DOCTOR OF PHILOSOPHY

High-velocity, low-load and low-velocity, high load resistance exercise and their Influence on physiological outcomes, affective responses and functional performance in older adults

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Award date:
2018

Awarding institution:
Coventry University

High-Velocity, Low-Load and Low-Velocity, High load Resistance Exercise and their Influence on Physiological Outcomes, Affective Responses and Functional Performance in Older Adults

By

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A thesis submitted in partial fulfilment of the university's requirements for the degree of Doctor of Philosophy

September 2018

Certificate of Ethical Approval

Applicant:

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Project Title:

A Reliability Study to Demonstrate the Amount of Familiarisation Needed to Achieve Consistent Speed of Movement during High and Low Velocity Exercise

This is to certify that the above named applicant has completed the Coventry University Ethical Approval process and their project has been confirmed and approved as Medium Risk

Date of approval:

14 March 2016

Project Reference Number:

P40329

Certificate of Ethical Approval

Applicant:

Darren Richardson

Project Title:

The efficacy of high and low velocity resistance exercise performed once or twice weekly on improvements in functional performance in older adults

This is to certify that the above named applicant has completed the Coventry University Ethical Approval process and their project has been confirmed and approved as Medium Risk

Date of approval:

10 February 2017

Project Reference Number:

P51432

Abstract

Exacerbated by physical inactivity, advancing age is characterised by sarcopenia, dynapenia, and a subsequent decline in functional performance. However, resistance exercise has demonstrated beneficial effects on these conditions in older adults. Subsequently, the aim of this thesis was to monitor physiological changes, affective responses, enjoyment and changes in maximal strength and functional performance when performing high-velocity, low-load (HVLL) and low-velocity, high-load (LVHL) resistance exercise.

Study one validated the use of a command and metronome-based protocol, demonstrating that it could be used to produce either high or low movement velocities when performing resistance exercise. Study two examined the acute physiological responses to volume-load matched HVLL and LVHL. Results revealed no significant differences in blood lactate, heart rate, systolic blood pressure or diastolic blood pressure, suggesting HVLL and LVHL produce comparable physiological strain.

Study three examined the acute affective responses and enjoyment of volume-load matched HVLL and LVHL. Rating of perceived exertion and fatigue were greater during LVHL compared to HVLL. Despite this, enjoyment was similarly high for HVLL and LVHL, meaning it is probable that both would have a positive effect on continued exercise behaviour. The fourth study extended this work over 10-weeks, and also examined affective responses between exercising once or twice-weekly. The findings were largely in agreement with study three, and affective responses were similar between exercise frequencies.

Study five examined how frequency (once vs. twice-weekly) and mode (HVLL vs. LVHL) of resistance exercise influenced functional performance, maximal strength and body composition. Only LVHL twice-weekly significantly improved functional performance compared to the control group. However, within-condition analysis revealed that HVLL and LVHL performed once and/or twice-weekly, significantly improved aspects of maximal strength and functional performance in older adults.

From the observations of these studies and the wider literature, it was concluded that whether utilising HVLL or LVHL, exercise professionals should ensure older adults experience sufficient intensity of effort whilst exercising. When the individual is ready, they should progress from minimal doses of resistance exercise to facilitate continued development of strength and functional performance, or at the very least, ensure current levels are maintained. Affective responses appeared to be analogous between HVLL and LVHL, however the role that social interaction, habitual physical activity levels and supervision played in producing these results, warrants further investigation.

Acknowledgements

I would first of all like to thank my director of studies, Dr Neil Clarke for providing encouragement, support, feedback and advice at all hours of the day (and night) during the course of my PhD. I am truly grateful for all his help and hard work. Needless to say, I would not be where I am today without his influence over my past 7 years at Coventry University. I would also like to thank my second supervisor Professor Michael Duncan for his valuable input, feedback and advice. He has always been one email away for the past 3 years and I am very thankful for all his hard work and support. I would also like to thank Professor Alfonso Jimenez for also providing support and feedback. Lastly, I would like to thank Victoria Jones who gave her summer to help me to collect the data for the first three studies of this PhD. I physically could not have done it without her.

Thanks, are extended to Dr Paul Juris and Cybex international who funded this PhD and provided guidance and support throughout.

I would also like to thank each and every participant who gave their time in each study. Along with supplying the data for this PhD, they also made the experience enjoyable. I made some great friends, many of whom I have learnt a lot of life lessons from, whilst having some interesting discussions and countless laughs.

Lastly, I am very lucky to have a family that have supported me both emotionally and financially while completing my PhD and my other degrees, so I would like to thank them for all their love and support.

Declaration

I declare that the work presented in this thesis is entirely my own, with the exception of the work that has been published in peer reviewed journal articles and presented at conferences:

Movement Velocity during High- and Low-Velocity Resistance Exercise Protocols in Older Adults

Published in: Experimental Gerontology.

Richardson, D. L., Duncan, M. J., Jimenez, A., Jones, V. M., Juris, P. M., and Clarke, N. D. (2018a) 'Movement Velocity During High- and Low-Velocity Resistance Exercise Protocols in Older Adults'. *Experimental gerontology* 107, 140-147

The Acute Physiological Effects of High and Low Velocity Resistance Exercise in Older Adults

Published in: European Journal of Ageing.

Richardson, D. L., Duncan, M. J., Jimenez, A., Jones, V. M., Juris, P. M., and Clarke, N. D. (2017) 'The Acute Physiological Effects of High-and Low-Velocity Resistance Exercise in Older Adults'. *European Journal of Ageing*, 1-9

And presented at BASES-FEPSAC 2017

The Perceptual Responses to High-Velocity, Low-Load and Low-Velocity, High-Load Resistance Exercise in Older Adults

Published in: Journal of Sports Sciences.

Richardson, D. L., Duncan, M. J., Jimenez, A., Jones, V. M., Juris, P. M., and Clarke, N. D. (2018b) 'The Perceptual Responses to High-Velocity, Low-Load and Low-Velocity, High-Load Resistance Exercise in Older Adults'. *Journal of sports sciences* 36 (14), 1594-1601

Effects of Movement Velocity and Training Frequency of Resistance Exercise on Functional Performance in Older Adults: A Randomised Controlled Trial

Published in: European Journal of Sport Science.

Richardson, D. L., Duncan, M. J., Jimenez, A., Juris, P. M., and Clarke, N. D. (2018) 'Effects of Movement Velocity and Training Frequency of Resistance Exercise on Functional Performance in Older Adults: A Randomised Controlled Trial'. *European journal of sport science*, 1-13

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Abbreviations

1RM	One Repetition Maximum
8-Ft Up-&-Go	8-Ft up and go test
ACSM	American College of Sports Medicine
ANOVA	Analysis of Variance
ANCOVA	Analysis of Covariance
CDC	Centre of Disease Control and Prevention
DEXA	Dual-Energy X-ray Absorptiometry
DNA	Deoxyribonucleic acid
FAS	Felt Arousal Scale
FS	Feeling Scale
$g/kg/day^{-1}$	Grams Per Kilogram Per Day
HDL	High Density Lipoproteins
HVLL	High-Velocity Low-Load Resistance Exercise
HVLL1	High-Velocity Low-Load Resistance Exercise Once-Weekly
HVLL2	High-Velocity Low-Load Resistance Exercise Twice-Weekly
IPAQ	International Physical Activity Questionnaire
LDL	Low Density Lipoproteins
LVHL	Low-Velocity High-Load Resistance Exercise
LVHL1	Low-Velocity High-Load Resistance Exercise Once-Weekly
LVHL2	Low-Velocity High-Load Resistance Exercise Twice-Weekly
MANOVA	Multivariate Analysis of Variance
MET	Metabolic Equivalent
MHC	Myosin Heavy Chain
NHS	National Health Service
PAAS	Physical Activity Affect Scale
PACES	Physical Activity Enjoyment Scale
RM	Repetition Maximum
RPE	Rating of Perceived Exertion
VAS	Visual Analogue Scales
$\dot{V}O_2max$	Maximal Oxygen Consumption

Chapter 1: Introduction

1.1 Introduction

It has been extensively documented that the population of older adults is increasing globally, due to increased lifespan (Chen et al. 2010). Ageing is characterised by the progressive loss of muscle mass, muscle strength, and decline of functional performance (Barber et al. 2015), subsequently increasing the strain on healthcare systems (Yu 2015). These age-related problems are worsened by physical inactivity (Doherty 2003), further augmenting both sarcopenia (Cruz-Jentoft and Landi 2014) and dynapenia (Clark and Manini 2008), and contributing to functional decline. As a significant number of older adults are not satisfying the physical activity guidelines in the United Kingdom (Jefferis et al. 2014) physical inactivity is a significant public health concern.

To date, numerous studies (Byrne et al. 2016; Hupin et al. 2015) have investigated the ability of various forms of physical activity in improving quality of life, function and general health in older adults. Aerobic exercise has been shown to have positive effects on: disease risk, maintenance of healthy body mass, blood pressure and blood lipid levels (Mersy 1991). Resistance exercise has also been implicated in reduced disease risk (Pollock and Evans 1999), improved hormonal profiles (Craig et al. 1989), increased strength and preserved muscle mass (Atha 1981). However, there are additional benefits of resistance exercise over aerobic exercise. Resistance exercise has been shown to be superior at producing muscle hypertrophy compared with endurance exercise (Borst 2004) and increasing voluntary force output through adaptations in neurophysiologic performance (Munn et al. 2005). Furthermore, resistance exercise has a profound positive effect on many of the physiological mechanisms in the muscular and nervous systems that influence strength (Law et al. 2016). All of which are important for the maintenance of function and independence in older adults (Hunter et al. 2004).

Early investigations into resistance exercise identified the importance of muscle strength for functional performance in older adults (Aniansson et al. 1980). More recently, it has been suggested that muscle power may be more relevant to functional performance, as being able to move a limb fast against a low external resistance (e.g. moving a limb quickly to stabilise to avoid a fall) is more useful than being able to move a limb slowly against a high external resistance (Sayers and Gibson 2014). Therefore, high-velocity, low-load (HVLL) and low-velocity, high-load (LVHL) resistance exercise (types of power and strength training) have been widely investigated (Tschopp et al. 2011). It appears that HVLL and LVHL may elicit similar responses in muscle strength (Henwood and Taaffe 2006), muscle cross sectional area (Claflin et al. 2011) and improvements in functional performance (Tschopp et al. 2011). Although more recently, there has been evidence presented that HVLL may be superior in delivering improvements in muscle power and/or functional performance (Byrne et al. 2016). Further to the type of resistance exercise that should be prescribed, there is significant interest in the minimal effective dose of resistance exercise required to obtain significant physical and functional benefits.

Commonly cited barriers to exercise for older adults are time and cost (Foley et al. 2011). Physical activity guidelines in the United Kingdom, recommend that older adults perform whole-body strength training at least twice-weekly. Considering many older adults need supervision, cost is a significant barrier to achieving this (Foley et al. 2011). Therefore, it would be beneficial to understand the minimal effective dose of resistance exercise that facilitates physiological and functional benefits. Taaffe et al. (1999) demonstrated that once-weekly, progressive resistance exercise using 3 sets of 8 exercises at 80% one-repetition maximum (1RM), produced similar strength gains to twice or thrice-weekly. Foley et al. (2011) observed that once-weekly exercise was equally effective as twice-weekly in maintaining strength and functional outcomes, three months following a rehabilitation programme. Furthermore, a systematic review by Byrne et al. (2016) advocated investigation into the minimal effective training dose of resistance exercise (training volumes and/or frequency), suggesting that the efficacy of once-weekly HVLL and LVHL for improvements in muscle power and functional performance warrants further investigation.

Despite the plethora of benefits that resistance exercise has on older adults (Hunter et al. 2004), the United Kingdom physical activity guidelines (Bull et al. 2010) from the chief medical office remain brief and somewhat understated in their recommendations of resistance exercise. In light of the weight of evidence, there are now more calls for emphasis to be placed on resistance exercise in aiding the public health effort (Steele et al. 2017a). Therefore, this thesis is focused on examining how type and frequency of resistance exercise influences: physiological responses, maximal strength, functional performance and affective responses in older adults. A major consideration of this thesis, is the poorly investigated area of exercise affect, and the affective responses to gym-based resistance exercise in older adults. It is much debated in the literature as to which type of resistance exercise e.g. LVHL (Traditional resistance training/ progressive resistance training) or HVLL (power training) delivers the most positive outcomes in older adults, in terms of physiologically driven concerns, but there are few studies that have attempted to understand poor exercise programme compliance rates by considering affective responses and enjoyment of resistance exercise.

The current physical activity guidelines in the United Kingdom primarily reflect physiologically driven considerations over addressing the significant participation problems (Lind et al. 2005). It is important to determine whether, and to what extent, individuals enjoy exercise in order to facilitate the design of not only physiologically effective exercise programmes, but also ones that are enjoyable, or at least, tolerable (Lind et al. 2005). As enjoyment of exercise is linked to adherence (Ekkekakis et al. 2011), examining affective responses may help to predict if the resistance exercise programmes used in this thesis are likely to be adhered to in the long-term. This is an area that has received very little investigation thus far, and so is potentially valuable for understanding exercise behaviour and informing resistance exercise programming for older adults.

The movement velocity that resistance exercise is performed at is an important, and often overlooked variable. It has been suggested that the intention to perform resistance exercise as fast as possible, is more important for high-velocity specific adaptations of the neuromuscular system, than the actual movement velocity achieved (Behm and Sale 1993). However, McBride et al. (2002) observed performing squat jumps with the intention to move at maximal movement velocity using 30% 1RM, improved peak velocity, peak power and jump height, whereas training at 80% 1RM did not. Therefore, the actual movement velocity that is achieved during resistance exercise could play a significant role in velocity specific adaptations (Kawamori and Newton 2006). Furthermore, older adults display a preference to train with lower loads (King et al. 1991), and attaining velocity specific adaptations using low external loads (e.g. 40% 1RM) may be particularly useful to sedentary older adults, who may be at greater risk of injury when training at high-movement velocities with heavy loads (Csapo and Alegre 2016).

Differentiating between high and low movement velocities is often achieved using the command “as fast as possible” for the concentric phase of high velocity exercise (Beltran Valls et al. 2014; Glenn et al. 2015; Sayers and Gibson 2010), whereas performing the concentric phase over two seconds has frequently been used during low velocity exercise (Sayers and Gibson 2010; 2014; Van Roie et al. 2013). Sayers et al. (2016) observed that self-selected maximal lower limb velocity varied considerably between individuals, and concluded that those individuals training at the highest movement velocities maximised improvements in functional performance. This highlights the importance of understanding the exact velocity that exercise occurs at. However, many studies have largely failed to measure and report the movement velocity that is produced using these commands, which could result in large inter-individual differences, depending on the ability and engagement of the participants (Rajan and Porter 2015). When Rajan and Porter (2015) measured the movement velocity of power and strength training velocities in a group of older adults using the commands: "as fast as possible" for power training and "slow and controlled" for strength training. The authors observed that there were large variances in movement velocities between individuals, e.g. some individuals trained faster during strength training than others did during power training and others had very small differences between their strength and power training velocities. This highlights the need to ensure there is a simple, reliable way of manipulating resistance exercise training velocity.

Furthermore, resistance exercise studies on older adults have rarely assessed the acute physiological changes that occur, with the few studies that have, focusing on hormonal changes (Hakkinen and Pakarinen 1995; Marcell et al. 1999). Understanding the acute physiological responses to resistance exercise are important (heart rate, blood lactate, blood pressure etc.), as the physiological mechanisms that are stimulated during resistance exercise are dependent on the nature of that exercise (e.g. sets, repetitions, velocity, mode etc.) with repeated exposure to a certain exercise stimulus, facilitating specific adaptations of those physiological mechanisms (Kraemer et al. 1988). Studying acute physiological responses to different resistance exercise protocols can aid in understanding how they differ (Kraemer et al. 1996) and may be useful in explaining likely adaptations from continuing that exercise (Ramirez-Campillo et al. 2014).

It is now well-established that resistance exercise attenuates losses of strength, power, muscle mass and enhances functional performance in older adults (Raj et al. 2010). As muscle power better predicts performance of activities of daily living than strength (Beltran Valls et al. 2014) and muscle power recedes faster than strength in older adults (de Vos et al. 2005), developing/maintaining peak power is key for retaining function and independence (Bean et al. 2002). However, the heterogeneous nature of research in older adults (Barbalho et al. 2017) (e.g. training frequency, velocity, volume, load, intensity, rest etc.) has led to equivocal conclusions as to whether power or strength training is most effective for improving physical function (Marsh et al. 2009). The debate about whether or not explosive muscle actions should be a part of resistance exercise programmes in older adults continued recently as Fisher et al. (2017) argued against their inclusion, whilst Cadore et al. (2018) strongly disagreed, presenting evidence of their importance and firmly recommending they be included in training programmes for older adults.

1.2 Aims of the Thesis

The overall aim of this thesis was to investigate the impact that HVLL and LVHL resistance exercise has on older adults to help refine the physical activity guidelines by providing suitable recommendations of resistance exercise for older adults. This thesis examined the velocities that are produced by a commonly used command and metronome-based protocol, whilst monitoring physiological (blood pressure, heart rate, blood lactate) and affective responses to HVLL and LVHL acutely, and then over a 10-week exercise intervention period. The intervention study examined the changes in functional performance, maximal strength and body composition when performing either HVLL or LVHL once or twice-weekly. Therefore, this thesis is comprised of five research studies that contribute novel data and original insight into resistance exercise prescription for older adults.

> **Study 1:** Measured movement velocity produced by HVLL and LVHL when following a command and metronome-based protocol.
> **Study 2:** Investigated the effect of volume-load matched HVLL and LVHL on acute physiological responses.
> **Study 3:** Examined affective responses, enjoyment, fatigue and rating of perceived exertion between the same volume-load matched HVLL and LVHL protocols.

The second data collection period then examined the impact of HVLL and LVHL when performed over a 10-week intervention period:

> **Study 4:** Examined the affective responses to HVLL and LVHL, when performed either once or twice-weekly for 10-weeks.
> **Study 5:** Examined the changes in functional performance, maximal strength and body composition between HVLL and LVHL when performed either once or twice –weekly for 10-weeks.

Chapter 2: Review of the literature

2.1 Introduction

This chapter outlines the benefits that physical activity and exercise can have on the health of older adults, and then discusses more specifically, how resistance exercise can be used to positively impact the health and functional performance of older adults. The effects of sarcopenia and dynapenia, two major contributing factors to functional decline in older adults are then discussed, followed by how resistance exercise can be a useful tool in combating their negative effects. This chapter also considers the affective responses to resistance exercise, recognising they are important factors in continued exercise behaviour and exercise adherence, but have received little investigation, especially in older adults. Finally, the findings of research that has examined the effects of resistance exercise in various interventions studies for older adults are reviewed, whilst highlighting gaps in the literature.

2.1.1 Terminology

Well-defined terminology is key to reducing ambiguity, so that the findings of one study can be compared to another (Lambert 2015). It is therefore important to establish the terminology that will be used throughout this thesis for clarity of communication. Terms such as: the aged, elder(s), (the) elderly, and seniors may be considered discriminatory or portray negative stereotypes, and therefore it is recommended that the term 'older adult' be used (Lundebjerg et al. 2017). To avoid potential derogatory terminology, such terms will be avoided throughout this thesis (even when discussing other studies which have used such terms), and 'older adult' will be used when referring to those aged 60 years and older.

There are some inconsistencies in the literature with the age range classified as 'older' with suitable cut-offs differing between studies. Many sources classify older adults as aged 60 and over (Bottaro et al. 2007; Gillespie et al. 2012; Karlsson et al. 2013; Kobayashi et al. 2014; Watanabe et al. 2014; Yasuda et al. 2015) whilst others classify older adults as aged 65+ (Jefferis et al. 2014; Nelson et al. 2007; NHS 2011; Office of Disease Prevention and Health Promotion 2015; Taylor et al. 2004) some studies have even classified 'older adults' as 55 onwards (Pollock et al. 2015) or 70 onwards (Reid et al. 2014). As it is reported that significant factors that affect strength and functional performance such as the atrophy of type II muscle fibres (Lexell et al. 1988) and loss of motor units (Campbell et al. 1973) onset from the sixth decade of life, older adults are classified as aged 60 and over in the present thesis.

Lastly, there are many terms used interchangeably in the wider literature to describe types of ‘power’ and ‘strength’ training. Some studies describe ‘strength training’ as: heavy resistance training (Kalapotharakos et al. 2005), traditional resistance training (Bottaro et al. 2007), slow speed strength training (Sayers and Gibson 2014), or progressive resistance training (Gonzalez et al. 2014) amongst many others. Similarly, power training is sometimes referred to as: high velocity training (Henwood et al. 2008), high velocity power training (Sayers and Gibson 2014) high speed resistance exercise (Ramirez-Campillo et al. 2014) etc. Many studies have used various loads and movement velocities and termed the training ‘power training’. For the purpose of the resistance exercise carried out in the studies within this thesis, strength training will be referred to as low-velocity, high-load resistance exercise (LVHL), and power training as high-velocity, low-load resistance exercise (HVLL), because these terms reflect both the movement velocity and loading used. When other studies are being described, the terminology they have used to describe the type of training, are repeated, so as not to lose context of the details of exercise they employed (variances in loads, rep ranges, time under tension and differences in movement velocity etc.). For simplicity, when multiple studies are being discussed that muddle terminology, the blanket terms ‘power training’ or ‘strength training’ are used.

2.2 The demographics of ageing and public health spending

The population of older adults is increasing globally (Chen et al. 2010), primarily due to increased life span (Okada 2012). It is predicted that by the year 2030, approximately 20% of the population of the United Kingdom (Parliament 2013) and 30% of the United States population will be made up of older adults (Hunter et al. 2004). This rise in the number of older adults presents significant challenges and strains on healthcare systems (Chen et al. 2010; Yu 2015). Statistics from the United States, report that ~30% of medical spending is on adults aged 65 and over, with medical expenditures on older adults, being 2.6 times higher than the national average (De Nardi et al. 2015). In the United Kingdom, national health service (NHS) spending per person starts to increase beyond the age of 50 and escalates after the age of 70 (Kelly et al. 2016). Public hospital spending in England reveals that individuals over the age of 65 have nearly twice the medical spending as individuals in the age group 25-64 (Kelly et al. 2016). Some of the age-related issues affecting costs to healthcare that are relevant to this review include; sarcopenia (Cruz-Jentoft and Landi 2014) and dynapenia (Clark and Manini 2008) which may lead to an increased incidence of falls (Landi et al. 2012b), loss of functional capacity, reduction in quality of life (Winett and Carpinelli 2001), and increased mortality rates (Landi et al. 2012a).

2.3 Physical activity guidelines for older adults

Notably, public health guidelines have previously focused on the prescription of aerobic based exercise over resistance exercise (Winett and Carpinelli 2001). However, the latest United Kingdom guidelines for physical activity (NHS 2011) include recommendations for resistance exercise. The guidelines state that for substantial health benefits, individuals should be carrying out 150 minutes each week of moderate-intensity aerobic physical activity or 75 minutes each week of vigorous-intensity aerobic physical activity or an equal combination of the two. The guidelines also state that strengthening exercises that are moderate or high intensity and involve all major muscle groups should be performed on two or more days per week. Concerning older adults, the guidelines recommend exercising as close to 150 minutes per week (at least 10 minute bouts or more) as an individual's health allows, including exercises that assist with balance as well as strengthening exercises for the whole body. These guidelines in the United Kingdom are consistent with those in the United States (Office of Disease Prevention and Health Promotion 2015). Despite the recommendations set by these physical activity guidelines, a recent systematic review and meta-analysis by (Hupin et al. 2015) examined the effectiveness of a low dose (~15 minutes per day) of moderate to vigorous physical activity, which is below the 150 minutes set by the physical activity guidelines, in a large sample (n = 122,417). The authors concluded that even low doses of moderate to vigorous physical activity were associated with a substantial 22% reduction in mortality risk in older adults aged 60 years and over. This evidences that the optimal exercise prescription and minimal effective dose of exercise for older adults is not well understood.

Furthermore, as described above, the physical activity guidelines are vague, meaning it is likely that the majority of community-dwelling older adults would struggle to competently devise an exercise regime unsupervised, that satisfies the requirements of these guidelines. In particular, the guidelines for improving strength are ambiguous, providing a single bullet point stating older adults should perform "strength exercises on two or more days a week that work all the major muscles (legs, hips, back, abdomen, chest, shoulders and arms)" (NHS 2011). Despite the substantial amount of research focused on resistance exercise in older adults since 2011, there has been a failure to refine and update these recommendations in the previous seven years. With such little guidance given by the physical activity guidelines, it is unsurprising that older adults in the United Kingdom are largely failing to achieve the amount of exercise recommended (Jefferis et al. 2014). Similarly, less than half of all Americans met the Centre of disease control and prevention (CDC) and American college of sports medicine (ACSM) exercise recommendations (Haskell et al. 2007). Data from the United States suggests that older adults are the most sedentary age group, spending ~60-70% of their waking hours being sedentary (Matthews et al. 2008), the most common sedentary behaviours in older adults are reported to be watching television, using a computer and reading (Gennuso et al. 2016).

2.4 The physiological benefits of physical activity

Physical activity can be simply defined as any bodily movement produced by skeletal muscle that results in energy expenditure (Caspersen et al. 1985) and so, includes all daily activities and movements, and not just exercise. Physical activity can bring about a substantial number of health benefits to people of all ages (Miles 2007), from school aged children (Janssen and Leblanc 2010) to adults (Warburton et al. 2006) and older adults (Taylor et al. 2004). Physical activity has been suggested to have a positive influence on the primary and secondary prevention of conditions such as: cardiovascular disease, strokes, type 2 diabetes, types of cancers, hypertension, obesity (Blair and Morris 2009), mental health problems, premature death and many others (Warburton et al. 2006).

Physical activity is proposed to have these effects through various different mechanisms. For example, increased levels of physical activity have a positive benefit on body composition by lowering levels of adiposity, and better controlling body weight (Seidell et al. 1991; Tremblay et al. 1990), improving lipid lipoprotein profiles through a reduction in low density lipoproteins (LDL) and an increase in high density lipoproteins (HDL) (Murphy et al. 2002; Warburton et al. 2001). Regular physical activity also lowers fasting plasma insulin (Donnelly et al. 2000), and elicits acute and chronic improvements in insulin sensitivity (Lakka and Laaksonen 2007), lowers blood pressure (Arroll and Beaglehole 1992), improves coronary blood flow (Hambrecht et al. 2000), reduces haemostatic and inflammatory markers (Lakka and Laaksonen 2007; Wannamethee et al. 2002), improves endothelial function (Lakka and Laaksonen 2007) and elicits marked reductions in circulating levels of C-reactive protein which is a marker of inflammation (Nicklas et al. 2005). High levels of C-reactive protein have been linked to the majority of the chronic diseases mentioned above (Warburton et al. 2006).

2.4.1 Psychological health benefits of physical activity

In addition to physiological benefits, physical activity has also been shown to have significant positive psychological benefits such as reduced anxiety, reduced depression and improved mental well-being (Fox 1999; Hassmen et al. 2000). A meta-analysis by Netz et al. (2005) suggests that physical activity has positive effects on self-efficacy and wellbeing in older adults which are further linked to improvements in strength, cardiovascular health and functional capacity. Furthermore, a review of the literature by Teychenne et al. (2008) concluded that there was an inverse relationship between physical activity and the likelihood of depression in adults, even when exercise was only performed in relatively small doses. Importantly, physical activity has been shown to produce a better health related quality of life for a large group of older adults when both physical and mental factors were assessed (Acree et al. 2006).

Physical activity also improves brain plasticity which is the brains ability to change structure and function e.g. through a learning experience and is imperative for cognitive function (Kolb and Whishaw 1998). Furthermore, exercise raises levels of brain-derived neurotrophic factor which is a key mediator of neuronal connectivity, synaptic efficacy, and importantly, use-dependent plasticity (Schinder and Poo 2000), and may stimulate neurogenesis, increase resistance to brain insult, and improve learning and mental performance (Cotman and Berchtold 2002). Lastly, physical activity has been linked to reductions in cognitive impairment, Alzheimer 's disease, and dementia in older adults (Laurin et al. 2001). These factors highlight the benefits of remaining physically active in older age on psychological well-being.

2.5 Health benefits of resistance exercise

Resistance exercise involves the voluntary contraction of targeted skeletal muscles against an external resistance, which may be provided by an individual's bodyweight, free weights, machines, springs, cables or bands (Winett and Carpinelli 2001). In addition to the long accepted views that resistance exercise can improve and aid in maintaining muscular power, strength endurance and muscle mass (Atha 1981), resistance exercise has been implicated in multiple positive health benefits which include: body fat reduction (Swift et al. 2014), reduced risk of chronic disease (Pollock and Evans 1999), improved cognitive ability (Cassilhas et al. 2007; Chang et al. 2014), increased lean body mass, reduced basal insulin levels, increased insulin sensitivity, increased HDL and reduced LDL cholesterol, decreased diastolic blood pressure, increased maximal oxygen consumption ($\dot{V}O_2$max), increased basal metabolic rate (Pollock and Evans 1999) and increased muscle aerobic capacity (Frank et al. 2015).

Moreover, resistance exercise can positively influence a number of age-related issues such as: sarcopenia, dynapenia, susceptibility to falls (Pollock and Evans 1999) and decreased bone mineral density, which may predispose osteoporosis (Macaluso and De Vito 2004). Even in moderately active older adults, resistance exercise participation may be important as Baroni et al. (2013) examined moderately active older men (determined by the international physical activity questionnaire) to understand if remaining moderately active in older age was sufficient to prevent muscle impairments in older adults. Importantly, the authors concluded that a physically active lifestyle without systematic training, was not enough to avoid the loss of muscle mass and strength that is associated with ageing.

