typical error. *A change in typical error across a threshold was considered meaningful

5.3.3 Long-term reliability

The mean change in power output between Trial 4 and Trial 5 remained trivial for the dominant and non-dominant leg of males and females (1.0-2.5%) (Table 5.2). All intraclass correlation coefficients were again rated as very high (0.94-0.96) and all typical errors small (5.8-8.6%) (Figure 5.4).

5.3.4 Sample size estimation

Table 5.3 Sample size estimation for chapter 6

	Typical error (CV; watts)	Smallest worthwhile effect (watts)	Sample size		
			Experimental	Control	Total
<i>Male</i>					
Dominant leg	14.4	13.3	14	14	28
Non-dominant leg	12.7	12.6	12	12	25
<i>Female</i>					
Dominant leg	8.4	8.3	12	12	25
Non-dominant leg	8.6	7.7	15	15	30

Typical errors, smallest worthwhile effects and sample size estimates are presented in Table 5.3. Typical error ranged from 8.4-14.4 watts with the observed smallest worthwhile effect 7.7-13.3 watts. These values resulted in sample size estimation of between 12-15 participants per group (25-30 participants in total).

5.4 Discussion

Through repeated tests performed on a relatively large group of older participants, the overarching aim of this study was to perform a rigorous evaluation of the short- and long-term reliability of the leg extensor power rig to provide validation of its use as an outcome measure and to enable sample-size estimation for the following experimental study in this thesis (chapter 6). Overall, the data presented here demonstrate that the leg extensor

power rig has good reliability for the assessment of leg power in older adults with minimal habituation effects. However, reductions in the typical error, from moderate to small, were evident with further repeat tests. Four repeat trials performed in the short-term were sufficient for measures of reliability to remain stable in the long-term.

Previous investigations into the reliability of the leg extensor power rig have focused only on short-term (usually one week) reliability performed over two trials. The data presented here, however, provide a more detailed evaluation of reliability, as the change in performance over four repeat trials was examined; this approach is needed to properly assess habituation (Atkinson & Nevill, 1998; Hopkins, 2015). In males and females, all between-trial changes in power output were trivial after only two trials and remained trivial with a further two repeat trials, suggesting minimal habituation is associated with the leg extensor power rig.

It is reasonable to suggest that for untrained older adults – as in this investigation – performing ten maximal effort leg extensions on four occasions within a two-week period could provide a training stimulus in this population. If this was the case, it would be expected that a ‘training effect’ would lead to a systematic change, represented by a change in the mean. The data presented here however, suggest that this was not the case as change in the mean remained trivial (i.e. no change) at all time points in both men and women, for dominant and non-dominant legs.

A statistical comparison of the change in the means between repeat tests should not be employed in isolation as an assessment of reliability given that very large random individual differences may still be evident when a mean change is negligible (Atkinson & Nevill, 1998). Changes in typical error over multiple repeat tests should also be appraised for researchers to make a truly informed decision over the number of pretests to employ. Indeed, it is the typical error that influences the precision of measurements in an experimental study (Hopkins, 2000). Further, a general advantage of the typical error over other indicators of reliability is that it enables extrapolation of the results of absolute reliability studies to new individuals and to compare reliability between different measurement tools (Atkinson & Nevill, 1998). In this study, performing two trials resulted in typical errors that were classified as moderate (~10%) for the dominant leg of males and females and the non-dominant leg of males, and small (8.3%) for the non-

dominant leg in females. These typical errors lie within the range of those previously described for closed-chain ergometer-based assessments of isokinetic power (Hopkins et al., 2001) and for the leg extensor power rig itself (6-16%) (Bassey & Short, 1990; Bassey et al., 1992; Blackwell et al., 2009; Lamb, Morse, & Evans, 1995; Robertson, Frost, Doll, & O'Connor, 1998; Schroeder et al., 2007; Skelton et al., 2002).

A novel aspect of this study was that performing more than two repeat trials reduced the typical error further. In the non-dominant leg of males and the dominant leg of females, typical error was reduced from moderate to small after three trials, whereas four trials were required to reduce typical error to small in the dominant leg of males. These reductions in typical error are consistent with Hopkins and colleagues (2001) who, when examining the reliability of power in physical performance tests, reported the typical error (CV) between the first two trials to be 1.3 times greater than the CV between subsequent trials. While heterogeneous study populations combined with methodological inconsistencies make it difficult to draw comprehensive between-study comparisons, CVs after four trials (5.8-7.5%) are lower than those reported by Bassey & Short (1990), Bassey et al. (1992), Blackwell et al. (2009), Robertson et al. (1998) and Schroeder et al. (2007) and similar to those reported by Lamb et al. (1995) and Skelton et al. (2002).

An important consideration when determining measurement reliability is that the time available to perform repeated tests may not be exhaustive. As such, there needs to be a trade-off between measurement stability and the time needed to complete testing (Ehrenbrusthoff et al., 2016). The data presented here show that, with the exception of the dominant leg of males, no meaningful reductions in typical error were evident after three repeat trials. Consequently, the practical implication of these findings is that when using the leg extensor power rig as an outcome measure in the final study of this thesis, three repeat trials will provide an optimal balance between measurement stability and time spent testing.

When reporting reliability data, a distinction between absolute and relative reliability should be made (Impellizzeri & Marcora, 2009). The coefficient of variation represents a measure of absolute reliability (the degree to which repeated measurements vary for individuals) (Atkinson & Nevill, 1998), whereas relative reliability (the degree to which individuals maintain their position in a sample of repeated measurements) is usually

assessed via correlation coefficients (Batterham & George, 2000). In this study, the relative reliability of the leg extensor power rig showed very high ICCs for all measures. Ideally, a confidence interval for the ICC should be calculated and reported to indicate the likely range of values containing the true population ICC (Batterham & George, 2000). In this instance, the likely range for relative reliability remained high to very high for all measures.

For long term-reliability, change in the mean remained trivial, with a small typical error and very high ICCs in both men and women, suggesting that after four repeat baseline trials 12-week reliability is good. Comparison of long-term reliability of muscle power assessment is challenging because of a lack of current available data. However, a study from Ditroilo et al., (2011) evaluated the inter-session reliability of vertical jump performance interspersed by 4-weeks and reported CVs ranging from 2.9-7.2% and 3.4-10.8% in middle-aged and older adults, respectively. In general, reliability is lower for longer time between trials (Hopkins, 2015) with greater variability expected as a result of increased biological and behavioural fluctuation (Atkinson & Nevill, 1998). For example, longer time periods (i.e. 12-week) allow for meaningful changes in fitness or physical capacity which is unlikely to change substantially when testing is performed 48h apart, as in this investigation. Intuitively, this suggests that biological variability may affect long-term reliability to a greater extent than short-term reliability. However, the results presented here contrast this tendency and also the findings of a previous study examining both short-term and long-term reliability of a repeated sprint test in soccer players (Impellizzeri et al., 2008). Here, the authors reported a slightly greater CV in a long-term reliability study than that obtained in the short-term reliability study and stated that this was expected since as in the short-term it can be assumed that there is no true change in individuals' measurements between trials (Impellizzeri et al., 2008). In the study of Impellizzeri et al. (2008) participants performed only two repeat trials in the short term, it is plausible that in the present study performing multiple baseline trials helped to secure good long-term reliability.

Reliability over the same time period as the prospective intervention is needed to inform sample size estimation for future investigations (Hopkins, 2000). The data from the current investigation, based on data from male and female participants on the dominant and non-dominant leg, resulted in sample size estimation of 12-15 participants per group.

However, as Hopkins (2006) has noted, sample-size estimates should be inflated by 10-30% to allow for participant drop-out. As such, recruiting 40 participants for the final experimental study of this thesis (chapter 6), would meet the upper limit of the sample size estimation while accounting for potential drop-outs. It should be noted however, that the purpose of sample size 'estimation' is not to calculate an exact number, but rather to subject the study design to scrutiny and to estimate whether tens, hundreds or thousands of participants are required (Batterham & Atkinson, 2005). Accordingly, the recommendations for sample size presented here provide a meaningful guide for participant recruitment targets for the following chapter.

Although similar, the results reported for dominant and non-dominant legs were not identical in this investigation with differences in change of the mean and typical errors evident between legs in both males and females. Previously, researchers have assessed right leg and left leg rather than considering leg dominance when using the leg extensor power rig; however, the results of this investigation have shown that reliability can vary between dominant and non-dominant limbs. Accordingly, when using the leg extensor power rig as an outcome measure in this thesis participants should be evaluated in terms of dominant and non-dominant limbs rather than right and left limbs.

Limitations

It is acknowledged that the results of the present investigation are representative of a healthy population aged 50-83 years and therefore should not be extrapolated to represent all middle-aged and older adults. Consequently, further investigation is needed to understand the long-term reliability of the leg extensor power rig in older participants and in populations with musculoskeletal complications. Further study should also evaluate long-term reliability of other methods of leg power assessment so that meaningful comparisons can be made.

5.5 Conclusion

This study evaluated both short- and long-term reliability of the leg extensor power rig, with the findings suggesting it to be a reliable method for assessing leg extension power, both in the short- and long-term. It is proposed that when using the leg extensor power

rig as an outcome measure in the following intervention study of this thesis (chapter 6), performing three repeat trials will provide an appropriate balance between measurement stability and the time demands of testing. Additionally, the data presented here will be used for sample size estimation prior to the recruitment of participants for the following study.

CHAPTER 6: TWELVE WEEKS OF COMBINED UPPER- AND LOWER-BODY HIT IMPROVES CARDIORESPIRATORY AND MUSCULAR FITNESS IN OLDER ADULTS

The data presented in chapter three of this thesis established that Speedflex is a viable exercise mode for performing HIT in older adults, while chapter four quantified the effects of same-session combined training on measures of fitness in the same population. Chapter five assessed the short- and long-term reliability of leg extensor power measurement in older adults demonstrating it to be a reliable measure in this population with this data used for sample-size estimation for the investigation presented in this chapter. Chapter 6 evaluates the effect of a 12-week training intervention performed using Speedflex on fitness in older adults.

6.1 Introduction

Exercise training is an effective strategy for counteracting age-related declines in cardiorespiratory and muscular fitness (Green & Crouse, 1995; Steib et al., 2010). The meta-analysis presented earlier in this thesis demonstrated that same-session combined exercise training is an effective strategy to simultaneously improve multiple components of fitness in adults aged over 50 years (chapter 4). However, adherence to traditional modes of exercise training in older adults remains poor, suggesting alternate training strategies are needed (Burton et al., 2017; Cohen-Mansfield et al., 2003; Schutzer & Graves, 2004).

High-intensity interval training (HIT) can elicit considerable improvements in cardiorespiratory and muscular fitness and is therefore, an attractive strategy for the training of older adults (Adamson et al., 2014; Buckley et al., 2015; Osawa et al., 2014; Sculthorpe et al., 2017). Previous investigations using HIT have typically used cycle ergometry or treadmill walking/running as the exercise mode (Gist, Fedewa, Dishman, & Cureton, 2014; Sloth, Sloth, Overgaard, & Dalgas, 2013; Weston, Taylor, et al., 2014), thereby providing a training stimulus predominantly for the lower-body (Østerås et al., 2005; Wang et al., 2014). It is likely that this is a sub-optimal approach to training in this

population as older adults require a combination of upper- and lower-body fitness to perform the basic tasks of daily living (Landers et al., 2001; Rikli & Jones, 1997).

Chapter three of this thesis demonstrated that Speedflex can elicit a high-intensity training stimulus in older adults – placing considerable physiological demand on the cardiorespiratory system as well as the upper- and lower-body musculature – thereby suggesting that a HIT intervention delivered using Speedflex could be an effective strategy for exercise training in older adults. Therefore, the aim of this investigation was to evaluate the effect of 12 weeks of combined upper- and lower-body HIT performed using Speedflex on measures of cardiorespiratory (e.g. $\dot{V}O_{2\max}$) and muscular fitness (e.g. leg extensor muscle power and handgrip strength) in adults aged over 50 years.

6.2 Methods

6.2.1 Experimental approach

Sample size estimation

Estimation of sample size for this study was based on leg extensor muscle power as the primary outcome measure as lower body muscle power is a more discriminant predictor of functional performance in older adults than muscle strength and appears to be the most important component of physical fitness for maintaining effective functioning in older adults (Macaluso & De Vito, 2004; Reid & Fielding, 2012). Chapter five of this thesis quantified the short- and long-term reliability of the Nottingham leg extensor power rig with data from this investigation used to estimate required sample size for this study (see chapter 5.3.4). Based on this data, the aim was to recruit 40 participants as this would meet the upper limit of the sample size estimation while allowing for participant drop-outs and being practically manageable for a single researcher to deliver all testing and training sessions.

Study design

This study used a pre-post parallel group design with two groups; 1) combined upper- and lower-body high-intensity interval training (HIT) and 2) no-exercise control (CON). Following baseline testing, participants who met the predetermined inclusion criteria were assigned to either HIT (n = 18) or CON (n = 18) using the minimisation approach (Hopkins, 2010). Traditionally, randomisation has been considered the best method to allocate subjects to intervention or control groups, however non-random allocation (i.e. minimisation) which specifically aims to minimise differences in group means is a superior approach (Scott et al., 2002; Treasure & MacRae, 1998). Using this method, investigators are able to ensure balance between groups at baseline for several prognostic factors even when sample sizes are small (Altman & Bland, 2005). In this study, minimisation was performed following baseline assessment by an investigator who was not involved in testing using a custom-made spreadsheet (Hopkins, 2010) with individual subject data coded to ensure blinded allocation. This approach assigns subjects to groups by giving primary importance to minimising the differences between the means of one characteristic and equal importance across a range of secondary characteristics. Typically, these characteristics are those which may reasonably be considered to influence observed effects. For example, baseline fitness is often a strong determinant of training response, whereby subjects with lower baseline fitness improve to a greater extent (Milanovic et al., 2015). In this investigation, peak power of dominant leg was the primary characteristic and outcome measure with age, sex, peak handgrip strength of dominant hand and aerobic fitness secondary characteristics. Figure 6.1 shows the flow of participants through the study with subject characteristics at baseline presented in Table 6.1. All participants (HIT and CON) were asked to maintain their current diet and physical activity habits during the 12-week intervention period with the exception of the scheduled exercise sessions for the HIT group.