2.6 Sarcopenia

One of the most prominent health-related issues of ageing, is the onset of sarcopenia, which is defined as the gradual loss of skeletal muscle mass with ageing caused by unbalanced protein synthesis and degradation, leading to the loss of muscle function (Park et al. 2017). Sarcopenia accelerates beyond the age of 50 (Hunter et al. 2004) with muscle mass being lost at a rate of ~1-2% per year (Rosado et al. 2016). The condition even occurs in master athletes, although sarcopenia's effects are hastened by physical inactivity (Roubenoff 2000). Sarcopenia has been linked with significant negative health outcomes such as: disability, frailty, comorbidities, hospital admissions and death (Yu 2015). The onset of sarcopenia can be divided into two categories, 1. Primary factors which are considered to be age-related and 2. Secondary factors which occur when one or more other causes are evident such as: physical inactivity, presence of disease or inadequate nutrition (Cruz-Jentoft and Landi 2014). The schematic diagram in Figure 2.1 created by Dickinson et al. (2013), highlights the main contributing factors to the aetiology of sarcopenia and will be discussed in detail. In many older adults, the causation of sarcopenia is multifactorial, which means that it may not be possible to characterise an individual with exclusively primary or secondary sarcopenia (Cruz-Jentoft and Landi 2014).

Figure 2.1. Schematic diagram of the key contributing factors to sarcopenia (Dickinson et al. 2013)

2.6.1 Sarcopenic obesity

Sarcopenic obesity is the term used to describe excessive weight gain and the reduction in muscular strength in older adults (Zamboni et al. 2008). This section describes the interaction between sarcopenia and obesity. Ageing and Obesity are the two most prominent epidemiological trends in recent times (Mokdad et al. 2001), evident by the dramatic rise in the number of obese, older adults in recent years (Ogden et al. 2006). Obesity has been linked with the decline of functional performance in older adults (Koster et al. 2008) and evidence suggests that obese and sarcopenic individuals are more likely to develop functional limitations than normal weight, non-sarcopenic individuals (Rolland et al. 2009). It is proposed that obesity and sarcopenia potentiate each other, causing maximal detriment to physical ability and higher mortality rates (Zamboni et al. 2008).

Obesity may become more prevalent in older adults because of the age-related decline in the ability to complete activities of daily living (Marcus 1995) and an increase in exercise difficulty (Landers et al. 2001) leading to a decrease in physical activity, lower energy expenditure and subsequent weight gain (Hunter et al. 2004). Furthermore, normal ageing is accompanied by an increase in fat mass (Prentice and Jebb 2001), especially in visceral fat and intramuscular fat, while areas of subcutaneous fat decrease (Beaufrere and Morio 2000). Older adults also experience fat infiltration into the muscle tissue which is associated with decreased muscle strength (Stenholm et al. 2008). Another hypothesised cause of weight gain in older adults is leptin resistance (Carter et al. 2013). Leptin is a protein made by adipose tissue that regulates fat mass in the body (Byrd-Bredbenner et al. 2009). As ageing increases fat mass, this leads to increased Leptin secretion, which may contribute to Leptin resistance and therefore cause a reduction in fatty acid oxidation within muscle (Zamboni et al. 2008). Figure 2.2 created by Zamboni et al. (2008) displays the factors that contribute to sarcopenic obesity and how the factors previously discussed involved in sarcopenia contribute to increased adiposity.

Figure 2.2. Summary of factors that influence sarcopenic obesity (Zamboni et al. 2008)

2.7 Dynapenia

The reductions in strength observed in sarcopenic individuals are not solely related to losses of muscle mass. Declines in strength can be ~60% greater (Hughes et al. 2001) and happen 2-5 times faster (Mitchell et al. 2012b), facilitated by alterations in the neuromuscular system (Clark and Manini 2008). Less than 5% of age-related changes in strength have been reported to be due to a loss of muscle mass (Hughes et al. 2001), with older adults experiencing approximate annual declines of 1.5% in muscle strength and 3.5% in muscle power (Young and Skelton 1994). Therefore, there is a disassociation between muscle mass and muscle strength (Clark and Manini 2008), meaning the loss of muscle mass is not the sole concern for older adults. Dynapenia, defined as the age-related loss of muscle strength (Clark and Manini 2012) also significantly affects older adults. In support of this idea, research has suggested that gaining or maintaining muscle mass may not prevent age-related decreases in muscle strength (Delmonico et al. 2009). Figure 2.3 created by Clark and Manini (2008) displays the factors influencing dynapenia and how they interact with sarcopenia.

Figure 2.3. Summary of the factors that influence dynapenia (Clark and Manini 2008)

2.8 How does resistance exercise influence Sarcopenia and Dynapenia?

There is limited evidence that pharmacologic interventions effectively ameliorate sarcopenia and/or dynapenia (Law et al. 2016), but there is a strong and increasing evidence base that suggests that resistance exercise does (Burton and Sumukadas 2010). Resistance exercise has been shown to be superior at producing muscle hypertrophy compared with endurance exercise (Borst 2004) and increasing voluntary force output through adaptations in neurophysiologic performance (Munn et al. 2005), Furthermore, resistance exercise has a profound positive effect on many of the physiological mechanisms in the muscular and nervous systems that influence strength (Law et al. 2016). Progressive resistance exercise involving the use of the major muscle groups has been established as a simple and effective way to counteract the negative effects of sarcopenia (Yu 2015) and there is strong evidence that resistance exercise is effective for attenuating age-related declines in muscle strength (Liu and Latham 2009). Resistance exercise is also a powerful stimulus for increases in muscle cross-sectional area, with numerous studies observing increases in older adults (Chale et al. 2013; Fiatarone et al. 1990; Frontera et al. 1988; McCartney et al. 1996; Walker et al. 2015).

In addition to strength and muscle mass gains, resistance exercise influences other non-mass dependant muscular factors such as muscle fibre fascicle length (Law et al. 2016) and tendon stiffness and function (Narici and Maganaris 2006). Maganaris et al. (2004) investigated changes in the mechanical properties of the patellar tendon in an exercise group (n = 9) who completed 14-weeks of knee extensor strength training, three times a week at 80% of 5-RM, compared to a non-exercise control group (n = 9). Results indicated that there was a 27% increase in rate of torque development in the exercise group compared to the non-exercise control group, and improvements were consistent with increased tendon stiffness, which led the authors to conclude that there was faster transmission of contractile forces to the skeleton. This has implications for the execution of potentially lifesaving motor tasks in older adults, such as moving the body quickly to react to a trip or fall.

As previously mentioned, the loss of alpha motor neurons and motor units that result in decreased strength (Roubenoff 2000) may be attenuated by resistance exercise. A systematic review and meta-analysis of the influence of strength training on muscle activation in older adults by Arnold and Bautmans (2014) concluded that there are significant neuromuscular adaptations involved in the steep incline in training-induced voluntary activation and subsequent strength gains in the lower extremities, observed in older adults at the onset of resistance exercise. The authors observed increased antagonist co-activation in the ankle muscles, which may mean that the agonist muscle co-contraction has a beneficial effect on joint stabilisation, and so acts as a safety mechanism. Resistance exercise has also been shown to improve maximal motor unit discharge rates by 49% which has an important benefit on muscle strength (Kamen and Knight 2004). Importantly, resistance exercise also has a beneficial effect on muscle architecture. Muscle fibre fascicle length has been shown to increase by 10% following resistance training in older adults (Reeves et al. 2003). Figure 2.4 from Law et al. (2016) displays a conceptual diagram of how resistance exercise influences sarcopenia and dynapenia.

Figure 2.4. Conceptual interactions between physical activity, sarcopenia, dynapenia, fatigability, exercise tolerance, and physical function (A) and how progressive resistance exercise training can modulate these various phenotypic factors (B) (Law et al. 2016).

2.9 Resistance exercise and hormonal profiles

Diminishing hormonal profiles have a significant influence on the loss of lean body mass. However, there is evidence that heavy resistance exercise can naturally enhance the hormonal profile of older men. Kraemer et al. (1999) investigated the effect of a periodised 10-week strength-power training programme on a group of younger (30 years) and older men (62 years). Blood samples were taken throughout the programme to assess total testosterone, free testosterone, cortisol, growth hormone, IGF-1 and lactate. The results of the study indicated that both the younger and older males experienced an increase in squat strength and muscle cross sectional area, but the younger males displayed higher total and free testosterone, as well IGF-I than the older men. However, the older males demonstrated a significant increase in total testosterone and a significant decrease in resting cortisol levels, demonstrating that resistance exercise can elicit beneficial changes to the hormonal profile of older men (Kraemer et al. 1999).

Another study observed a substantial increase in growth hormone during a bout of resistance exercise, but a 16-week progressive resistance exercise programme did not affect baseline concentrations of anabolic hormones (Nicklas et al. 1995). Although Nicklas et al. (1995) did suggest that daily secretion, hepatic clearance and cellular degradation rates all may have affected their conclusions despite using multiple blood draws. Furthermore, Nicklas et al.

(1995) suggested that muscle tissue may have become more sensitive to anabolic hormones, eliciting increases in muscle mass without changes to baseline hormone concentrations. The hormonal response to exercise may also be blunted in older females. Free testosterone has been shown to be elevated in young women by 25% following acute resistance exercise, consisting of 6 sets of 10-RM squats with two-minute intervals (Nindl et al. 2001). However, no changes in free testosterone were observed following an acute bout of resistance exercise in middle-aged and older women (Hakkinen et al. 2000). Table 2.1 summarises some of the studies that have monitored the influence of resistance exercise on the hormonal profiles of older adults.

Table 2.1. Resistance exercise and hormonal profiles in older adults

References	*n*	Sex ratio female/male	Age (Years) mean ± SD	Training Status	Duration	Exercise Protocol	Outcomes
Pyka et al. (1994)	*n* = 14	9/5	70 ± 1	Undisclosed	52 Weeks	12 Weight-lifting exercises (3 sets of 8 repetitions at 85% 1RM, 3 times per week).	No significant changes in basal GH and IGF-1 nor the GH secretory response to exercise.
Craig et al. (1989)	*n* = 15	0/15	Older: 63 ± 1 Young: 23 ± 2	Untrained	12 Weeks	Isotonic weight training exercises for the upper and lower body performed 3 times per week for 3 sets of 8 repetitions for each exercise.	Significant increase in GH in both groups but response was significantly higher in younger adults. Testosterone secretion was unchanged in both groups.
Nicklas et al. (1995)	*n* = 13	0/13	60 ± 4	Undisclosed	16 Weeks	16-week progressive resistance training programme for the upper and lower body.	Large increase in GH after a single bout of resistance exercise. However, baseline concentrations of testosterone, GH and IGF-1 were unaffected by training.
Pyka et al. (1992)	*n* = 23	11/12	Older: 72 ± 1 Young: 27 ± 2	Sedentary – moderately active	?	3 sets of 8 repetitions with 30 seconds rest between sets on 13 various exercises for the upper and lower body performed on separate occasions at 60%, 70% and 85% 1RM.	GH responses were not different between sexes in either group and the GH response was grossly diminished in older adults compared to young adults.
Hakkinen and Pakarinen (1995)	*n* = 47	23/24	Young: 30 Middle-aged: 50 Older: 70	Undisclosed	Acute	Heavy resistance exercise using 5 sets of 3 exercises with the heaviest load possible for 10 reps, with 3 minutes recovery between sets.	GH release significantly lower in older adults compared to young and middle-aged males and females
Kraemer et al. (1999)	*n* = 17	0/17	Younger: 30 Older: 62	Physically active, not resistance trained	10 Weeks	Periodised programme of 10 exercises performed 3 times per week that varied in load, rest times and the volume over the week.	Increase in total testosterone and decrease in resting cortisol in older men but not as pronounced as younger men.
Hakkinen et al. (2000)	*n* = 42	21/21	Middle-Aged Men: 42 ± 2 Middle-Aged Women: 39 ± 3 Older Men: 72 ± 3 Older Women: 67±3	Habitually, physically active. No background in strength training	6 Months	The programme combined heavy resistance and "explosive" strength training. Each training session included two exercises for the knee-extensor muscles and four to five other exercises for the other main muscle groups of the body. Reps and sets were manipulated during the course of the study.	None of the groups showed systematic changes in the mean serum concentrations of testosterone, GH, cortisol, or sex hormone-binding globulin.

Note: Values are presented as Mean ± SD; *n* = Number of participants; GH = Growth Hormone; IGF-1 = Insulin like Growth Factor-1

2.10 Resistance exercise for fall prevention

With advancing age, the incidence of falls rises steeply in older adults (Scott et al. 2015). This is no surprise as between the second and seventh decade of life (Narici and Maffulli 2010), it is estimated that men and women lose around 24-27% of muscle mass essential for effective locomotion. Falls can have devastating consequences, leading to fractures, soft tissue injuries, longstanding pain, reduced functional capacity, reduced quality of life and increased mortality (Karlsson et al. 2013). Significantly, 20-30% of older adults who suffer a hip fracture will die within a year of the incident (Magaziner et al. 1997). Older women are more prone to falling than men (Luukinen et al. 1995), with it estimated that bone fractures occur in 3-12% of all falls suffered by older adults (Tinetti et al. 1995). It has been shown that poor grip strength (Furrer et al. 2014) and lower limb strength (Scott et al. 2014) are good indicators of fall risk in both sexes. Causes of falls in older adults are usually multifactorial, and include: unstable balance, gait, low muscle strength, poor visual acuity, cognition, dizziness, confusion, postural hypotension and the presence of chronic diseases (Rubenstein 2006; Tinetti and Speechley 1989).

A systematic review and meta-analysis carried out by Moreland et al. (2004) concluded that low muscle strength, particularly in the lower extremities should be addressed in older adults that are at risk of falls. Resistance exercise has become a popular and cost-effective practice for the prevention of falls in older adults (Borst 2004; Piirtola et al. 2003) with Inacio (2016) concluding that specifically targeting the development of muscular power being most beneficial for the avoidance of falls. Importantly, the relationship between resistance exercise and fall risk is non-linear i.e. once an individual has gained the strength to avoid the risk of falling, the additional benefits of more resistance exercise may be diminished (Sherrington et al. 2008). Although performing balance training in conjunction with resistance exercise and other forms of physical activity may produce the best results for reducing incidence of falls (Sherrington et al. 2008), a systematic review by Sherrington et al. (2017) concluded that exercise as a lone intervention, can be used to effectively prevent falls in community-dwelling older adults.

2.11 Resistance exercise and functional performance

Low levels of strength and power correlate with reduced functional performance in older adults (Foldvari et al. 2000). Even though the strength decreases that accompany age are unavoidable, it has been suggested that 70-year-old master athletes can have similar strength, power and functional capabilities to a sedentary 20-year-old (Macaluso and De Vito 2004). Similarly, an 85-year-old weight lifter can have similar power outputs to an untrained 65-year-old (Pearson et al. 2002) through the maintenance of neuromuscular function (Arnold and Bautmans 2014). This illustrates that significant improvements in strength are able to be made with resistance exercise in older adults. This maintenance and/or improvement of strength and power into older age may translate into increased functional performance, and the ability to complete activities of daily living that require strength (e.g. carrying shopping bags) (Rejeski and Mihalko 2001) and power (e.g moving a limb quickly to stabilise and prevent falling) (Sayers and Gibson 2014) extending independence and quality of life. Tables 2.2, 2.3 and 2.4 extensively examine studies that have measured functional performance following various resistance exercise protocols. These studies reveal overwhelming evidence that resistance exercise can improve numerous aspects of functional performance in older adults.

2.12 Resistance exercise, affective responses and exercise adherence

An affective response to a given exercise task relates to the individuals subjective experience and can be defined as “the general psychological state of an individual, including but not limited to emotions and mood” (Haile et al. 2015). Despite ~80-90% of exercise participants reporting that they “feel better” when exercising, paradoxically, around 50% drop out of exercise programmes (Morgan and O’Connor 1988). Thus, effective strategies need to be developed to increase adherence to exercise programmes in older adults (Winters-Stone et al. 2012). Despite the large number of adults and older adults that do not satisfy the physical activity guidelines (Jefferis et al. 2014; Schoenborn and Stommel 2011) and the high dropout rates from structured exercise programmes (Marcus et al. 2006), the current physical activity guidelines primarily reflect physiologically driven considerations over addressing participation issues (Lind et al. 2005). It is important to determine whether, and to what extent, individuals enjoy exercise to aid in prescription of exercise that is not only physiologically effective, but also enjoyable, or at least tolerable (Lind et al. 2005). Acute affective responses to exercise have previously been shown to predict continued exercise behaviour (Williams et al. 2008), which has the potential to aid exercise professionals in designing programmes that are likely to be adhered to in the long-term. A review by Ekkekakis et al. (2011) revealed that in general, there is an inverse relationship between exercise intensity and affective responses i.e. as intensity of exercise increases, enjoyment decreases.

Hedonic theory provides a theoretical framework for understanding how the affective responses to certain exercise tasks are related to exercise adherence in the long-term (Williams et al. 2008) via the affective judgements of that task, based on the individuals experience (Kahneman et al. 1999). Another theory than can be used to help explain exercise adherence, is self-determination theory. Self-determination theory is a comprehensive and evolving macro-theory of human personality and behaviour that can be used to understand how motivation can affect behaviour (Deci and Ryan 2000). Self-determination theory distinguishes between intrinsic and extrinsic motivations. For example, intrinsic motivation relates to one's participation in exercise because of its inherent rewards such as enjoyment etc. Whereas, extrinsic motivation is when an individual participates in an activity for instrumental reasons e.g. to gain approval or avoid disapproval of peers (Teixeira et al. 2012). The theory postulates that humans are inherently motivated to feel connected to others in a social environment (relatedness) and to effectively function as part of that environment (effectance) whilst feeling confident in doing so (autonomy) (Weinberg and Gould 2011). Studies that have examined this theory in exercise behaviour, have generally observed that those individuals that display autonomy and have strong social support systems, better adhere to exercise programmes (Weinberg and Gould 2011). Therefore, these theories are important to consider when examining the affective responses to resistance exercise in older adults, as they may aid in providing explanations of the observations.

Studies examining the affective responses of older adults during resistance exercise are lacking. Previous research studies examining exercise affect, have used both multi-item and single-item scales (Ekkekakis et al. 2011). However, many studies examining affective responses are heterogeneous in their assessment methods, making it hard to draw effective comparisons between studies. Single-item scales e.g. Feeling Scale (FS) (Hardy and Rejeski 1989) are minimally intrusive, and easily allow participants to report exercise affect over multiple time points (Ekkekakis et al. 2011). The FS can be combined with the Felt Arousal Scale (FAS) (another single-item scale) (Svebak and Murgatroyd 1985), to plot a circumplex model of affect. Circumplex models are derived from two independent neurophysiological systems; valence and arousal. Every affective experience is a combination of both of these two components and can then be interpreted as experiencing a particular emotion (Posner et al. 2005). This circumplex model assumes that affective responses are interrelated, and may encompass a combination of dimensions that can be useful for investigating the affective responses to acute bouts of exercise (Ekkekakis and Petruzzello 2002). Figure 2.5 displays an example circumplex model of affect. Established scales can be added to the horizontal axis that measure valence such as the FS and the FAS can be added to the vertical axis to assess activation.

Figure 2.5. Circumplex model of affect example with the horizontal axis representing valence and the vertical axis representing activation (Posner et al. 2005).

Multi-item scales are also useful as they do not depend on a single measure, meaning they are less likely to be influenced by factors such as participant carelessness (Ekkekakis et al. 2011). The Physical Activity Enjoyment Scale (PACES) is regarded as the most widely used measure of enjoyment (Kendzierski and DeCarlo 1991), and has proven to be a reliable instrument for assessing the enjoyment of physical activity in older adults (Mullen et al. 2011). The Physical Activity Affect Scale (PAAS) (Lox et al. 2000) is used to measure acute, exercise-induced affect and incorporates a multi-dimensional perspective assessing both valence and arousal (Magnan et al. 2013). The positive and negative affect schedule (PANAS) (Watson et al. 1988) contains 20 different words that describe feelings and emotions, participants must rate how they feel each word from that scale from 1 = very slightly or not at all to 5 = extremely in order to provide an assessment of both positive and negative affect. These methods are all useful ways in which exercise affect could be monitored during resistance exercise in older adults.

To date, studies have examined exercise affect in older adults during aerobic exercise (Katula et al. 1999; McAuley et al. 2000; McAuley et al. 2003; Smith et al. 2015), but surprisingly few studies have examined exercise affect during resistance exercise. One of the few studies that has examined exercise affect during resistance exercise in older adults was conducted by Ferreira et al. (2013). They examined the affective responses to different muscle actions during weight training in older women. The participants performed five different exercises in three different sessions that included concentric, eccentric, and dynamic training. Affective responses were measured using the FS (Hardy and Rejeski 1989) as well as rating of perceived exertion (RPE) from the OMNI-RES scale (Robertson et al. 2003). Ferreira et al. (2013) observed that RPE and affective responses were similar for all five of the exercises. Yet, the eccentric exercise session appeared to promote better perceptual and affective responses for some of the exercises in older women. This may be important to consider when selecting the type of exercise to include in an older adult’s exercise programme. In general, there has been little research conducted on the affective responses to resistance exercise in older adults. This line of research may help to bridge the gap between satisfying the physiological demands of the physical activity guidelines, whilst also considering strategies to tackle the adherence issues.

2.13 Resistance exercise and the role of supervision in older adults

There is evidence that performing exercise under supervision has a positive influence on performance outcomes. A systematic review of randomised controlled trials comparing the benefits of exercise programmes that were supervised to those that were not, revealed that supervised programmes improved performance outcomes to a greater extent, than those that were unsupervised (Lacroix et al. 2016; Wind and Koelemay 2007). As many older adults are sedentary, supervised programmes may be more effective as they provide continued guidance, allowing safe and effective progression of the resistance exercise programme. Indeed, a study of middle aged adults revealed that even following five months of supervised exercise sessions, participants were still not equipped to exercise effectively whilst unsupervised (Fennell et al. 2016).

Finally, Ramirez-Campillo et al. (2017) examined the impact of a high-speed resistance exercise programme performed over 12-weeks on indices of muscle strength and functional performance in older women. The participants were randomised into a high supervision group, a low supervision group or a control group. Results indicated that the high supervision group made significantly greater improvements in muscle power, muscle strength, functional performance and quality of life compared to both the low supervision and control groups. These studies highlight the influence that supervision appears to have, and this must be considered when examining the functional outcomes and affective responses to exercise interventions in older adults.

2.14 The minimum effective dose of resistance exercise

There is some debate over the minimum dose of resistance exercise that is needed to gain physiological and functional benefits in older adults. All of the studies in Table 2.2, 2.3 and 2.4 employed a training frequency of at least twice-weekly. Training at least twice-weekly places a significant burden on the individual, possibly increasing the likelihood that exercise would not be continued in the long-term, as two of the most commonly cited barriers to exercise for older adults are time and cost (Foley et al. 2011). This makes realising the minimal effective dose of exercise, a significant interest of researchers. Studies have shown that performing exercise just once-weekly can elicit significant improvements in strength, body composition and physical function in older adults (DiFrancisco-Donoghue et al. 2007; Foley et al. 2011; Izquierdo et al. 2004; Sousa et al. 2013; Taaffe et al. 1999; Westcott et al. 2009) but not all agree (Nakamura et al. 2007; Stiggelbout et al. 2004). However the low intensity nature of the training stimulus employed in these two studies may explain why no improvements were found (Byrne et al. 2016).

Furthermore, Foley et al. (2011) reported that 66% of 94 older adults, preferred training once-weekly, while 26% preferred twice-weekly, 1% preferred thrice-weekly and only 7% elected to discontinue gym-based exercise, three months following a rehabilitation programme. Therefore, given that exercising once-weekly may deliver valuable improvements in strength and function in older adults, and lower exercise frequency may be preferential in older adults, it would be beneficial to examine physiological and functional benefits, whilst monitoring the affective responses to HVLL and LVHL, either once or twice-weekly in order to provide further guidance for resistance exercise programming in older adults. Conclusive evidence of the efficacy of once-weekly resistance exercise would have the ability to influence changes to the recommendations made by the physical activity guidelines.

2.15 Resistance exercise and adverse events

A systematic review of progressive resistance strength training in older adults by Latham et al. (2004) reported that 32 out of 62 studies examined, did not make any comments regarding adverse events. Of the remaining 30 studies, 14 reported that there were no adverse events, while there were some adverse events reported in the other 16 studies, meaning adverse events are likely underreported. Liu and Latham (2010) suggest that adverse events may be underreported because there is no consensus on the definition. They suggested that authors should define what is meant by an adverse event and clearly report their occurrences. In the review by Latham et al. (2004) only 6 of the 62 studies provided a priori definition of an adverse event and 5 of those 6 studies reported some adverse events. This provides some evidence that adverse events are more common than is reported in the literature, which means monitoring adverse events in older adults is important, and authors should provide a clear definition of adverse events for the reader. Previously, serious adverse events have been defined as those causing: deaths; prolonged hospital visits; significant incapacity or substantial disruptions in performing everyday tasks (e.g. cardiac arrest), and minor adverse events as any event causing minor discomfort or inconvenience (e.g. muscular aches and pains) (Goodrich et al. 2007).

2.16 Types of resistance exercise

Despite the wealth of investigation in this literature review (Table 2.2, 2.3 and 2.4) examining the optimal methods of resistance exercise for older adults e.g. LVHL (strength training) or HVLL (power training) in terms of gains in: strength, functional performance and body composition, there are still no firm conclusions on the ideal recommendations. The following sections, explore HVLL and LVHL resistance exercise.

2.16.1 Low-velocity, high-load resistance exercise

Table 2.2 displays the functional and physiological outcomes of LVHL exercise. As is apparent in the table, all of the studies have produced desirable outcomes in functional performance and/or physiological outcomes. A meta-analysis by Peterson et al. (2010) on resistance exercise for muscular strength in older adults concluded that resistance exercise is an effective modality of exercise for ageing men and women to engage in, and can significantly improve strength capacity. Peterson et al. (2010) also noted there was an association between intensity of resistance exercise and degree of strength improvement. Further concluding that, as low strength is linked to significant functional deficits and comorbidities in older adults, it would be conceivable that resistance exercise would help to maintain independence, health, and overall well-being. The limitations of this meta-analysis identified by the authors themselves, were the fact that only 25 out of the 47 studies included in the meta-analysis were randomised-controlled trials, which suggests the possibility of design quality issues in almost half of the included studies.

However, another review presented similar findings. Law et al. (2016) concluded that resistance exercise is associated with increases in muscle strength, that are linked to the intensity that it is performed at. When examining low intensity (<60% 1RM), low/moderate intensity (60-69% 1RM), moderate/high intensity (70-79% 1RM) and high-intensity (≥80% 1RM) the average strength increase was 5.3% across all intensities, with the higher intensities stimulating greater muscle strength gains.

Despite LVHL resistance exercise clearly being beneficial, not all researchers agree that it is optimal for improving functional outcomes in older adults. Izquierdo et al. (1999) examined 3 groups of men; young males (mean age of 20), middle-aged (mean age of 40) and older men (mean age of 70). The participants were tested on maximal and explosive force production of leg extensor muscles in both isometric and dynamic actions (squat jump, counter movement jump, and standing long-jump). Analysis of the findings displayed that the reduction in power outputs was drastically reduced in older males compared to younger males. Maximal isometric force generated by older men was as much as 46% lower and maximal rate of force development as much as 64% lower than younger males. The authors concluded that older males have a reduced ability to develop force rapidly, that appears to be associated with a lower capacity for neuromuscular response in controlling postural sway. Therefore, this provides a brief rationale as to why the ability to develop force rapidly, may be more beneficial to older adults than developing greater maximal force.

Furthermore, a meta-analysis by Schoenfeld et al. (2016) that reviewed muscular adaptations to low versus high load resistance training, concluded that training with loads <60% 1RM in untrained individuals was able to elicit significant increases in muscle strength and size. However, a strong trend was noted for superiority of heavy resistance exercise in both muscle size and strength, which may be of more use to a younger population. The authors made special reference to the fact that these observations had particular relevance to older adults or sufferers of conditions such as osteoporosis, as significant muscle size and strength gains can be made from using more easily tolerated, lighter loads. Schoenfeld et al. (2016) stated the fact that the studies included in the review used either untrained or recreationally trained subjects would have had a bearing on their conclusions, as there is a ‘ceiling’ effect in regular lifters, meaning that low loads may not continue to produce strength and hypertrophic gains. Therefore, there is strong evidence that strength training can positively influence a number of functional and health outcomes in older adults, but there is also debate on the necessary loading and movement velocity to maximise these improvements. Table 2.2 explores studies that have employed strength training and presents their findings.

Table 2.2. Effects of strength training on functional and physiological outcomes

Study	*n* =	Sex ratio female/male	Age (Years) mean ± SD	Duration	Exercise Protocol	Functional Outcomes	Physiological Outcomes
Ades et al. (1996)	24	Not specified	70 ± 4	12 weeks	2 Groups: Resistance training vs. non-exercising control.	Increased walking endurance by 38%.	Increase in lower body fat free mass.
McCartney et al. (1996)	Exercise: 57 Control: 56	63/50	60-80	2 years	2 groups: Exercise vs. control. Whole body weight training twice-weekly. 2 × 10 (arms) or 12 (legs) repetitions. Progressed from 2 sets of each exercise at 50% of 1RM to 3 sets at 80% 1RM.	Increase in treadmill walking and stair-climbing endurance. Dynamic strength was still increasing in the weight training group after 2 years.	8.7% increase in cross sectional area of knee extensors.
Binder et al. (2005)	Exercise: 53 Control: 38	49/42	Exercise: 83 ± 4 Control: 83 ± 3	9 months	2 groups: Exercise Training vs. control. Exercise programme used 22 exercises. Progressed from 1–2 sets of 6–8 repetitions at 65% 1RM, thrice-weekly to 3 sets of 8–12 repetitions at 85%–100% of the initial 1RM.	Not Measured	Increase in whole body fat free mass Increase in thigh muscle strength.
Brochu et al. (2002)	Exercise: 13 Control: 12	25/0	Exercise: 71 ± 4 Control: 71 ± 5	6 months	2 groups: Exercise vs. Control. The exercise group performed 8 exercises that progressed from 50% to 80% 1RM twice-weekly. Exercise progressed from one set of 10 reps per exercise, to two sets.	Strength training vs. control ↑ Upper body strength (+18 vs. +6%) ↑ Lower body strength (+23 vs. +6%) ↑ Endurance (+26 vs. +1%), ↑ Balance and coordination (+29 vs. -2%) ↑ 6-min walk (+15 vs. +7%)	Body composition, aerobic capacity, and self-reported physical function did not change in either group.
Hartman et al. (2007)	29	Not specified	67 ± 4	26 weeks	One resistance training group. Participants completed 2 × 10 repetitions of 10 exercises thrice-weekly. Intensity was progressed from 65% to 80% 1RM.	Significant decrease in perceived exertion during functional tasks.	Increase strength and fat free mass.
Haykowsky et al. (2000)	RT: 10 CT: 10	0/20	RT: 68 ± 3 CT: 68 ± 4	16 weeks	2 groups: Resistance training vs. control. Resistance training (RT) performed thrice-weekly for 16-weeks using whole body exercises. Intensity progressed from 60-80% 1RM.	leg press and bench press maximal strength increased compared to CON.	No changes in left ventricle cavity size, wall thickness, mass, or systolic function.
Kalapothara kos et al. (2005)	CS: 10 HRT: 11 MRT: 12	21/12	HRT: 65 ± 5 MRT: 66 ± 4 CS: 64 ± 3	12 weeks	3 groups: Heavy resistance training (HRT), Moderate resistance training (MRT) and control (CS). Trained thrice-weekly using 6 upper and lower body exercises. HRT: 3 × 8 repetitions at 80% of 1RM. MRT: 3 × 15 repetitions at 60% of 1RM.	Both HRT and MRT similarly improved walking velocity, chair-rising time, stairclimbing time and sit and reach. HRT saw larger improvements in strength than MRT.	Not measured

Table 2.2 Continued. Effects of strength training on functional and physiological outcomes

Study	*n* =	Sex ratio female/male	Age (Years) mean ± SD	Duration	Exercise Protocol	Functional Outcomes	Physiological Outcomes
Reeves et al. (2003)	Training: 9 Control: 9	10/8	Training: 74 ± 4 Control: 67 ± 2	14 weeks	2 groups: Training vs. control. Training group performed 2 ×10 repetitions at 80 % 5-RM thrice-weekly using leg extension and leg press.	Not measured	Young's modulus increased 69 % Tendon stiffness increased 65 % Rate of torque development increased 27 %.
Fiatarone et al. (1990)	10	Not specified	90 ± 1	8 weeks	High-Intensity weight training programme.	Tandem gait speed increased 48% and strength increased 174% ± 31%.	Mid-thigh muscle mass increased (9.0% ± 4.5%).
Nelson et al. (1994)	Exercise: 20 Control: 19	39/0	50 - 70	12 months	2 groups: High intensity strength training vs. control. High intensity strength training twice-weekly using 5 different exercises.	Improved dynamic balance.	Increase lumbar spine bone mineral density and increase in strength and muscle mass.
Walker et al. (2015)	Training: 27 Control: 11	0/38	Training: 65 ± 4 Control: 65 ± 3	20 weeks	2 groups: Resistance training vs. control. 8 upper and lower body exercises twice-weekly. Sets, reps and resistance were manipulated during the programme.	Not measured	Maximal isometric and dynamic force production and vastus lateralis cross-sectional area increased.
Judge et al. (1993)	Exercise: 18 Control: 13	Not specified	Exercise: 82 ± 1 Control: 83 ± 2	12 weeks	2 groups: Exercise vs Control for 3 × 8-10 reps at 75-80% 1RM, thrice-weekly using lower body and postural control exercises. The control group performed flexibility exercises once-weekly.	Increased muscle strength, knee extension 1RM and gait velocity in exercise group.	Not measured
Gonzalez et al. (2014)	PRT: 23 CO: 11	11/12	71 ± 6	6 weeks	2 groups: Progressive resistance training (PRT) vs control (CO). PRT trained twice-weekly using 7-8 exercises for 3 × 8-15 repetitions. Load used varied.	PT increased static balance by ~42% Static balance performance decreased by ~37% in CO.	Not measured
Galvao and Taaffe (2005)	1-SET: 12 3-SET: 16	11/17	1-SET: 69 ± 5 3-SET: 70 ± 4	20 weeks	2 groups: single-set group (1-SET) vs. three-set group (3-SET). Progressive resistance training using 7 exercises for the upper and lower body. Exercise was performed twice-weekly at 8-RM for each exercise.	Chair rise (1-SET:10.1%; 3-SET: 13.6%), 6m backwards walk (1-SET: 14.3%; 3-SET: 14.8%), 400-m walk (1-SET: 3.8%; 3-SET: 7.4%), stair climbing test (1-SET: 7.7%; 3-SET: 6.4%).	Not measured
Lustosa et al. (2011)	EG: 32 CG: 16	32/0	EG: 72 ± 4 CG: 72 ± 4	10 weeks	2 groups: Experimental (EG) vs. Control (CG). Thrice-weekly ankle weight exercise and semi-squats.	Gait speed, timed up and go, muscle strength and power significantly improved in EG.	Not measured

Note: Acronyms used are specific to each study and are defined in the exercise protocol section; Values are presented as Mean ± SD; *n* = Number of participants

2.16.2 High-velocity, low-load resistance exercise

As described in the previous section, within resistance exercise, there is debate as to whether LVHL or HVLL is most beneficial to an ageing population in preserving functional performance (Marsh et al. 2009). Development of peak power has been identified as an important variable in maintenance of function and independence in older populations (Bean et al. 2002; Foldvari et al. 2000), as power is a stronger predictor than strength for activities of daily living (Beltran Valls et al. 2014) such as: fast walking, stair climbing and rising from a chair (Bean et al. 2003). Furthermore, muscle power recedes quicker than strength in an ageing population (de Vos et al. 2005; Metter et al. 1997), making the maintenance of muscle power essential to maintaining functional performance.

As power is the product of both velocity and force, a change is needed in one or both of these components in order to influence an individual's peak power (Sayers and Gibson 2014). Lighter loads that are moved 3.5 times faster than a heavier load, may also be able to procure similar adaptive responses in muscle fibres to LVHL resistance exercise (Claflin et al. 2011). Therefore, older adults can train with less resistance, using more rapid muscle contractions to get the same training adaptations in the type II muscle fibres, as strength training such as: increase in muscle cross-sectional area, absolute force and absolute power production (Claflin et al. 2011). Indeed, lower loads lifted to failure have been shown to produce similar hypertrophic muscle gains to heavier loads lifted to failure (Mitchell et al. 2012a).

Attaining velocity specific adaptations and improvements in functional performance using low external loads, may be particularly appealing to sedentary older adults, who are at greater risk of injury when training at high-movement velocity with heavy loads (Csapo and Alegre 2016). Furthermore, training with high-movement velocity against a low external resistance has been shown to shift the development of peak power to a lower external resistance (Sayers and Gibson 2014). This shift in peak power may be of more benefit to activities of daily living for older adults, than possessing high levels of maximum strength e.g. being able to move a lower limb quickly to re-stabilise and prevent a fall (Sayers and Gibson 2014). Furthermore, training at a high-movement velocity with 40% of 1RM for 12-14 repetitions has been shown to elicit similar improvements in strength and power, as training at a low movement velocity for 8-10 repetitions with 80% 1RM (Sayers and Gibson 2014).

It is argued that the ability to move a greater absolute load at lower speeds is less likely to be needed in activities of daily living for older adults (Sayers and Gibson 2014), but is still useful in certain situations e.g. lifting and carrying heavy objects such as shopping bags. Zbinden-Foncea et al. (2014) state that the velocity at which training is conducted at, is an important factor in determining specific functional outcomes. For example, some tasks such as getting up out of a chair require power with a greater force component than velocity, which is important when considering the functional outcome goals of resistance exercise. However, although power training is potentially more beneficial, it is important to remember that strength underpins power development (Zamparo et al. 2002), and so strength training should not be overlooked completely. Table 2.3 examines the literature that have investigated the effects of HVLL resistance exercise on older adults with all of the studies reporting some improvement in aspects of maximal strength and/or functional performance.

Table 2.3. Effects of power training on functional and physiological outcomes

Study	*n =*	Sex ratio female/male	Age (Years) Mean ± SD	Duration	Exercise Protocol	Functional Outcomes	Physiological Outcomes
de Vos et al. (2005)	80%: 28 50%: 28 20%: 28 CG: 28	Not specified	80%: 69 ± 6 50%: 68 ± 5 20%: 69 ± 6 CG: 68 ± 6	12 weeks	4 groups at different % of 1RM: low (20%), medium (50%), high intensity (80%) or control (CG). 3 × 8 reps with a rapid concentric and slow eccentric phase on 5 exercises, twice-weekly.	Average peak power increase:80% (14 ± 8%), 50% (15 ± 9%) and 20% (14 ± 6%).Strength increase: 80% (20 ± 7%), 50% (16 ± 7%), and 20% (13 ± 7%). Muscle endurance increase: 80% (185 ± 126%, 50% (103 ± 75% and 20% (82 ± 57%).	Not measured
Glenn et al. (2015)	Loaded: 30 Unloaded: 27	41/16	Over 65	20 weeks	2 groups: Loaded vs unloaded. Both groups did 3 × 8 reps on upper and lower body exercises. Loaded group used 70% 1RM and unloaded used no external resistance. Both groups performed the concentric phase "as fast as possible".	Arm curl, chair sit-to-stand, 8 ft. up-and-go, 8 ft. walk and peak power production increased similarly in both groups.	Not measured
Reid et al. (2015)	LO: 25 HI: 27	Not Specified	LO: 78 ± 5 HI: 78 ± 4	16 weeks	2 groups: 40% 1RM (LO) vs 70% 1RM (HI) Lower body exercise performed at maximum voluntary velocity, twice-weekly. Both groups used 3 ×5 reps with 30 s rest.	Short physical performance battery test scores, leg extensor strength and peak power improved similarly regardless of training intensity.	Increase in mid-thigh cross sectional area in both groups.
Cadore et al. (2014)	Exercise: 11 Control: 13	Not Specified	Exercise: 93 ± 3 Control: 90 ± 1	12 weeks	Exercise group vs. control group Control group performed mobility exercises on 4 days per week. Exercise group did an upper and lower body programme. 8–10 reps at 40–60 % of 1RM. as well as balance, gait training and chair rises.	Exercise group significantly improved strength, power, time up-and-go tests, balance, rise from a chair and reduced the incidence of falls. Functional outcomes and strength deteriorated in the control group.	Exercise group increased muscle cross sectional area.
Nicholson et al. (2015)	Intervention:32 Control: 36	49/19	Body pump: 66 ± 4 Control: 66 ± 5	26 weeks	Intervention vs control Body pump consisted of whole body resistance exercises. Classes were twice-weekly and loads used were recorded by the participants for each exercise.	Improved 1RMs for squats and bench press, increase in normal gait-speed and single leg balance.	Not measured
Beltran Valls et al. (2014)	Training: 13 Control: 10	11/12	Training: 72 ± 1 Control: 72 ± 1	12 weeks	Training group vs. Control group 4 different resistance exercises, twice-weekly. First 2 weeks participants trained at 40–50 % 1RM (4 ×15 reps) at a moderate velocity. Thereafter, explosive training was used for 3–4 sets of 10–12 repetitions at 70 % 1RM.	Muscle power increased between 28-36%. Muscle strength increased 15-20%. Quicker walking and stair climbing, both with and without carrying loads.	No changes in resting HR, HR, systolic or diastolic blood pressure but the trained group did improve cardiovascular health.

Table 2.3 continued. Effects of power training on functional and physiological outcomes

Study	*n* =	Sex ratio female/male	Age (Years) Mean ± SD	Duration	Exercise Protocol	Functional Outcomes	Physiological Outcomes
Orr et al. (2006)	HI: 28 MED: 28 LOW: 28 CON: 28	68/44	69 ± 6	10 weeks	3 Training groups: 20% (LOW), 50% (MED), or 80% (HI) of 1RM and a control group (CON). Participants trained twice-weekly on 5 exercises using pneumatic resistance machines performing 3 × 8 rapid concentric/ slow eccentric repetitions.	Balance increased in all exercise groups with LOW making the biggest improvements in balance. Strength increased in all groups, but the heavier the training, the greater the improvements. Muscular endurance increased in MED and LOW but HI increased more than all other groups.	Not measured
Earles et al. (2001)	PG: 18 WG: 22	27/13	PG: 77 ± 5 WG: 78 ± 5	12 weeks	High velocity resistance exercise (PG) vs. self-paced walking (WG). PG performed high-velocity leg exercises, thrice-weekly with weekly increases in resistance, combined with 45 minutes of moderate, non-resistance based exercise. WG did moderate intensity exercise 30 minutes daily, 6 days per week.	Peak power increased 22% in PG and was unchanged in WG. Leg extensor power increased in PG. Muscular strength increased 22% in PG and 12% in WG. Functional task performance did not improve in either group.	Not measured
Henwood and Taaffe (2005)	EX: 14 CON: 10	16/8	EX: 70 ± 7 CON: 71 ± 6	8 weeks	2 groups: Exercise (EX) vs. Control (CON). Twice-weekly upper and lower body machine-based exercise. Initial conditioning phase and the 12 power sessions (3 × 8 at 35, 65 and 75% 1RM). Concentric as fast as possible and eccentric 2-3 s.	EX improved dynamic muscle strength for all exercises and improvements in 3/5 functional tasks.	No changes in body composition.

Note: Acronyms used are specific to each study and are defined in the exercise protocol section; Values are presented as Mean ± SD; *n* = Number of participants

2.17 The comparison between HVLL and LVHL

As can be observed in tables 2.2, and 2.3, both HVLL and LVHL improve aspects of functional performance and/or strength. This review now considers studies that have compared HVLL to LVHL, with the findings of previous investigations summarised in table 2.4. As mentioned previously, it is inconclusive as to whether HVLL or LVHL resistance exercise is most beneficial to older adults in health and performance outcomes. It is evident from table 2.4 that many studies that have compared HVLL and LVHL, have rarely considered both acute and chronic physiological outcomes.

It is also clear from table 2.4 that both HVLL and LVHL elicit desirable improvements in functional outcomes, with HVLL seemingly more beneficial than LVHL in many of the studies. These observations are further verified by a recent systematic review conducted by Byrne et al. (2016), who concluded that 10 out of 13 studies that compared power training with traditional resistance exercise found that power training was superior in delivering improvements in indices of muscle power and/or functional performance. It is also interesting to note that some of the power training studies managed to achieve similar, or greater improvements in functional performance with ~20% less work (Henwood et al. 2008; Ramirez-Campillo et al. 2014).

The evidence examined thus far in this section of the review, demonstrates that both LVHL and HVLL resistance exercise can elicit significant improvements in functional outcomes in older adults. However, there should be consideration of the heterogeneity of the study designs. It is evident that studies (Table 2.4) have varied in exercises, repetition ranges, loads, volumes, rest times and equipment, such that drawing conclusions on the ideal exercise prescription is very difficult.

Table 2.4. HVLL vs. LVHL in older adults

Study	*n* =	Sex ratio female/male	Age (Years) Mean ± SD	Duration	Exercise Protocol	Functional Outcomes	Physiological Outcomes
Bottaro et al. (2007)	PT: 11 TRT: 9	0/20	PT: 67 ± 6 TRT: 66 ± 5	10 weeks	Workload matched power training (PT) vs Traditional resistance training (TRT). PT performed 3 × 8–10 repetitions as fast as possible at 60% 1RM. TRT performed 3 × 8–10 repetitions with 2–3s contractions at 60% 1RM. Both groups trained twice-weekly.	Significant PT improvements compared TRT. Arm curling increased by 50% vs. 3% and 30 s chair-stand by 43% vs. 6%, bench press by 37% vs. 13%, and leg press by 31% vs. 8%. No significant differences in muscular strength between groups.	Not measured
Henwood and Taaffe (2006)	HV: 23 CT: 22 CO: 22 CB: 15	37/30	HV: 71 ± 6 CT: 70 ± 5 CB: 69 ± 4 CO: 69 ± 4	8 weeks	4 groups: Twice-weekly High-velocity, varied resistance (HV), twice-weekly slow to moderate-velocity constant-resistance training (CT), combined once-weekly high-velocity varied-resistance and once-weekly gym-based functional training (CB) or no training (CO).	Increase muscle strength in all groups compared to CO. Only HV significantly increased chair rise ability compared to CO. Within groups, HV improved stair-climbing and chair rise ability, while CB improved the fast 6-m walk and CT improved static balance.	Not measured
Miszko et al. (2003)	CG: 15 ST: 13 PT: 11	22/17	CG: 72 ± 7 ST: 73 ± 5 PT: 72 ± 7	16 weeks	3 groups: Control (CG), Strength training (ST) and power training (PT). ST and PT trained thrice-weekly. ST did 3 × 6-8 reps of upper and lower body exercises that progressed from 50-80% 1RM over the 16 weeks. PT did the same exercises and the same initial 8 weeks, and then changed to 6-8 reps at 40% 1RM and performed the concentric phase as fast as possible.	The PT group performed significantly better than ST in The Continuous Scale Physical Functional Performance test. Maximal strength increased in ST compared to CG.	Not measured
Bean et al. (2009)	InVEST: 59 ST: 58	80/37	In VEST: 75 ± 7 ST: 76 ± 7	16 weeks	2 groups: Increased velocity exercise specific to task (InVEST) vs. strength training (ST). Both groups trained all major muscles thrice-weekly. InVEST used a weighted vest as resistance and ST used free weights. InVEST produced the concentric action as fast as possible for 2 sets of each exercise. ST performed the concentric phase over 3 s and 2 × 10 reps were performed for all exercises.	InVEST increased lower limb power compared to ST and both groups improved strength similarly. Self-reported function and performance in the Short Physical Performance Battery improved similarly between groups.	Not Measured
Henwood et al. (2008)	HV: 23 ST: 22 CO: 22	36/31	HV: 71±1 ST: 70±1 CO: 69±1	24 weeks	3 groups: high-velocity varied resistance (HV), constant resistance (ST), or control group (CO). Upper and lower body exercise twice-weekly. ST used 3 × 8 repetitions at 75% 1RM with 3 s per concentric and eccentric phase. HV performed the concentric phase as fast as possible with 3 s eccentric phase and variable 1RM% during 3 sets (45-75% 1RM).	Muscle strength increased similarly in both groups compared with CO. Peak muscle power also increased with no differences between groups. Some functional tasks improved in both ST and HV. Improvements were similar in both groups, but HV performed around 20% less work.	Not measured
Marsh et al. (2009)	PT: 12 ST: 11 CO: 13	25/11	PT: 77 ± 6 ST: 75 ± 5 CO: 74 ± 5	12 weeks	3 groups: Strength training (ST), Power training (PT) and Control (CO). Exercise performed thrice-weekly. 70% 1RM used in both groups, PT performed the concentric phase as fast as possible and ST over 2-3 seconds. 1-2 ×10-12 reps for upper body exercises and 3 × 8-10 reps for the lower body were performed.	Both groups significantly and similarly improved their maximal strength but maximum lower body power increased approximately two-fold in PT compared to ST.	Not measured
Sayers and Gibson (2014)	HSPT: 24 SSST: 22 CON: 18	43/21	HSPT: 71 ± 7 SSST: 69 ± 8 CON: 72 ± 6	12 weeks	3 groups: high speed power training (HSPT), slow speed strength training (SSST) and control (CON). Leg press and knee extension machines, thrice-weekly. HSPT performed 3 ×12-14 reps at 40% 1RM. The concentric phase was as fast as possible. SSST used 3 × 8-10 reps at 80% 1RM and a 2-3 seconds eccentric phase.	Power and 1RM strength increased similarly in HSPT and SSST groups, but the HSPT group shifted the external resistance at which peak power occurred to a lower external resistance (67%1RM to 52%1RM) compared to SSST (65%1RM to 62%1RM).	Not measured

Table 2.4 Continued. HVLL vs. LVHL in Older Adults

Study	*n* =	Sex ratio female/male	Age (Years) Mean ± SD	Duration	Exercise Protocol	Functional Outcomes	Physiological Outcomes
Pamukoff et al. (2014)	ST: 10 PT: 10	9/11	ST: 68 ± 3 PT: 73 ± 4	6 weeks	2 groups: strength training (ST) and power training (PT). Both groups trained thrice-weekly using 7 lower body exercises. Both groups performed (2 × 8 reps at 50% 1RM), loads were progressed when needed. ST completed the concentric phases in 2-3 s and PT completed it as fast as possible.	Both PT and ST training improved single-step balance recovery by similar magnitudes.	Not measured
Ramirez-Campillo et al. (2014)	EG: 15 SG: 15 CG: 15	45/0	EG: 66 ± 4 SG: 69 ± 6 CG: 67 ± 5	12 weeks	3 groups: high speed resistance exercise group (EG) low speed resistance exercise group (SG) and control (CG). Both exercise groups trained thrice-weekly using 6 upper and lower body exercises. SG completed 3 × 8 repetitions at 75% 1RM with 3 s for the concentric and eccentric phases. EG completed 3 ×8 reps at 45, 60 and 75% 1RM. EG performed the concentric phase as fast as possible with a 3 s eccentric phase.	Both interventions increased functional capacity, muscle performance and quality of life in older women. EG induced the greatest increase in muscle power and functional capacity with ~20% less total work.	No resting heart rate differences.
Van Roie et al. (2013)	HIGH: 18 LOW+: 19 LOW: 19	30/26	HIGH: 68 ± 4 LOW+: 67 ± 6 LOW: 69 ± 5	12 weeks	3 training groups: HIGH (80% 1RM, 2 × 10-15 reps) LOW (20% 1RM, 1 × 80-100 reps) LOW+ (20% 1RM, 1 × 60 reps immediately after another 1 × 10-20 reps at 40% 1RM was performed). Exercise was performed on a leg press and leg extension and all groups trained thrice-weekly.	HIGH and LOW+ resulted in significantly greater improvements in 1RM strength than LOW.	HIGH and LOW+ resulted in greater muscle hypertrophy than LOW.
Seynnes et al. (2004)	HI: 8 LI: 6 PC: 8	Not Specified	HI: 83 ± 3 LI: 81 ± 2 PC: 80 ± 2	10 weeks	3 groups: high intensity (HI), low intensity (LI) and a weight free placebo-control group (PC). HI trained at 80% of 1RM and LI trained at 40% 1RM while CG performed the exercise with no resistance. All groups performed 3 × 8 reps thrice-weekly.	Improvements in knee extensor strength, endurance and 6-minute walk were greater in HI compared to LI. However, LI and HI improved knee extensor strength, endurance, stair-climbing power, and chair-rising compared with CG.	Not measured
Fielding et al. (2002)	HI: 15 LO: 15	30/0	HI: 73 ± 1 LO: 72 ± 1	16 weeks	2 groups: high velocity (HI) and low velocity (LO). Leg press and knee extension performed thrice-weekly. HI performed 3 × 8 reps at 70% 1RM with the concentric phase as fast as possible, pause for 1 s and then a 2 s eccentric phase. LO did the same exercise with the only difference being, the concentric phase was performed over 2 s.	Leg press and knee extension 1RM increased similarly in both training groups. Leg press peak power increased significantly more in HI compared to LO. HI saw greater improvements in leg press power at 40%, 50%, 60%, 70%, 80%, and 90% of the 1RM compared to LO.	Not measured

Note: Acronyms used are specific to each study and are defined in the exercise protocol section; Values are presented as Mean ± SD; *n* = Number of participants

2.18 Conclusions from the literature

Multiple studies suggest that HVLL appears to be the most effective method of resistance exercise in assisting older adult's complete activities of daily living (Bassey et al. 1992; Bottaro et al. 2007; Hazell et al. 2007; Ramirez-Campillo et al. 2014; Reid and Fielding 2012). Some authors have concluded that neither power or strength training is better than the other for outcome measures such as balance recovery (Pamukoff et al. 2014) and various other functional performance tests (Fielding et al. 2002). Furthermore, a review by Tschopp et al. (2011) concluded that no firm recommendations could be made, but power training appeared to have a small advantage over strength training in terms of functional outcomes. A more recent review concluded that that HVLL may be superior in delivering improvements in muscle power and/or functional performance (Byrne et al. 2016). Interestingly, it appears to have gone largely undiscussed in the wider literature, that many of the conclusions as to the efficacy of power training have been drawn from investigations largely involving female participants. From the Byrne et al. (2016) review, 3/13 studies used exclusively female participants, and a further 7/13 recruited more female participants than males. Greater numbers of female participants, may skew conclusions, as the majority of high-velocity resistance exercise is carried out with lighter loads, to which females adapt more favourably (Glenn et al. 2015).

Furthermore, physiological outcomes of resistance exercise in older adults appear to have been inadequately examined, especially during HVLL. Lastly, there is a lack of well-designed studies that consider the affective responses to resistance exercise in older adults. As previously discussed, hedonic theory states that humans gravitate towards pleasure and the avoidance of displeasure (Mees and Schmitt 2008). Therefore, in order to establish the optimal resistance exercise prescription for older adults, affective responses must be considered because affective responses to exercise predict future exercise behaviours (Williams et al. 2008). The current physical activity guidelines state that resistance exercise should be performed twice-weekly, and many of studies conducted thus far tables 2.2, 2.3 and 2.4 have used training twice or thrice-weekly. This presents a significant time and cost burden on older adults, if one session weekly is enough to make significant gains in functional performance, it would mean that exercise is more accessible, and possibly more tolerable to a greater number of older adults.

The current literature that has examined various performance outcomes from power training vs strength training in older adults have largely produced results which are unclear (Rajan and Porter 2015; Tschopp et al. 2011). The inconclusive findings are likely down to the heterogeneous nature of research in older adults (Barbalho et al. 2017) (e.g. training frequency, movement velocity, volume, load, intensity, rest etc.). The equipment used in studies, lack of measurement of movement velocity (Rajan and Porter 2015), sex of study population (Glenn et al. 2015), lack of understanding of the clinical meaningfulness of significant changes (Reid et al. 2015), short intervention periods (Maganaris et al. 2004) and a lack of physiological measurements (Ramirez-Campillo et al. 2014) all contribute to conclusions being unclear. These methodological considerations are discussed in detail below.

2.19 Methodological considerations

2.19.1 Movement velocity

As highlighted by Rajan and Porter (2015) the majority of studies that have examined resistance exercise interventions in older adults have not measured the movement velocity training occurred at. Instead, it has been assumed, that when older adults are requested to exercise at different movement velocities, the correct execution is possible, and has been achieved. Advancing age induces a loss in the adaptability of movement (Vaillancourt and Newell 2003), making movement tasks, such as differentiating between different movement velocities of resistance exercises more challenging, such that velocities become less variable (Harbourne and Stergiou 2009). This was evident when Rajan and Porter (2015) measured the movement velocity of power and strength training velocities in a group of older adults. They observed that there were large variances in movement velocities between individuals, for example some individuals trained faster during strength training than others did during power training. Similarly, others had very small differences between their strength and power training velocities. With the majority of research not measuring the velocity at which training occurs, it brings into question how reliable the conclusions are that have been drawn from interventions involving strength and power training where older adults have been asked to exercise at "fast" or "slow" velocities.

2.19.2 Equipment

The studies that have controlled or measured movement velocity, have used equipment such as isokinetic dynamometers (Signorile et al. 2002) or Keiser pneumatic machines (Fielding et al. 2002). These pieces of equipment are expensive and not widely available to the public. Therefore, the majority of intervention studies tables 2.2, 2.3 and 2.4 have used exercise machines or free weight exercises to examine power training against strength training, and have largely failed to use other systems such as accelerometers or 2D video analysis that would be able to disclose the movement velocities produced during the training interventions.

2.19.3 Frequency of resistance exercise

As discussed previously, understanding the minimal effective does of resistance exercise is important as cost and time are two frequently cited barriers to exercise in older adults (Foley et al. 2011). Tables 2.2, 2.3 and 2.4 demonstrate the efficacy of resistance exercise twice or thrice-weekly but very few studies have examined the effectiveness of carrying out resistance exercise just once-weekly. If once-weekly resistance exercise significantly impacts physiological and functional outcomes in older adults, it has the potential to influence an update to the current physical activity guidelines. The need to perform resistance exercise twice-weekly may discourage many sedentary adults from beginning exercise programmes. If meaningful benefits can be made using resistance exercise once-weekly, this may have a positive impact on resistance exercise participation in older adults.