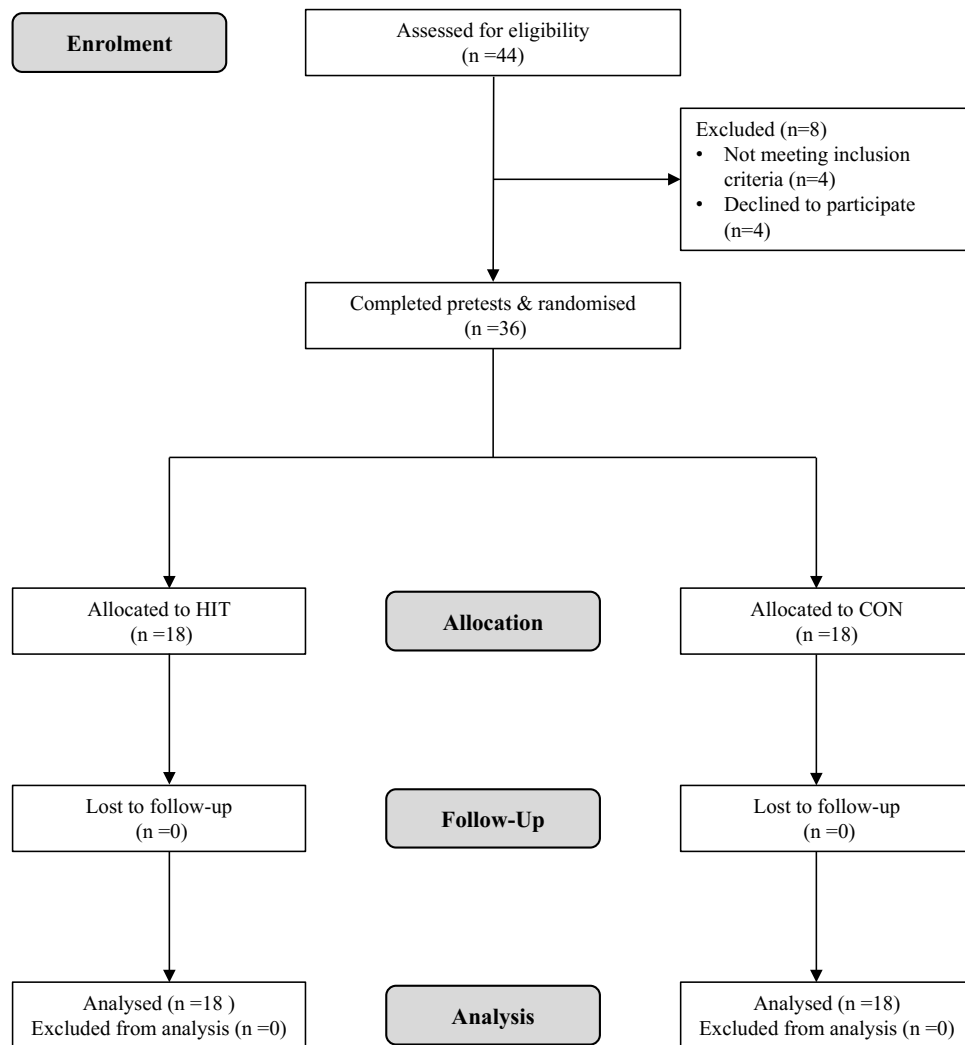


Figure 6.1 Participant flow

HIT, High-intensity interval training group; CON, No-exercise control group

6.2.2 Participants

A total of 36 untrained older adults (21 male, 62 ± 7 years,) were recruited for this study through advertisements in local newspapers and via word of mouth between February 2016 and April 2016 in Newcastle-Upon-Tyne, UK and the surrounding areas. Inclusion criteria were: age 50-85 years, willingness to commit to an exercise training programme for 12-weeks, and not currently undertaking any formal, structured exercise training. On the initial screening visit, participants were provided with an extensive explanation of the purpose, risks and procedures of the study, and were questioned about their past medical

history and current medications. Prior to enrolment, all participants completed a medical screening questionnaire to identify any medical conditions that could affect their ability to perform the required exercise training and testing. Participants with pre-existing, neuromuscular or skeletal conditions, systemic disease (e.g. diabetes mellitus, cancer, heart disease) or those currently taking medications known to influence fitness or interpretation of the findings were excluded (n = 3). Participants who had engaged in formal and systematic (moderate to high intensity) endurance or strength training within the last year were excluded (n = 1). All individual subjects provided written, informed consent to participate in the study, which conformed to the requirements of The Declaration of Helsinki and was approved by Teesside University Research and Ethics Committee (Appendix H). This trial was prospectively registered at www.clinicaltrials.gov as NCT02714088 (Appendix I).

Table 6.1 Participant characteristics at baseline

	HIT (n = 18)	CON (n = 18)
Age (yr)	61.9 ± 8.4	62.8 ± 6.4
Sex (male/female)	11/7	10/8
Height (cm)	167.6 ± 10.3	169.2 ± 9.4
Body mass (kg)	79.1 ± 14.4	78.9 ± 18.9
Body Mass Index (kg/m ²)	28.1 ± 4.4	27.4 ± 5.3
Dominant leg extensor muscle power (W)	159.2 ± 64.8	161.8 ± 63.2
Dominant handgrip strength (kg)	36.2 ± 10.9	33.9 ± 11.0
Predicted $\dot{V}O_{2\max}$ (mL·kg ⁻¹ ·min ⁻¹)	33.8 ± 8.3	33.9 ± 5.4

Data are mean ± SD.

HIT, High-intensity interval training group; CON, No-exercise control group

6.2.3 Experimental procedures

Exercise intervention

Training programme

Participants allocated to the HIT group completed two combined upper- and lower-body HIT sessions per week for 12-weeks (May - August 2016) with 72 h recovery between sessions (eg. Monday, Thursday). Training frequency was based on previous investigations showing that two training sessions per week is as effective as three sessions for improving cardiorespiratory and muscular fitness in older adults (Ferrari et al., 2013; Ferrari et al., 2016). All HIT sessions were performed in small groups of between two and five participants, at the same training facility and delivered by the author. As the nature of this study was to evaluate the effectiveness of the exercise training, effort was made to promote maximal attendance for all participants. As such, when a participant was unable to attend a session for good reason (i.e. work, family commitments, illness), the session was rescheduled wherever possible. Individual participants performed all training sessions at the same time of day. Participants were required to attend a minimum of 90% ($\geq 22/24$) of HIT sessions to be included in the final analysis.

The HIT intervention was performed using a hydraulic resistance machine (Speedflex, AlphaTech Inc, Nelson, NC) which has been previously demonstrated to be a viable exercise mode for performing HIT in this population, placing considerable demand on the cardiorespiratory and neuromuscular systems simultaneously (chapter three). The HIT programme consisted of eight exercises, performed in a circuit. Exercises were: 1) squat and 2) split-squats (lower-body focus); 3) bent over row and 4) shoulder press (upper-body focus); 5) power clean and press, 6) step and press; 7) pulldown to squat and 8) high pull (combined upper- and lower-body). Diagrammatic representation of exercises can be found in Appendix J of this thesis. Exercise order was randomised within- and between-sessions with participants completing each exercise approximately the same number of times across the 12-week intervention. This approach meant that participants could perform the same exercises in multiple consecutive sets – but not in

consecutive bouts – with all exercises not necessarily performed in each session. The aim of each session was to deliver a full-body workout for all participants.

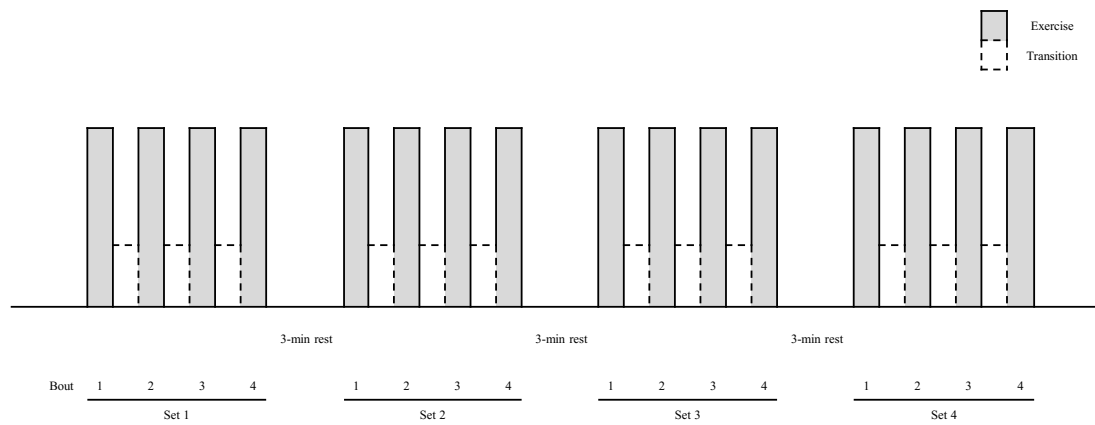


Figure 6.2 Schematic of HIT session

Exercise intensity: Prescription

The exercise protocol (see Figure 6.2) was based on previous HIT programmes shown to be safe and effective for improving fitness in older adults (Rognmo et al., 2004; Wisløff et al., 2007; Wyckelsma et al., 2017). It was however, different from that used for performing HIT in chapter 3 of this thesis for a number of reasons. Firstly, it was felt that sessions with repetitions of various durations would have added extra complexity for participants performing unfamiliar exercise in a group environment. Secondly, anecdotal feedback from participants in chapter 3 suggested that they preferred repetitions longer than 30s in duration. Finally, training data from chapter three suggested that 30s repetitions induced a lower physiological load than longer repetitions (e.g. HR_{peak} was 87% [30s reps], 90% [45s reps], 91% [60s reps]) – a potentially important consideration as longer repetitions induce greater physiological adaptation following HIT (Milanovic et al., 2015). Each session began with a warm up (~6 min) progressing in intensity to ~75% HR_{max} and concluded with a cool down (~4 min). Over the duration of the intervention (see Table 6.2), total exercise time increased from 12-minutes to 20-minutes (67% increase) with a similar increase in work: rest ratio (67%; 3:1-5:1).

Table 6.2 HIT intervention progression

Training block	Week	Bout duration (s)	Transition period (s)	Within set W:R	Bouts per set	Sets	Rest between set (min)	Total exercise time per set (min)	Total exercise time per session (min)
1	1-3	45	15	3:1	4	4	3	3	12
2	4-6	55	15	3.7:1	4	4	3	3.7	14.7
3	7-9	65	15	4.3:1	4	4	3	4.3	17.3
4	10-12	75	15	5:1	4	4	3	5	20

Abbreviations: W:R, work:rest ratio

As the nature of the Speedflex machine does not permit the setting of a fixed external resistance, participants were asked to work at “high-intensity” during exercise bouts with a threshold for high-intensity being defined as $>80\%$ of age predicted maximal heart rate ($\%HR_{\max}$) (Weston, Wisløff et al., 2014). Subjects were provided with strong verbal encouragement throughout each HIT session and were instructed to reach target heart rate by increasing the speed of movement during exercises.

Exercise intensity: Monitoring

Heart rate

Heart rate was monitored continuously at 5-s intervals during all HIT sessions using the Polar Team2 system (Polar Electro, Kempele, Finland). Following each session, heart rate data files were downloaded onto a laptop computer (HP ProBook 455, Hewlett Packard, Palo Alto, CA) using the Polar ProTrainer software (Polar Electro, Kempele, Finland). All raw heart rate data was visually inspected and if any values appeared outside of the normal physiological range ($>220 \text{ beats}\cdot\text{min}^{-1}$ or $<40 \text{ beats}\cdot\text{min}^{-1}$) data were corrected using the error correction function within the Polar ProTrainer software. For purposes of analysis, participants’ maximal heart rate was estimated using the formula from Gellish et al. (2007) of: Maximal heart rate (HR_{\max}) = $207 - 0.7 \times \text{age}$. If a participant exceeded this predicted value during training their HR_{\max} was amended to the higher observed value (Weston et al., 2004).

Ratings of Perceived Exertion

Following each HIT session, participants provided ratings of perceived exertion (RPE)

using the CR100[®] scale (Borg & Borg, 2002). As an overall measure of exercise intensity may lack sensitivity, the use of differential RPE can provide enhanced precision (McLaren et al., 2016; Weston et al., 2015). As such, participants provided differential RPE scores for upper-body muscle exertion (RPE-U), lower-body muscle exertion (RPE-L) and perceived sense of breathlessness in the chest (RPE-B) (Weston et al., 2015; Weston et al., 2017). For convenience, individual participants provided their values privately ~10 minutes after the completion of each exercise session (Fanchini et al., 2014). Each participant was familiarised with the CR100[®] scale and the concept of differential RPE at the study outset.

Outcome measures

Participants were evaluated at baseline (~5-7 days prior to commencement of training intervention; April 2016) and post-intervention (~3-7 days following final training session; August 2016) by the same researchers, strictly adhering to the prescribed standardised testing procedures with individual subject data coded to ensure blinding during data analysis. Outcome measures were: leg extensor muscle power (dominant and non-dominant leg), isometric handgrip strength (dominant and non-dominant hand) and cardiorespiratory fitness (predicted $\dot{V}O_{2max}$). These variables were selected as they represent the components of fitness most relevant to determination of functional performance in older adults (Bassey et al., 1992; Paterson et al., 2004; Posner et al., 1995; Reid & Fielding, 2012). At baseline, participants performed multiple pre-tests to reduce systematic bias and stabilise random variability (Atkinson & Nevill, 1998; Hopkins, 2000); lower body muscular power and handgrip strength were assessed on three separate occasions with predicted $\dot{V}O_{2max}$ assessed twice. Testing sessions were performed a minimum of 48 hours apart and at the same time of day to minimise the impact of circadian variation (Atkinson & Reilly, 1996). Participants were asked to avoid strenuous physical activity and alcohol for 24h and caffeine for 12h, prior to each testing session.

Body composition

Body mass was measured (SECA, Hamburg, Germany) to the nearest 0.1 kg with participants barefoot and wearing light clothing (i.e. shorts and vest). Participants were asked to wear the same clothing for post-intervention testing.

Leg extensor muscle power

Leg power was assessed using the Nottingham leg extensor power rig (Medical Engineering Unit, University of Nottingham, Nottingham, UK), which has been demonstrated to be a reliable method for assessing lower body muscular power in this population over a 12-week period (Chapter five). Testing procedures were as per chapter five (see section 5.2.2). To assess reliability in this study, typical error (Coefficient of variation; CV) was calculated for both dominant and non-dominant legs using a custom-made spreadsheet (Hopkins, 2015). Typical error was small on both the dominant (7.4%) and non-dominant legs (5.6%) for males and females combined after baseline test three. These CVs are comparable to those reported in chapter five of this thesis (male dominant leg, 10.5%; male non-dominant leg, 6.2%; female dominant leg 9.6%; female non-dominant leg, 7.3%), thus demonstrating good reliability.

Handgrip strength

Handgrip strength was assessed using a digital strain-gauge dynamometer (TKK 5401; Grip-D, Takei Scientific Instruments Co., Ltd., Tokyo, Japan). Testing was performed in a randomised, counterbalanced order with participants performing all testing sessions in the same order (e.g., always dominant hand first or always non-dominant hand first based on initial randomisation) with hand dominance determined using the lateral preference inventory (Coren, 1993). Following a submaximal practice attempt, participants performed three maximal efforts, with 30 s rest following each attempt. The highest recorded value across the three attempts was used for analysis.

Body position was standardised using the protocol from the National Health and Nutrition Examination Survey (NHANES) muscle strength procedures manual (e.g. Perna et al., 2016). Briefly, participants were instructed to maintain the standard bipedal position, with the arm in complete extension with feet positioned hip width apart. Participants were

provided with standardised instructions of “squeeze as hard as you can until you can’t squeeze any harder”. The dynamometer was adjusted appropriate to the individual’s hand size. Scores were recorded in kilograms to the nearest 0.1 kg. Typical error was small (CV, 7.1%) on the dominant hand and small on the non-dominant hand (4.6%) after baseline test three. These CVs compare favourably to test-retest typical error of 9% cited by Cooper et al. (2014).

Cardiorespiratory fitness

Cardiorespiratory fitness (predicted $\dot{V}O_{2max}$) was assessed using the Chester Step test, a submaximal, multi-stage step test which has previously been shown to be a reliable ($-0.7 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ [95% limits of agreement $\pm 4.5 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$]) tool for the estimation of aerobic capacity with an overall standard error of the estimate of $\pm 3.9 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ (Buckley et al., 2004; Sykes & Roberts, 2004). Although maximal incremental exercise testing is the gold standard for evaluating cardiorespiratory fitness, the need for laboratory access combined with the considerable time required to perform this type of test meant it was impractical in this study. All testing was carried out by the lead investigator, with only minimal assistance during data collection, therefore performing 72 (two baseline-tests per participant) maximal $\dot{V}O_{2max}$ tests was not possible.

The Chester Step test consists of five stages, each of 2-minutes duration with a maximum test time of 10 minutes (i.e. 5 x 2-minute stages). Stepping cadence began at 15 steps/min (60bpm) and increases by 5 steps/min at the end of every 2-minute stage with step frequency controlled by an electronic metronome (Apple iPad, Apple, California, USA). Step height was 20 cm. The test was terminated when the participant reached $>80\%$ of predicted HR_{max} . Heart rate (Polar RS400, Polar Electro, Kempele, Finland) was recorded throughout each 2-minute stage and maximal heart rate was calculated as: $(207 - 0.7 \times \text{age})$ (Gellish et al., 2007). Following completion of the test, $\dot{V}O_{2max}$ was estimated using the Chester Step test calculator (Assist Creative Resources, Wrexham, United Kingdom) which uses a regression line through submaximal heart rate up to a horizontal line that corresponds to predicted maximal heart rate. A minimum of two exercise heart rates (i.e. completing at least the first two stages) is required. In normal subjects the accuracy of this estimate is approximately 5-15% (Sykes & Roberts, 2004). After the second baseline

test in this investigation, typical error (TE; represented as a CV) – as per chapter 5 of this thesis (Hopkins, 2015) – was small (6.2%).

6.2.4 Statistical analysis

Prior to all analyses plots of the residuals versus the predicted values revealed no evidence of non-uniformity of error. For training data, the proportion of HIT repetitions that met the prespecified heart rate criteria for high-intensity was determined, with the median and interquartile range (IQR) for these proportions calculated subsequently. Linear mixed modelling, to allow for fixed (RPE) and random effects (within-participant) was used (SPSS v.23, Armonk, NY: IBM Corp) to examine the difference between differential RPE scores and to determine within-subject variability (expressed as a standard deviation [SD]) in RPE-U, RPE-L and RPE-B) with the SD doubled to interpret its magnitude (Smith & Hopkins, 2011). Assessment of exercise progression (HR_{mean} , HR_{peak} , RPE-U, RPE-L, RPE-B) across the 12-week intervention was also determined via linear mixed modelling with ‘training block’ (1-4) as a fixed effect with a random slope and intercept for training block (unstructured covariance matrix). Raw change (HR, RPE) over the intervention was determined using the slope of the relationship between training block and outcome.

Outcome measures were log transformed and then back transformed to obtain the percent difference between baseline and post-intervention, with uncertainty of the estimates expressed as 90% confidence limits (CL). Mixed effects linear modelling (SPSS v.23, Armonk, NY: IBM Corp) was used to analyse the intervention effect as this method allows for and quantifies (as an SD) individual differences in response to the intervention, which are frequently highly variable. Where individual responses were larger in the control group compared to the intervention group (as evidenced by a negative standard deviation), data are not reported as negative standard deviations are indicative of a lack of clinically important individual response (Atkinson & Batterham, 2015).

An analysis of covariance (ANCOVA) model was adopted to compare the two groups (HIT vs. CON). Model covariates were age, sex and baseline value of the outcome measure, to control for any imbalances between the groups at baseline even after minimisation (Senn, 2006). A stepwise approach was used to determine covariance

structure using the ‘smaller is better’ approach on -2 Restricted Log Likelihood, Akaike’s Information Criterion and Schwarz’s Bayesian Criterion for each data set (Field, 2009). As robust clinical anchors for the chosen outcome measures remain to be determined in this population, all inferences were based on standardised thresholds for small, moderate and large changes of 0.2, 0.6 and 1.2 standard deviations (SDs), respectively (Hopkins et al., 2009) and derived by averaging appropriate between-subject variances for all outcome measures. For body mass, magnitude thresholds were 4.9, 14.7 and 29.4%. For dominant leg and non-dominant leg power, magnitude thresholds were 8.9, 26.8 and 53.6% and 9.0, 27.0 and 53.9% for small, moderate and large effects respectively. For dominant hand and non-dominant hand grip strength thresholds were 9.1, 27.3 and 54.5% and 8.1, 24.4 and 48.8% for small, moderate and large effects respectively. Thresholds for predicted $\dot{V}O_{2max}$ were 4.6, 13.7 and 27.3% for small, moderate and large effects respectively. The chance of the true effect being trivial, beneficial or harmful was then interpreted using the following scale: 25-75%, possibly; 75-95%, likely; 95-99.5%, very likely; >99.5%, most likely (Hopkins et al., 2009). Effects were evaluated clinically given that interventions can be potentially harmful and impact on activities of daily living. The default probabilities for declaring an effect clinically beneficial are <0.5% (most unlikely) for harmful and >25% (possibly) for benefit; a clinically unclear effect is therefore possibly beneficial (>25%) with an unacceptable risk of harm (>0.5%) (Hopkins et al, 2009). Data are presented as mean \pm standard deviation (SD) or, for adjusted mean change, as 90% confidence limits (CL).

6.3 Results

Attendance

Overall attendance was 99% (429 out of a possible 432 HIT sessions) across the 12-week HIT intervention, with all participants meeting the prespecified criteria of >90% attendance. Sixteen participants completed all twenty-four HIT sessions, one participant completed twenty-three sessions and one participant completed twenty-two. The reasons for missed sessions were: 1) injury unrelated to the study (two sessions missed) and 2) family commitments (one session missed). It was not possible to rearrange these sessions because of a lack of time during the intervention period. No adverse events during any of the exercise testing or training sessions were reported.

Exercise intensity

Mean exercise intensity data are presented in Table 6.3. The percentage of repetitions meeting the high-intensity criterion (Mean HR \geq 80% HR_{max}) was 81% (IQR 48%, 89%). Overall mean RPE values are presented in Table 6.3. Analysis of the RPE scores revealed most likely small differences between RPE-U and RPE-L (6 Arbitrary units [AU]; 90% confidence limits \pm 1 AU) and RPE-L and RPE-B (6 AU \pm 1 AU). The difference between RPE-U and RPE-B was most likely trivial (0 AU; \pm 1 AU). The magnitude of the within-subject variability for all RPE measures was moderate.

Table 6.3 Training session descriptives

	Heart rate		Differential ratings of perceived exertion		
	Mean HR (%)	Peak HR (%)	RPE-U	RPE-L	RPE-B
Block 1 (Week 1-3)	82 ± 6	90 ± 7	43 ± 19	36 ± 15	43 ± 19
Block 2 (Week 4-6)	83 ± 6	90 ± 6	44 ± 18	39 ± 16	46 ± 22
Block 3 (Week 7-9)	82 ± 6	89 ± 6	43 ± 21	36 ± 15	41 ± 20
Block 4 (Week 10-12)	81 ± 7	88 ± 7	41 ± 21	34 ± 17	38 ± 20
Overall intervention	82 ± 6	89 ± 6	42 ± 19	36 ± 16	42 ± 20

Data presented as mean ± SD

RPE-U, rating of perceived upper-body muscle exertion; RPE-L, rating of perceived lower-body muscle exertion; RPE-B, rating of perceived breathlessness

Exercise progression

Figures 6.3 and 6.4 show the mean exercise intensity responses (HR and RPE) per HIT session along with individual data points to illustrate variability around the mean. The regression slope demonstrated a rate of change in HR_{mean} and HR_{peak} of -0.5 percentage points (90% confidence limits ±0.4 percentage points) and -0.7 percentage points (±0.4 percentage points), respectively with a between-subject variability of 0.8 percentage points (±0.3 percentage points) and 0.9 percentage points (±0.3 percentage points). The rate of change in RPE-U, RPE-L and RPE-B across the 4 training blocks (24 sessions) was -0.9 (±1.9 AU), -0.9 (±1.8 AU) and -2.1 (±1.6 AU), respectively with a between-subject variability of 4.3 (±1.4 AU), 4.0 (±1.3 AU) and 3.5 (±1.2 AU).

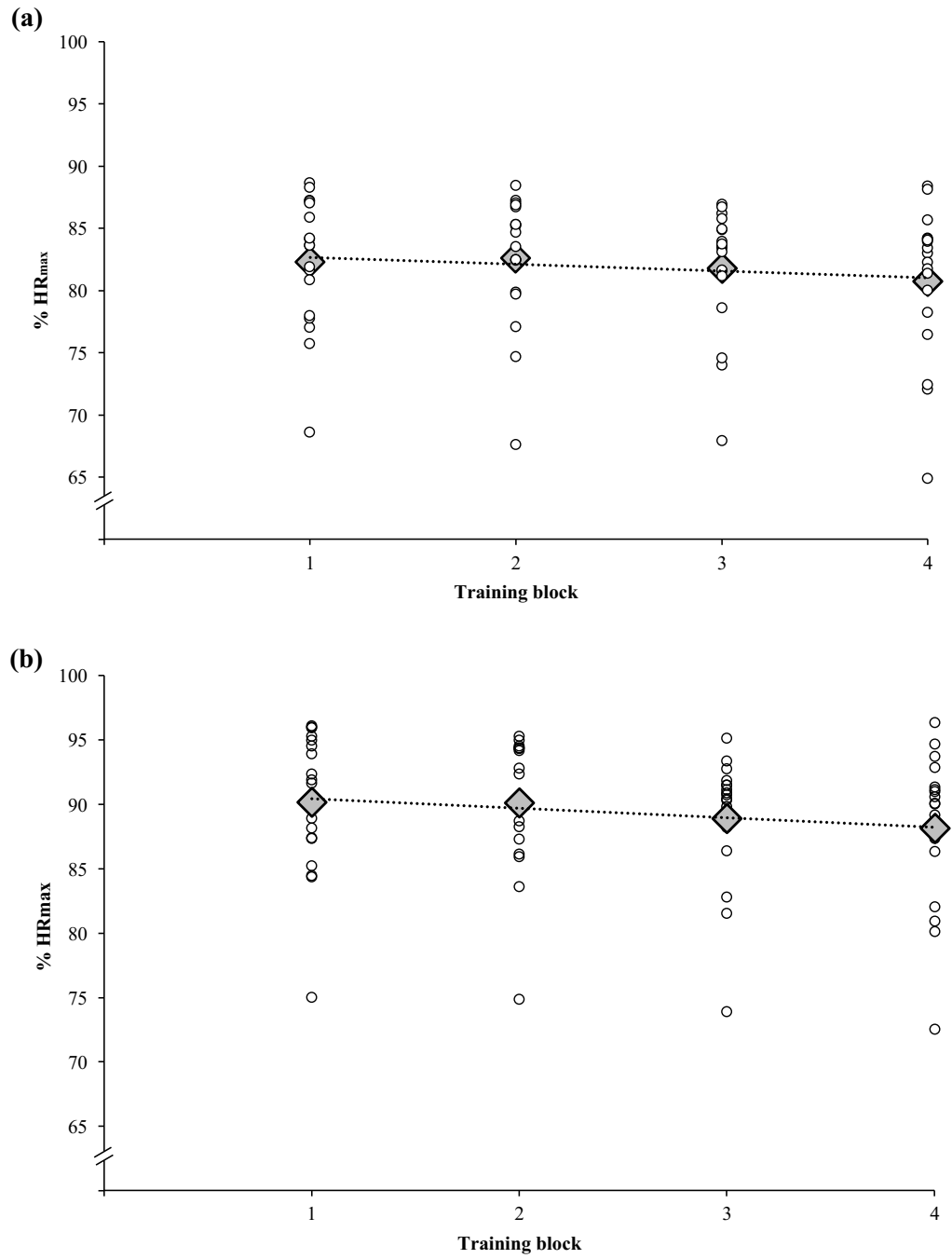


Figure 6.3 Mean (large closed diamonds) and individual (small open circles) mean heart rate (a) and peak heart rate (b) per training block across 12-week HIT intervention. Dotted line represents regression line.

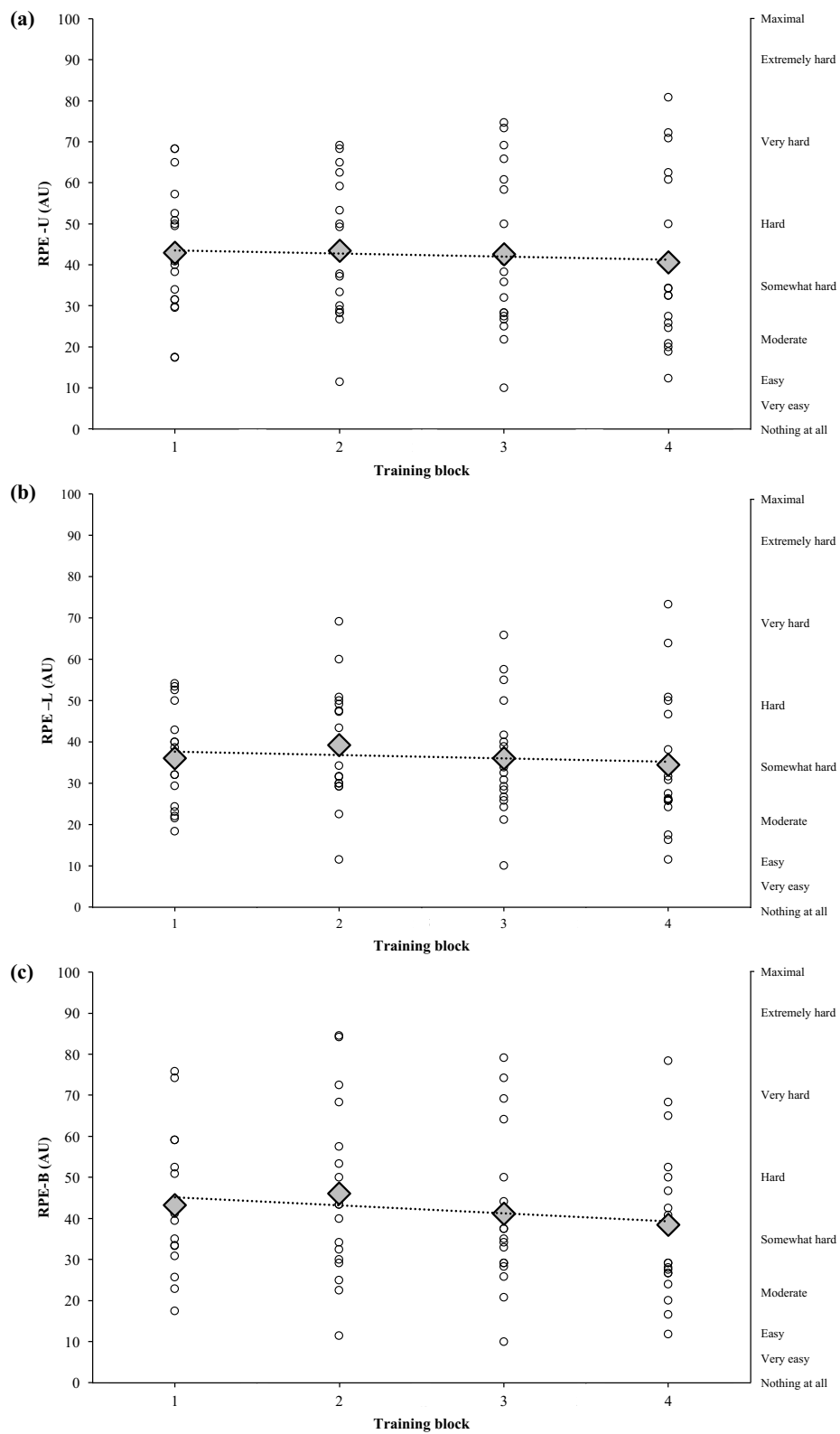


Figure 6.4 Mean (large closed diamonds) and individual (small open circles) RPE-U (a), RPE-L (b) and RPE-B (c) per training block across 12-week HIT intervention. Dotted line represents regression line.

Outcome measures

Baseline values, along with effect statistics and qualitative inferences for the within- and between-group (HIT v CON) comparisons are presented in Table 6.4. The HIT intervention showed a likely small beneficial effect for predicted $\dot{V}O_{2\max}$ (SD of the individual responses, 0.9% \pm 90% confidence limits \pm 1.2%). There were possibly small beneficial effects for dominant leg power (SD of the individual responses 1.1% \pm 1.4%) and non-dominant leg power (SD of the individual responses 0.9% \pm 1.1%). There was a possibly small beneficial effect for non-dominant handgrip strength, while for dominant handgrip strength, the effect was likely trivial. There change in body mass (SD of the individual responses 0.1 \pm 0.2%) was most likely trivial.

Table 6.4 Baseline, adjusted mean change values and between-group comparisons for body mass, leg extensor muscle power, handgrip strength and cardiorespiratory fitness.