2.19.4 Sex of participants

Examining the studies in the review by Byrne et al. (2016), the ratios of males to females selected to participate in resistance exercise interventions, generally favour the use of female participants. The studies documented in tables 2.2, 2.3 and 2.4 in general, also have greater numbers of female participants compared to males. This may have skewed the results and influenced the conclusions suggested by the authors, as females have been shown to adapt more favourably to low resistance training than males (Glenn et al. 2015). In a study by Glenn et al. (2015), 72% of the study population were females and the authors concluded that unloaded high-velocity training was able to improve functional fitness and power to a similar extent to loaded training. It is unclear and often unstated why females appear to have been used as participants more regularly than males, but declines in strength and power occur earlier in females than in males (Skelton et al. 1994), arguably making it more important to address the issue in females. Additionally, previous research has shown that older males are less likely to engage with evidence-based health promotion programmes than females (Anderson et al. 2016) and so, it may be easier to recruit female participants into such exercise interventions.

2.19.5 Physiological measurements

Tables 2.2 and 2.3 reveal that there has been more investigation into the physiological changes in response to strength training/ LVHL than in power training/ HVLL. There have been studies into progressive resistance exercise and older adults that have examined changes in physiological outcomes such as: fat free mass (Ades et al. 1996), body fat percentage (Brochu et al. 2002), bone mineral density (Nelson et al. 1994), muscle cross-sectional area (McCartney et al. 1996), cytokine levels (Greiwe et al. 2001) and tendon properties (Reeves et al. 2003). In contrast, studies that have examined power training have largely failed to report physiological changes which could contribute to an understanding of the underlying mechanisms of adaptations in older adults. The physiological mechanisms that are stimulated during resistance exercise are dependent on the nature of that exercise (e.g. sets, repetitions, velocity, mode etc.) with repeated exposure to a certain exercise stimulus, facilitating specific adaptations of those physiological mechanisms (Kraemer et al. 1988). It has been shown that the assessment of acute physiological responses to resistance exercise protocols can aid in understanding how they differ (Kraemer et al. 1996) and may be useful in explaining the mechanisms of potential adaptations (Ramirez-Campillo et al. 2014). Importantly, there has been very little comparison of the acute physiological changes (blood lactate, heart rate, blood pressure etc.) in studies that have compared power training and strength training in older adults. These measurements are important in elucidating the physiological influences that each type of training has on older adults.

2.19.6 Exercise interventions

The studies in table 2.4 that have compared the effects of HVLL and LVHL are heterogeneous in their designs (different sets and reps, load used, types of exercise, muscle groups trained and also outcome measures assessed etc.). This makes comparing findings somewhat difficult. Furthermore, some studies that have compared power to strength training have not matched total volume-load performed (Henwood et al. 2008; Ramirez-Campillo et al. 2014).

2.19.7 Affective responses of older adults to resistance exercise

As discussed previously, surprisingly few studies have examined exercise affect during resistance exercise in older adults. This is an important area that requires investigation as enjoyment of exercise is essential to adherence (Ekkekakis et al. 2011). Further investigation into the affective responses to resistance exercise in older adults may be valuable to developing effective programme design.

2.20 Justification of research

Analysis of the literature makes it clear that further investigation is needed in order to further clarify the optimal resistance exercise prescription for older adults. Studies need to be conducted that measure the movement velocity of training on equipment that would be used by older adults that choose to adopt these styles of training. This would provide ecologically valid data on the movement velocities produced by older adults during HVLL and LVHL. Furthermore, very few studies have analysed physiological markers during their training interventions. Measuring metrics such as heart rate, blood lactate and blood pressure, will aid in understanding the physiological stimulus provided by HVLL and LVHL, which will help exercise professionals quantify benefits of each type of training and any possible adverse effects. Likewise, it is important for continued exercise behaviour and adherence that affective responses to resistance exercise are understood. Few studies have investigated if resistance exercise is enjoyed by older adults and if so, is there a preference for either HVLL or LVHL? Perception of exercise is arguably the most important variable to consider. If the most effective resistance exercise programme for improvements in functional performance, is not enjoyable or is perceived to be "too hard", it is likely that few older adults will continue to follow the programme and therefore gain any of the health and functional performance benefits.

Finally, based on the findings of the preliminary work, which includes establishing the movement velocity of HVLL and LVHL, and the acute physiological and affective responses to both types of resistance exercise, the findings will feed into designing a 10-week training intervention. Following the exercise intervention, changes in functional performance, maximal strength and affective responses can be compared between HVLL and LVHL. Importantly, this research needs to be carried out with equal numbers of male and female participants so that differences in responses can be compared without the potential bias of a greater ratio of female to male participants.

Chapter 3: Study 1

Published in: Experimental Gerontology:

Richardson, D. L., Duncan, M. J., Jimenez, A., Jones, V. M., Juris, P. M., and Clarke, N. D. (2018) 'Movement Velocity During High- and Low-Velocity Resistance Exercise Protocols in Older Adults'. *Experimental Gerontology* 107, 140-147

The present study sought to validate a metronome and command-based protocol that is used to manipulate the movement velocity of resistance exercise. The efficacy of this protocol needed to be established to ensure that it would be suitable to compare the two methods of resistance exercise used in this thesis.

3.1 Introduction

Sarcopenia is a common manifestation of ageing (McLean and Kiel 2015). However, losses in muscle strength can be approximately 60% greater than predictions from the loss of muscle cross-sectional area in older adults (Hughes et al. 2001). This loss of muscle strength is known as dynapenia, and predisposes older adults to severe clinical consequences which include: reduced functional performance, disability and mortality (Clark and Manini 2012). However, there is strong evidence that resistance exercise is effective in counteracting sarcopenia (Yu 2015) and attenuating age-related declines in muscle strength (Liu and Latham 2009). Many studies have attempted to identify the optimal resistance exercise prescription for older adults through manipulation of movement velocity, load, and number of repetitions etc. (Tschopp et al. 2011). Thus far, it appears HVLL (high-velocity, low-load) and LVHL (low-velocity, high-load) (commonly termed power and strength training respectively) may elicit similar increases in muscle strength (Henwood and Taaffe 2006), muscle cross sectional area (Claflin et al. 2011) and improvements in functional performance (Tschopp et al. 2011).

It has been suggested that the actual movement velocity that resistance exercise is performed at may not be the most important factor in achieving velocity-specific adaptations. Behm and Sale (1993) concluded that the intention to move as fast as possible is more important for high-velocity specific adaptations of the neuromuscular system, than the actual movement velocity of training. However, McBride et al. (2002) observed performing squat jumps with the intention of maximal movement velocity at 30% 1RM (one repetition maximum) improved peak velocity, peak power and jump height, whereas training at 80% 1RM did not. These findings suggest that the actual movement velocity that is achieved during resistance exercise could play a significant role in velocity specific adaptations (Kawamori and Newton 2006).

Attaining velocity specific adaptations using low external loads may be particularly beneficial to sedentary older adults, who may be at greater risk of injury when training at high-velocity with heavy loads. Furthermore, training at high-velocity, against a low external resistance has been shown to shift the development of peak power to a lower external resistance (Sayers and

Gibson 2014). This shift in peak power may be of more benefit to activities of daily living for older adults, than possessing high levels of maximum strength e.g. being able to move a lower limb quickly to re-stabilise and prevent a fall (Sayers and Gibson 2014).

The command “as fast as possible” has commonly been used to control the velocity of the concentric phase of HVLL in older adults (Beltran Valls et al. 2014; Glenn et al. 2015; Sayers and Gibson 2010), whereas performing the concentric phase over two seconds has frequently been used during LVHL (Sayers and Gibson 2010; 2014; Van Roie et al. 2013). Sayers et al. (2016) observed that self-selected maximal lower limb velocity varied considerably between individuals, with those individuals training at the highest movement velocities maximising improvements in functional performance. This highlights the importance of understanding the exact velocity that exercise occurs at. However, many studies have failed to measure and report the velocity that is produced using these commands, which could result in large inter-individual differences, depending on the ability and engagement of the participants (Rajan and Porter 2015). Therefore, it would be useful to measure the velocities that common protocols are producing.

There are several techniques used to measure exercise velocity such as isokinetic dynamometers (Signorile et al. 2002), linear position transducers (Conceicao et al. 2016) and two-dimensional video analysis (Moss et al. 2003). Isokinetic dynamometers have been shown to be both valid and reliable at controlling velocity of exercise (Drouin et al. 2004). However, isokinetic dynamometers only permit constant motion of the exercising limb at a pre-set velocity (Barnes 1980), not allowing self-selected velocity. Linear position transducers are most commonly used during vertical plane movements such as squats and deadlifts. They are cost effective and portable, but their reliability and validity vary depending on the exercises used, exercise equipment and loading (Harris et al. 2010). Two-dimensional video analysis is a common tool used to evaluate the kinematics of dynamic movements (Maykut et al. 2015) and has been used by others as the established method to validate velocity measuring equipment, such as a telemetry-based velocometer (Moss et al. 2003). Furthermore, the reliability and validity of two-dimensional video analysis for measuring velocity has been shown to be high when tested against an isokinetic dynamometer (Selfe 1998) and a linear position transducer (Sanudo et al. 2016).

Given that the velocity resistance exercise is performed at, may be an important variable of resistance exercise for older adults, the aim of this study was to measure the velocity that a group of older adults produce during eight different exercises, when following two methods of manipulating the movement velocity of resistance exercise. Furthermore, as there are morphological (Miller et al. 1993) and neuromuscular (Quatman et al. 2006) differences between males and females, a secondary aim of this study was to examine any sex differences in movement velocity during HVLL and LVHL. It was hypothesised that velocities produced in the concentric phase during HVLL would be significantly faster than those of LVHL for each exercise.

3.2 Methods

3.2.1 Design

The present study used a randomised, crossover design. The two protocols were designed to be simple and pragmatic to provide a direct comparison of the velocities produced during volume-load matched HVLL and LVHL. Each participant was required to attend a familiarisation session where 1RM for each exercise was obtained. Participants were then randomised to complete volume-load matched HVLL and LVHL (identical total load lifted). Three days of rest was given between each of the three sessions for each velocity, and a 7-day break was given before crossing over to the other protocol. All sessions were performed as close to the same time of day to minimise fluctuations in strength due to circadian variation.

3.2.2 Participants

Following institutional ethics approval (Appendix A), nine older adults (four males and five females; Table 3.1) were recruited by word of mouth for participation. All participants were made aware of the exercise protocols and associated risks before providing written informed consent (samples shown in Appendix B). Each participant met specific eligibility criteria: (a) absence of cognitive impairment using the mini-mental state examination (Folstein et al. 1975), (b) absence of acute or terminal illness, myocardial infarction, symptomatic coronary artery disease, congestive heart failure, neuromuscular disease, or uncontrolled hypertension (>150/90 mmHg), (c) no upper or lower extremity fracture in the previous six months, (d) not carried out resistance exercise in the previous six months (e) aged 60 years or older. Fifteen participants volunteered to take part, three were excluded because they were already involved in resistance training programmes and a further two were excluded with hypertension. Therefore, ten participants completed all testing, although all data for one male participant was excluded, as some video files were corrupted and unable to be analysed.

Table 3.1 Participant Characteristics

	Males (*n* = 4)	Females (*n* = 5)
Age (years)	67 ± 3	68 ± 2
Age Range (years)	63 – 71	67 – 71
Height (cm)	175.6 ± 5.6	162.6 ± 5.8
Body Mass (kg)	91.5 ± 14.8	70.9 ± 10.7
BMI ($kg \cdot m^{-2}$)	30 ± 4	27 ± 3
Medications taken	1 ± 1	1 ± 1
Mini mental state examination (0-30)	29 ± 1	29 ± 1

Note: Values are means ± SD; *n* = number of participants

3.2.3 Procedures

Prior to familiarisation and all sessions, participants were asked to refrain from all other fatiguing exercise for 24 hours. Firstly, height (cm) and mass (kg) were recorded (Seca Instruments, Hamburg, Germany). Participants then completed a warm-up protocol which consisted of five minutes cycling at a self-selected pace (Marsh et al. 2009), followed by four dynamic stretches (arm circles, arm hugs, partial squats with arm swings, and heel-to-toe walk). This warm-up targeted the main muscles used in the sessions, and was repeated before all subsequent sessions. Following the warm-up, the preferred individual anthropometric setup for each of the eight exercises (chest press, leg press, calf raise, leg extension, leg curl, seated row, bicep curl and tricep extension) performed on Cybex exercise equipment (Cybex, Medway, MA, USA) was obtained and recorded for future sessions. The correct technique for all exercises, as described by Cybex, were demonstrated to participants and practiced.

Finally, participants were taken through a protocol to predict 1RM for all exercises. For each exercise, participants performed repetitions with a load they felt was challenging but manageable. The resistance was progressively increased, with regular 3-minute rest intervals, until momentary failure occurred within 10 repetitions where possible. Ten repetitions was selected, as the prediction equation used (Brzycki 1993) becomes less accurate when more than ten repetitions are performed. It must be noted (Table 3.2), that some participants reached 12 repetitions on some exercises, likely resulting in slightly overestimated 1RM's. Load lifted and number of repetitions completed were used to provide an estimation of 1RM for each exercise (Table 3.2) using the prediction equation: load lifted ÷ (1.0278- (0.0278 × number of repetitions performed) (Brzycki 1993). Although this prediction equation was not designed for older adults, it produces valid estimations of 1RM on multiple machine based exercises (Knutzen et al. 1999). Predicted 1RM's were used as they pose less of a risk of muscle or bone injuries and are more time efficient for use in older adults (Tan et al. 2015). Estimations of 1RM were achieved by all participants in no more than four attempts. Following a minimum three days of recovery after the familiarisation session, participants attended the sports centre for their first session.

Table 3.2 Predicted 1RM data (Brzycki 1993) with the median and range of repetitions used to predict 1RM

	Leg Press	Seated Row	Chest Press	Leg Extension	Leg Curl	Calf Raise	Tricep Extension	Bicep Curl
Male 1RM (kg)	122 ± 26	64 ± 8	57 ± 3	62 ± 17	55 ± 6	121 ± 30	38 ± 6	32 ± 8
Median	10	10	10	10	9	10	10	7
Range	10-12	10-11	8-10	10-11	7-10	10-10	8-10	2-10
Female 1RM (kg)	79 ± 13	34 ± 5	21 ± 3	29 ± 7	26 ± 4	89 ± 20	16 ± 7	13 ± 6
Median	10	10	8	10	10	10	10	10
Range	8-12	9-12	4-10	7-12	5-10	9-10	6-11	6-12

Note: Values are means ± SD; 1RM = One repetition maximum

3.2.4 Exercise protocols

The exercise protocols used in the present study (Table 3.3) were based on others that have previously demonstrated a positive impact on functional performance in older adults (Kalapotharakos et al. 2005; Reid et al. 2015), with the number of sets and repetitions being similar to others that have attempted to match volume-loads (Hortobagyi et al. 2001; Sayers and Gibson 2014). Additionally, the protocols were volume-load matched, based on both conditions lifting the same total load. The concentric phases of the HVLL exercises were performed "as fast as possible" without causing dangerous fly away (unloading) of the weight stack, and the eccentric phase was performed over three seconds (Henwood et al. 2008). During the LVHL exercises, the concentric phase was performed over two seconds, and the eccentric phase over three seconds (Van Roie et al. 2013). A 60-bpm metronome (iOS app, Pro metronome, EUMlab, Hangzhou, China) provided the cadence for exercise. Different sounds were used to denote each second of both the concentric and eccentric phases, except during the concentric phase of the HVLL protocol. During the sessions, feedback was provided to participants, emphasising the need to produce the fastest velocities they could during the concentric phase of HVLL, and to follow the metronome closely during LVHL. Figure 3.1 displays a schematic diagram of the study.

Table 3.3 Exercise protocols

HVLL	**LVHL**
40% 1RM	80% 1RM
3 sets	3 sets
14 repetitions	7 repetitions
Concentric phase: “as fast as possible”	Concentric phase: 2 s
Eccentric phase: 3 s	Eccentric phase: 3 s
2 minutes recovery between sets	2 minutes recovery between sets
3 minutes between exercises	3 minutes between exercises

Note: HVLL = High-velocity, low-load; LVHL = Low-velocity, high-load; 1RM = One repetition maximum

3.2.5 Measurement of movement velocity

A high definition camera (Sony HDR-HC9E, Sony Corporation, Tokyo, Japan) was used to record every set of each exercise at 50 frames per second. The camera was mounted on a stable tripod and a 3,4,5 triangle used to ensure that the camera was placed perpendicular to the plane of motion for each exercise. Flat disk reflective markers were attached to the moving parts of each piece of exercise equipment on a black background, these markers remained attached for the duration of the study to ensure identical placement for each session. An external, direct light source was placed directly above and behind the camera to illuminate the markers for filming. A 50 cm x 50 cm calibration board was placed directly in the plane of motion for each video as a known distance reference point for two-dimensional digitisation in Quintic software (9.03 version 17, Quintic Consultancy Ltd, Coventry, United Kingdom). All videos were calibrated for automatic digitisation by the same experimenter. Following digitisation, the data was smoothed using the optimal Butterworth filter values recommended by Quintic software to smooth any data anomalies that may have occurred during the digitisation process. Using the data outputs, each repetition was manually analysed by the same experimenter to calculate velocity in meters per second ($m \cdot s^{-1}$) for both the concentric and eccentric phases of each exercise. The total number of repetitions analysed was the sum of sets, repetitions, exercises, number of sessions and participants. HVLL (3 sets x 14 repetitions x 8 exercises x 3 sessions =1,008 repetitions) for each of the 9 participants (*n* = 9,072 total repetitions; male *n* = 4,032; female *n* = 5,040), and for LVHL (3 sets x 7 repetitions x 8 exercises x 3 sessions = 504 repetitions) for each of the 9 participants (*n* = 4,536 total repetitions; male *n* = 2,016; female *n* = 2,520). Velocity estimates were calculated using each individual's mean concentric velocity and mean eccentric velocity for each set of each exercise.

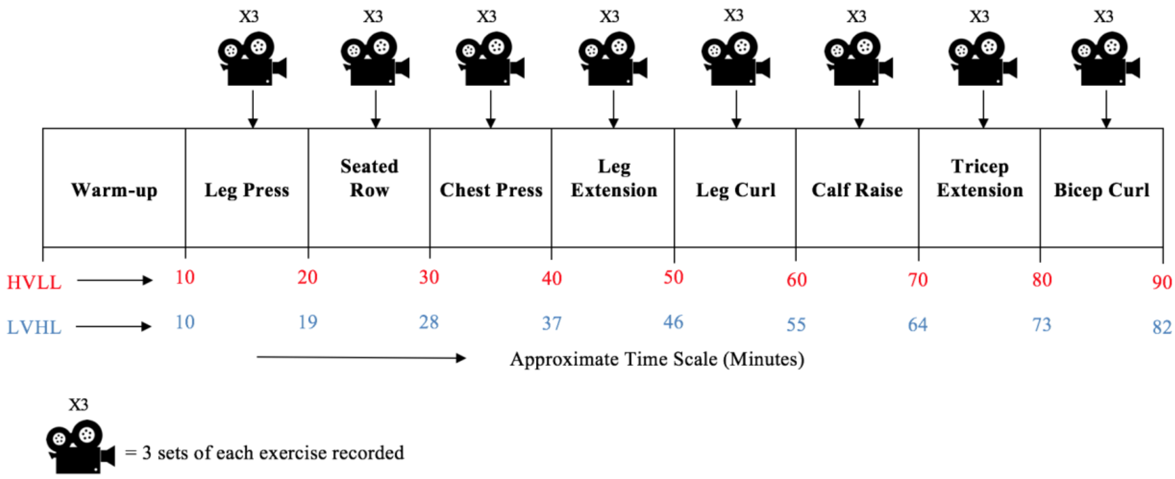

Figure 3.1. A schematic diagram of the experimental protocols
Note: HVLL = High-velocity, low-load; LVHL = Low-velocity, high-load

3.2.6 Statistical analysis

All data was analysed using IBM SPSS Statistics for Windows, Version 22.0 (Armonk, NY: IBM Corp) and descriptive statistics are presented as mean ± SD and 95% confidence intervals (95%CI). Normality of data was assessed using the Shapiro-Wilk test and manual analysis of the plotted data. Any scale data that was non-normally distributed was log transformed and reassessed for normality using the residuals (Kozak and Piepho 2018). Providing the data presented a normal distribution, it was analysed with the appropriate parametric statistical test. Factorial analysis of variance (ANOVA) with repeated measures examined the effect of the independent variables: exercise protocol and sex on the dependent variable: exercise velocity. When Mauchly's test of sphericity was significant and the Greenhouse-Geisser level of violation was >0.75, degrees of freedom were corrected using Huynh-Feldt adjustment. When violation was <0.75, Greenhouse-Geisser correction was used. Where any statistical differences were found, pairwise comparisons with Bonferroni correction were used to show exactly where they lay. Significance was determined by a p value of <0.05 and reported as exact values unless below p=0.001. Effect size was used to quantify the meaningfulness of any differences found between conditions, and was calculated using η_p^2 and defined as: trivial (<0.1), small (0.1-0.29), moderate (0.3-0.49) or large (0.5>) (Hopkins et al. 2009). An *a priori* power calculation using G*Power software (version 3.1.9.2, Franz Faul, Universitat Kiel, Dusseldorf, Germany) for repeated measures ANOVA revealed, detection of a moderate effect size (0.4) with α as 0.05 and a 1–β error probability of 0.8, required a sample size of eight.

3.3 Results

3.3.1 Bicep curl

The concentric phase was 42% faster ($F_{(1,7)}$=174.480; p<0.001; 95%CI: 0.52,0.74; η_p^2 =0.96; Figure 3.2) and the eccentric phase 17% faster ($F_{(1,7)}$=36.674; p=0.001; 95%CI: 0.08,0.17; η_p^2 =0.84; Figure 3.4) during HVLL compared to LVHL respectively. There was a large significant interaction between sex and velocity for the concentric phase ($F_{(1,7)}$=19.830; p=0.003; η_p^2 =0.73; Figure 3.3), males produced significantly greater velocities than females during the concentric phase of HVLL but not LVHL. However, there were no significant differences in velocity during the eccentric phase between males and females (Bonferroni p=0.456; 95%CI: -0.13,0.25; Figure 3.5).

3.3.2 Calf raise

The concentric phase was 68% faster ($F_{(1,7)}$=49.163; p<0.001; 95%CI: 0.16,0.33; η_p^2 =0.88; Figure 3.2) and the eccentric phase 31% faster ($F_{(1,7)}$=24.032; p=0.002; 95%CI: 0.02,0.05; η_p^2 =0.77; Figure 3.4) during HVLL compared to LVHL respectively. There were no significant differences in velocities produced in the concentric phase (Bonferroni p=0.973; 95%CI: -0.12,0.12; Figure 3.3) or eccentric phase (Bonferroni p=0.551; 95%CI: -0.02,0.04; Figure 3.5) between males and females.

3.3.3 Chest press

The concentric phase was 48% faster ($F_{(1,7)}$=91.291; p<0.001; 95%CI: 0.33,0.54; η_p^2 =0.93; Figure 3.2) and the eccentric phase 12% faster ($F_{(1,7)}$=31.128; p=0.001; 95%CI: 0.02,0.05; η_p^2 =0.82; Figure 3.4) during HVLL compared to LVHL respectively. There was a large significant interaction between sex and velocity for the concentric phase ($F_{(1,7)}$=11.670; p=0.011; η_p^2 =0.63; Figure 3.3). Males produced greater velocities than females during the concentric phase of the chest press during HVLL but not LVHL. However, there were no significant differences in velocity of the eccentric phase between males and females (Bonferroni p=0.215; 95%CI: -0.03,0.10; Figure 3.5).

3.3.4 Leg curl

The concentric phase was 48% faster ($F_{(1,7)}$=89.084; p<0.001; 95%CI: 0.39,0.65; η_p^2 =0.93; Figure 3.2) and the eccentric phase 30% faster ($F_{(1,7)}$=59.878; p<0.001; 95%CI: 0.11,0.21; η_p^2 =0.90; Figure 3.4) during HVLL compared to LVHL respectively. There were no significant differences in velocities produced in the concentric phase (Bonferroni p=0.100; 95%CI: -0.04,0.38; Figure 3.3) or eccentric phase (Bonferroni p=0.784; 95%CI: -0.14,0.11; Figure 3.5). between males and females.

3.3.5 Leg extension

The concentric phase was 54% faster ($F_{(1,7)}$=105.224; p<0.001; 95%CI: 0.53,0.85; η_p^2 =0.94; Figure 3.2) and the eccentric phase 22% faster ($F_{(1,7)}$=95.342; p<0.001; 95%CI: 0.06,0.10; η_p^2 =0.93; Figure 3.4) during HVLL compared to LVHL respectively. There were no significant differences in velocities produced in the concentric phase (Bonferroni p=0.157; 95%CI: -0.07,0.35; Figure 3.3) or the eccentric phase (Bonferroni p=0.312; 95%CI: -0.03,0.07; Figure 3.5) between males and females.

3.3.6 Leg press

The concentric phase was 52% faster ($F_{(1,7)}$=81.002; p<0.001; 95%CI: 0.33,0.56; η_p^2 =0.92; Figure 3.2) and the eccentric phase 36% faster ($F_{(1,7)}$=151.013; p<0.001; 95%CI: 0.09,0.14; η_p^2 =0.96; Figure 3.4) during HVLL compared to LVHL respectively. There were no significant differences in velocities produced in the concentric phase (Bonferroni p=0.497;

95%CI: -0.14,0.26; Figure 3.3) or the eccentric phase (Bonferroni p=0.632; 95%CI: -0.06,0.09; Figure 3.5) between males and females.

3.3.7 Seated row

The concentric phase was 57% faster ($F_{(1,7)}$=103.407; p<0.001; 95%CI: 0.58,0.94; η_p^2 =0.94; Figure 3.2) and the eccentric phase 28% faster ($F_{(1,7)}$=211.889; p<0.001; 95%CI: 0.11,0.15; η_p^2 =0.97) during HVLL compared to LVHL respectively. Males produced significantly faster concentric velocities compared with females for HVLL (Bonferroni p=0.014; 95%CI: 0.06,0.40; Figure 3.3), but there were no sex differences for the eccentric phase (Bonferroni p=0.162; 95%CI: -0.03,0.15; Figure 3.5).

3.3.8 Tricep extension

The concentric phase was 43% faster ($F_{(1,7)}$=123.192; p<0.001; 95%CI: 0.45,0.69; η_p^2 =0.95; Figure 3.2) and the eccentric phase 16% faster ($F_{(1,7)}$=28.883; p=0.001; 95%CI: 0.05,0.13; η_p^2 =0.81) during HVLL compared to LVHL respectively. There was a large significant interaction between sex and velocity for the concentric phase ($F_{(1,7)}$=8.043; p=0.025; η_p^2 =0.54; Figure 3.3) where males produced greater velocities than females during the concentric phase of the tricep extension during HVLL but not LVHL. However, there were no significant sex differences during the eccentric phase (Bonferroni p=0.393; 95%CI: -0.09,0.19; Figure 3.5).