	Intervention (HIT; n = 18)		Control (CON; n = 18)		Between group comparison (HIT – CON)	
	Baseline value (mean ± SD)	Adjusted mean change (% mean; ±90% CL)	Baseline value (mean ± SD)	Adjusted mean change (% mean; ±90% CL)	Difference between groups	
					(% mean; ±90% CL)	Qualitative Inference
<i>Body composition</i>						
Body mass (kg)	79.1 ± 14.4	-1.4 ± 0.9	78.9 ± 18.9	-0.9 ± 0.9	-0.5 ± 1.3	Most likely trivial
<i>Leg extensor muscle power</i>						
Dominant leg (watts)	159.2 ± 64.8	10.6 ± 7.0	161.8 ± 63.2	0.1 ± 4.5	10.5 ± 8.5	Possibly beneficial
Non-dominant leg (watts)	166.7 ± 57.9	10.4 ± 5.5	175.1 ± 68.3	0.9 ± 3.3	9.4 ± 6.3	Possibly beneficial
<i>Grip strength</i>						
Dominant hand (kg)	36.2 ± 10.9	4.2 ± 3.8	33.9 ± 11.0	-1.5 ± 3.6	5.9 ± 5.5	Likely trivial
Non-dominant hand (kg)	33.6 ± 10.8	5.0 ± 3.6	31.2 ± 9.4	-1.1 ± 3.4	6.3 ± 5.2	Possibly beneficial
<i>Cardiorespiratory fitness</i>						
$\dot{V}O_{2max}$ (mL·kg ⁻¹ ·min ⁻¹)	33.8 ± 8.3	11.5 ± 5.9	33.9 ± 5.4	2.8 ± 3.8	8.4 ± 6.8	Likely beneficial

*Analysis adjusted for age, sex and baseline fitness

6.4 Discussion

Exercise interventions which train the upper- and lower-body are appealing in older adults because of their need for whole-body fitness to perform the basic tasks of daily living (Rikli & Jones, 1997). Speedflex is a potential exercise mode for training of older adults and elicits considerable demand on both the upper- and lower-body musculature and the cardiorespiratory system (chapter 3). Accordingly, this investigation evaluated the effects of 12-weeks of combined upper- and lower-body HIT performed using Speedflex on cardiorespiratory and muscular fitness in older adults observing possibly beneficial improvements in leg power and grip strength as well as a likely beneficial improvement in cardiorespiratory fitness. These data provide support for HIT performed using Speedflex as a combined training tool in older adults.

Notwithstanding any potential training induced physiological and performance improvements, exercise training interventions must be acceptable and safe for participants. Evaluation of attendance and compliance (i.e. meeting the prescribed exercise intensity [Taylor et al., 2015]) can provide a useful quantification of the feasibility of an intervention. The attendance for the 18 participants across the 12-week intervention reported in this study is considerably higher than that the 58% to 77% range for older adults undertaking exercise programmes reported in the systematic review of Picorelli et al. (2014). However, the practicalities of this training intervention meant a flexible approach to exercise session timing was possible to promote and achieve maximal possible attendance for all participants. It is acknowledged that this is unlikely to be feasible within the reality of a funded trial. As such, the data presented here can be considered to represent ‘best case’ scenario which may be considerably different from a ‘real-world’ scenario. The attendance figures reported here, combined with 100% of participants completing the study suggest that Speedflex HIT is a feasible training approach in this population. Despite there being no adverse events recorded during the training programme, the limited sample size and training programme duration mean that considerably more data is needed to fully quantify the risks associated with Speedflex in older adults. In comparison to other HIT interventions, Hwang et al. (2016) reported that 83% of participants completed their 8-week exercise training intervention with subjects in the HIT group attending 88% of the scheduled exercise sessions, while Lunt et al. (2014) and Shepherd et al. (2015) reported attendance of 59% and 83%, respectively. The

present data therefore provide support for the feasibility of instructor-led group based HIT using Speedflex as a method for engaging older adults with previous work showing that in older adults, group based exercise training may be a more effective approach as group or facility based programmes show higher attendance rates compared to individual or home-based exercise programmes (Hong et al., 2008). Although the exact reasons remain unknown, it is possible that the structure of the intervention, i.e. instructor led, small-group sessions in combination with a flexible approach to timing of training sessions contributed to the high attendance and completion statistics reported here. Additionally, the high socioeconomic status and general good health of the participants involved in this investigation may also have played a role in the observed attendance figures as these factors have been associated with better programme attendance (Picorelli et al., 2014).

As well as attendance, assessing if participants have performed the exercise as intended is essential when evaluating interventions (Taylor et al., 2015). Using a prespecified threshold for high-intensity, 81% of repetitions met the criteria. Previous evaluation of intervention fidelity has suggested that high-intensity criterion attainment in 58% of HIT repetitions represented ‘moderate’ intervention fidelity (Taylor et al., 2015), while Weston et al. (2017) reported ‘low’ fidelity with ~23% compliance to HIT criteria. Based on these previous interpretations, it seems fair to categorise intervention fidelity as ‘high’ in this study.

Mean RPE scores in this investigation fell in the range of ‘somewhat hard’ to ‘hard’, lower than previously reported following Speedflex training (chapter three) and previous studies prescribing HIT intensity as ‘hard’ to ‘very hard’ (Cassidy et al., 2016; Weston et al., 2017) but similar to those reported by Kilpatrick et al. (2015) following HIT in overweight young adults. Between study differences are likely multifactorial in nature with heterogeneous study populations as well as differences in exercise programming factors (e.g. interval duration [Martinez, Kilpatrick, Salomon, Jung, & Little, 2015], exercise intensity [Green et al., 2009] and exercise mode [McLaren et al., 2016]) contributing to these observed differences. For example, the transition periods employed between exercise bouts in the present protocol may have reduced RPE as periods of recovery in between HIT bouts allow for a break from the physical and cognitive demands associated with intense exercise, a potentially important consideration as mental stress

increases perception of effort (Saaniijoki et al., 2015). Despite lower perceived exertion responses than typically prescribed during HIT, the present investigation has reported a clear beneficial effect on predicted $\dot{V}O_{2max}$. This finding has clear practical implications as exercise that is perceived to be less intense may be more palatable to potential exercisers (Kilpatrick et al., 2015).

As well as quantifying the acute demands of the training stimulus, the use of RPE also provides a valid means of assessing training progression within an exercise programme (Weston et al., 2017). In the present investigation, both heart rate and ratings of perceived exertion remained consistent over the duration of the intervention thereby demonstrating clear progression. Compared to week 1, participants were completing 67% greater volume of exercise by week 10. As both physiological and perceptual responses remained consistent in spite of this increase in external work load it is feasible to suggest that increased fitness led to this observed finding.

A clear difference was observed between upper- and lower-body perceived exertion with RPE-U rated higher than RPE-L. This difference may be related to increased peripheral fatigue during upper-body exercise (Sawka, 1986) while participants are also generally less accustomed to upper-body exercise than lower-body (Hoekstra, Bishop, & Leicht, 2017). All differences between measures of RPE were at most, small, similar to reported in previous investigations (McLaren et al., 2016; Weston et al., 2017). The assessment of overall session RPE could have provided validation of the ability of dRPE to differentiate between central and peripheral sensory inputs in this population during HIT. As such, the lack of session RPE is acknowledged as a limitation of this investigation.

Possibly small beneficial improvements in leg power on both the dominant and non-dominant leg were observed in this investigation. This finding has clear practical implications as improvements in leg power have been shown to make an important contribution to clinically meaningful improvements in gait speed and are associated with improved functional performance (Bean et al., 2010; Bassey et al., 1992; Hruda, Hicks, & McCartney, 2003; Reid & Fielding, 2012). However, despite evidence demonstrating a significant association between muscular fitness and functional performance (Bassey et al., 1992; Suzuki et al., 2001), training induced improvements in muscle strength or power may not directly translate into improved functional performance. For example,

Earles et al. (2001) reported ~22% improvements in muscle strength and peak power following a 12-week high-velocity resistance training programme, but no improvements in functional task performance. While previous investigations have shown that HIT can improve functional fitness (Adamson et al., 2014) it remains to be seen if the increases in fitness demonstrated in this thesis would translate into more functional improvements.

Previous studies using HIT have shown potential for increases in muscular power (Buckley et al., 2015; Sculthorpe et al., 2017; Zelt et al., 2014); however, these studies have primarily used training protocols classified as sprint-interval training (SIT) or performed at 'all out' intensity. The present findings have shown that HIT does not need to be performed 'all out', with submaximal HIT capable of inducing substantial improvements in muscular power. As SIT may not be suitable (Gibala et al., 2012; Levinger et al., 2015) or appealing to all (Biddle & Batterham, 2015), submaximal HIT may widen the potential impact of HIT across various populations. The reported improvements in lower body muscular power are of a similar magnitude to those of Wang et al. (2014) who reported an improvement of 10% in peak power after 8-weeks of HIT measured via a graded maximal cycle ergometer test. However, as Sculthorpe et al. (2017) have noted, the mechanical and metabolic differences between single expressions of power (e.g. during a leg extension) versus 30 s of high-intensity cycling mean that between-study comparisons are limited. To the authors knowledge this is the first study demonstrating that submaximal HIT increases explosive power in older adults. As muscle power is the product of force and velocity (Reid & Fielding, 2012), neural or morphological changes that lead to an increase in either of these parameters can increase muscle power (Folland, Buckthorpe, & Hannah, 2014; Macaluso & De Vito, 2004). In the present investigation, it is unclear if the positive adaptations in muscle power observed are force or velocity related. Further research is needed to elucidate this.

The robust relationship between greater cardiorespiratory fitness and reduced mortality and morbidity means that the likely small beneficial improvement in $\dot{V}O_{2max}$ reported in this investigation is an important and clinically relevant finding (Blair et al., 1995; Kodama et al., 2009; Myers et al., 2002). As lower cardiorespiratory fitness is associated with increased odds of dependent living – ultimately leading to a reduced quality of life (Paterson et al., 2004) – performing HIT using Speedflex may be an effective strategy to

counteract these negative consequences of ageing. The improvement in $\dot{V}O_{2\max}$ presented here falls within the range of previous studies investigating HIT in older adults, employing the archetypal 4 x 4 min protocol of between 6% and 15% (Hwang et al., 2016; Østerås et al., 2005; Støren et al., 2017; Wang et al., 2014). It should be noted however, that the study reporting the largest improvement (15%; Østerås et al., 2005) involved a 10-week training programme with three training sessions per week equating to 25% more training sessions performed than in the current investigation. Additionally, caution is also warranted when making between-study comparisons as improvements in $\dot{V}O_{2\max}$ are affected by baseline fitness, with greater benefit observed for less fit participants (Milanovic et al., 2015; Weston, Taylor, et al., 2014). The investigation from Wang et al. (2014) reported a 6% improvement in $\dot{V}O_{2\max}$, smaller than reported here, yet these participants were considered moderately active and had a baseline $\dot{V}O_{2\max}$ of 47.9 mL·kg⁻¹·min⁻¹. The increase in $\dot{V}O_{2\max}$ observed in the HIT group in the present investigation is lower than the increase of 3.6 mL·kg⁻¹·min⁻¹ resulting from same-session combined exercise training reported earlier in this thesis (chapter 4). This difference may be attributable to differences in baseline fitness which was considerably higher in the present investigation (33.8 mL·kg⁻¹·min⁻¹) compared with the meta-analysis (22.0 mL·kg⁻¹·min⁻¹). Although speculative, it is possible that both central and peripheral adaptations, such as increased cardiac output and skeletal muscle mitochondrial density, contribute to increased cardiorespiratory fitness following HIT as reported in this investigation (Daussin et al., 2008; Gibala et al., 2012; Macinnis & Gibala, 2017; Wisløff et al., 2007). Further research is needed to establish the mechanisms behind improved cardiorespiratory fitness following Speedflex training.

Handgrip strength is a useful indicator of overall muscle strength and is a robust predictor of mortality and disability, while a reduction in grip strength is related to difficulty in performing activities of daily living (Ensrud et al., 1994; Rantanen, Era, Kauppinen, & Heikkinen, 1994; Rantanen et al., 1999). The present data indicate a possibly beneficial improvement in grip strength on the non-dominant hand of a similar magnitude to Pereira et al. (2012) who reported improvements of 5% (dominant hand) and 6.9% (non-dominant hand) after 12-weeks of high-speed power training. It is of interest that both the current study and that of Pereira et al. (2012) have shown greater improvements in grip strength on the non-dominant hand. This may be related to lower levels of baseline

strength on the non-dominant hand as improvements in strength are related to initial strength level with higher magnitude increases in participants with lower baseline levels (Lexell, 2000). The improvement in handgrip strength reported here is less than the 2.9 ± 5.3 kg reported in the meta-analysis earlier in this thesis, although between-study differences make it difficult to draw conclusive inference from this while baseline handgrip strength was considerably higher in the present investigation (33.6-36.2kg) compared with the meta-analysed data (27.3 kg).

Limitations

Although this study has demonstrated that 12-weeks of HIT performed using Speedflex can elicit improvements in cardiorespiratory fitness as well as muscular strength and power, it is not without limitations. The outcome measures employed in this investigation provide an understanding of the effects of Speedflex training on isolated components of physical fitness (e.g. lower-body muscle power, upper-body muscle strength, cardiorespiratory fitness), yet performance on functional fitness tests (e.g. 30-s chair stand test [Jones et al., 1999] and the 8-foot up and go [Rose, Jones, & Lucchese, 2002]) may be more relevant to assess the effects of an intervention on the ability to perform the activities of daily living as these tests provide composite measures of physical fitness (Lord et al., 2002; Weston et al., 2016). Logistical (e.g. time and space) constraints within the present investigation meant that using these tests was not feasible.

Another potential limitation relates to the use of a submaximal prediction of $\dot{V}O_{2max}$, acknowledged as not being the gold standard measure of cardiorespiratory fitness (Bennett et al., 2016; Noonan & Dean, 2000). Although laboratory based determination of $\dot{V}O_{2max}$ via incremental exercise testing is the benchmark for assessing cardiorespiratory fitness, it was not feasible within this investigation to perform 72 (two baseline-tests per participant) laboratory based $\dot{V}O_{2max}$ assessments as most testing was carried out by a single researcher. Despite this, the Chester Step test does provide a quantification of cardiorespiratory fitness in terms of $\dot{V}O_{2max}$, allowing the present results to be placed in context of previous investigations (Sykes & Roberts, 2004). Selection of the Chester Step test as the protocol for $\dot{V}O_{2max}$ determination may be questioned however, because of the relatively high eccentric component involved in stepping (Startzell et al., 2001). Nonetheless, eccentric actions are an important contributor to

performance of a considerable number of activities of daily living (Dickinson et al., 2000) suggesting this method of assessment is directly relevant to functional performance in older adults. Highlighting this further, the test was performed using a step height of 20 cm in this investigation – similar to that of a household step (22 cm). While the functional relevance of this test may be high, the use of a fixed step height may be problematic as leg length differs considerably between participants. If the step is too high this may result in a mechanical disadvantage, while a step that is too small may not promote the desired cardiorespiratory response (Bennett et al., 2016). As such, the results presented in this chapter should be interpreted with caution.

In terms of the exercise training it may have been beneficial to count the number of repetitions performed in each session by participants as this could have provided an indication of the amount of work done across the intervention. Increased repetitions may have been indicative of increased fitness, although this would be confounded by the variable external resistance resulting from hydraulic resistance training. Practically, it was not possible to record the number of completed repetitions in small groups of up to five participants.

More broadly, it is acknowledged that the results of the present investigation are representative of a healthy population aged 50-85 years and therefore should not be extrapolated to represent all older adults. The participants involved in this investigation exhibited a relatively high fitness level with baseline $\dot{V}O_{2max}$ of $\sim 33 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ which would be classified as ‘fair’ to ‘excellent’ based on normative data from the American College of Sports Medicine (ACSM, 2013). This level of baseline fitness is also considerably higher than reported in previous HIT studies involving older adults of $\sim 25 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ (Hwang et al., 2016; Østerås et al., 2005). As well as demonstrating high fitness levels, all of the participants in the present investigation were free from long-term conditions. As a large number of older adults have at least one long-term condition by the age of 50 (e.g. hypertension, COPD, diabetes mellitus) with approximately 65% of those aged 65-84 affected by multimorbidity (Barnett et al., 2012) – commonly defined as the presence of two or more long term medical conditions (Fortin, Bravo, Hudon, Vanasse, & Lapointe, 2005) – the wider translational value of this investigation is limited because of differences in phenotypes between healthy adults and those with long-term

conditions. Further research is needed to understand the effects of Speedflex training in older adults with long-term conditions.

While the length of the intervention period utilised in this study (12 weeks) is favourable compared to many others (e.g. Hwang et al., 2016; Wang et al., 2014), this still represents a relatively short-term follow up period. This limits the ability to draw firm conclusions about the long-term acceptability and effects of Speedflex training. This is an important consideration as it is possible that training induced gains in fitness may be reversed after a period of detraining (Toraman & Ayceman, 2005), meaning that individuals need to continue to exercise for an extended period of time to maintain fitness benefits. Accordingly, studies of longer duration in this population are required to evaluate the long-term feasibility and effectiveness of both Speedflex training and HIT in older adults.

Within any research study there is a risk of expectation influencing findings leading to biased results (Day & Altman, 2000). Blinding – the concealment of group allocation (Karanicolas et al., 2010) – is used in an attempt to eliminate such bias and ensure the credibility of study findings (Day & Altman, 2000). Blinding is a critical methodological element of randomised controlled trials with the optimal strategy to minimise the likelihood of differential treatment or outcomes being to blind as many people as possible within a trial (Karanicolas et al., 2010). Consideration should be given to blinding of participants, therapists, assessors and statisticians during study design who should all be unaware of which group (e.g. treatment or control) an individual has been assigned to in order to ensure that risk of bias is minimised. Moreover, it has also been suggested that blinding of the statistician is an important consideration to ensure that data analysis and statistical issues are handled in an objective manner (Page & Persch, 2013). While the information presented above represents best practice, the nature of this investigation (i.e. being part of a PhD programme) meant that allocation concealment (i.e. participant blinding), assessor blinding and statistician blinding were all not possible with the author acting as principal investigator. This meant that the author delivered the training intervention, carried out baseline and post-intervention testing and performed the statistical analysis. The advantage of this approach is that the exercise training sessions as well as assessment of outcome measures were performed in a standardised manner. More broadly, blinding participants to treatment is often not a feasible aim in an exercise training study such as this and the lack of blinding discussed here represents inherent

limitations with this type of work. Nonetheless, attempts were made where possible in this investigation to limit bias. For example, group allocation was performed by a member of the supervisory team who was blinded while group allocation was not determined until after baseline testing was performed. It remains difficult to estimate how great an impact the lack of blinding had on the presented results and a fully-blinded study following the same protocol would be needed to elucidate this.

Another consideration relating to bias in this investigation concerns the delivery of the study on Speedflex property. Attempts were made to limit involvement with the commercial element of Speedflex and all training and testing was performed in a separate building to the commercial Speedflex centre. There was limited branding within the training facility and participants had no direct contact with any representative of Speedflex. It is challenging to quantify if this factor had a substantial impact however, it may be that this influenced participants' attendance, enjoyment or effort during training sessions. There remains however, a lack of empirical data to support this assertion and further research is needed to quantify this fully.

Substantial evidence exists demonstrating that industry sponsorship is associated with findings that are favourable to the sponsor's product (Lexchin, Bero, Djulbegovic & Clark, 2003; Lundh, Sismondo, Lexchin, Busuioic & Bero, 2015). For example, the systematic review of Lexchin and colleagues (Lexchin et al., 2003) found that studies sponsored by pharmaceutical companies were more likely to have outcomes that favoured the sponsor compared with studies with other sponsors (odds ratio 4.05; 95% CI 2.98 to 5.51). While in this research programme the sponsor had no involvement in design, data collection, analysis and interpretation of the work, while also placing no restrictions on publication of this data, this risk of bias is still acknowledged. It may be that unintentional biases (e.g. choice of comparator, selection and recruitment of participants) that cannot be explained by standard 'Risk of bias' assessment tools affect observed findings (Lundh et al., 2015). Considering the factors discussed here relating to risk of bias collectively, the presented findings should be interpreted with caution.

6.5 Conclusion

This study has demonstrated that 12-weeks of HIT performed using Speedflex is a viable method for improving cardiorespiratory and upper- and lower-body muscular fitness in adults aged over 50 years. Moreover, the present findings have shown that HIT does not need to be performed at an ‘all out’ intensity to improve multiple components of fitness. Further research is now needed to elucidate the mechanisms underlying physiological adaptation to this type of training. More broadly, this study has provided further evidence that HIT is a feasible and effective approach to exercise training in older adults with high adherence and intervention fidelity reported. This finding has important implications for exercise programming for older adults with HIT being a potential approach to improve current low levels of adherence to physical activity recommendations in this population.

CHAPTER 7: SYNTHESIS OF FINDINGS

The aim of this chapter is to interpret and contextualise the data presented throughout the thesis. The general discussion will attempt to understand and synthesise the presented findings while considering the training and practical implications. Reflections on the work as well as the limitations and recommendations for future research will also be discussed.

7.1 Realisation of aims and objectives

The overall aim of this thesis was to develop an understanding of a new exercise training mode which could have potential health and fitness benefits for older adults. The thesis began by attempting to establish the viability of using the Speedflex machine for exercise training in older adults by quantifying the acute physiological and perceptual responses to HIT and strength training performed using Speedflex (chapter 3). Following this, the thesis synthesised the current literature on combined training in older adults by undertaking a systematic review and meta-analysis of the effects of same-session combined endurance and strength training on measures of fitness in older adults, providing a detailed quantification of the effects of this type of training (chapter 4). Chapter 5 aimed to establish the reliability of a commonly used method of leg power assessment by performing a comprehensive evaluation of the short- and long-term reliability of the Nottingham leg extensor power rig as a method for assessing lower-body muscular power in older adults. Data from this investigation was used to estimate sample-size for the final experimental trial. The experimental work in this thesis concluded by examining the effectiveness of Speedflex training for improving fitness in older adults (chapter 6).

7.2 General discussion

7.2.1 Training implications

As maintenance of cardiorespiratory *and* muscular fitness – in particular muscular power – is of considerable importance for older adults, exercise training should impact on both

of these physical components (Cadore & Izquierdo, 2013a; Evans, 2000). Despite some recent encouraging findings (Konopka & Harber, 2014), neither endurance nor strength training performed in isolation is capable of eliciting substantial improvements in both cardiorespiratory and muscular fitness. Combined exercise training programmes provide a viable method for multicomponent fitness improvement, yet adherence to traditional modes of exercise in older adults remains poor (Jefferis et al., 2014; Strain et al., 2016). HIT is a strategy which could meet the needs of older adults because of its potential to positively impact on cardiorespiratory *and* muscular fitness (MacInnis & Gibala, 2017; Sculthorpe et al., 2017), leading to improvements in health-related quality of life (Knowles et al., 2015) and functional fitness (Adamson et al., 2014). Despite considerable evidence supporting the effectiveness of HIT for fitness improvement, delivery of HIT has typically been limited to treadmill running / walking or cycle ergometry. While capable of robust fitness improvements, these training modes may be unsuitable or prohibitive for older adults with lower-body musculoskeletal, balance and mobility complications. As such, alternative exercise modes for performing HIT may increase accessibility for a greater number of individuals.

Preliminary evaluation of Speedflex in young adults (26-39 years) has reported similar acute responses following low-volume HIT (10 x 60 s repetitions) compared with cycle ergometry (HR [93 v 95%HR_{max}] and $\dot{V}O_2$ [88 v 87% $\dot{V}O_{2peak}$]) (Taylor et al., 2014). This data corroborated previous findings suggesting that hydraulic resistance training is capable of inducing a significant cardiorespiratory stimulus (Falcone et al., 2015; Katch et al., 1985). Despite these encouraging findings, it remained unknown if the desired physiological responses could be induced in older adults when performing HIT. The observed acute physiological responses (see section 3.3) to HIT (90% HR_{peak}; 83% $\dot{V}O_{2peak}$) reported in this thesis demonstrated that Speedflex is capable of inducing a substantial and enjoyable high-intensity training stimulus in older adults. These data compare favourably to the recommended target intensity for performing HIT (80-100%HR_{peak} [Weston, Wisløff et al., 2014]) and a previous investigation reporting the acute demands of HIT (Little et al., 2011). However, the between-study comparison of physiological responses is confounded by differences in programming variables (Wood et al., 2016); for example, the duration of work and rest periods (Buchheit & Laursen, 2013a; Gosselin et al. 2012), making it difficult to contextualise these findings. In

addition to the encouraging physiological response observed, perceptual responses (i.e. RPE) suggested that Speedflex places a considerable demand on the upper- and lower-body musculature during HIT suggesting that this training mode may provide a strategy for muscular fitness improvement. Despite Speedflex inducing training responses adequate for fitness improvement and exercise induced remodelling being the cumulative result of repeated exercise bouts (Fyfe et al., 2014), it remained unknown if these acute responses would translate into fitness improvements following a longer-term training programme.

In an attempt to answer this question, participants completed a 12-week HIT intervention involving two training sessions per week delivered using Speedflex (chapter 6). Following this, beneficial improvements were found for participants in the intervention group compared to those in the control group for cardiorespiratory fitness, muscle power and muscle strength. Post-intervention, predicted $\dot{V}O_{2max}$ improved by 8.4% (~3.0 mL·kg⁻¹·min⁻¹). This improvement was of a similar magnitude to several previous investigations (Adamson et al., 2014; Grace et al., 2015; Wang et al., 2014) but less than others (Hwang et al., 2016; Østerås et al., 2005; Støren et al., 2017) evaluating HIT in older adults and less than the meta-analysed effect of combined exercise training reported in chapter 4 of this thesis of 3.6 mL·kg⁻¹·min⁻¹. These between-study comparisons add context to the presented findings, yet differences in assessment of $\dot{V}O_{2max}$ (i.e. predicted vs actual), participant characteristics (including baseline fitness [Weston, Taylor, et al., 2014]) and training prescription (Gibala et al., 2012; MacInnis & Gibala, 2017) mean comparisons should be interpreted with caution. Despite demonstrating a clear beneficial improvement in predicted $\dot{V}O_{2max}$, the heterogeneous nature of the participants (e.g. male / female) used within chapter 6 of this thesis may have diminished potential effects. For example, if data analysis had been stratified by sex, observed effects may have been of a greater magnitude. However, to get the same precision of estimation, twice as many participants are needed in each subgroup (i.e. males [72 participants] and females [72 participants]), (Hopkins, 2006) which was not feasible in the present work.

More generally, the present data provide further support for the use of HIT as a method for cardiorespiratory fitness improvement in older adults irrespective of age (Støren et al., 2017). While this thesis has not sought to determine the mechanisms explaining the

observed training induced changes in cardiorespiratory fitness, HIT has been shown to induce changes in both central (Astorino et al., 2017; Daussin et al., 2008; Wang et al., 2014; Warburton et al., 2004) and peripheral factors relating to improved $\dot{V}O_{2\max}$ (Burgomaster et al., 2006; Jacobs et al., 2013; MacInnis & Gibala, 2017). Further work is needed to clarify the mechanisms behind the adaptive response to HIT in older adults.

In contrast to cardiorespiratory fitness improvements, training induced changes in muscular fitness following HIT have received only limited attention, although Buckley et al. (2015) have reported improvements in 1RM squat (39%), 1RM press (27%) and squat endurance (280%) following multi-modal HIT in recreationally active young women. Traditionally, strength training has been viewed as the most effective method for improving muscular fitness in older adults (Hunter et al., 2004; Liu & Latham, 2009; Steib et al., 2010), yet few older adults regularly engage (Strain et al., 2016) signifying a clear need for alternate methods to enhance muscular strength. The present work has demonstrated that Speedflex is capable of improving upper-body muscular strength – necessary for older adults to perform the activities of daily living (Landers et al., 2001) – with improvements of ~6% in handgrip strength reported following 12 weeks of training. While this improvement was of a smaller magnitude than the meta-analysed effect for combined training presented in chapter 4 (2.9 kg; $\pm 95\%CL$ 5.3 kg), it should be noted that baseline strength was considerably lower in the meta-analysed studies and as with cardiorespiratory fitness, greater increases in strength are possible for those with lower baseline values (Lexell, 2000).

In addition to positive effects on muscular strength, the improvements in muscular power reported in this thesis may be of greater practical significance because of their impact on functional performance (Basseley et al., 1992; Skelton et al., 1994). Several investigations have indicated that HIT can increase muscular power with improvements of 6% (Buckley et al., 2015), ~10% (Astorino et al., 2012; Wang et al., 2014) and 26.5% previously reported (Sculthorpe et al., 2017). However, the investigations of Astorino et al. (2012) and Sculthorpe et al. (2017) involved training protocols classified as SIT and there remains little evidence to support submaximal HIT as an effective method to increase muscle power. Nevertheless, Wang et al. (2014) did report an increase in power output (assessed via maximal incremental test) of $10 \pm 6\%$ after 8 weeks of three HIT cycle sessions (4 x 4 min at 90-95% HR_{\max}) per week. Attention should be given to the

methodological differences in the assessment of muscle power as substantial metabolic and mechanical differences exist between assessment of peak power during an incremental test (Wang et al., 2014) and a single expression of muscular power as used in this thesis making it difficult to reconcile between-study differences (Sculthorpe et al., 2017). To the authors' knowledge, this is the first study which has demonstrated increases in lower-body muscle power assessed during a single explosive movement following submaximal HIT in older adults. While the mechanistic basis of changes in muscular fitness following HIT remains largely unknown, both neural and morphological adaptations may be responsible for improved muscular fitness (Hunter et al., 2004) with these adaptations potentially mediated by the need for increased neural drive and additional fast-twitch motor unit recruitment during high-intensity activity (Buchheit & Laursen, 2013b; Ross & Leveritt, 2001). Further research is needed to elucidate the mechanistic basis of training induced changes in muscular fitness following HIT in older adults.

Considering the wider implications of training prescription in this population – for example, the consequences of increased time demands on exercise adherence – an important finding of the present work is that the observed fitness improvements were induced via a training programme performed only twice per week. This contrasts with recommendations from the ACSM (Haskell et al., 2007) who advocate performing 3 training sessions per week to improve cardiorespiratory fitness. This finding is reinforced by previous experimental and meta-analytical work showing that substantial fitness improvements are possible with reduced training frequency (Milanovic et al., 2015; Sculthorpe et al., 2017; Vollaard et al., 2017). While the improvements in $\dot{V}O_{2peak}$ following same-session combined training (chapter 4) were of a greater magnitude than those reported following 12 weeks of Speedflex HIT, these training programmes typically involved three exercise sessions per week, equating to 50% more exercise sessions over the course of a 12-week intervention. Consequently, this places a considerable increased time demand on prospective exercisers, an important consideration as lack of time remains a considerable barrier to exercise participation (Cohen-Mansfield et al., 2003; Trost et al., 2002). It remains to be determined if HIT performed using Speedflex could induce positive training adaptations with a lower training frequency (e.g. 1 session per week) than used in this investigation.

The interdependent relationship between exercise volume and intensity (i.e. greater volume = lower intensity and vice versa) would suggest that improvements in fitness with a lower exercise frequency necessitate a higher training intensity. Several studies demonstrating the benefits of reduced training volume have used SIT protocols performed at ‘all out’ or ‘maximal’ intensity (Weston, Taylor, et al., 2014; Weston, Wisløff et al., 2014; Vollaard et al., 2017). However, SIT may be too demanding for some participants (Gibala et al., 2012) while older adults need extended recovery between training sessions (5 days) to restore peak power output (Herbert, Grace, & Sculthorpe, 2015). A temporal reduction in power output may be significant for older adults who depend on the ability to produce power to rise from a chair, climb stairs and prevent themselves from falling. Accordingly, the present work has shown that improvements in cardiorespiratory and muscular fitness can be induced with a training frequency of two sessions per week without the need for exercise to be performed at maximal or all-out intensity. In comparison to SIT, submaximal HIT may be more appealing because of the lower relative exercise intensity. The RPE data presented in this thesis supports this further as clear beneficial fitness improvements were observed despite lower than recommended perceived exertion (Weston et al., 2017).