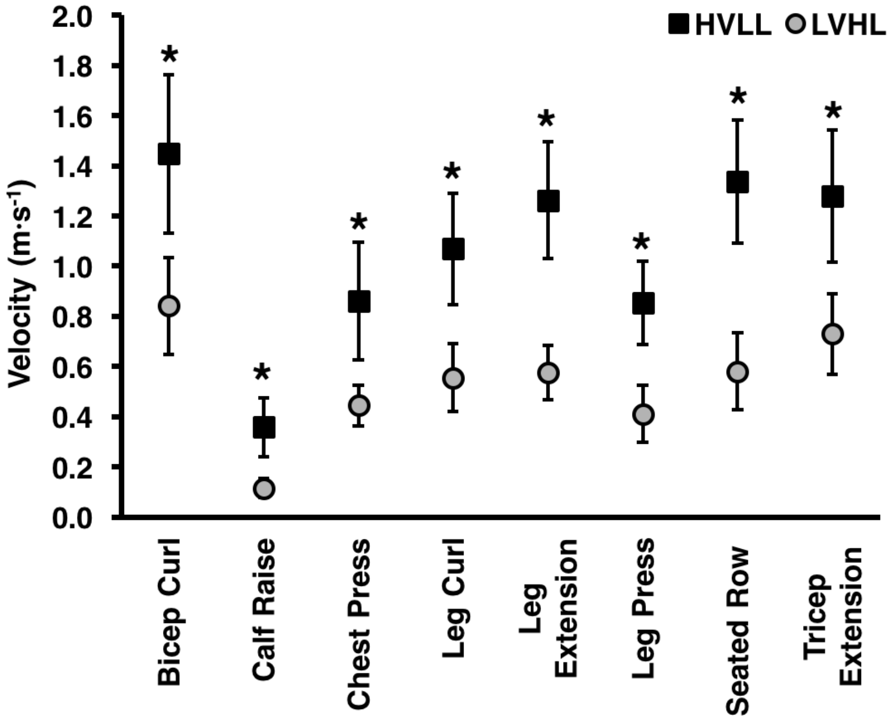

Figure 3.2. Movement velocity of the concentric phase for all exercises
Note: Values are means ± SD; HVLL = High-velocity, low-load; LVHL = Low-velocity, high-load
* = HVLL significantly faster than LVHL ($p \leq 0.05$) as determined by Bonferroni correction

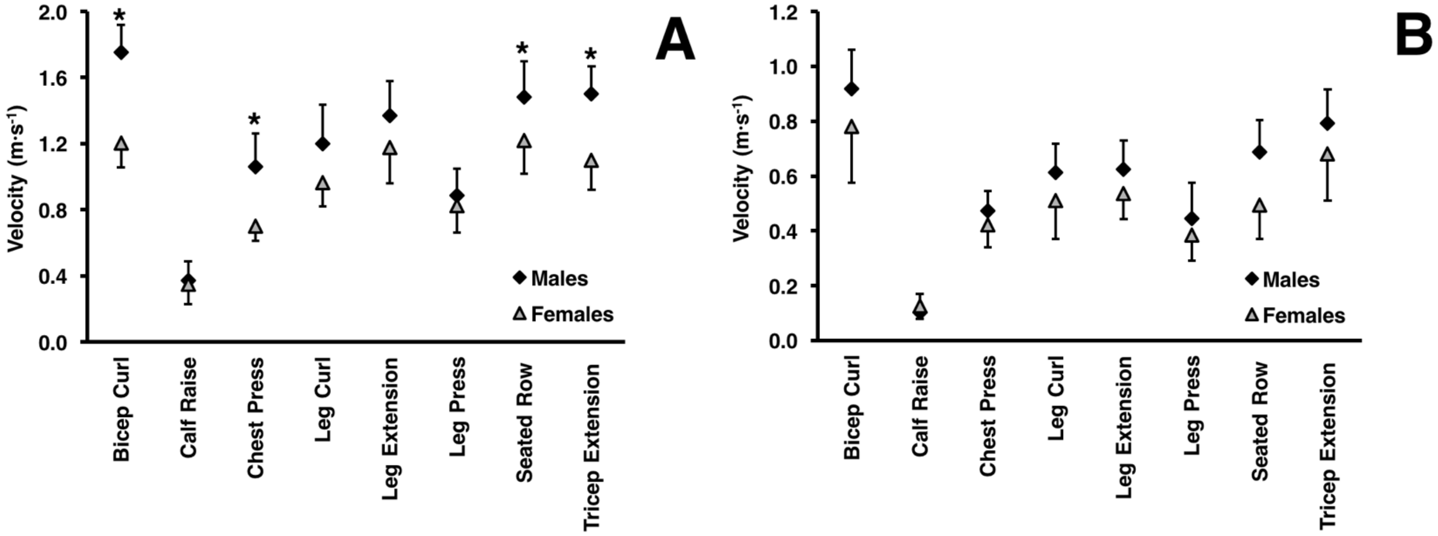

Figure 3.3. Movement velocity during the concentric phase for males and females during (A) HVLL and (B) LVHL
Note: Values are means ± SD; HVLL = High-velocity, low-load; LVHL = Low-velocity, high-load
* = Significantly faster than females ($p \leq 0.05$) as determined by Bonferroni correction

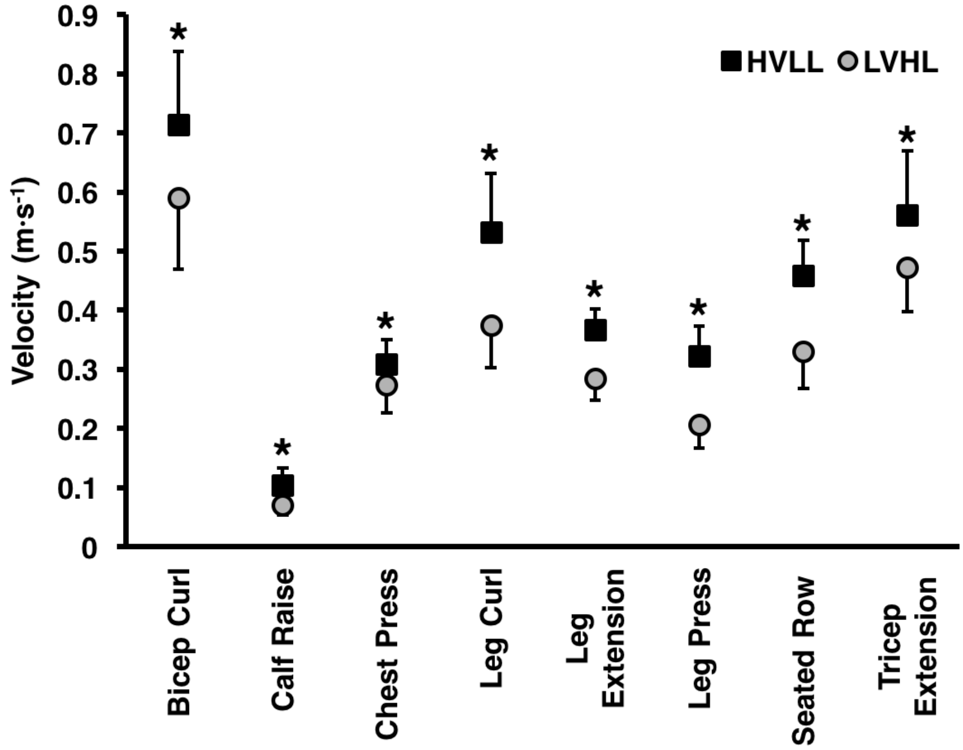

Figure 3.4. Movement velocity for the eccentric phase for all exercises
Note: Values are means ± SD; HVLL = High-velocity, low-load; LVHL = Low-velocity, high-load
*= HVLL significantly faster than LVHL ($p \leq 0.05$) as determined by Bonferroni correction

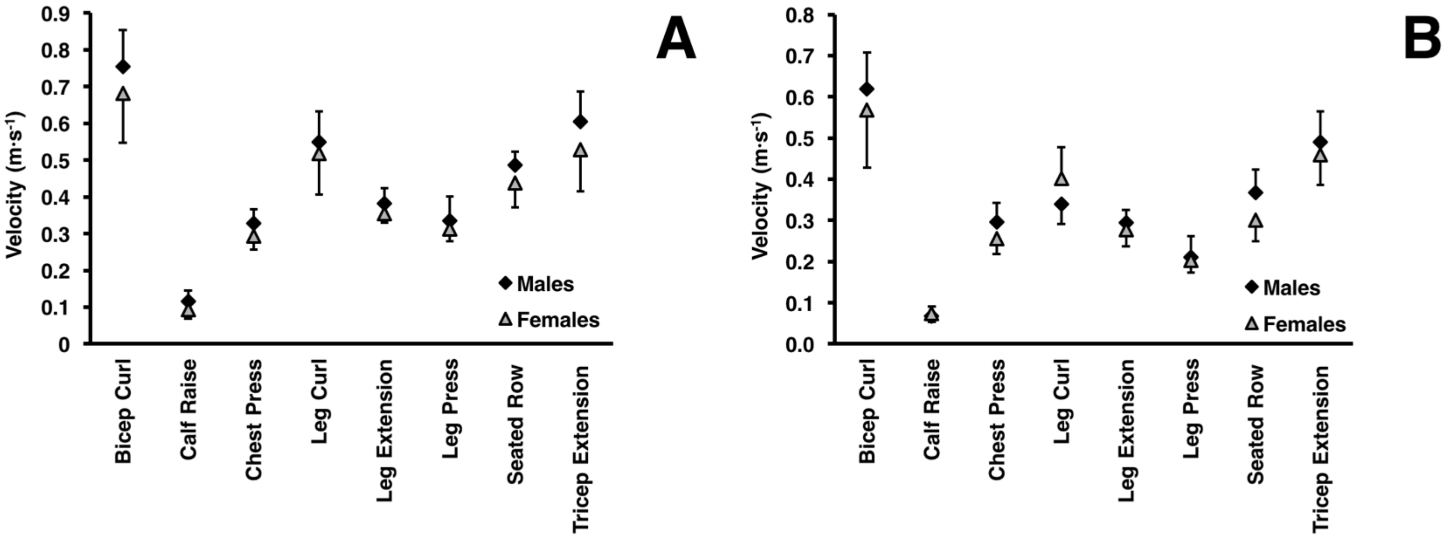

Figure 3.5. Movement velocity during the eccentric phase for males and females during (A) HVLL and (B) LVHL
Note: Values are means ± SD; HVLL = High-velocity, low-load; LVHL = Low-velocity, high-load

3.4 Discussion

The primary aim of the present study was to measure the differences in movement velocity produced during eight different exercises, in a sample of older adults, between two different protocols used to manipulate the movement velocity of exercise. The current study assessed movement velocity when the concentric phase was performed "as fast as possible" or over two seconds, and the eccentric phases for both protocols were performed over three seconds. A secondary aim of this study was to examine the differences in velocities produced between males and females. The main findings of the present study are supportive of the hypothesis and suggest that this command and metronome-based protocol can be used to produce significiantly faster concentric movememnt velocities during HVLL compared to LVHL. Therefore, these protocols can be used by exercise professionals as a simple way to manipulate exercise velocity, to produce high or low-velocity resistance exercise. Additionally, these findings may help to dispel some criticism of research that has used the same metronome based protocols and not reported velocity.

It is important to note that the present study only established whether older adults can execute resistance exercises using different movement velocities, with no assessment of force or power output. Literature is supportive of the notion that high-velocity training, resulting in higher peak power output, is beneficial for functional performance and activities of daily living in older adults (Sayers and Gibson 2014). Prior studies have reported that high-velocity resistance exercise shifts the resistance at which peak power is produced to a lower percentage of 1RM (Sayers and Gibson 2014). However, many studies have made no attempt to ascertain if movement velocity differed when participants were asked to execute resistance exercises at different velocities (Rajan and Porter 2015). Instead, such studies appear to assume, that when requested to move at different velocities, the execution of these movements are possible, consistent, and that HVLL and LVHL are demonstrably different in older adults. With advancing age, there is a loss in the adaptability of movement (Vaillancourt and Newell 2003) meaning optimal movement variability may not be possible. With this loss in adaptability of movement, movement tasks, such as the resistance exercises performed in the current study become more rigid, homogenous and less variable in nature (Harbourne and Stergiou 2009). The present study addresses this issue and as such, provides original information which can be used to better understand the movement velocity produced during commonly used methods of manipulating exercise velocity.

In this study, movement during the eccentric phase was also significantly faster for HVLL compared to LVHL for all exercises. Both protocols used a three second eccentric phase and so, it is surprising that velocities produced were significantly different. One simple explanation is that the maximal velocity produced in concentric phase of HVLL meant participants exceeded the minimum range of motion for each exercise, this would mean that a greater movement velocity would be required over the three second eccentric phase, to return to the start position. As placing range of motion constraints on resistive exercise equipment may inhibit the ability to produce maximal velocity (Brown et al. 1995), and may have presented an injury risk when reaching the end range, range of motion was not controlled. The fact that range of motion differed slightly between protocols, and eccentric velocity was faster during HVLL was not considered to be a key variable, as the protocols produced a difference in concentric velocity while being safe to use for older adults.

It has long since been established that males are generally stronger than females because of morphological differences such as: larger body size, greater muscle mass (Heyward et al. 1986), greater muscle fibre size (Miller et al. 1993) and a higher ratio of type two to type one muscle fibres (Schiaffino and Reggiani 2011). Males have also been shown to have greater neuromuscular performance than females from the age of puberty (Quatman et al. 2006). In the present study males produced significantly greater velocities on four of the eight exercises compared to females despite lifting heavier loads. The exercises that males performed faster than females for both HVLL and LVHL were the four upper body exercises. Such a finding agrees with research reported by (Frontera et al. 1991) who observed that 70-year-old females had 59.8% and 58.7% the strength of 70-year-old males in the lower extremities when examined at low and high velocities respectively. Whereas, in the upper extremities females had 50.2% and 46.1% the strength of males, showing there are sex differences in upper and lower extremity strength. These differences as likely due to the fact that females have a smaller proportion of lean tissue distributed in the upper body compared to males (Miller et al. 1993).

This study is not without limitations. As this study was designed to look at two pragmatic exercise protocols, all estimations of 1RM were made on the same day, meaning some estimations may have been affected by fatigue. Furthermore, some participants reached 12 repetitions before momentary failure on the predicted 1RM test which would likely resulted in slightly overestimated 1RM’s. Finally, both protocols differed in intended movement velocity, the loads used, and potentially the Participants' effort, meaning it is unclear how these variables might have impacted movement velocity.

3.5 Conclusion

The protocols used for both HVLL and LVHL, produce an appreciable difference in movement velocity during resistance exercise. During the HVLL protocol, participants performed the concentric phase significantly faster for all exercises compared with LVHL: bicep curl (42%), calf raise (68%), chest press (48%), leg curl (48%), leg extension (54%), leg press (52%), seated row (57%) and tricep extension (43%). The eccentric phases for all exercises were also significantly faster for all exercises during HVLL compared to LVHL. Furthermore, males produced significantly faster velocities for all four of the upper body exercises during HVLL compared to females. Therefore, these protocols provide a simple way for exercise professionals to ensure that older adults are training at the desired velocities, without the need for specialist equipment to measure velocity. Future research would also be useful to separate participants into groups based on decade of life to examine how the velocities produced, varies with age.

Chapter 4: Study 2

Published in: European Journal of Ageing:

Richardson, D. L., Duncan, M. J., Jimenez, A., Jones, V. M., Juris, P. M., and Clarke, N. D. (2017a) 'The Acute Physiological Effects of High-and Low-Velocity Resistance Exercise in Older Adults'. *European Journal of Ageing*, 1-9, *Study 1 demonstrated that the 'as fast as you can' command and metronome-based protocols were effective at manipulating movement velocity. Therefore, these protocols were used when assessing a number of acute physiological variables in older adults when performing volume-load matched HVLL and LVHL, as there has previously been little investigation.*

4.1 Introduction

Ageing is associated with the loss of skeletal muscle mass known as sarcopenia and the loss of muscle strength known as dynapenia (Clark and Manini 2008), both of which contribute to disability, frailty, comorbidities, hospital admissions and death in older adults (Yu 2015). In addition to ageing, a lack of physical activity has been identified as playing a significant role in the loss of muscle size and strength (Cruz-Jentoft and Landi 2014), contributing to functional decline and loss of independence in older adults (Clark and Manini 2008). To effectively address such issues, requires a multidisciplinary approach, comprising aspects of both exercise prescription and nutritional strategies (Cruz-Jentoft and Landi 2014). Within exercise prescription, one approach that has been explored is resistance exercise. Resistance exercise has been shown to be effective in attenuating age related declines in muscle strength (Liu and Latham 2009), whilst having beneficial effects on functional status, health and quality of life in older adults (Hunter et al. 2004).

The fact that resistance exercise has been shown to have these positive effects, has led to major health organisations such as the American College of Sports Medicine (ACSM), developing resistance exercise guidelines for older adults. These ACSM guidelines state that 10-15 repetitions of 8-10 exercises that target the major muscle groups should be performed on two or more non-consecutive days per week, partnered with other activities that improve flexibility and balance (Nelson et al. 2007). These are similar to the physical activity guidelines in the United Kingdom (Bull et al. 2010). However, as these guidelines are so brief, it is unsurprising that few older adults in the United kingdom are meeting them (Jefferis et al. 2014). Therefore, there is a need for these physical activity guidelines to be expanded upon to provide more guidance to older adults.

An important step in providing more guidance, is to understand the most pertinent mode of resistance exercise for producing positive effects on functional status, strength and muscle mass in older adults. Early investigation into resistance exercise identified the importance of muscle strength for functional performance in older adults (Aniansson et al. 1980). More recently, it has been highlighted that muscle power may be more relevant to functional performance, as being able to move a limb fast against a low external resistance (e.g. moving a limb quickly to stabilise to avoid a fall) is more useful than being able to move a limb slowly against a high external resistance (Sayers and Gibson 2014). This has led to investigation into the influence of HVLL (high-velocity, low-load) and/or LVHL (low-velocity, high-load) resistance exercise on functional performance (Ramirez-Campillo et al. 2014), muscle mass (Van Roie et al. 2013) and strength gains (Marsh et al. 2009). Yet, despite numerous investigations, the most effective mode of resistance exercise remains unclear (Tschopp et al. 2011).

Surprisingly, it appears there has been little consideration of the acute physiological changes that resistance exercise may facilitate in older adults, with the few studies that have, focusing on hormonal changes (Hakkinen and Pakarinen 1995; Marcell et al. 1999). As discussed in section 2.19.5, it is important to understand the acute physiological responses to resistance exercise to better understand potential future adaptations. As an example, associated with the intensity it is performed at, exercise can be a potent stimulator of lactate production which has been linked to greater growth hormone secretion (Wideman et al. 2002). Growth hormone has numerous beneficial effects on the body such as: increased protein synthesis; increased bone mineralization; increased lipolysis etc. (Kraemer et al. 2017). Therefore, long-term stimulation of greater lactate concentrations would likely lead to greater stimulation of growth hormone release, potentially eliciting such desirable long-term adaptations. This provides a rationale as to why understanding the acute physiological responses to resistance exercise are important for understanding potential long-term adaptations. Furthermore, such investigation is important to better understand the utility and safety of each type of resistance exercise for exercise prescription in older adults.

As ageing negatively influences the structure and function of the cardiovascular system, arteries, peripheral circulation and the autonomic nervous system (Queiroz et al. 2010), the effect resistance exercise can have on blood pressure is a significant concern for older adults. At the time of performing resistance exercise, there can be very large increases in blood pressure (MacDougall et al. 1985) but following cessation, blood pressure can decrease below that of baseline, also known as post-exercise hypotension (Hurley and Gillin 2015). However, it is unclear if factors such as: frequency, intensity, time, mode and volume have an effect on blood pressure following exercise (Hurley and Gillin 2015), meaning the differences between

HVLL and LVHL in older adults are not well understood. Additionally, other useful measures can be derived from blood pressure data, such as mean arterial pressure which has been shown to be a predictor of cardiovascular disease (Sesso et al. 2000) and combined with heart rate, rate pressure product which can be used as a measure of myocardial oxygen demand and cardiac workload (Hermida et al. 2001).

Differing intensity, load and velocity of resistance exercise has been shown to have a varying influence on blood lactate responses in young men, with greater exercise intensity showing a greater increase in blood lactate than low intensity (Arazi et al. 2014). However, it is hard to compare physiological responses between studies, as protocols have varied in combinations of intensity, number of sets, rest times and movement velocity (Arazi et al. 2014). Mazzetti et al. (2007) observed that LVHL elicited a greater lactate response than HVLL whereas, Nitzsche et al. (2017) observed that both blood lactate and heart rate responses were similar following three different resistance exercise protocols that varied in load, repetitions, number of sets and rest times.

As prior research has not fully considered whether velocity of resistance exercise elicits different acute physiological responses in older adults, the optimal prescription of resistance exercise in this population remains to be fully elucidated. Therefore, an important first step is to examine acute physiological markers such as heart rate, blood pressure and blood lactate. Such data is key in better refining resistance exercise programming for older adults, and informing health care professionals on how physiological responses vary with velocity of resistance exercise. Therefore, the aims of this study were to measure the physiological responses of a group of older adults to workload matched HVLL and LVHL protocols. Although the exercise protocols are volume-load matched, due to the greater intensity of LVHL, it was hypothesised that physiological responses would be greater during LVHL compared to HVLL.

4.2 Methods

4.2.1 Design

The present study used a randomised, counterbalanced crossover design. All other design elements were identical to those described in section 3.2.1.

4.2.2 Participants

Following institutional ethics approval (Appendix A), 10 recreationally active older adults (five males and five females; Table 4.1) were recruited by word of mouth for participation. All participants were made aware of the exercise protocols and associated risks before providing informed consent, and completing a health screen questionnaire prior to each trial. After providing details of any current medications, each participant was required to meet the same inclusion criteria as detailed in section 3.2.2.

Table 4.1 Participant characteristics

Participant Information	Males (*n*=5)	Females (*n*=5)
Age (years)	66±3	68±2
Age Range (years)	63-71	67-71
Height (cm)	174.5 ± 5.4	162.6 ± 5.8
Body Mass (kg)	89.4 ± 13.6	70.9 ± 10.7
Body Mass Index (kg/m^2)	29 ± 4	27 ± 3
Baseline Systolic Blood Pressure (mmHg)	141 ± 9	140 ± 7
Baseline Diastolic Blood Pressure (mmHg)	80 ± 6	81 ± 6
Baseline Mean Arterial Pressure (mmHg)	100 ± 7	101 ± 6
Medications Taken	1 ± 1	1 ± 1
Mini-Mental State Examination score (0-30)	29 ± 1	29 ± 1

Note: Values are means ± SD; *n* = number of participants

4.2.3 Procedures

Identical procedures were followed for the warm-up and prediction of one repetition maximum (1RM) for all exercises as those described in section 3.2.3. The achieved 1RM's for each exercise and details of the HVLL and LVHL protocols are detailed in table 4.2.

4.2.4 Exercise protocols

Participants followed the same exercise protocols detailed in section 3.2.4.

Table 4.2 One repetition maximum data and details of the exercise protocols

Exercises	**1RM Males (kg)**	**1RM Females (kg)**	**HVLL Protocol**	**LVHL Protocol**
Leg Press	130 ± 30	79 ± 13	40% 1RM	80% 1RM
Seated Row	63 ± 8	34 ± 5	3 sets	3 sets
Chest Press	54 ± 5	21 ± 3	14 repetitions	7 repetitions
Leg Extension	59 ± 16	29 ± 7	Concentric phase “as fast as possible” with 3 s eccentric phase	2 s concentric phase and 3 s eccentric phase
Leg Curl	52 ± 9	26 ± 4	2 mins rest between sets	2 mins rest between sets
Calf Raise	118 ± 27	89 ± 20	3 mins between exercises	3 mins between exercises
Tricep Extension	36 ± 7	16 ± 7		
Bicep Curl	30 ± 8	13 ± 6		

Note: Values are means ± SD; HVLL = High-velocity, low-load; LVHL = Low-velocity, high-load; 1RM = One repetition maximum

4.2.5 Physiological measurements

Systolic and diastolic blood pressure were measured with an automatic blood pressure monitor (Omron M3 Intellisense HEM-7200-E, Omron Matsusaka Co Ltd, Kyoto, Japan) from the left arm, while seated in an upright position, prior to every trial and immediately following the last exercise of each session. Mean arterial pressure (2 × diastolic blood pressure + systolic blood pressure)/3 and rate pressure product (systolic blood pressure × heart rate) were calculated prior to and post-exercise using the blood pressure data. A fingertip blood sample was collected via a capillary tube, prior to and immediately following each session and samples were analysed using a blood lactate analyser (Biosen C-line clinic, EKF Diagnostics, Magdeburg, Germany). Finally, heart rate was measured using heart rate telemetry (Polar Electro Oy, Kempele, Finland) before exercise and immediately following each set of each exercise. Figure 4.1 displays a session timeline detailing when all measurements were taken.

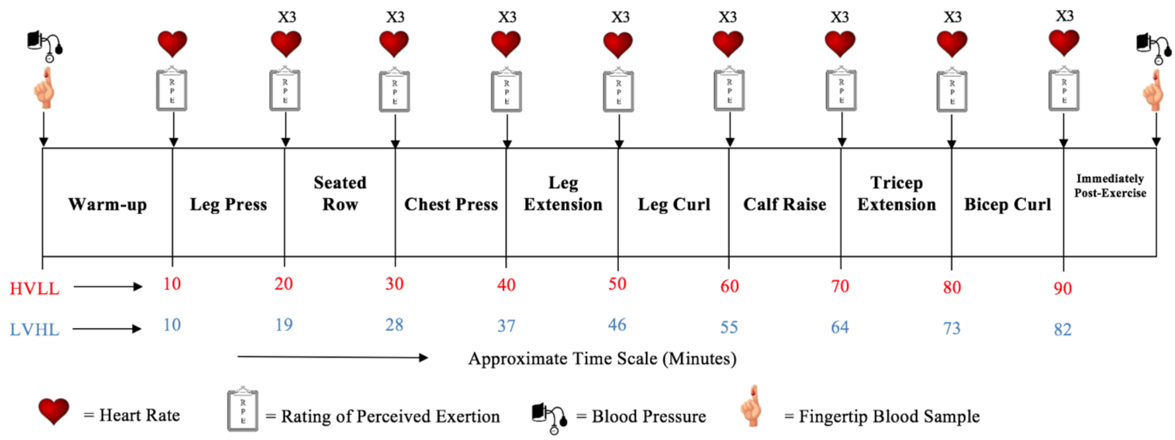

Figure 4.1 A schematic diagram of the experimental protocol

Note: X3 = Collected following all three sets; HVLL = High-velocity, low-load; LVHL = Low-velocity, high-load

4.2.6 Statistical analysis

All data was analysed using IBM SPSS Statistics for Windows, Version 22.0 (Armonk, NY: IBM Corp) and descriptive statistics are presented as mean ± SD and 95% confidence intervals (95% CI). Normality of data was assessed using the Shapiro-Wilk test and manual analysis of the plotted data. Any scale data that was non-normally distributed was log transformed and reassessed for normality using the residuals (Kozak and Piepho 2018). Providing the data presented a normal distribution it was analysed with the appropriate parametric statistical test. Factorial analysis of variance (ANOVA) with repeated measures examined the effect of the independent variable: exercise condition on the dependent variables: heart rate; blood pressure and blood lactate. Within group changes were further investigated using repeated measures ANOVA and t-tests with Bonferroni correction where necessary. When Mauchly's test of sphericity was significant and the Greenhouse-Geisser level of violation was >0.75, degrees of freedom were corrected using Huynh-Feldt adjustment. When violation was <0.75, Greenhouse-Geisser correction was used. Where any differences were found, pairwise comparisons with Bonferroni correction were used to show exactly where they lay. Significance was determined by a p value of <0.05 and reported as exact values unless below p=0.001. Effect size was used to quantify the meaningfulness of any differences found between conditions, it was calculated using η_p^2 and defined as: trivial (<0.1), small (0.1-0.29), moderate (0.3-0.49) or large (0.5>) (Hopkins et al. 2009). An *a priori* power calculation suggested that a sample size of ten participants would be necessary to detect a statistical difference given an estimated effect size of 0.25, a 1-β error probability of 0.90 and a p value significance level less than 0.05.

4.3 Results

4.3.1 Blood lactate

There were trivial differences in blood lactate concentrations between HVLL and LVHL ($F_{(1,9)}$=0.028; p=0.872; 95% CI: -0.7, 0.6; η_p^2 =0.003;Table 4.3) but large increases in blood lactate concentrations from pre- to post-exercise regardless of velocity ($F_{(1,9)}$=13.828; p=0.005; 95% CI: 0.9, 3.7; η_p^2 =0.61).

4.3.2 Systolic blood pressure

There were trivial differences in systolic blood pressure between HVLL and LVHL ($F_{(1,9)}$=0.023; p=0.884; 95% CI: -5.6, 4.9; η_p^2 =0.003; Table 4.3) and moderate increases in systolic blood pressure from pre- to post-exercise regardless of velocity ($F_{(1,9)}$=4.068; p=0.074; 95% CI: -0.6, 10.3; η_p^2 =0.31).

4.3.3 Diastolic blood pressure

There were small differences in diastolic blood pressure during HVLL and LVHL ($F_{(1,9)}$=1.516; p=0.249; 95% CI: -1.1, 3.6; η_p^2 =0.14; Table 4.3) and small differences between pre- and post-exercise regardless of velocity ($F_{(1,9)}$=2.010; p=0.190; 95% CI: -4.8, 1.1; η_p^2 =0.18).

4.3.4 Mean arterial pressure

There were trivial differences in mean arterial pressure between HVLL and LVHL ($F_{(1,9)}$=0.408; p=0.539; 95% CI: -2.1, 3.5; η_p^2 =0.04; Table 4.3) and trivial differences in mean arterial pressure between pre- and post-exercise regardless of velocity ($F_{(1,9)}$=0.074; p=0.792; 95% CI: -2.7, 3.4; η_p^2 =0.01).

4.3.5 Rate pressure product

There were trivial differences in rate pressure product between HVLL and LVHL ($F_{(1,9)}$=0.580; p=0.466; 95% CI: -1329, 660; η_p^2 =0.06; Table 4.3) and trivial differences between pre- and post-exercise regardless of velocity ($F_{(1,9)}$=0.867; p=0.376; 95% CI: -922, 2213; η_p^2 =0.09).

Table 4.3 Physiological measures for both HVLL and LVHL for all trials

	HVLL		LVHL	
	Pre-Exercise	Post-Exercise	Pre-Exercise	Post-Exercise
Blood Lactate (mmol/l)	2.3 ± 1.2	4.3 ± 2.1*	2.0 ± 0.8	4.6 ± 2.8*
Systolic Blood Pressure (mmHg)	131.8 ± 14.5	138.7 ± 18.7	133.5 ± 17.4	136.3 ± 18.4
Diastolic Blood Pressure(mmHg)	75.0 ± 7.3	72.5 ± 7.3	75.6 ± 6.6	74.4 ± 8.9
Mean Arterial Pressure(mmHg)	93.9 ± 8.9	94.6 ± 9.6	94.9 ± 9.4	95.0 ± 10.2
Rate Pressure Product (mmHg.bpm)	12383 ± 1846	12720 ± 2853	11740 ± 2425	12694 ± 2392

Note: Values are means ± SD; HVLL = High-velocity, low-load; LVHL = Low-velocity, high-load
* = Post-exercise significantly greater than pre-exercise ($p \leq 0.05$) as determined by Bonferroni correction

4.3.6 Heart rate

There was a significant interaction between velocity of exercise and different exercises ($F_{(7,63)}$=8.841; p<0.001; η_p^2 =0.50; Figure 4.2). Repeated measures ANOVA revealed that there were significant differences in heart rate between exercises for both HVLL ($F_{(7,63)}$=10.202; p<0.001; η_p^2 =0.53) and LVHL ($F_{(7,63)}$=12.263; p<0.001; η_p^2 =0.58). Pairwise comparisons revealed heart rate during the leg press (Bonferroni p=0.001; 95% CI: 3.7, 10.1) was significantly greater during LVHL compared to HVLL. But for the chest press (Bonferroni p<0.040; 95% CI: 3.2, 10.6) heart rate was significantly higher during HVLL.