Several investigations have shown that HIT is perceived as being more enjoyable than traditional endurance training (Bartlett et al., 2011; Jung et al., 2014) possibly because of its time efficiency and varying stimulus (Thum, Parsons, Whittle, & Astorino, 2017). While this thesis has not compared between exercise modes, the data presented in chapter 3 suggested that participants viewed Speedflex as an enjoyable training mode. Moreover, anecdotal feedback from participants suggested that they enjoyed the 12-week intervention (chapter 6), with participants noting that they “felt fitter” and “invigorated”, a similar finding to that of Eyigor, Karapolat, & Durmaz (2007) who reported that participants had an increased overall feeling of being more active and of higher well-being, which provided further motivation for them to continue with the exercise program. As enjoyment is an important mediator of exercise adherence in older adults (Dacey et al., 2008), HIT performed using Speedflex may offer an appealing training strategy in this population.

7.2.2 Practical implications

As well as the implications for exercise training discussed previously, a number of broader practical implications have also arisen from the programme of work presented in this thesis. These are related to the general application and evaluation of exercise training in older adults as well as future exercise training studies involving this population. It is acknowledged that the information presented in this section is based around factors relating to the tightly controlled studies within this thesis, involving healthy older adults with a maximum duration of 12 weeks. It may be that additional or alternative considerations around recruitment or logistical factors are required in longer term studies or in investigations involving different population groups.

The recruitment of older adults into clinical trials remains a difficult process (Levy, Kosteas, Slade, & Myers, 2006) and there remains no optimal recruitment strategy (Veenhof, Dekker, Bijlsma, & Van Den Ende, 2005). The studies presented in this thesis included 20, 19, 72 and 36 participants, all of whom were recruited solely by the author with recruitment strategies primarily including word of mouth, and advertisement at local church groups, sports groups and fitness facilities. Although difficult to quantify the effectiveness of these approaches, they were met with varying degrees of success. What was clear however, was that 'cold' calling or emailing was largely unsuccessful but required a significant time commitment. As such, researchers should be cautioned against using this approach as their main strategy for participant recruitment. For the final study of this thesis (chapter 6), advertisements were placed in local newspapers on three separate occasions in an attempt to recruit participants. In contrast to previous findings (Unson et al., 2004) this was an effective strategy, with ~50 prospective participants expressing an interest in taking part in the investigation. This data provides further evidence that older adults are willing and able to take part in exercise training studies. Despite this, researchers need to maintain an awareness that participants who self-select for study participation may differ systematically from the target population as a whole (Golomb et al., 2012). Participants likely to volunteer for an exercise study report less physical decline, more physical activity and less chronic pain than those who do not volunteer (Barreto, Ferrandez, & Saliba-Serre, 2013) potentially limiting generalisability of research findings.

Developing an understanding of motivators to take part in research studies may aid recruitment during future studies. Although these are not formal responses, anecdotal feedback from participants suggested that motivators to participate included, 'social interaction', 'meeting new people', 'potential health and fitness benefits', 'something to do', 'have taken part in other unrelated research projects previously and found it interesting' and 'like to help research'. Conversely, barriers to participation included lack of time (childcare responsibilities, holidays, other activities e.g. choir, group activities), health issues and a preference for other activities. This final barrier was particularly relevant in the summer months when participants suggested they would rather spend their recreational time outdoors. Often participants were keen to take part if they could attend at the same time as a family member or a friend as a means of providing social support. Researchers need to consider these barriers, and devise strategies to overcome them to promote recruitment of older adults into future investigations. Another well documented issue with recruitment of older adults relates to concerns they have over negative consequences for their health that participation may have (Ridda, MacIntyre, Lindley, & Tan, 2010). In the authors' personal experience, this typically resulted from a lack of knowledge about participation requirements. In those participants especially unfamiliar to exercise, the familiarisation and pre-study meetings were important to convey information and demonstrate exercises as this information is difficult to convey over the phone or by email. This helped to ensure the participants were clear on what was required of them and made them feel more comfortable in the exercise environment. This process is recommended for future investigations.

Logistical considerations around the delivery of training and testing sessions within this thesis also highlighted a number of issues. The organisation and planning of exercise sessions needed considerable thought as previous research has shown that the accessibility of an exercise programme is directly related to exercise adherence (Cohen-Mansfield et al., 2003; Falck, Davis, Milosevic, & Liu-Ambrose, 2017; Schutzer & Graves, 2004). For example, a number of participants taking part in the investigations had childcare responsibilities, for these participants sessions had to be completed by 1430 to allow them to collect children from school. In contrast, for participants who were still in employment, training and testing sessions had to fit in around working hours (i.e. prior to 0900 and after 1700 or at the weekend). A number of participants used public transport to travel to the sessions, however, as free public transport for over 65s cannot be used

until 0930 these participants were unable to attend any sessions until 1000 at the earliest. A flexible approach to scheduling was needed throughout to offset these potential barriers to attendance. This approach appears to have been effective as evidence for good attendance is demonstrated throughout this thesis – the main training intervention delivered within this thesis (chapter 6) demonstrated attendance of 99% – while adopting a flexible approach to timing of sessions within this programme undoubtedly helped meet recruitment goals. As the research process does not exist inside a vacuum, researchers should consider these real-world issues when planning future training interventions to maximise recruitment and attendance.

As well as the flexible approach to session timing, the group based nature of the main trial may have also contributed to the high attendance rates observed as group based exercise provides opportunity for social engagement, allowing participants to make new friends and have new experiences (Falck et al., 2017; King, 2001). As mentioned previously, anecdotal feedback from participants suggested that this was a motivating factor for them to participate. Previous authors have speculated that supervised, group-based activity increases motivation (Eyigor et al., 2007), though further empirical evidence is needed to support this assertion as it would be wrong to assume that all older adults prefer group exercise rather than individual activities (Wilcox, King, Brassington, & Ahn, 1999). Therefore, in an ideal scenario, training interventions would be delivered in a way that is most suitable for each individual participant. Logistically however, this is unlikely to be feasible.

While participant related factors required considerable thought throughout this programme of work, determination of exercise protocols also presented a significant challenge. Manipulation of programming variables means that HIT is infinitely variable (Gibala et al., 2012), allowing a creative approach to protocol design. However, as this investigation considered HIT rather than SIT, exercise bouts needed to be longer duration – although not too long to prevent local muscular fatigue and boredom – while logistical issues, for example moving from one machine to the next meant that frequent rest periods were needed to allow this to happen. Although primarily based on current available evidence, training protocol selection also considered practice based evidence, i.e. the authors' previous experience of training prescription. For example, during both the HIT protocols used (chapter 3 and chapter 6) exercise bouts of differing duration were selected

in an attempt to provide greater variety within the exercise sessions in contrast to the archetypal 4 x 4 min protocol. The selection of a criterion exercise mode in part two of chapter 3 was challenging as it was limited to portable exercise modes which could be used at the Speedflex facility. This meant that using equipment such as resistance machines, although an effective training approach, was not possible. Considerable thought and pilot work was needed to finalise appropriate exercises in an attempt to closely replicate the exercises performed on Speedflex by using the same muscle groups. On reflection, the acute training responses and fitness improvements reported in this thesis suggest that the training protocols used were effective.

7.2.3 Research implications

While the experimental work presented in this thesis has begun to develop an understanding of the effects of exercise training performed using Speedflex, a number of questions remain unanswered. Furthermore, the approach taken to meet the aims of this thesis has also stimulated several recommendations for future research which will be discussed in the following section.

Despite the encouraging findings reported in this thesis on the effectiveness of Speedflex, it is acknowledged that a larger scale trial including a greater number of participants is needed before definitive conclusions can be drawn around its effectiveness for fitness improvement and to fully quantify the risk of adverse events in older adults. Moreover, questions remain over the scalability of Speedflex as a training approach in older adults, because of the need for the specialised equipment and the associated costs. Although clear beneficial effects on multiple components of fitness were observed, the inclusion of functional fitness measures in the main experimental trial of this thesis may have provided further useful information. The manipulation of exercise programming variables (e.g. exercise selection, exercise duration, rest duration) should also be investigated in an attempt to delineate optimal training prescription using Speedflex.

Considering HIT more broadly, future research should attempt to quantify the minimal dose needed for fitness improvements in older adults following HIT (Vollaard & Metcalfe, 2017) because of the potential impact reduced training volume could have on exercise uptake and adherence. Despite the increase in experimental work demonstrating

the positive physiological benefits of HIT in older adults, questions remain over the wider application and feasibility of this training approach in this population (Biddle & Batterham, 2015). While well controlled laboratory studies have highlighted the efficacy of HIT for fitness improvement, translation of these findings outside of the laboratory is needed. Recently, both Lunt et al. (2014) and Shepherd et al. (2015) have shown HIT to be effective outside of the laboratory, however, it remains to be determined if this training approach is viable in the 'real world' in this population (i.e. older adults).

Within the wider context of exercise training research, future investigations must seek to develop an understanding of what constitutes a clinically important improvement in fitness in terms of physical competency rather than disease risk or life expectancy in older adults. Cardiorespiratory fitness is a key surrogate end-point of exercise training interventions and a number of studies have reported the effect of a 1-MET increase in cardiorespiratory fitness with a corresponding increase in life expectancy. For example, Kodama et al. (2009) found a 1-MET higher level of maximal aerobic capacity was associated with 13% and 15% decrements in risk of all-cause mortality and CHD/CVD, respectively. Although convenient to assess changes in terms of 1-MET (i.e. $3.5 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) it is likely that an improvement of a lower magnitude than this may still be functionally relevant. For example, a change of less than 1-MET may also confer significant functional benefit, particularly in participants with low baseline fitness where small changes in physiological capacity can have large effects on functional performance (Macaluso & De Vito, 2004). In terms of functional performance, muscular fitness is a more important discriminating factor than cardiorespiratory fitness in older adults. Despite this, there remains no robust thresholds for interpreting the magnitude of training induced changes. Future research should attempt to quantify the degree of improvement necessary to improve functional outcomes in older adults, as this is likely to be a greater relevance to older adults compared to an increased life span.

As highlighted in chapter 4 of this thesis, standardised evaluation and reporting of exercise training interventions would help future attempts to synthesise between study findings. Accordingly, Table 7.1 and Table 7.2 provide a clear guide for the prescription, monitoring and evaluation of exercise training studies in older adults to allow this to happen in future investigations. Researchers are encouraged to provide the following

information to allow the reader to make an informed interpretation of the data presented. Doing this will also aid future meta-analytic attempts to synthesise data.

Table 7.1 Proposed recommendations for reporting of prescription, monitoring and evaluation of exercise training in older adults

<i>Prescription</i>	<ol style="list-style-type: none"> 1. Training frequency (e.g. how many sessions per week) 2. Training intensity (see Table 7.2) 3. Training volume (eg. ET: duration, ST: 3 sets of 12 repetitions, HIT: number of exercise bouts) 4. Exercise mode (e.g. treadmill, stationary cycle, elastic resistance bands)
<i>Monitoring</i>	ET: %HR _{max} , dRPE, sRPE ST: %1RM, dRPE, sRPE HIT: %HR _{max} , dRPE, sRPE
<i>Evaluation</i>	<ol style="list-style-type: none"> 1. Selection of relevant outcome measures (eg. cardiorespiratory fitness) including familiarisation with testing equipment and habituation with testing procedures. Reliability statistics of outcome measures used 2. Group and individual training data (e.g. heart rate, dRPE) 3. Assessment of intervention fidelity (see Table 7.3)
ET, endurance training; ST, strength training; HIT, high-intensity interval training; dRPE, differential ratings of perceived exertion; sRPE, session rating of perceived exertion	

Table 7.2 Suggested classification of relative exercise intensity for exercise prescription (Adapted from Garber et al., 2011; Baechle, Earle & Wathen, 2008)

Endurance exercise				Resistance exercise		
Intensity	%HR _{max}	% $\dot{V}O_{2max}$	Perceived exertion (CR100 ^{®*})	%1RM	RM based prescription	Perceived exertion (CR100 ^{®*})
Light	<64	<46	< Easy (RPE <12)	<50	>20RM	< Easy (RPE <12)
Moderate	64-76	46-73	Easy to somewhat hard (RPE 12-34)	50-69	13-20RM	Easy to somewhat hard (RPE 12-34)
Vigorous	77-95	64-90	Somewhat hard to very hard (RPE 35-70)	70-84	6-12RM	Somewhat hard to very hard (RPE 35-70)
Near-maximal to maximal	≥96	≥91	> Very hard (RPE >70)	≥85	<6RM	> Very hard (RPE >70)

* Borg & Borg, 2002; %1RM, percentage of one repetition maximum; RM, repetition maximum

Recently, increased attention has been given to understanding individual responses to exercise training (Bouchard et al., 1999) and how best to quantify ‘non-responders’ (Atkinson & Batterham, 2015). However, Montero & Lundby (2017) have suggested that non-response to endurance training (i.e. increasing cardiorespiratory fitness) can be abolished by increasing exercise volume, while Churchward-Venne et al. (2015) reported that there were no non-responders to resistance training in their study with older adults. Combined, these findings suggest that a lack of response to exercise training may primarily result from a combination of ineffective training programming and poor adherence to prescribed training activities. Consequently, quantifying intervention fidelity is an important strategy to allow researchers and clinicians to make a reasoned judgement about the effectiveness of a training programme. Work from Taylor and colleagues (Taylor et al., 2015) which quantified the fidelity of a HIT intervention based on heart rate data highlighted that reconciliation with the work of others was not possible because this was the first work of its kind. The authors suggested that future studies using the same approach would allow for development of robust qualitative inferences for the assessment of intervention fidelity. Wider translation of this may be enhanced by providing a qualitative descriptor allowing for simple between-study comparisons (see Table 7.3). Accordingly, it is recommended that as per Taylor et al. (2015) authors report the median (Altman, Gore, Gardner, & Pocock, 1983) along with the interquartile range of sessions meeting pre-specified criteria and quantify this using the corresponding qualitative descriptor as in Table 7.3. The thresholds provided here are based on the authors’ personal experiences of exercise training prescription and evaluation. Further research is needed to evaluate the proposed qualitative descriptors and their corresponding thresholds.

Table 7.3 Proposed qualitative scale for intervention fidelity

Qualitative descriptor	Compliance*
Low	<50%
Moderate	50-70%
High	>70%

*Median number of sessions / repetitions meeting predetermined criteria

7.3 Conclusion

The work presented in this thesis has evaluated a recently developed hydraulic resistance exercise machine (Speedflex) demonstrating that a 12-week HIT intervention offers a potent stimulus for improving both cardiorespiratory and muscular fitness in adults aged over 50 years. The present data provide further evidence supporting the viability and effectiveness of HIT in older adults while also highlighting that alternate exercise modes can induce a training stimulus appropriate for multicomponent fitness improvement. A novel finding of this presented work is that submaximal HIT is capable of inducing improvements in explosive lower body muscular power. Additionally, this thesis has also presented a thorough quantification of the effects of same-session combined exercise training demonstrating it to be an effective method for inducing substantial fitness improvements in older adults. Future investigations should attempt to address questions relating to the potential long-term effects of Speedflex training as well as developing an understanding of the mechanisms responsible for training induced adaptation. As well as this, researchers should attempt to delineate the effects of exercise programming variables to optimise future prescription of both Speedflex, and combined exercise training. The wider translation and acceptability of Speedflex remains uncertain until a definitive trial can be performed.

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APPENDICES

Appendix A: Confirmation of ethical approval (chapter 3)

Dr Mark Simpson
Dean
School of Social Sciences & Law
Teesside University Middlesbrough
Tees Valley TS1 3BA UK

T: +44 (0)1642 342301
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tees.ac.uk



19 March 2014

Matt Weston

Dear Matt

School Research Ethics Committee

Project title: The validity of the Speedflex training system as a high-intensity aerobic interval training tool, and a resistance training tool.

Researcher(s) Names: Christopher Hurst

The above proposal has received ethical clearance and the project may proceed.

If the research should change or extend beyond the indicated dates, the researcher must report the nature of the proposed changes and the revised end date to the Chair/Secretary of the Research Ethics Committee.

Yours sincerely

A handwritten signature in black ink, appearing to read 'M. A. Tayler'.

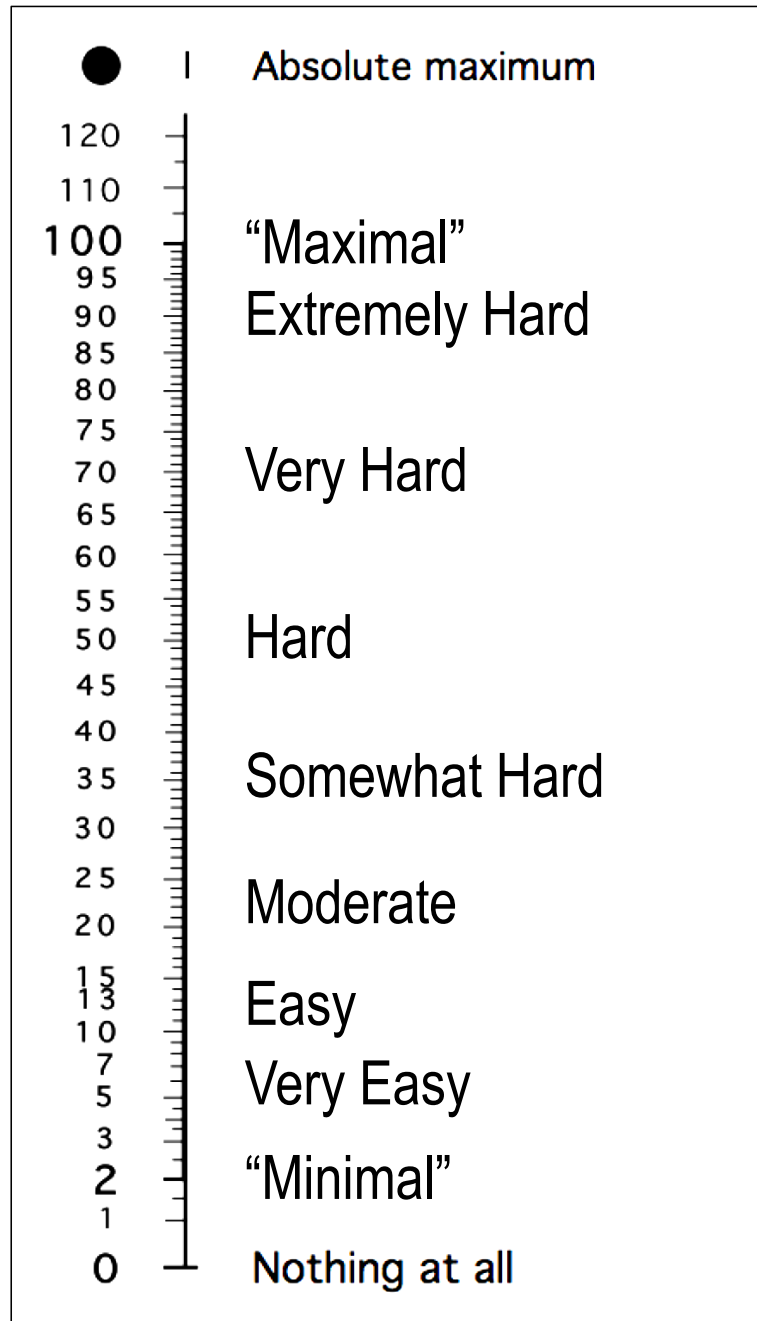
Dr Martin Tayler
Chair
Research Ethics Committee
School of Social Sciences and Law

VAT REG NO. GB 686 4809 81



Appendix B: CR100[®] scale

CR100 Scale



Appendix C: Exercise descriptions (chapter 3)

PART ONE

SPEEDFLEX EXERCISES

1. Power clean and press



Description of exercise:

Participant starts holding the handles of the Speedflex machine with feet shoulder width apart. Movement begins by bending at the knees, keeping back flat and arms fully extended. Keeping arms extended, participant lifts the bar by standing up extending hips and knees. As the bar approaches chest height, participant bends knees and brings the bar to shoulder height. From shoulder height, participant presses the bar above the head, fully extending the arms. From the top position, participant pulls the bar back to shoulder height and reverses the movement.

2. Squat



Description of exercise:

Participant begins by standing with feet hip width apart or slightly wider with toes pointing forwards with the pads of the Speedflex machine resting on shoulders. Keep the head and chest up looking straight forward. Participant should keep a flat or naturally slightly arched back. Allowing knees to bend slowly for the downwards phase of the movement, making

sure to keep heels on the floor throughout. Once at the bottom of the movement, participant should extend the hips and knees together at the same speed. Make sure the shoulder pads remain in contact with shoulders at all times.

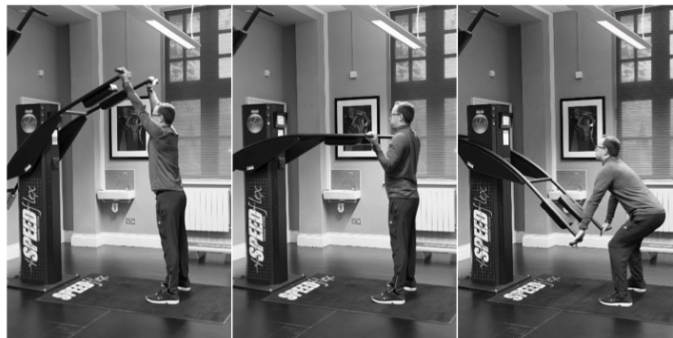
3. Step and press



Description of exercise:

Participant starts with both feet on the floor and bar at shoulder height. Participant step both feet up (one at a time) and onto the box. Participant should press the bar above the head (i.e. fully extend arms) at the same time as stepping until the arms are fully extended. Once at the top of the movement, participant should step back down and pull the bar back to the starting position.

4. Pulldown to squat



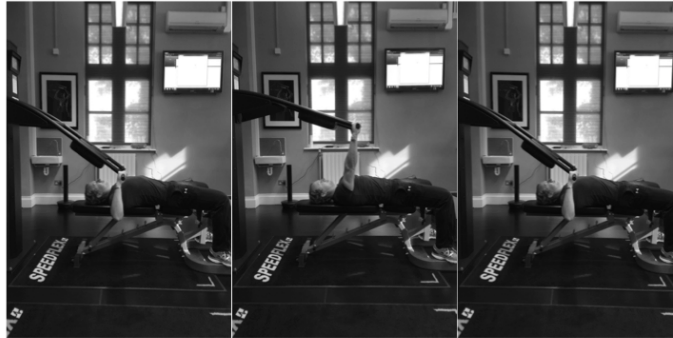
Description of exercise:

Movement starts with participant's arms fully extended holding the handles with a supinated grip and feet hip width apart. Looking straight forward the participant should pull the bar down to shoulder height (the pulldown phase of the exercise). Keeping hands in line with shoulders and back in a neutral position with a slight arch lower into a squat phase. Participant should allow the knees to bend and keep heels on the floor at all times. Once at the bottom of the movement, participant should extend the hips and knees together at the same rate making sure hands are still in line with shoulders. Once the participant is standing tall press the bar above the head.

PART TWO

SPEEDFLEX EXERCISES

1. Bench press with flat row



Description of exercise:

Participant begins by lying supine on the bench. Holding the Speedflex machine by the handles the participant begins with the bar resting just above the on chest. Participant then fully extends the arms. Once arms are fully extended, the participant should then pull the bar back down to chest.

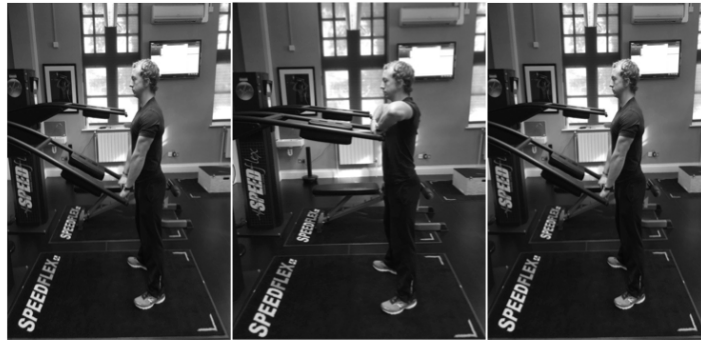
2. Shoulder press with pull down



Description of exercise:

Participant begins with both hands on the Speedfle machine (pronated grip) with the bar at shoulder height. Participant then fully extends the arms above the head. Once at full extension the participant should change the hand position on the machine (pronated to supinated). Participant should then pull the bar back down to shoulder height.

3. Upright row with press down



Description of exercise:

Participant should stand with feet approximately shoulder width apart and arms at full extension with bar at approximately hip height. Participant should then pull bar up to chest height. From this position, the participant should then push back down until the arms are fully extended and back to start position.

PART TWO

RESISTANCE BAND EXERCISES

1. Bench press



Description of exercise:

Participant lies supine on bench. Holding the resistance bands by the handles at chest height. Participant performs a full extension of the arms. Participant should then relax arms and return to the starting position.

2. Flat row



Description of exercise:

Participant begins lying supine on the bench. Movement begins with arms fully extended holding the resistance bands by the handles. Participant then pulls down until the handles reach the chest. Participant should then relax the arms allowing the resistance bands to return to the position at the start of the movement.

3. Shoulder press



Description of exercise:

Movement begins with participant standing with feet approximately hip width apart with both feet pointing forward. Participant should hold the resistance bands by the handles (pronated grip) with the hands at shoulder height. Participant should then extend arms fully above the head (Full extension at the shoulders). Once at the top of the movement the participant should then relax allowing the resistance bands to return to the starting position (shoulder height).

4. Pull down



Description of exercise:

Participant begins by being seated in neutral position with feet resting flat on the floor. The movement begins with arms fully extended with hands in a neutral grip (i.e. palms facing each other). From this position the participant should then pull down to a level between the shoulders and chest. Once in this position the participant should relax allowing the resistance bands to naturally return to the starting position.

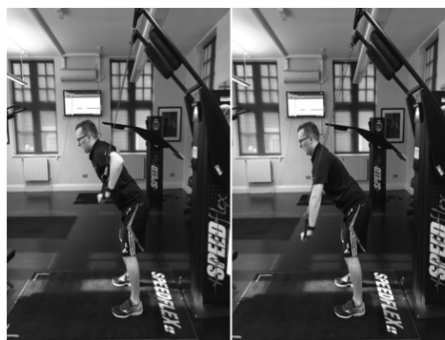
5. Upright row



Description of exercise:

Participant begins in a neutral stance with feet approximately shoulder width apart with both feet pointing forwards. Participants should hold the handles at waist height (supinated grip). From this position the participant should then pull directly upwards until hands are at just below shoulder height (in front of the chest). Once at the top of the movement, the participant should relax the arms allowing the resistance bands to naturally return to the starting position.

6. Press down



Description of exercise:

Participant should stand with feet approximately shoulder width apart with both feet pointing forward. The participant should hold the handles at chest height just below armpits (supinated grip). It is important that the participant leans the torso forward to ensure that the chest muscles work during the movement. Once in the correct position then the participant should fully extend the arms to around thigh height. Once at the bottom of the movement the participant should relax, allowing the resistance bands to naturally return to the starting position.

Appendix D: PROSPERO registration

UNIVERSITY *of York*
Centre for Reviews and Dissemination

NHS
National Institute for
Health Research

PROSPERO International prospective register of systematic reviews

Effects of multicomponent exercise training on measures of physical performance in older adults: a meta-analysis

Christopher Hurst, Alan Batterham, Kathryn Taylor, Matthew Weston

Citation

Christopher Hurst, Alan Batterham, Kathryn Taylor, Matthew Weston. Effects of multicomponent exercise training on measures of physical performance in older adults: a meta-analysis. PROSPERO 2015:CRD42015019577
Available from http://www.crd.york.ac.uk/PROSPERO_REBRANDING/display_record.asp?ID=CRD42015019577

Review question(s)

What is the effect of multicomponent exercise training on measures of functional physical performance in older adults?

Searches

The following electronic databases will be searched: PubMed, MEDLINE, Scopus, BIOSIS and Web of Science. In addition, reference lists of all identified articles will be screened for additional studies.

The search strategy will include terms related to the exercise intervention of interest (i.e. multicomponent exercise training, circuit training, combined exercise training) in combination with outcomes of interest (i.e. physical performance, functional fitness, muscle power).

Each database will be searched from the date of the earliest available record until the specified date that the search was conducted. Searches will be re-run prior to analyses for additional eligible studies. Only studies published in English will be considered for inclusion.

Types of study to be included

Both controlled and non-controlled trials will be included.

Condition or domain being studied

Human ageing is a complex, multifactorial process characterised by a progressive decline in physiological systems, including the cardiovascular and neuromuscular systems. This physical degradation leads to a decrease in functional abilities, contributing to a reduced quality of life. Exercise training has been demonstrated to be an effective strategy for counteracting ageing related changes in physiological systems. In particular, multicomponent training has been suggested as a viable training tool for older adults because of its capacity to impact on functional outcomes. The nature of multicomponent training aims to tax multiple energy systems to induce improvements across various physiological systems, with the ultimate aim of improving functional performance.

Participants/ population

This review will consider studies which include community dwelling adults aged 50 years or older. Studies involving adults aged under 50 years of age, or institutionalised adults will be excluded.

Intervention(s), exposure(s)

This review will consider studies employing multicomponent exercise training, defined as exercise training consisting of both (1) aerobic and (2) resistance training activities performed within the same exercise session. Only supervised exercise interventions will be included and exercise interventions must be longer than two weeks in duration.

Studies which contain only: (1) aerobic or (2) resistance training activities will be excluded, as will training programmes containing both aerobic and resistance training activities delivered in separate sessions.

Comparator(s)/ control

We will include studies which compare:

- 1) Multicomponent training versus non-exercise controls
- 2) Multicomponent training versus resistance training only
- 3) Multicomponent training versus aerobic training only
- 4) Multicomponent training versus other form of exercise intervention

Outcome(s)

Primary outcomes

The primary outcomes of interest are measures of functional physical fitness including: 6-minute walk test, chair rise time, timed up-and-go and handgrip strength. In addition, health related quality of life measures will also be considered.

Secondary outcomes

Secondary outcomes relating to body composition, cardiovascular fitness, muscular strength and muscular power will also be considered.

Risk of bias (quality) assessment

Two reviewers will independently assess the risk of bias (methodological quality). Any disputes which can not be resolved through discussion, will be settled by a third reviewer.

Strategy for data synthesis

A meta-analysis will be conducted.

Analysis of subgroups or subsets

Meta-regression will be conducted to examine the influence of key study level covariates such as exercise intensity, exercise volume and exercise modality on key outcome measures.

Dissemination plans

A paper will be submitted to an academic journal in this field.