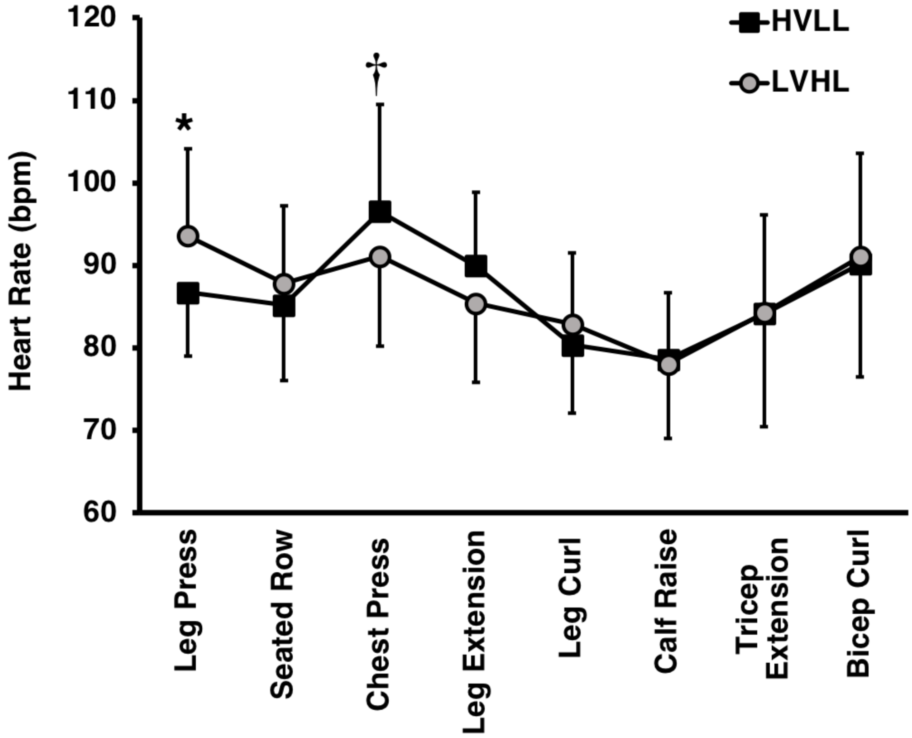

Figure 4.2. Heart rate (mean ± SD) for all participants during HVLL and LVHL

Note: HVLL = High-Velocity, Low-Load; LVHL = Low-Velocity, High-Load
*= LVHL significantly greater than HVLL ($p \leq 0.05$) as determined by Bonferroni correction
†= HVLL significantly greater than LVHL ($p \leq 0.05$) as determined by Bonferroni correction

4.4 Discussion

The present study reports the physiological responses to volume-load matched HVLL and LVHL in a sample of older adults. These measures are important in understanding how the ageing biological system responds to these modes of resistance exercise. This information can then feed forward, recognising the effect of exercise is multifaceted and multidisciplinary in nature. It was hypothesised that as LVHL was performed at greater intensity (i.e. same volume-load over a shorter time) it would elicit a greater physiological response than HVLL. However, this hypothesis must be rejected, as overall, physiological responses were similar between HVLL and LVHL. The findings of the present study suggest there are no significant differences between volume-load matched HVLL and LVHL in blood lactate, systolic blood pressure, diastolic blood pressure, mean arterial pressure or rate pressure product responses in older adults. As would be expected, heart rate varied between exercises, due to body position (Achten and Jeukendrup 2003) and the varying blood demands of active muscle (Peçanha et al. 2013). The leg press elicited significantly greater heart rate responses during LVHL, while the chest press, elicited significantly greater heart rate responses during HVLL. Heart rates may have differed between these two exercises due to the loading used. Particularly for females, low

1RM's were achieved on the chest press, and as weights needed to be rounded due to the precision offered by the equipment (absence of incremental weights between 15-30lbs), weight lifted between HVLL and LVHL was not always largely different, but the HVLL condition had double the number of repetitions to complete. Conversely for the leg press, heavier loads lifted in the 80% 1RM condition may have increased the likelihood that older adults performed the Valsalva manoeuvre, which has been shown to increase heart rate following resistance exercise (Elisberg 1963).

Although not significantly different between conditions, HVLL produced increases in systolic blood pressure of approximately 10 mmHg in trials one and two from pre- to post-exercise, whereas LVHL saw a 10 mmHg increase in trial one and trivial changes in trials two and three. A similar trend was observed by da Silva et al. (2007) who examined acute systolic blood pressure changes following three sets of maximum velocity bench press exercise in untrained older women. The authors reported that blood pressure was significantly lower at baseline than after the first, second, and third sets. This potential increase in systolic blood pressure is something that practitioners should be aware of when designing resistance exercise programmes for older adults, especially in hypertensive populations.

Previously, it has been reported that resistance exercise can have a post-exercise hypotensive effect (Hardy and Tucker 1998). Although changes were not significant, it is important to note that diastolic blood pressure decreased from pre- to post-exercise following both HVLL and LVHL in the present study. As the participants were normotensive, and individuals with an elevated blood pressure are those who experience the greatest post-exercise hypotensive effect of resistance exercise (Cardoso et al. 2010), it is unsurprising that only insignificant decreases were observed. Therefore, it may have been more useful to measure blood pressure during each exercise to observe if there were differences in blood pressure between LVHL and HVLL in addition to pre- and post-trial. Furthermore, monitoring blood pressure throughout recovery could have been useful to further examine any potential, post-exercise hypotensive effects.

4.5 Conclusion

Volume-load matched HVLL and LVHL produced comparable heart rate, blood lactate, systolic blood pressure and diastolic blood pressure responses in a group of older adults. As physiological responses appear analogous, investigation of the affective responses to both HVLL and LVHL would be useful in further clarifying general resistance exercise recommendations for older adults.

Chapter 5: Study 3

Published in: Journal of Sports Sciences:

Richardson, D. L., Duncan, M. J., Jimenez, A., Jones, V. M., Juris, P. M., and Clarke, N. D. (2018b) 'The Perceptual Responses to High-Velocity, Low-Load and Low-Velocity, High-Load Resistance Exercise in Older Adults'. *Journal of Sports Sciences* 36 (14), 1594-1601

Data for this study was collected at the same time as study 2

Study 2 demonstrated that there were no differences in acute physiological responses between volume-load matched HVLL and LVHL, indicating both provide a similar physiological stimulus. Therefore, study 3 investigated the existence of any differences in affective responses and enjoyment between the same volume-load matched protocols.

5.1 Introduction

The global population of older adults is growing rapidly (He et al. 2016), causing strain on healthcare systems worldwide, due to costs associated with decreased functional capacity, increased incidents of falls and the development of numerous age related illnesses (Yu 2015). Ever-increasing financial strain has prompted investigation into lowering healthcare costs, and maintaining the physical function of older adults. Resistance exercise is one of many avenues that have been explored, with strong evidence provided that it can have positive effects on functional status, health and quality of life in older adults (Hunter et al. 2004) .

Although the benefits of resistance exercise on health are well known (Hunter et al. 2004), additional research is needed to better inform exercise professionals of the optimal resistance exercise prescription for an older population. Doing so would aid in facilitating a simple, pragmatic programme of resistance exercise that expands on the existing exercise guidelines. Many studies have attempted to identify which mode of resistance exercise should be prescribed to older adults (Tschopp et al. 2011). As previously discussed in section 3.1, it appears HVLL (high-velocity, low-load) and LVHL (low-velocity, high-load) resistance exercise may elicit similar responses in muscle strength (Henwood and Taaffe 2006), muscle cross sectional area (Claflin et al. 2011) and improvements in functional performance (Tschopp et al. 2011). Although more recently, there appears to be growing evidence that HVLL may be superior in delivering improvements in muscle power and/or functional performance (Byrne et al. 2016).

To date, studies have examined exercise affect in older adults during aerobic exercise (Katula et al. 1999; McAuley et al. 2000), but surprisingly few studies have examined exercise affect during resistance exercise (Bibeau et al. 2010). As acute affective responses have been shown to predict long-term adherence to exercise programmes (Williams et al. 2008), it may mean that understanding the differences in exercise affect is one of the most important aspects in effective exercise prescription for older adults. Bibeau et al. (2010) suggested that low effort resistance exercise programmes may be beneficial for maximising the psychological benefits of resistance exercise in novice exercisers, which may carry over to improved programme compliance and adherence. These findings may be important when considering resistance exercise prescription for older adults, particularly given that many older adults are sedentary, or at least not satisfying the physical activity guidelines.

To examine and understand the responses to resistance exercise in older adults, it is key that the methods used to assess exercise affect are considered. As previously discussed in section 2.12, research studies on exercise affect, have used both multi-item and single-item scales (Ekkekakis et al. 2011). Yet, conclusions regarding the effect of resistance exercise on affective responses are often drawn across studies that use different methods of assessment. Based on the discussion in 2.12 on measures that could be used, the Feeling Scale (FS), Felt Arousal Scale (FAS), Physical Activity Enjoyment Scale (PACES), Physical Activity Affect Scale (PAAS) and Rating of Perceived Exertion (RPE) were selected to assess affective responses, enjoyment and rating of perceived exertion. In addition to measuring exercise affect with Likert-type scales, visual analogue scales (VAS) have been suggested to be more sensitive, with better ability to detect clinically significant changes, meaning they may be more valid and reliable (Joyce et al. 1975). Therefore, VAS were also included as an assessment of the perception of exercise. Arguably, studies using both single and multi-item scales may provide a more encompassing overview of affective responses.

As there has been little previous investigation into exercise affect during resistance exercise in older adults, it would be beneficial to investigate the acute affective responses to HVLL and LVHL in older adults. The aim of the present study was to examine exercise affect during pragmatically designed, volume-load matched HVLL and LVHL sessions in older adults. As both HVLL and LVHL may be similar in producing improvements in functional performance, and enjoyment of exercise is linked to adherence (Ekkekakis et al. 2011), one of the most important factors in exercise prescription may be selecting the mode of resistance exercise that is more likely to be enjoyed and adhered to. As volume-loads are matched between HVLL and LVHL, it is hypothesised that affective responses and enjoyment will be similar.

5.2 Methods

5.2.1 Design

The present study used a randomised, counterbalanced, crossover study design. All other design elements were identical to those described in section 3.2.1.

5.2.2 Participants

Following institutional ethics approval (Appendix A), ten older adults (Table 5.1) were recruited by word of mouth for participation. All participants were made aware of the exercise conditions and associated risks before providing informed consent. Each participant was required to meet the same inclusion criteria, as section 3.2.2. Fifteen participants volunteered to take part, three were excluded because they were already involved in resistance exercise programmes and a further two were excluded because of uncontrolled hypertension.

Table 5.1 Participant characteristics

	Males (*n* = 5)	Females (*n* = 5)
Age (years)	66 ± 3	68 ± 2
Age Range (years)	63 – 71	67 – 71
Height (cm)	174.5 ± 5.4	162.6 ± 5.8
Body Mass (kg)	89.4 ± 13.6	70.9 ± 10.7
BMI (kg/m^2)	29 ± 4	27 ± 3
Medications taken	1 ± 1	1 ± 1
Mini mental state examination (0-30)	29 ± 1	29 ± 1

Note: Values are means ± SD; *n* = number of participants

5.2.3 Procedures

Identical procedures were followed for the warm-up and prediction of one repetition maximum (1RM) for all exercises as those described in section 3.2.3. The predicted 1RM values are displayed in table 5.2.

5.2.4 Exercise protocols

Participants followed the same exercise protocol detailed in section 3.2.4.

Table 5.2 Predicted 1RM data with the median and range of repetitions used with the equation (Brzycki 1993) to predict 1RM

	Leg Press	Seated Row	Chest Press	Leg Extension	Leg Curl	Calf Raise	Tricep Extension	Bicep Curl
Male 1RM (kg)	130 ± 30	63 ± 8	54 ± 5	59 ± 16	52 ± 9	118 ± 27	36 ± 7	30 ± 8
Median	10	10	10	10	9	10	10	5
Range	10-12	10-11	8-10	10-11	7-10	10-10	8-10	2-10
Female 1RM (kg)	79 ± 13	34 ± 5	21 ± 3	29 ± 7	26 ± 4	89 ± 20	16 ± 7	13 ± 6
Median	10	10	8	10	10	10	10	10
Range	8-12	9-12	4-10	7-12	5-10	9-10	6-11	6-12

Note: Values are means ± SD; 1RM = One repetition maximum

5.2.5 Affective measures

Participants completed a PAAS questionnaire (Lox et al. 2000) prior to each session and again on completion. The PAAS questionnaire displays twelve words that might describe how a person is feeling (Appendix C1). The participant must indicate to what extent they feel each statement: Do not feel (0), feel slightly (1), feel moderately (2), feel strongly (3) or feel very strongly (4). The questionnaire can be broken down into four subscales: positive affect, negative affect, fatigue and tranquillity. The FAS (Svebak and Murgatroyd 1985) was used to measure arousal before exercise started, and following the session. The FAS is a six-point scale that participants rate their arousal level from 1 (very low) to 6 (very high). Verbal anchors were provided to help describe the ways in which arousal may be experienced (Appendix C2). Participants were explained that high arousal might be characterised by feelings of excitement, anxiety, or anger, and low arousal by feelings of relaxation, boredom or calmness. The single item FS (Hardy and Rejeski 1989) was used to assess changes in mood prior to exercise, and following every set of each exercise. Participants were shown the scale which ranges from very bad (-5) to very good (+5) and asked to provide a value (Appendix C3).

5.2.6 Rating of perceived exertion

Rating of perceived exertion (Borg 1982) was recorded from a scale ranging from 6-20 (6 = no exertion at all, 20 = maximal exertion), before exercise began, and after every set of each exercise (Appendix C4).

5.2.7 Enjoyment

Following the session, participants indicated their enjoyment and perception of exercise using visual analogue scales (VAS) (Kuys et al. 2011). Participants were asked to rate their level of enjoyment, fatigue, perception of the volume-load and perceived effectiveness of exercise. All visual analogue scales spanned a single 100 mm horizontal line with a headline statement at the top (Appendix C5). To the extreme left of the line, was an answer that indicated no agreement with the headline statement e.g. no enjoyment, and to the extreme right, the statement indicated strong agreement e.g. very enjoyable. Participants were asked to indicate their feelings in that moment with a single vertical line. Finally, participants completed a modified PACES post-exercise (Graves et al. 2010) to indicate their level of enjoyment of the session. The PACES display two contrasting statements about exercise e.g. 'I like it' and 'I dislike it'. Between the two statements, participants rated their agreement with each statement on a 7-point Likert-type scale (Appendix C6) Figure 5.1 displays when these measurements were taken during each session for both HVLL and LVHL.

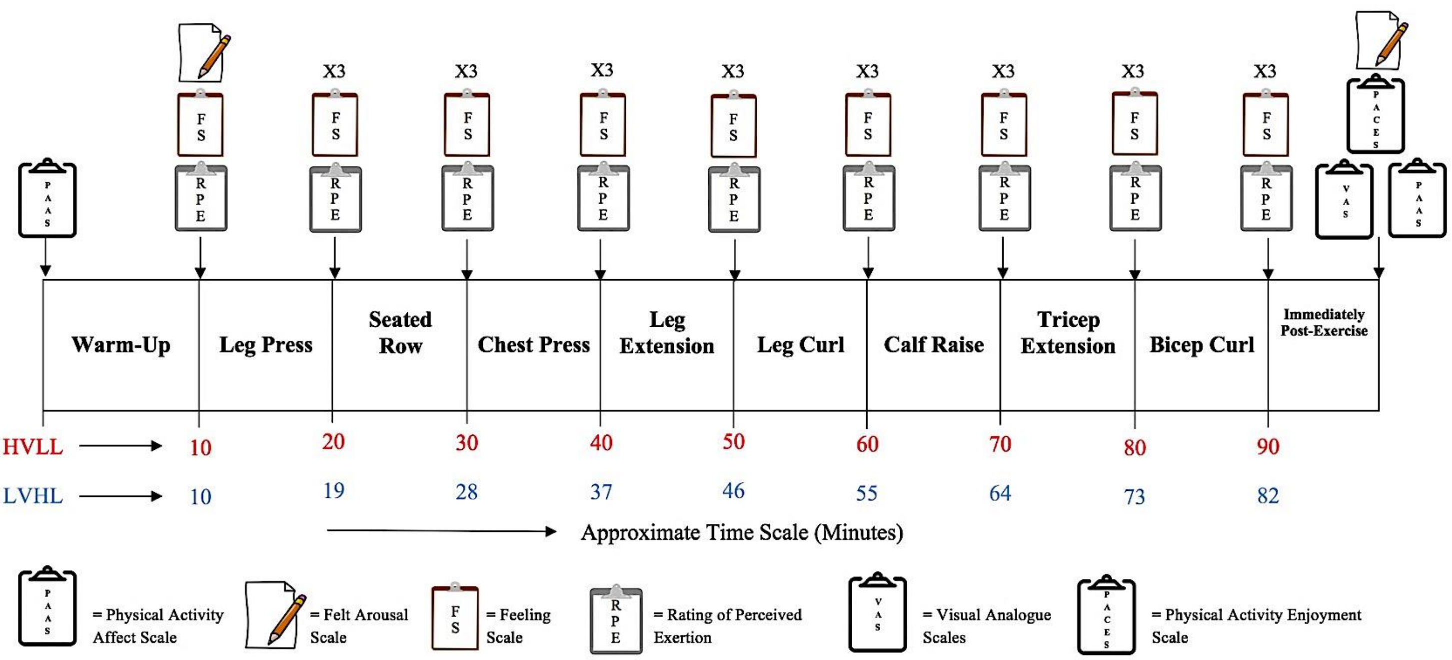

Figure 5.1. A schematic diagram of the experimental conditions

Note: HVLL = High-velocity, low-load; LVHL = Low-velocity, high-load; X3 = following each of the 3 sets

5.2.8 Statistical analysis

All data were analysed using IBM SPSS Statistics for Windows, Version 22.0 (Armonk, NY: IBM Corp) and descriptive statistics are presented as mean ± SD, and 95% confidence intervals (95% CI). Factorial analysis of variance (ANOVA) with repeated measures examined the effect of the independent variable: exercise condition on the dependent variables: PAAS; PACES; RPE; VAS; FS and FAS. Normality of data was assessed using the Shapiro-Wilk test and manual analysis of the plotted data. Any scale data that was non-normally distributed was log transformed and reassessed for normality using the residuals (Kozak and Piepho 2018). Providing the data presented a normal distribution it was analysed with the appropriate parametric statistical test. Statistical analysis was performed on the PAAS, subscales rather than individual questions, and the two inversely scored PACES questions were corrected before analysis. Any within-condition changes were further analysed using t-tests where necessary. An *a priori* power calculation using G*Power software (version 3.1.9.2, Franz Faul, Universitat Kiel, Dusseldorf, Germany) for repeated measures ANOVA, revealed that detection of a moderate effect size (0.35) with α as 0.05 and a 1–β error probability of 0.8, required a minimum sample size of ten participants. When Mauchly's test of sphericity was significant and the Greenhouse-Geisser level of violation was >0.75, degrees of freedom were corrected using Huynh-Feldt adjustment, and when violation was <0.75, Greenhouse-Geisser correction was used. Where any differences were found, pairwise comparisons with Bonferroni correction were used to show exactly where they lay. Significance was determined by a p value of <0.05 and reported as exact values unless below p=0.001. Effect size was used to quantify the meaningfulness of any differences and was calculated using η_p^2 and defined as: trivial (<0.1), small (0.1-0.29), moderate (0.3-0.49) or large (≥0.5) (Hopkins et al. 2009).

5.3 Results

5.3.1 PAAS subscales

There were moderate differences in positive exercise affect between HVLL and LVHL ($F_{(1,9)}$=4.466; p=0.067;95% CI:-0.02,0.53; η_p^2=0.33; Table 5.3) and moderate differences between pre-and post-exercise ($F_{(1,9)}$=4.342; p=0.064;95% CI:-0.49,0.02; η_p^2=0.33). There were trivial differences in negative exercise affect between HVLL and LVHL ($F_{(1,9)}$=0.015; p=0.904;95% CI:-0.11,0.10; η_p^2=0.002; Table 5.3), with moderate differences between pre- and post-exercise ($F_{(1,9)}$=4.487; p=0.063; 95%CI:-0.01,0.26; η_p^2=0.33). There were small differences in fatigue between HVLL and LVHL ($F_{(1,9)}$=3.066; *p*=0.114;95% CI:-0.46,0.06; η_p^2=0.25; Table 5.3) and small differences between pre- and post-exercise ($F_{(1,9)}$=3.582; *p*=0.091; 95% CI:-0.27,0.02; η_p^2=0.29). Lastly, there were small differences in tranquillity between HVLL and LVHL ($F_{(1,9)}$=1.593; *p*=0.239;95% CI:-0.14,0.48; η_p^2=0.15; Table 5.3) and trivial differences between pre- and post-exercise ($F_{(1,9)}$=0.027; *p*=0.873; 95% CI:-0.21,0.25; η_p^2=0.003).

5.3.2 Felt arousal scale

There were small differences in FAS between HVLL and LVHL ($F_{(1,9)}$=2.951; *p*=0.120;95% CI:-0.12,0.85; η_p^2=0.25; Table 5.3), with moderate increases between pre- and post-exercise regardless of exercise condition ($F_{(1,9)}$=6.311; *p*=0.033; 95% CI:-0.82,-0.04; η_p^2 =0.41). Figure 5.2 displays FS data and FAS data plotted in a circumplex model of affect.

5.3.3 Feeling scale

There were trivial differences in FS rating between HVLL and LVHL ($F_{(1,9)}$=0.144; *p*=0.713;95% CI:-0.29,0.41; η_p^2 =0.02; Table 5.3) and moderate differences between exercises ($F_{(2.8,25.6)}$=3.868; *p*=0.022; η_p^2=0.30), although pairwise comparisons revealed that only leg curl approached having a significantly greater FS rating than leg extension (Bonferroni *p*=0.056; 95% CI:-0.45, 0.004).

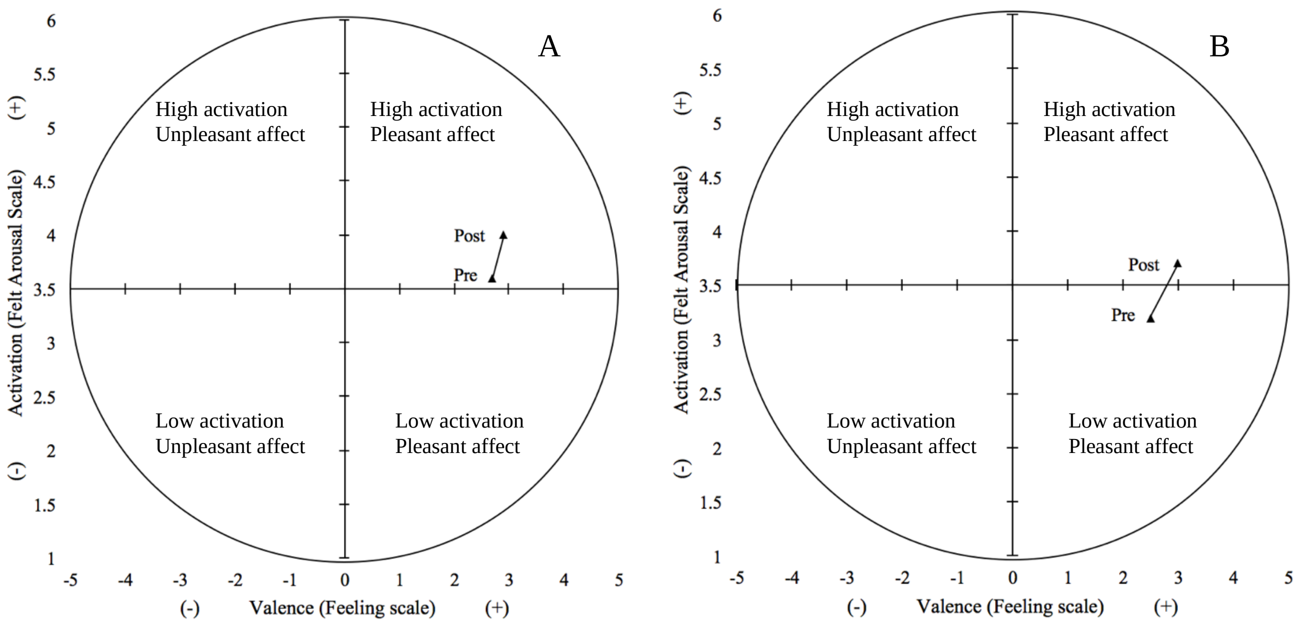

Figure 5.2 Circumplex models of affect for both (A) HVLL and (B) LVHL pre- and post-exercise
Note: HVLL = High-velocity, low-load; LVHL = Low-velocity, high-load

5.3.4 Rating of perceived exertion

There was a significant interaction between conditions and exercises ($F_{(7,63)}$=6.184; p<0.001; η_p^2 =0.41;Figure 5.3). The interaction plot revealed that all exercises were perceived as harder during LVHL compared with HVLL except for the chest press. During LVHL, pairwise comparisons revealed that participants rated RPE significantly greater for leg press (Bonferroni p<0.001;95% CI: -3.4,-2.5), seated row (Bonferroni p<0.001;95% CI:-2.0,-1.4), leg curl (Bonferroni p<0.001;95% CI:-2.4,-1.5), and calf raise (Bonferroni p<0.001;95% CI:-2.0,-1.1) than during HVLL.

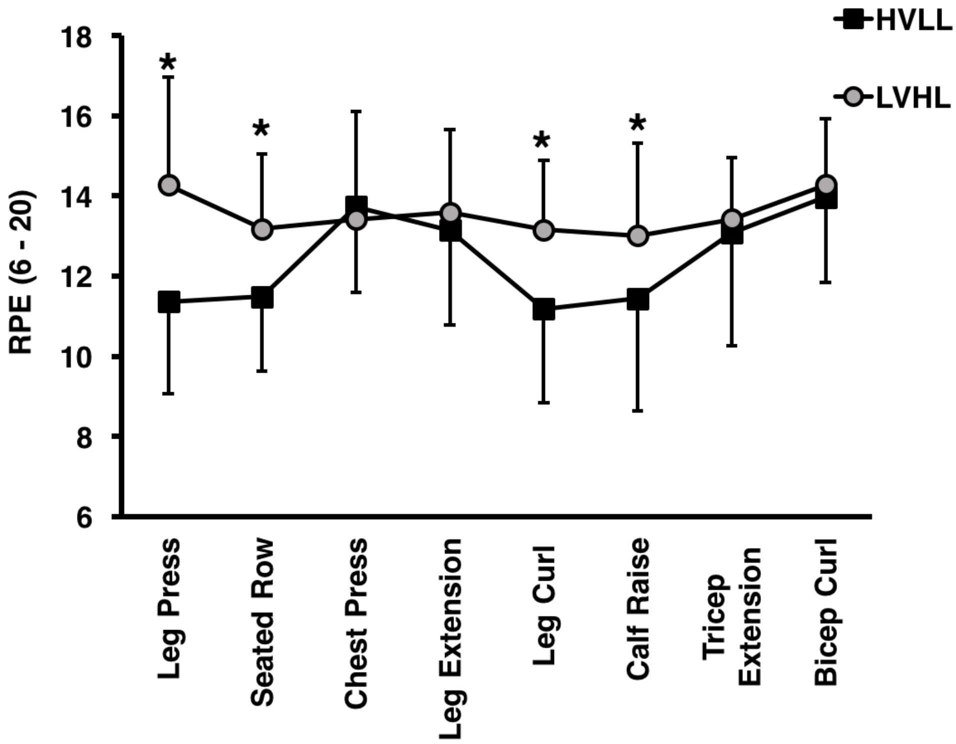

Figure 5.3. RPE for all participants during HVLL and LVHL
Note: Values are means ± SD; HVLL = High-velocity, low-load; LVHL = Low-velocity, high-load
* = LVHL significantly greater than HVLL ($p \leq 0.05$) as determined by Bonferroni correction

5.3.5 Visual analogue scales

There were small differences in enjoyment between HVLL and LVHL ($F_{(1,9)}$=1.229; p=0.296;95% CI:-2.15,6.28; η_p^2 =0.12; Table 5.3). There were trivial differences in both perceived effectiveness ($F_{(1,9)}$=0.106; p=0.752;95% CI:-5.35,7.15; η_p^2 =0.01; Table 5.3) and perception of volume-load between HVLL and LVHL ($F_{(1,9)}$=0.581; p=0.466;95% CI:-15.08,7.48; η_p^2 =0.06; Table 5.3). However, there were large differences in the VAS for fatigue between HVLL and LVHL ($F_{(1,9)}$=9.920; p=0.012;95% CI:-17.26,-2.21; η_p^2 =0.52; Figure 5.4).

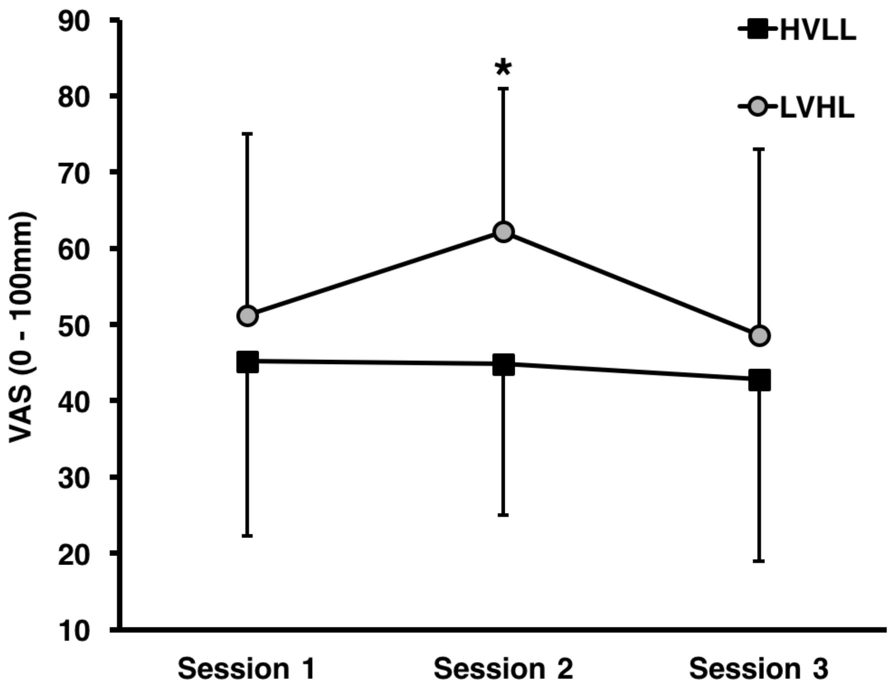

Figure 5.4 VAS fatigue for all participants following HVLL and LVHL.
Note: Values are means ± SD; HVLL = High-velocity, low-load; LVHL = Low-velocity, high-load
* = Fatigue significantly greater for LVHL than HVLL ($p \leq 0.05$) as determined by Bonferroni correction

5.3.6 PACES questions

There were small differences in PACES Item 1: I enjoy it - I hate it, between HVLL and LVHL ($F_{(1,9)}$=2.928; p=0.121;95% CI:-0.10,0.70; η_p^2 =0.25; Table 5.3). There were trivial differences in PACES Item 2: I dislike it – I like it, between HVLL and LVHL ($F_{(1,9)}$=0.880; p=0.373;95% CI:-0.33,0.80; η_p^2 =0.09; Table 6.3) and also trivial differences in PACES Item 3: It's no fun at all – It's a lot of fun, between HVLL and LVHL ($F_{(1,9)}$=0.375; p=0.555;95% CI:-0.36,0.63; η_p^2 =0.04; Table 5.3). There were small differences in PACES Item 4: I feel good physically when doing it – I feel bad physically when doing it, between HVLL and LVHL ($F_{(1,9)}$=1.702; p=0.224;95% CI:-0.47,1.73; η_p^2 =0.16; Table 5.3). Lastly, there were small differences in PACES Item 5: I am very frustrated by it – I am not at all frustrated by it, between HVLL and LVHL ($F_{(1,9)}$=1.914; p=0.200;95% CI:-0.23,0.97; η_p^2 =0.18; Table 5.3).

Table 5.3 Comparison table for all measures of exercise affect

	HVLL		LVHL	
	Pre-Exercise	Post-Exercise	Pre-Exercise	Post-Exercise
PAAS (0 - 4)				
Positive Exercise Affect	2.4 ± 1.2	2.7 ± 0.9	2.2 ± 1.1	2.4 ± 1.0
Negative Exercise Affect	0.2 ± 0.4	0.01 ± 0.04	0.1 ± 0.3	0.1 ± 0.1
Fatigue	0.7 ± 0.8	0.8 ± 0.9	0.8 ± 0.9	1.1 ± 0.9
Tranquillity	2.9 ± 0.9	2.8 ± 0.9	2.6 ± 1.0	2.7 ± 0.9
Felt Arousal Scale	3.7 ± 1.4	4.0 ± 1.2 †	3.2 ± 1.2	3.7 ± 1.1 †
Feeling Scale	2.7 ± 1.3	2.9 ± 1.0	2.5 ± 1.3	2.8 ± 0.9
RPE	9.6 ± 2.2	12.4 ± 2.5	9.9 ± 2.1	13.5 ± 2.0 *
Visual Analogue scales (0 - 100 mm)				
Enjoyment	-	73.0 ± 14.8	-	71.0 ± 15.9
Perceived Effectiveness	-	73.8 ± 12.0	-	72.9 ± 12.2
Perception of Volume-load	-	60.6 ± 14.8	-	64.4 ± 17.6
Fatigue	-	44.3 ± 21.5	-	54.0 ± 22.5 *
PACES Questions (1 - 7)				
Item 1: I hate it - I enjoy it	-	6.0 ± 0.9	-	5.7 ± 1.0
Item 2: I dislike it – I like it	-	5.8 ± 1.2	-	5.6 ± 1.2
Item 3: It's no fun at all – It's a lot of fun	-	5.4 ± 1.1	-	5.3 ± 1.3
Item 4: I feel bad physically when doing it – I feel good physically when doing it	-	5.6 ± 1.2	-	5.0 ± 1.8
Item 5: I am very frustrated by it – I am not at all frustrated by it	-	6.8 ± 0.5	-	6.4 ± 1.0

Note: Values are means ± SD; HVLL = High-velocity, low-load; LVHL = Low-velocity, high-load; PAAS = Physical Activity Affect Scale; RPE = Rating of Perceived Exertion; PACES = Physical Activity Enjoyment Scale
* = LVHL significantly greater than HVLL ($p \leq 0.05$) as determined by Bonferroni correction
† = Significant increase from pre-to post exercise ($p \leq 0.05$) as determined by Bonferroni correction

5.4 Discussion

The present study investigates the affective responses and enjoyment of two, volume-load matched, HVLL and LVHL conditions in a group of older adults. Although conducted on young adults during aerobic exercise, Kilpatrick et al. (2007) observed that when exercise was workload matched and performed either at a higher intensity over a shorter duration, or a moderate intensity over a longer duration, affective valence was reduced in the high intensity short duration group. The present study observed a similar trend with the LVHL condition being approximately eight minutes shorter, with half the amount of repetitions, yet RPE responses and perception of fatigue were significantly greater than HVLL for some exercises. Therefore, the study hypothesis must be rejected. Additionally, LVHL may have been perceived as harder and more fatiguing, as a greater percentage of 1RM was used, meaning exercise was likely performed at closer proximity to momentary failure. Furthermore, HVLL elicited slightly more favorable ratings (less exertion, more enjoyment etc) for all measures but it is unclear whether these insignificant differences would translate into more meaningful differences when these exercise conditions were performed over a period of months with a larger population of participants.

Apart from RPE and the VAS for fatigue, the ratings of exercise affect were similar between HVLL and LVHL during the present study. However, it is a key finding that in general, older adults rated both methods of resistance exercise similarly enjoyable on both the VAS and the PACES questions. This is interesting, as although LVHL was perceived to be significantly more fatiguing with a greater rating of perceived exertion, LVHL was still comparably enjoyable to HVLL. As greater improvements in positive exercise affect have been observed when carrying out high preference exercise modes (Miller et al. 2005), this may mean that individual exercise preference is important. These observations may have significant implications for exercise prescription, possibly supporting the suggestion that personal preference of effort is one of the key determining factors as to which mode of resistance exercise should be prescribed (Ekkekakis et al. 2005).

Acute bouts of resistance exercise have previously been shown to improve affective responses with measurement using the FS (Focht et al. 2015). In the present study, FS ratings were not significantly different between exercise conditions, but similarly to Focht et al. (2015), FS ratings did increase throughout exercise for both HVLL and LVHL. In addition to the FS data, FAS was not significantly influenced by condition, but did increase significantly from pre- to post similar to another study (Kilpatrick et al. 2007). Likewise, the circumplex models of affect revealed comparable responses between HVLL and LVHL. Previously, it has been suggested that moderate loads yield the best improvements in affective responses to resistance exercise (Arent et al. 2005), and although affective responses could be considered to be slightly more desirable during HVLL in the present study, they were in general, not significantly different from LVHL.

The present study observed the VAS for fatigue was significantly greater for LVHL despite volume-loads being matched. Furthermore, perception of fatigue was also greater from the PAAS subscale for LVHL, but not significantly. Similar findings have previously been reported by Gearhart et al. (2002) who observed that when a group of males and females performed workload matched, heavier resistance exercise for less repetitions, and lighter resistance exercise for more repetitions, rating of perceived exertion was significantly greater in the heavy load condition. The PACES data show that HVLL had a slightly more favourable rating for all five PACES items compared to LVHL, although again, these differences were not statistically significant. Participants rated they enjoyed it, liked it, found it more fun, felt better physically when doing it and were less frustrated by HVLL compared to LVHL. These results, suggest that in almost all forms of measurement of exercise affect, there appeared to be a marginal preference for HVLL over LVHL.

This study is not without limitations. As focus was placed on the exploration of a pragmatic solution to resistance exercise prescription in older adults, the estimations of 1RM for all eight exercises were made on the same day to minimise participant burden. Performing all estimations of 1RM on the same day, may have meant that fatigue affected performance, and influenced some predictions of 1RM.

5.5 Conclusion

These findings reveal that older adults perceived volume-load matched HVLL to be less exerting than LVHL. Furthermore, fatigue and rating of perceived exertion were significantly greater during LVHL, and although all other measures of exercise affect slightly favoured HVLL, they were not significantly different from LVHL. This may mean that although LVHL was perceived as harder, it may not necessarily have been less enjoyable to all participants. This supports the notion that exercise professionals should consider individual preference when prescribing exercise programmes. When the findings of the present study are combined with a recent systematic review by Byrne et al. (2016), which revealed that 10 of 13 studies observed power training was superior at delivering improvements in muscle power and/or functional performance, it is possible that exercise professionals should favour prescribing HVLL over LVHL to older adults. However, it is important to consider that these two ecologically valid resistance exercise conditions differed in actual movement velocity, intended movement velocity, loading, and potentially effort of the participants. These variables may not only affect perceptual outcomes in ways not yet clear, but their manipulation has the potential to impact upon adaptations to exercise. Therefore, balancing the prescription of efficacious interventions, with those that are most likely to be adhered to, is an important consideration for exercise professionals. Future research is needed extending this work over months to examine the affective responses to HVLL and LVHL in older adults.

Chapter 6: Study 4

Study 3 demonstrated that both volume-load matched protocols produced similarly positive affective responses and levels of enjoyment, despite LVHL being perceived as significantly more fatiguing and exerting. As study 3 only examined three HVLL sessions and three LVHL sessions, further investigation was warranted to observe if the acute observations differed following multiple sessions over a 10-week intervention period.

6.1 Introduction

The age-related decline in physical activity predisposes older adults to losses in muscle size and strength, negatively influencing functional capacity, independence and quality of life (Burton and Sumukadas 2010). Few older adults in the United Kingdom (15% of men and 10% of women) are achieving the recommended amounts of physical activity set by the physical activity guidelines (Jefferis et al. 2014). Notably, the current physical activity guidelines primarily reflect physiological driven considerations over addressing these significant participation issues (Lind et al. 2005). Therefore, it is important to determine whether, and to what extent, individuals enjoy exercise (Lind et al. 2005), as enjoyment is a key motivator for exercise (Allender et al. 2006) and is important for adherence to exercise interventions (Williams et al. 2008). Previously, there has been investigation into affective responses to aerobic exercise, but much less into resistance exercise (Greene and Petruzzello 2015) especially in older adults, despite the well-documented benefits that resistance exercise has on this population (Hunter et al. 2004).

As outlined previously throughout this thesis, two types of resistance exercise; HVLL and LVHL (forms of power and strength training) have garnered research interest. Despite a systematic review by Byrne et al. (2016) suggesting that power training appears to be more beneficial than strength training for gains in muscle power and/or functional performance in older adults, Fisher et al. (2017) suggested that slower velocity movements should be favoured, and explosive movements should be avoided during resistance exercise in older adults. This claim that was strongly refuted in a short commentary by Cadore et al. (2018), as they discussed the strong scientific evidence that explosive contractions should be performed by older adults. This demonstrates that the optimal exercise prescription from a physiological standpoint is still being debated, while the psychological considerations for resistance exercise programming in older adults go largely uninvestigated.

To better understand the psychology of enjoyment and adherence to resistance exercise, it is important to consider relevant theories. The basic premise of hedonic theory is that human behaviour is motivated by the pursuit of pleasure and the avoidance of displeasure (Mees and Schmitt 2008). The theory focuses on the affective responses to behaviours, and how they influence decisions on whether or not a behaviour is repeated (Fredrickson and Kahneman 1993). The theory behind why affective responses to physical activity may alter future behaviours is principally based on operant conditioning, where behaviour outcomes influence continuation of that behaviour through learned associations (Rhodes and Kates 2015). Exercise affect is a key component of the exercise experience and may be influenced through bodily sensations (e.g. pain or pleasure) or may follow from cognitive appraisal (e.g. feelings of failure or achievement) (Ekkekakis et al. 2010). Indeed, measurement of these acute affective responses to exercise have been shown to predict future exercise behaviour (Williams et al. 2008). Therefore, understanding older adult's affective responses to resistance exercise are important, and may be used to influence resistance exercise programme design in this population.

As many older adults need supervision to realise the full benefits of resistance exercise (Steele et al. 2017b), costs to the individual can be substantial. Therefore, investigation into the minimal effective dose of resistance exercise for older adults is warranted (Byrne et al. 2016). Various studies have demonstrated that performing resistance exercise once-weekly can elicit improvements in strength and physical function in older adults (Foley et al. 2011; Sousa et al. 2013). Recently Fisher et al. (2017) proposed that as little as 10 to 30 minutes resistance exercise, twice-weekly may be sufficient to obtain considerable physiological and psychological benefits. Furthermore, lower frequency resistance exercise may be preferable to older adults, as Foley et al. (2011) observed that 66% of 94 older adults, preferred training once-weekly, as opposed to twice (26%) or thrice-weekly (1%), demonstrating a strong preference for low volume/ frequency resistance exercise. Given the potential importance of low-dose resistance exercise to older adults, investigation into the affective responses to lower (once-weekly) and higher doses (twice-weekly) of resistance exercise would be an important contribution to the extant literature.

Study 3 of this thesis indicated that despite LVHL (low-velocity, high-load) being perceived as more exerting and fatiguing, both HVLL (high-velocity, low-load) and LVHL were enjoyed similarly. As volume-loads in study 3 were matched, but intensity likely differed (due to loading used), affective responses fluctuated in-task, but similarly to Focht et al. (2015), post-exercise affect for both HVLL and LVHL similarly improved. In fact, similar patterns have been observed in a number of studies that have examined affective responses to resistance exercise (Arent et al. 2005; Focht 2002). Therefore, the observations of study 3 formulated the basis for this study. The present study aims were to compare the affective responses of a group of older adults when carrying out a supervised 10-week training intervention of either HVLL or LVHL (exercise velocity) performed either once or twice-weekly (exercise frequency). It was hypothesised that: 1) there will likely be greater perceived exertion in the LVHL conditions that will not negatively impact affective responses compared to HVLL and 2) given the active nature of the participants in the present study, both once and twice-weekly will deliver similarly positive affective responses.

6.2 Methods

6.2.1 Design

The present study used a randomised, multi-armed, parallel design. Minimisation ensured only minor differences between exercise conditions in both sex and age. Blinding was not applied, as it was apparent to participants which exercise condition they had been allocated and a control group was not deemed necessary as between-condition effects were the primary focus of the study.

6.2.2 Participants

An *a priori* power calculation using G*Power software (version 3.1.9.2, Franz Faul, Universitat Kiel, Dusseldorf, Germany) for repeated measures analysis of variance (ANOVA), between-within interaction design [4 (conditions) by 3 (weeks 1, 5, and 10)], revealed that detection of a “medium” effect size ($f = 0.20$), with $\alpha = 0.05$, $1–\beta = 0.80$, correlated dependent variables ($r = 0.70$), and a violation of the assumption of sphericity ($\varepsilon = 1$) required a minimum total sample size of 40 participants. Following institutional ethics approval (Appendix A), community-dwelling men and women (aged 60-79) (Table 1) were recruited by self-selection through advertisements for participation. Prior to randomising, each participant was required to meet the following inclusion/ exclusion criteria (a) absence of cognitive impairment (b) absence of acute or terminal illness, myocardial infarction, symptomatic coronary artery disease, congestive heart failure, neuromuscular disease, or uncontrolled hypertension (>150/90 mmHg) (c) no upper or lower extremity fracture in the previous six months (d) not participated in strength or power training in the previous six months (e) aged 60 years or older. After meeting these criteria, each older adult was assigned one of four progressive resistance exercise conditions using minimisation: (1) high-velocity, low-load resistance exercise once weekly (HVLL1) (2) low-velocity, high-load resistance exercise once weekly (LVHL1) (3) high-velocity, low-load resistance exercise twice weekly (HVLL2) (4) low-velocity, high-load resistance exercise twice weekly (LVHL2). All participants were made aware of the exercise conditions and associated risks before providing informed consent. Ninety-two participants (50 females and 42 males) volunteered, 49 were excluded for not meeting the inclusion/ exclusion criteria or later refused participation. Three participants dropped out during the training intervention (knee pain HVLL2: n = 1 (causation unclear), injury not associated with intervention HVLL1: n = 1, and time commitment LVHL2: n = 1). Therefore, 40 participants (20 males and 20 females) completed all sessions and were included in the analyses.

Table 6.1. Participant characteristics

	HVLL1 (n = 10; 5m, 5f)	LVHL1 (n = 10; 5m, 5f)	HVLL2 (n = 10; 5m, 5f)	LVHL2 (n = 10; 5m, 5f)
Age (years)	66 ± 5	67 ± 4	67 ± 6	66 ± 6
Age Range (years)	60 – 74	60 – 72	60 – 78	60 – 79
Height (cm)	168.7 ± 7.4	167.2 ± 11.1	173.3 ± 9.7	166.8 ± 8.9
Body Mass (kg)	80.0 ± 16.9	76.3 ± 11.8	83.2 ± 13.5	73.0 ± 13.4
Body Mass Index (kg/m^2)	28 ± 5	28 ± 5	28 ± 5	26 ± 4
Weekly Activity (MET-minutes)	2919 (1771 – 4345)	3264 (2064 – 4067)	3095 (2381 – 4487)	2355 (1074 – 4026)
Sitting per day (min)	330 (255 – 368)	195 (165 – 285)	240 (180 – 263)	360 (255 – 465)
Medications Taken	2 ± 5	1 ± 1	1 ± 1	2 ± 2
Most Commonly Medicated Condition(s)	High Blood Pressure (3/10)	Acid Reflux (2/10)	High Blood Pressure (2/10)	High Blood Pressure (5/10) Acid Reflux (2/10)
Most Common medication(s)	Simvastatin Atorvastatin	Omeprazole	Amlodipine Ramipril	Simvastatin Valsartan Omeprazole

Note: Values are mean ± SD except for activity and sitting which are the median and interquartile ranges; m = male f = female; HVLL1 = High-velocity, Low-load once weekly; LVHL1 = Low-velocity, High-load once weekly; HVLL2 = High-velocity, Low-load twice weekly; LVHL2 = Low-velocity, High-load twice weekly

6.2.3 Procedures

Prior to familiarisation and estimation of one repetition maximum (1RM) for each exercise, participants were asked to refrain from caffeine use for a minimum of 12 hours, and any other fatiguing exercise or physical activity for 24 hours. Firstly, anthropometric data was recorded (Seca Instruments, Hamburg, Germany) and participants completed an International physical activity questionnaire (IPAQ) (Craig et al. 2003) to assess habitual physical activity levels (Table 6.1). The IPAQ was scored and data reported in accordance with instructions on the IPAQ website (www.ipaq.ki.se). Although the IPAQ is not specifically designed to assess the physical activity levels of adults over the age of 65, Tomioka et al. (2011) concluded it is a useful tool for assessing the physical activity of older adults. As participants who exercise more frequently report a more positive exercise experience (McAuley et al. 2003), participants self-reported physical activity levels (MET-minutes per week) were used as a covariate for all measures of exercise affect. The procedure for the warm-up and prediction of 1RM's was identical as described in section 3.2.3. Table 6.2 displays estimations of 1RM both pre- and post-intervention.

Table 6.2. Predicted 1RM data (Brzycki 1993) pre- and post-intervention

	Leg Press (kg)	Seated Row (kg)	Chest Press (kg)	Leg Extension (kg)	Leg Curl (kg)	Calf Raise (kg)	Tricep Extension (kg)	Bicep Curl (kg)
HVLL1 Baseline	103 ± 23	53 ± 14	35 ± 14	41 ± 8	40 ± 12	116 ± 21	25 ± 10	20 ± 10
HVLL1 Post	117 ± 29	57 ± 13*	39 ± 16	45 ± 9	45 ± 6	136 ± 29*	29 ± 8*	23 ± 9
LVHL1 Baseline	104 ± 29	51 ± 15	33 ± 21	42 ± 14	37 ± 12	97 ± 31	23 ± 12	20 ± 10
LVHL1 Post	125 ± 32*	58 ± 17*	38 ± 20*	52 ± 15*	45 ± 17*	126 ± 32*	28 ± 12*	24 ± 10*
HVLL2 Baseline	135 ± 39	59 ± 21	44 ± 21	55 ± 21	48 ± 17	139 ± 31	30 ± 16	26 ± 12
HVLL2 Post	150 ± 44	65 ± 24*	50 ± 20*	60 ± 19*	53 ± 20*	148 ± 32	35 ± 15*	29 ± 11*
LVHL2 Baseline	114 ± 28	51 ± 15	38 ± 19	42 ± 10	41 ± 11	117 ± 26	25 ± 10	20 ± 10
LVHL2 Post	143 ± 41*	65 ± 18*	48 ± 23*	60 ± 15*	53 ± 14*	158 ± 26*	33 ± 12*	29 ± 13*

Note: Values are mean ± SD; 1RM = One repetition maximum; HVLL1 = High-velocity, Low-load once weekly; LVHL1 = Low-velocity, High-load once weekly; HVLL2 = High-velocity, Low-load twice weekly; LVHL2 = Low-velocity, High-load twice weekly

* = Significantly greater than pre-intervention ($p \leq 0.05$) as determined by Bonferroni correction

6.2.4 Measures of exercise affect

Consistent with hedonic theory (Greene et al. 2018), the measures selected, assessed the pleasantness and enjoyment of the resistance exercise conditions using both dimensional model and distinct state approaches and are identical to those described in study 3. In-task affect has been suggested as an important consideration in the intensity-affect-enjoyment relationship during resistance exercise (Greene and Petruzzello 2015). However, previous research has shown that in-task responses are typically stronger and in the same direction as post-task affect (Kwan and Bryan 2010). Additionally, as study 3 of this thesis displayed similarly positive affective responses to alike HVLL and LVHL conditions, when affect was measured immediately following each set of each exercise in older adults, the decision was made to not include measurement of in-task affect in the present study. Finally, when completing all applicable measures, participants were advised to base their responses on the exercise they performed, and not the overall experience (socialising or interaction with others etc). All scales used can be found in Appendix C.

6.2.5 Physical activity affect scale

Participants completed a Physical Activity Affect Scale (PAAS) questionnaire (Lox et al. 2000) prior to, and immediately following sessions in week 1, 5 and 10 in identical fashion as described in 5.2.5.

6.2.6 Felt arousal scale and feeling scale

The Felt Arousal Scale (FAS) (Svebak and Murgatroyd 1985) and single item Feeling Scale (FS) (Hardy and Rejeski 1989) were used to measure arousal and affective valence respectively, prior to exercise, and immediately following sessions in weeks 1, 5 and 10 in identical fashion as described in 5.2.5.

6.2.7 Rating of perceived exertion

Rating of perceived exertion (RPE) (Borg 1982) was recorded from a scale ranging from 6 - 20 (6 = no exertion at all, 20 = maximal exertion), immediately following sessions in weeks 1, 5 and 10. As well as monitoring perceived exertion, RPE was used to progress exercise intensity. Similar to Levinger et al. (2017), when a participant rated the session 10/20 on the Borg scale (too light/ easy), any exercises that were highlighted as too easy by the participant were increased in resistance by 5-10%. Participants were not informed that rating a session 10/20 would result in increasing resistance, to avoid the possibility of deliberate manipulation of RPE ratings. One participant in the LVHL2 condition rated the final session as RPE 10. In the HVLL1 condition, 4/10 participants rated the sessions as RPE 10 by week 8, and two participants rated sessions as RPE 10 by week 6 in the HVLL2 condition. Finally, zero participants in the LVHL1 condition rated sessions as RPE 10 or lower.

6.2.8 Visual analogue scales

Following sessions in weeks 1, 5 and 10, participants completed four visual analogue scales (VAS) (Kuys et al. 2011) in identical fashion as described in 5.2.5.

6.2.9 Physical activity enjoyment scale

Finally, participants completed a modified Physical Activity Enjoyment Scale (PACES) (Graves et al. 2010) following sessions in weeks 1, 5 and 10 in identical fashion as described in 5.2.5.

6.2.10 Resistance exercise conditions

During each supervised session, all exercise conditions performed eight exercises a) leg press, b) seated row, c) chest press, d) leg extension, e) leg curl, f) calf raise, g) tricep extension and h) bicep curl. Both the HVLL1 and HVLL2 conditions performed three sets of fourteen repetitions at 40% predicted 1RM on each exercise. The concentric phase was performed "as fast as possible" without causing unloading of the weight stack, followed by a three second eccentric phase. Both the LVHL1 and LVHL2 conditions performed three sets of seven repetitions at 80% predicted 1RM. The concentric phase was performed over two seconds with a three second eccentric phase. All exercise conditions had 90 secs recovery between sets, and three mins recovery between exercises. Sessions were completed at the same time of day, on the same days per week where possible to control for possible diurnal variation. The HVLL1 and LVHL1 conditions performed one session per week for 10-weeks (10 sessions) and the HVLL2 and LVHL2 conditions performed two sessions per week over 10-weeks (20 sessions). It is important to highlight that this study design means that the twice-weekly conditions performed double the weekly volume compared to the once-weekly condition. Matching volumes between once and twice-weekly is not time efficient i.e. half the volume on two days per week, or may overload participants i.e. double the volume on just one day per week. Where any sessions were missed, the intervention period was extended so that all sessions could be completed. Therefore, mean number of weeks to complete all sessions were: HVLL1: 10.4 ± 0.7, LVHL1: 10.8 ± 0.9, HVLL2: 10.6 ± 0.7, LVHL2: 10.8 ± 1.2. Figure 6.1 displays the timeline of sessions and displays when all measurements of exercise affect were taken during each session.

6.2.11 Supervision

A single male researcher supervised all baseline, post-intervention and weekly exercise sessions to a) ensure participant attendance b) provide feedback, technical instructions and motivation c) provide social and mental support d) provide a supportive attitude (Ramirez-Campillo et al. 2017). The baseline and post-testing sessions were closely supervised (1:1). Each subsequent session was supervised 1:2 (researchers: participants) throughout the duration of the intervention period. Participants were allowed to socialise with each other and the researcher during the warm-up, but once the session began they had no interaction with each other, as they performed different exercises. Once the session had finished participants completed all scales separately, before continuing to socialise with the other participant and researcher.

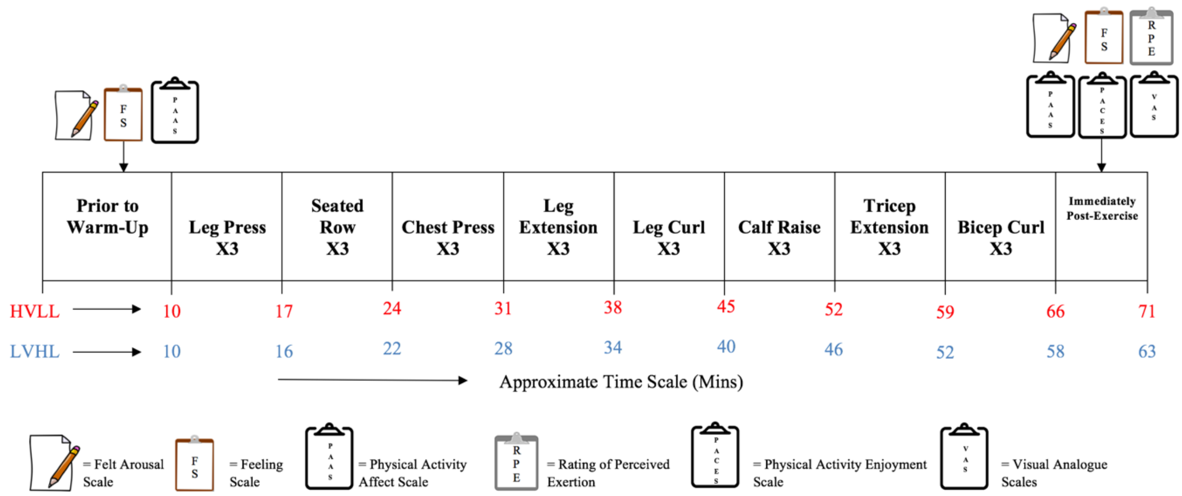

Figure 6.1: A schematic diagram of each exercise session
Note: X3 = 3 sets; HVLL = High-velocity, low-load; LVHL = Low-velocity, high-load

6.2.12 Statistical analysis

All data were analysed using IBM SPSS Statistics, Version 24.0 (Armonk, NY: IBM Corp). Descriptive statistics are presented as mean ± SD, and 95% confidence intervals (95% CI). Normality of data was assessed using the Shapiro-Wilk test and manual analysis of the plotted data. Any scale data that was non-normally distributed was log transformed and reassessed for normality using the residuals (Kozak and Piepho 2018). Providing the data presented a normal distribution it was analysed with the appropriate parametric statistical test. Recognising they are highly correlated measures, the FS, FAS and the 4 PAAS subscales were analysed using multivariate analysis of variance (MANOVA) with repeated measures, before and following sessions in weeks 1, 5 and 10. Further analysis using factorial analysis of variance (ANOVA) with repeated measures examined the effect of the independent variable: exercise condition on the dependent variables: PAAS; PACES; RPE; VAS; FS and FAS. When Mauchly's test of sphericity was significant and the Greenhouse-Geisser level of violation was >0.75, degrees of freedom were corrected using Huynh-Feldt adjustment, and when violation was <0.75, Greenhouse-Geisser correction was used. Significant interactions and main effects were investigated with Bonferroni corrected pairwise comparisons. Significance was determined by a p value of <0.05 and reported as exact values unless below p = 0.001. Effect size was used to quantify the meaningfulness of any differences and was calculated using η_p^2 and defined as: trivial (<0.1), small (0.1-0.29), moderate (0.3-0.49) or large (≥0.5) (Hopkins et al. 2009). One-way ANOVA was used to confirm no significant differences in activity levels between conditions and paired sample t-tests were used to show where differences in strength changes lay (Table 2). Analysis of covariance (ANCOVA) was used to examine the effect of habitual physical activity (MET-minutes) on the dependant variables. However, there were no significant effects of the covariate MET-mins/week on any of the dependant variables. Ancillary ANOVA analyses were performed to analyse the effects of movement velocity only [HVLL (n = 20) vs. LVHL (n = 20)] or frequency of exercise only [Once (n = 20) vs. twice weekly (n = 20)] and are only reported when significant.