Contact details for further information

Mr Hurst

Department of Sport and Exercise Sciences,

School of Social Sciences, Business and Law,

Teesside University,

Middlesbrough,

United Kingdom,

TS1 3BA

c.hurst@tees.ac.uk

Organisational affiliation of the review

None

Review team

Mr Christopher Hurst, Teesside University
Professor Alan Batterham, Teesside University
Dr Kathryn Taylor, Teesside University
Dr Matthew Weston, Teesside University

Anticipated or actual start date

15 April 2015

Anticipated completion date

31 October 2015

Funding sources/sponsors

None

Conflicts of interest

None known

Other registration details

None

Language

English

Country

England

Subject index terms status

Subject indexing assigned by CRD

Subject index terms

Adult; Exercise; Humans; Physical Fitness

Stage of review

Ongoing

Date of registration in PROSPERO

21 April 2015

Date of publication of this revision

21 April 2015

DOI

10.15124/CRD42015019577

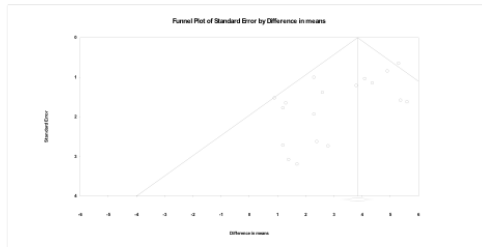
Stage of review at time of this submission	Started	Completed
Preliminary searches	Yes	No
Piloting of the study selection process	Yes	No
Formal screening of search results against eligibility criteria	No	No
Data extraction	No	No
Risk of bias (quality) assessment	No	No
Data analysis	No	No

PROSPERO

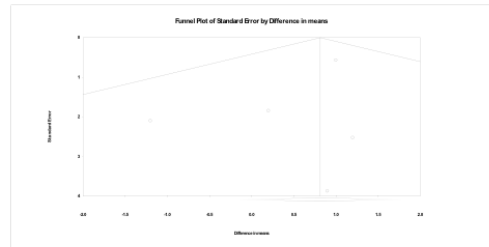
Appendix E: Publication bias

VO₂peak

Combined vs Control

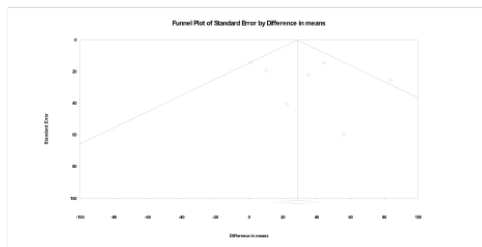


Combined vs Endurance

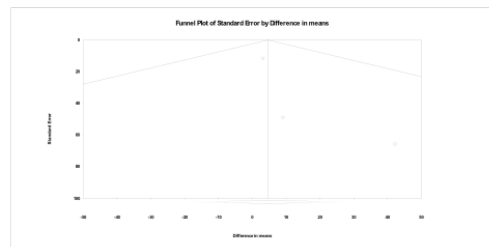


6MWT

Combined vs Control

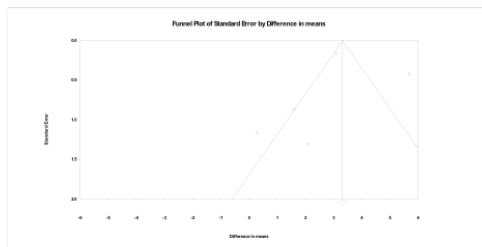


Combined vs Strength



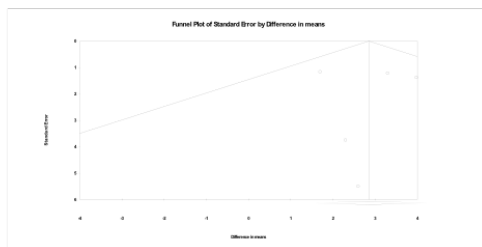
30s Chair stand

Combined vs Control

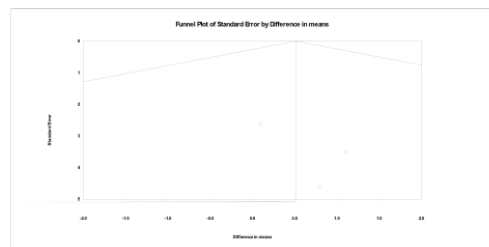


Handgrip strength

Combined vs Control



Combined vs Endurance



Appendix F: Confirmation of ethical approval (chapter 5)



22 April 2015

Dr Matt Weston

Dear Matt

School Research Ethics Committee

Project title: The reliability of a leg extensor power rig for measuring lower body muscular power.

Researcher(s) Names: Christopher Hurst

The above proposal has received ethical clearance and the project may proceed.

If the research should change or extend beyond the indicated dates, the researcher(s) must report the nature of the proposed changes and the revised end date to the Chair/Secretary of the Research Ethics Committee.

Yours sincerely

A handwritten signature in black ink that reads 'M. A. Tayler'.

Dr Martin Tayler
Chair
Research Ethics Committee
School of Social Sciences and Law

Appendix G: Descriptive data (chapter 5)

Peak power output (watts) from each trial

	Short-term reliability				Long-term reliability
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
<i>Male</i>					
Dominant leg	217.5 ± 65.8	225.4 ± 67.6	226.6 ± 64.0	229.9 ± 61.8	238.1 ± 71.5
Non-dominant leg	219.9 ± 63.7	222.3 ± 65.5	219.1 ± 63.3	224.2 ± 62.3	228.7 ± 65.2
<i>Female</i>					
Dominant leg	129.3 ± 35.9	136.9 ± 41.1	140.1 ± 42.5	143.1 ± 43.0	144.3 ± 42.6
Non-dominant leg	133.5 ± 35.9	138.3 ± 38.7	140.8 ± 39.8	147.1 ± 38.5	148.6 ± 39.0

Data presented as mean ± SD

Appendix H: Confirmation of ethical approval (chapter 6)



17 February 2016

Dr Matt Weston

Dear Matt

School Research Ethics Committee

Project title: The effects of a novel high intensity interval training programme on measures of physical fitness in adults aged over 50 years

Researcher(s) Name: Christopher Hurst

The above proposal has received ethical clearance and the project may proceed.

If the research should change or extend beyond the indicated dates, the researcher(s) must report the nature of the proposed changes and the revised end date to the Chair/Secretary of the Research Ethics Committee.

Yours sincerely

A handwritten signature in black ink, appearing to read 'M. A. Tayler'.

Dr Martin Tayler
Chair
Research Ethics Committee
School of Social Sciences and Law

Appendix I: Clinical trial registration

ClinicalTrials.gov

A service of the U.S. National Institutes of Health

Now Available: [Final Rule for FDAAA 801 and NIH Policy on Clinical Trial Reporting](#)

Trial record 1 of 7 for: teesside university

[Previous Study](#) | [Return to List](#) | [Next Study](#)

The Effect of Novel High-intensity Interval Training on Physical Fitness in Older Adults

This study is ongoing, but not recruiting participants.

Sponsor:

Teesside University

Information provided by (Responsible Party):

Christopher Hurst, Teesside University

ClinicalTrials.gov Identifier:

NCT02714088

First received: March 8, 2016

Last updated: June 1, 2016

Last verified: June 2016

[History of Changes](#)

[Full Text View](#)

[Tabular View](#)

[No Study Results Posted](#)

[Disclaimer](#)

[How to Read a Study Record](#)

► Purpose

High-intensity interval training (HIT) has been demonstrated to be an effective strategy to improve markers of health and fitness across a wide range of healthy and clinical populations. Currently however, there is only limited evidence which has examined the effectiveness of HIT in older adults (>50 years). HIT is an appealing strategy in this group as it has the potential to impact both cardiorespiratory and muscular fitness, which both play an important role in maintaining functional fitness and quality of life in a time-efficient manner. Developing an understanding of novel strategies for delivering this type of exercise training may ultimately provide a viable alternative to traditional modes of exercise training for a broader range of participants. As such, the purpose of this study is to evaluate the effects of a novel, high-intensity interval training exercise protocol to improve physical fitness in adults aged over 50 years. This research also aims to evaluate if this type of training intervention is feasible in this population, through analysis of adherence and intervention fidelity.

Condition	Intervention
High-intensity Interval Training	Other: Novel high-intensity interval training

Study Type: Interventional

Study Design: Allocation: Randomized

Intervention Model: Parallel Assignment

Masking: Open Label

Primary Purpose: Prevention

Resource links provided by NLM:

[MedlinePlus related topics:](#) [Exercise and Physical Fitness](#)

[U.S. FDA Resources](#)

Further study details as provided by Teesside University:

Primary Outcome Measures:

- Change in lower body muscular power [Time Frame: Baseline and following exercise training (12 weeks)] [Designated as safety issue: No]
Assessed via Nottingham Leg Extensor Power Rig
- Change in Aerobic fitness [Time Frame: Baseline and following exercise training (12 weeks)] [Designated as safety issue: No]
Assessed via Chester step test
- Change in upper extremity muscular strength [Time Frame: Baseline and following exercise training (12 weeks)]
[Designated as safety issue: No]
Hand grip strength assessed using handheld dynamometer
- Change in quality of life [Time Frame: Baseline and following exercise training (12 weeks)] [Designated as safety issue: No]
Assessed via Short form quality of life questionnaire (SF36)

Other Outcome Measures:

- Heart rate during high-intensity interval training exercise sessions [Time Frame: Up to 12 weeks] [Designated as safety issue: No]
- Rating of perceived exertion (RPE) during high-intensity interval training exercise sessions [Time Frame: Up to 12 weeks] [Designated as safety issue: No]

Enrollment: 36
Study Start Date: April 2016
Estimated Primary Completion Date: August 2016 (Final data collection date for primary outcome measure)

Arms	Assigned Interventions
Experimental: Intervention Participants will undertake a high-intensity interval training intervention, completing two exercise sessions per week for 12 weeks. The exercise sessions will consist of 4 sets of 4-6 repetitions of 60s (45s high-intensity exercise, followed by 15s rest), interspersed with 3 minutes rest. During each exercise repetition participants will be encouraged to reach >90% of their maximal heart rate.	Other: Novel high-intensity interval training
No Intervention: Control Participants will not undertake any formal intervention and will be asked to maintain their usual physical activity habits and diet.	

► **Eligibility**

Ages Eligible for Study: 50 Years to 85 Years (Adult, Senior)
Genders Eligible for Study: Both
Accepts Healthy Volunteers: Yes

Criteria

Inclusion Criteria:

1. Must be aged 50-85 years
2. Must be able to provide informed consent to participate
3. Must be free from all exclusion criteria

Exclusion Criteria:

1. Symptoms of or known presence of heart disease or major atherosclerotic cardiovascular disease
2. Early family history of sudden cardiac death
3. Condition or injury or co-morbidity affecting the ability to undertake exercise
4. Diabetes mellitus
5. Pregnancy or likelihood of pregnancy

► **Contacts and Locations**

Choosing to participate in a study is an important personal decision. Talk with your doctor and family members or friends about deciding to join a study. To learn more about this study, you or your doctor may contact the study research staff using the Contacts provided below. For general information, see [Learn About Clinical Studies](#).

Please refer to this study by its ClinicalTrials.gov identifier: NCT02714088

Locations

United Kingdom

Teesside University
Middlesbrough, Tees Valley, United Kingdom, TS1 3BA

Sponsors and Collaborators

Teesside University

► **More Information**

Responsible Party: Christopher Hurst, Postgraduate Researcher, Teesside University
ClinicalTrials.gov Identifier: [NCT02714088](#) [History of Changes](#)

Other Study ID Numbers: TEES-CH170216-SSSBL
Study First Received: March 8, 2016
Last Updated: June 1, 2016
Health Authority: United Kingdom: Research Ethics Committee

Keywords provided by Teesside University:
High-intensity interval training
Functional fitness
Quality of life
Older adults

ClinicalTrials.gov processed this record on October 12, 2016

Appendix J: Exercise descriptions (chapter 6)

Power clean and press



Exercise description:

Participant starts holding the handles of the Speedflex machine with feet shoulder width apart. Movement begins by bending at the knees, keeping back flat and arms fully extended. Keeping arms extended, participant lifts the bar by standing up extending hips and knees. As the bar approaches chest height, participant bends knees and brings the bar to shoulder height. From shoulder height, participant presses the bar above the head, fully extending the arms. From the top position, participant pulls the bar back to shoulder height and reverses the movement.

Step and press



Exercise description:

Participant starts with both feet on the floor and bar at shoulder height. Participant step both feet up (one at a time) and onto the box. Participant should press the bar above the head (i.e. fully extend arms) at the same time as stepping until the arms are fully extended. Once at the top of the movement, participant should step back down and pull the bar back to the starting position.

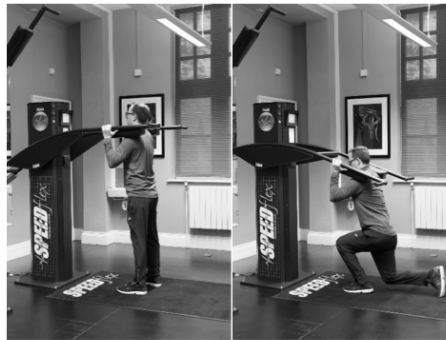
Squat



Exercise description:

Participant begins by standing with feet hip width apart or slightly wider with toes pointing forwards with the pads of the Speedflex machine resting on shoulders. Keep the head and chest up looking straight forward. Participant should keep a flat or naturally slightly arched back. Allowing knees to bend slowly for the downwards phase of the movement, making sure to keep heels on the floor throughout. Once at the bottom of the movement, participant should extend the hips and knees together at the same speed. Make sure the shoulder pads remain in contact with shoulders at all times.

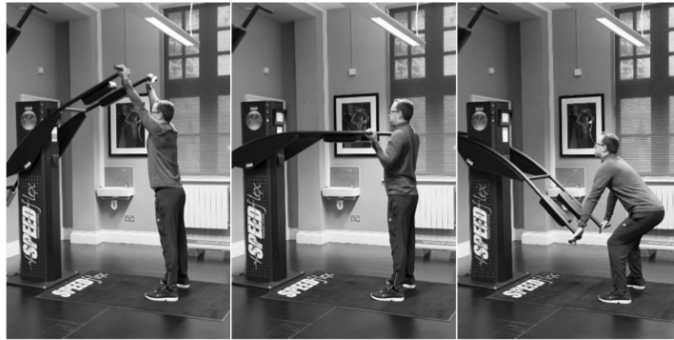
Split squat



Exercise description:

Participant begins by standing with feet hip width apart or slightly wider with toes pointing forwards with the pads of the Speedflex machine resting on shoulders. Keep the head and chest up looking straight forward. Participant should keep a flat or naturally slightly arched back. Squat down by flexing knee and hip of front leg. Allow heel of rear foot to rise up while knee of rear leg bends slightly until it almost makes contact with floor. Return to original standing position by extending hip and knee of forward leg. Repeat. Continue with opposite leg. Make sure the shoulder pads remain in contact with shoulders at all times.

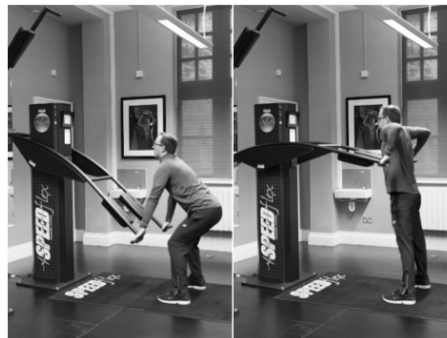
Pulldown to squat



Exercise description:

Movement starts with participant's arms fully extended holding the handles with a supinated grip and feet hip width apart. Looking straight forward the participant should pull the bar down to shoulder height (the pulldown phase of the exercise). Keeping hands in line with shoulders and back in a neutral position with a slight arch lower into a squat phase. Participant should allow the knees to bend and keep heels on the floor at all times. Once at the bottom of the movement, participant should extend the hips and knees together at the same rate making sure hands are still in line with shoulders. Once the participant is standing tall press the bar above the head.

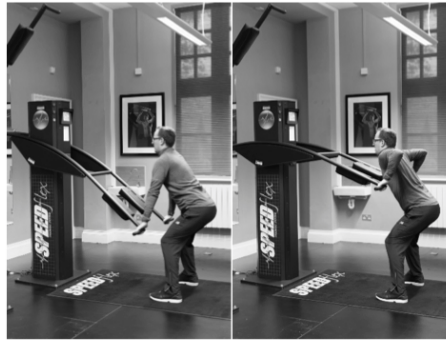
High pull



Exercise description:

Participant holds the Speedflex bar with feet shoulder width apart. Pushing the hips back and letting the knees bend slightly as the Speedflex bar lowers to about knee height. The back should be flat. Participant should explosively thrust the hips forward simultaneously pulling the Speedflex bar to lower chest height with the elbows high. At the peak Speedflex bar position heels can either remain on the floor or for more range come up onto your toes. Participant should push the Speedflex bar back down reversing the process in a smooth, rapid fashion as heels return to the floor. Hips push back, and the back stays flat.

Bent over row



Exercise description:

Participant holds the Speedflex bar with feet shoulder width apart. Pushing the hips back and letting the knees bend slightly with the Speedflex bar at about knee height. The back should be flat. Participant should hold this position keeping the lower body still. Participant should drive the hands up towards the chest (under the arm pit) keeping the back flat. The arms should then be fully extended to return to the starting position.

Shoulder press



Exercise description:

Participant begins by standing with feet hip width apart or slightly wider with toes pointing forwards. From shoulder height, participant presses the bar above the head, fully extending the arms. From the top position, participant pulls the bar back to shoulder height.