6.3 Results

6.3.1 MANOVA analysis

The MANOVA performed on the 4 PAAS subscales, FAS and FS between exercise conditions indicated a non-significant effect (Pillai's V = 0.33; $F_{(15,180)}$= 0.710; p=0.773; η_p^2 = 0.06). This suggests that all four exercise conditions produced similar affective responses. However, there was a significant, interaction between FS, FAS and the 4 PAAS × weeks × pre/post (Pillai's V = 0.61; $F_{(6,202)}$= 3.445; p=0.004; η_p^2 = 0.09) which was further investigated with factorial ANOVA.

6.3.2 PAAS positive affect

There were large increases in positive exercise affect from pre- to post-session ($F_{(1,9)}$=36.179; p<0.001; 95% CI: 0.2, 0.5; η_p^2 =0.80) but only trivial differences between all four exercise conditions ($F_{(3,27)}$=0.746; p=0.534; η_p^2 =0.08). When only velocity of exercise was analysed, there were trivial differences between HVLL and LVHL ($F_{(1,19)}$=0.587; p=0.453; 95% CI: -0.7, 0.3; η_p^2 =0.03) and when only frequency was analysed, there were trivial differences between once and twice per week ($F_{(1,19)}$= 0.000; p=0.991; 95% CI: -0.5, 0.5; η_p^2 =0.00).

6.3.3 PAAS negative affect

There were small differences in negative exercise affect between all four exercise conditions ($F_{(3,27)}$=1.974; p=0.142; η_p^2 =0.18) with moderate decreases in negative affect from pre- to post-session ($F_{(1,9)}$=4.853; p=0.055; 95% CI: -0.1, 0.0; η_p^2 =0.35). However, when only velocity of exercise was analysed, there was a moderate interaction between exercise velocity and pre- and post-session ($F_{(1,19)}$=9.314; p=0.007; η_p^2 =0.33; Figure 6.2A). Pairwise comparisons revealed that negative exercise affect was significantly lower post-exercise in week 1 and 5 compared to pre-exercise in the HVLL condition. When only frequency was analysed, there was a small interaction between frequency and week ($F_{(2,38)}$=4.523; p=0.017; η_p^2 =0.19) pairwise comparisons were used to show exactly where any significant differences lay (Figure 6.2).

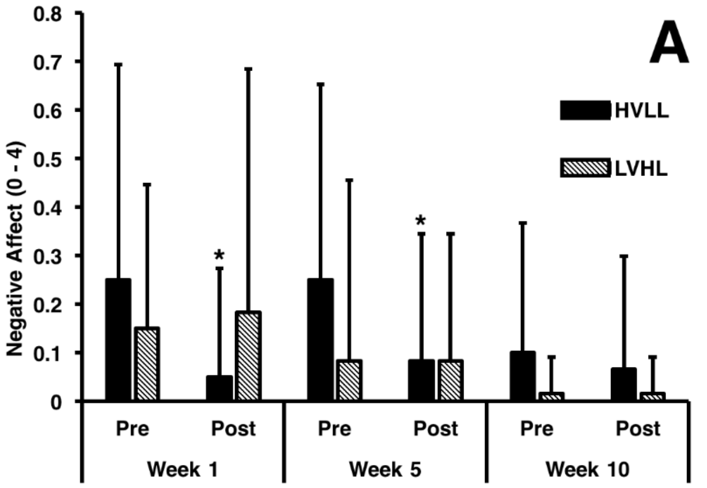

Figure 6.2A. PAAS negative exercise affect when only velocity of exercise was analysed
***** = Post-exercise significantly lower than pre-exercise ($p \leq 0.05$) as determined by Bonferroni correction

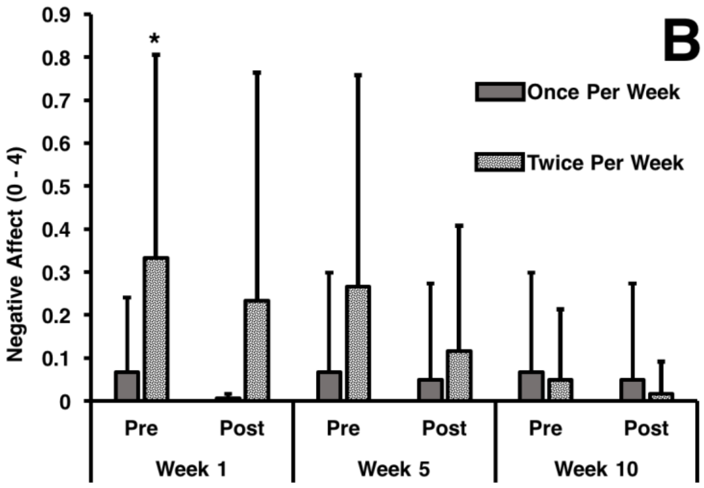

Figure 6.2B. PAAS negative exercise affect when only frequency of exercise was analysed
***** = Significantly greater than pre-week 1, once per week ($p \leq 0.05$) as determined by Bonferroni correction

6.3.4 PAAS fatigue

There were trivial differences in fatigue between all four exercise conditions ($F_{(3,27)}$=0.396; p=0.757; η_p^2 =0.04) and there were similarly large increases in rating of fatigue between pre- and post-session regardless of exercise condition ($F_{(1,9)}$ =26.320; p=0.001; 95% CI: 0.2, 0.5; η_p^2 =0.75). When only velocity of exercise was analysed, there were trivial differences between HVLL and LVHL ($F_{(1,19)}$ =0.138; p=0.715; 95% CI: -0.3, 0.4; η_p^2 =0.001), and when only frequency was analysed, there were trivial differences between once and twice per week ($F_{(1,19)}$ =0.034; p=0.856; 95% CI: -0.3, 0.3; η_p^2 =0.002).

6.3.5 PAAS tranquillity

There were small differences in tranquillity between all four exercise conditions ($F_{(3,27)}$= 1.496; p=0.238; η_p^2 =0.14) with moderate improvements in tranquillity from pre- to post-session regardless of exercise condition ($F_{(1,9)}$= 4.300; p=0.068; 95% CI: -0.0, 0.3; η_p^2 =0.32). When only velocity of exercise was analysed, there were trivial differences between HVLL and LVHL ($F_{(1,19)}$ =0.326; p=0.575; 95% CI: -0.4, 0.7; η_p^2 =0.02), and when only frequency of exercise was analysed, there were trivial differences between once and twice per week ($F_{(1,19)}$ =0.048; p=0.828; 95% CI: -0.5, 0.6; η_p^2 =0.003).

6.3.6 Felt arousal scale

There were large increases in FAS rating from pre- to post-session ($F_{(1,9)}$=36.506; p<0.001; 95% CI: -0.87, 0.40; η^2_p =0.80) with only trivial differences between the four exercise conditions ($F_{(3,27)}$=0.396; p=0.757; η^2_p =0.04). When only velocity of exercise was analysed, there were trivial differences between HVLL and LVHL ($F_{(1,19)}$ =1.103; p=0.307; 95% CI: -0.7, 0.2; η^2_p =0.06). When only frequency of exercise was analysed there was a small interaction between frequency and week and pre- to post-session ($F_{(2,38)}$=4.669; p=0.015; η^2_p =0.20). Pairwise comparisons revealed that there were significant increases in FAS from pre- to post session for once-weekly following week 1 (Bonferroni p=0.028; 95% CI: 0.1, 1.4) and week 5 (Bonferroni p=0.002; 95% CI: 0.3, 1.1) and twice-weekly saw significant increases in FAS following week 1 (Bonferroni p=0.001; 95% CI: 0.6, 2.0), week 5 (Bonferroni p=0.008; 95% CI: 0.1, 0.7) and week 10 (Bonferroni p=0.017; 95% CI: 0.1, 0.7).

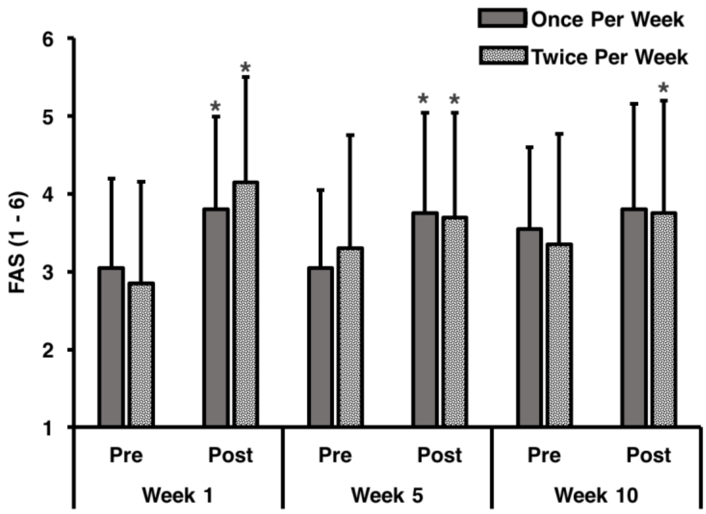

Figure 6.3. FAS for all participants when only frequency of exercise was analysed
***** = Post-exercise values significantly greater than pre-exercise ($p \leq 0.05$) as determined by Bonferroni correction

6.3.7 Feeling scale

There were large increases in FS rating from pre- to post-session ($F_{(1,9)}$=35.485; p<0.001; 95% CI: 0.5, 1.0; η^2_p =0.80) with only a trivial effect of exercise condition ($F_{(3,27)}$=0.467; p=0.708; η^2_p =0.05). When only velocity of exercise was analysed, there were trivial differences between

HVLL and LVHL ($F_{(1,19)}$ =0.515; p=0.482; 95% CI: -0.5, 0.9; η_p^2 =0.03) and when only frequency of exercise was analysed, there were trivial differences between once and twice per week ($F_{(1,19)}$ =0.023; p=0.880; 95% CI: -0.6, 0.5; η_p^2 =0.001). A circumplex model of affect for each exercise condition is shown in Figure 6.4.

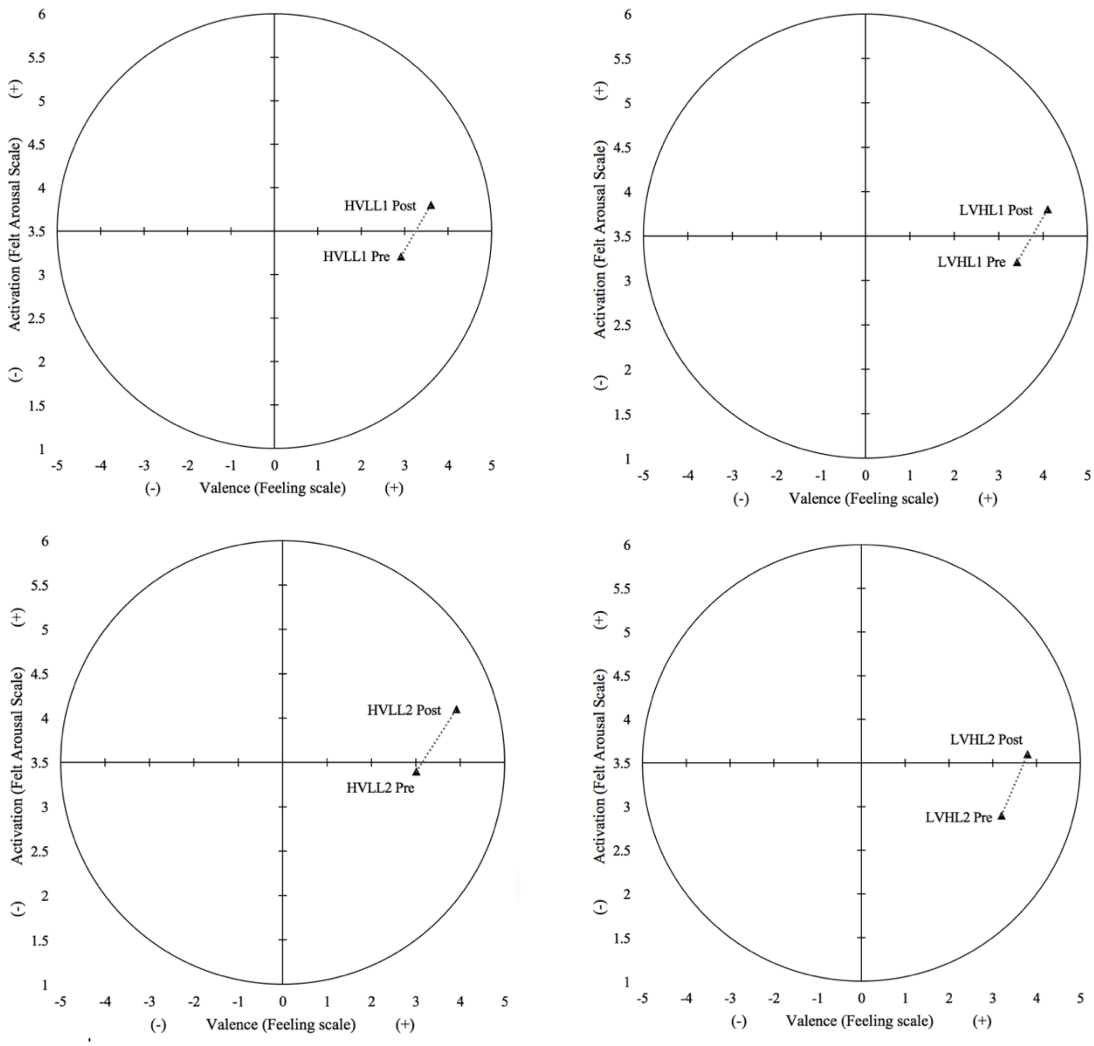

Figure 6.4. Circumplex models of affect for the average pre- to post changes for each exercise condition

6.3.8 Rating of perceived exertion

There were large decreases in RPE from week 1 (14.5 ± 1.9), to week 5 (13.4 ± 1.8) to week 10 (13.0 ± 1.8) ($F_{(2,18)}$= 17.189; p<0.001; η_p^2 = 0.66) with only small differences between all four exercise conditions ($F_{(3,27)}$=1.188; p=0.333; η_p^2 =0.12). When only velocity of exercise was analysed, there were trivial differences between HVLL and LVHL ($F_{(1,19)}$ =1.227; p=

0.282; 95% CI: -0.4, 1.3; η_p^2 =0.06) and when only frequency of exercise was analysed, there were trivial differences between once and twice per week ($F_{(1,19)}$ =0.009; *p*=0.926; 95% CI: -1.2, 1.1; η_p^2 =0.00).

6.3.9 VAS Item 1: How enjoyable was the exercise you just did?

There were small differences in enjoyment between exercise conditions ($F_{(3,27)}$= 1.347; *p*=0.280; η_p^2 =0.13). When only velocity of exercise was analysed, there were trivial differences between HVLL and LVHL ($F_{(1,19)}$ =1.812; *p*=0.194; 95% CI: -1.9, 8.8; η_p^2 =0.09), and when only frequency of exercise was analysed, there were trivial differences between once and twice per week ($F_{(1,19)}$ =0.386; *p*=0.542; 95% CI: -6.9, 3.8; η_p^2 =0.02).

6.3.10 VAS Item 2: How fatiguing was the exercise you just did?

There were small differences in fatigue between exercise conditions ($F_{(3,27)}$= 2.733; *p*=0.063; η_p^2 =0.23). When only velocity of exercise was analysed, LVHL exercise was significantly more fatiguing than HVLL ($F_{(1,19)}$ =5.258; *p*=0.033; 95% CI: 1.3, 29.0; η_p^2 =0.22; Figure 6.5), pairwise comparisons revealed that LVHL was significantly more fatiguing following weeks 1 (Bonferroni *p* =0.009; 95% CI: 5.0, 30.0) and 5 (Bonferroni *p* =0.028; 95% CI: 2.2, 35.0). Finally, when only frequency of exercise was analysed there were trivial differences between once and twice per week ($F_{(1,19)}$ =0.109; *p*=0.745; 95% CI: -17.2, 12.5; η_p^2 =0.006).

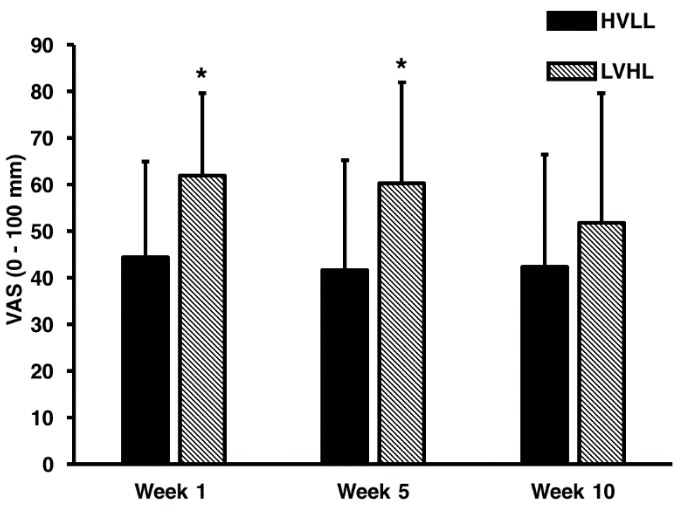

Figure 6.5. VAS Item 2 when only velocity of exercise was analysed
***** = LVHL significantly greater rating of fatigue than HVLL ($p \leq 0.05$) as determined by Bonferroni correction

6.3.11 VAS Item 3: What was your perception of the workload?

There was a significant interaction between exercise condition and week ($F_{(6,54)}$=2.978; *p*=0.014; η_p^2 =0.25; Figure 6.6A), although pairwise comparisons revealed that only LVHL2 week 5 had a significantly greater perception of workload than LVHL2 week 10 (Bonferroni *p*=0.008; 95% CI: 4.4, 26.4). When only velocity of exercise was analysed, LVHL exercise was perceived as having a significantly greater workload than HVLL ($F_{(1,19)}$ =4.766; *p*=0.042; 95% CI: 0.5, 21.7; η_p^2 =0.20; Figure 6.6B). Pairwise comparisons revealed that LVHL had a greater workload in week 1 (Bonferroni *p*=0.008; 95% CI: 4.7, 27.4). Finally, when only frequency of exercise was analysed, there were trivial differences between once and twice per week ($F_{(1,19)}$= 0.310; *p*=0.584; 95% CI: -7.7, 13.2; η_p^2 =0.02).

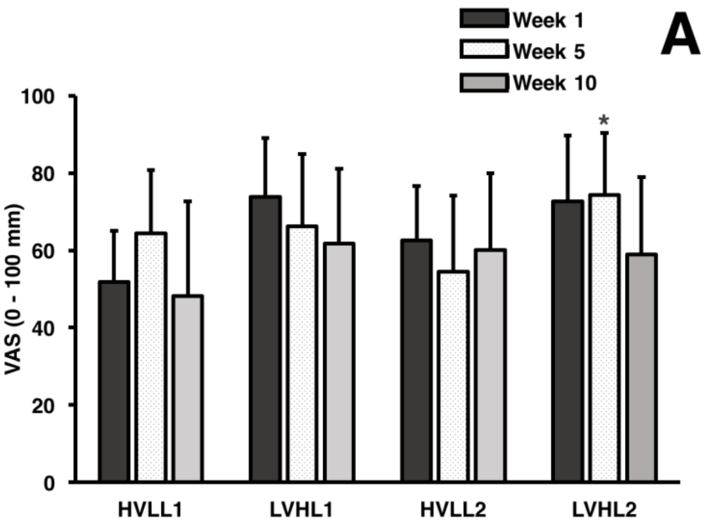

Figure 6.6A: VAS item 3: Perception of workload between all four exercise conditions
***** = LVHL2 week 5 significantly greater than LVHL2 week 10 ($p \leq 0.05$) as determined by Bonferroni correction

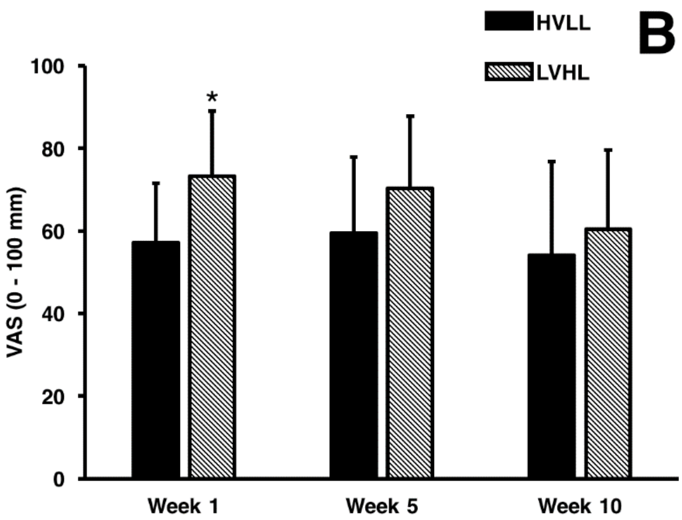

Figure 6.6B: VAS Item 3: Perception of workload when only velocity of exercise was analysed
***** = LVHL significantly greater than HVLL ($p \leq 0.05$) as determined by Bonferroni correction

6.3.12 VAS Item 4: What was your perceived effectiveness of the workload?

There were small differences in VAS perceived effectiveness between all four exercise conditions ($F_{(3,27)}$= 0.959; *p*=0.426; η_p^2 = 0.10). When only velocity of exercise was analysed, there were small differences between HVLL and LVHL ($F_{(1,19)}$ = 2.084; *p*= 0.165; 95% CI: -2.3, 12.4; η_p^2 =0.10), and when only frequency of exercise was analysed, there were trivial differences between once and twice per week ($F_{(1,19)}$ = 0.826; *p*= 0.375; 95% CI: -10.9, 4.3; η_p^2 = 0.04).

6.3.13 PACES total score

There were trivial differences in PACES scores between all four exercise conditions ($F_{(3,27)}$= 0.571; p=0.639; η_p^2 = 0.06). When only velocity of exercise was analysed, there were trivial differences between HVLL and LVHL ($F_{(1,19)}$ = 0.027; p= 0.870; 95% CI: -1.7, 2.0; η_p^2 = 0.001) and when only frequency of exercise was analysed, there were trivial differences between once and twice per week ($F_{(1,19)}$ = 0.727; p= 0.404; 95% CI: -2.9, 1.2; η_p^2 = 0.04). Table 6.3 shows PACES total score (out of 35).

Table 6.3. Physical Activity Enjoyment Scale (PACES) total score

	Week 1	Week 5	Week 10
HVLL1	30.7 ± 2.5	30.4 ± 2.5	31.6 ± 2.3
LVHL1	31.3 ± 3.7	32.0 ± 3.8	32.4 ± 3.6
HVLL2	30.2 ± 2.6	31.1 ± 4.1	31.4 ± 3.8
LVHL2	29.7 ± 3.6	30.1 ± 3.5	30.8 ± 4.2

Note: Values are mean ± SD; HVLL1 = High-velocity, low-load once-weekly; LVHL1 = Low-velocity, high-load once-weekly; HVLL2 = High-velocity, low-load twice-weekly; LVHL2 = Low-velocity, high-load twice-weekly;

6.4 Discussion

The present study sought to investigate the affective responses to performing HVLL and LVHL once or twice-weekly in older adults. Little is known about the affective responses to resistance exercise (Greene and Petruzzello 2015) and even less so in older adults. No other study has monitored the affective responses to 10-week interventions of resistance exercise, differing in frequency, volume and load in older adults. The observations of the present study are in agreement with a number of other studies that have demonstrated positive affective responses to resistance exercise (Arent et al. 2005; Focht et al. 2015; Greene and Petruzzello 2015; Miller et al. 2009). These findings appear to replicate the acute observations of study 3 within this thesis, in that LVHL elicited greater perceived workload and fatigue than HVLL, without having a detrimental impact on enjoyment. It was also observed that affective responses were not different between those who performed resistance exercise once or twice-weekly. Although older adults have previously indicated a preference for a lower frequency of resistance exercise (Foley et al. 2011), performing double the weekly volume in the twice-weekly conditions did not negatively impact enjoyment. As participants in the present study had moderate-high levels of habitual physical activity, they were more likely to report a positive exercise experience

(McAuley et al. 2003) regardless of the exercise condition they were randomised to. Therefore, based on these observations the findings support the hypotheses.

PAAS positive affect increased from pre- to post-exercise across all exercise conditions, while negative exercise affect significantly decreased from pre- to post in the HVLL conditions, for week 1 and week 5, but by week 10, ratings were similar for both HVLL and LVHL. All exercise conditions saw large increases in FAS and FS from pre-to post-exercise, similar to the previous findings in study 3. Results from the PACES and VAS revealed that all exercise conditions were found to be highly enjoyable. Despite RPE decreasing similarly in all exercise conditions between weeks 1 and 10, the VAS for fatigue revealed that when data was analysed by exercise velocity, the LVHL conditions were perceived as being significantly more fatiguing for weeks 1 and week 5, but not week 10. Similarly, when VAS perception of workload was analysed between exercise velocities, LVHL had a significantly greater perception of workload following week 1, but not week 5 or week 10. This suggests that although older adults may have initially perceived LVHL as harder and more fatiguing, as they progressed through the programme, perceptions of HVLL and LVHL became more similar. This may be explained by the fact that 30% of participants in the HVLL conditions rated sessions as 10 or lower on the RPE scale, meaning volume-load was increased, whereas none of the participants in the LVHL conditions progressed through RPE ratings. Therefore, the volume-load increases in HVLL conditions may be a reason why perception of fatigue become more similar by week 10. Over a longer period of time, the ability for HVLL participants to progress workloads (increase in total load lifted) at a quicker rate than LVHL conditions may provide a greater stimulus for adaptations. However, it is important to note that even though volume-loads were matched between HVLL and LVHL, possibly due to greater intensity, the LVHL conditions produced improvements in more estimations of 1RM than HVLL at both frequencies of training despite not progressing resistance.

The findings of the present study are consistent with those of study 3, in that there was a greater perception of fatigue with no negative impact on enjoyment or affective valence during LVHL compared to HVLL exercise in older adults. As the intensity of exercise in the LVHL conditions was greater than in HVLL, based on hedonic theory, it may have been reasonable to assume this would have a negative impact on affective responses. The theory of optimal stimulation (Csikszentmihalyi 2014) suggests that when an individual considers an activity threatening or beyond their capabilities (e.g. undertaking high intensity resistance exercise as in the LVHL conditions) it will result in feelings of negative effect and anxiety. Therefore, it is possible that given the moderate-highly physically active nature of the participants in the present study, despite LVHL (80% 1RM) being performed at a greater intensity than HVLL (40% 1RM), the intensity was not enough to negatively impact affective responses. This may have been observed because of the high habitual activity levels of the older adults in the present study. Therefore, further investigation is required to investigate if more physically active older adults report more positive affective responses to higher intensities of resistance exercise compared to more sedentary older adults.

The effect that supervision had on the reported affective responses during the present study is unclear. There is evidence that supervision has a positive influence on various physiological and performance outcomes during exercise programmes (Ramirez-Campillo et al. 2017; Steele et al. 2017b), but there is very little investigation into how the role of the supervisor impacts exercise enjoyment and subsequent programme adherence. Previously it has been suggested that supervised exercise programmes provide greater motivation for exercise (Gentil and Bottaro 2010) whilst improving psychosocial factors and quality of life through improvements in strength and functional performance (Ramirez-Campillo et al. 2017). However, the role that supervisors play in influencing affective responses to resistance exercise in older adults remains uninvestigated. Due to the high cost of exercise supervision, it is unlikely to be widely available to many older adults. Therefore, future research should aim to establish the role of supervision on affective responses to resistance exercise in older adults to further inform programme design and predict long-term adherence of resistance exercise with/without supervision.

This study is not without limitations. It is possible that the high PACES scores were not a true indication that the exercise was enjoyed to a high extent. Despite clear instructions to respond to all measures based on the exercise performed, it is unclear if socialisation between participants and/or the researcher was really the driving force behind the high enjoyment found across all conditions. Future research examining if or how supervision can influence enjoyment of resistance exercise in older adults would therefore be welcome. Secondly, although the older adults that volunteered for the present study were resistance exercise naïve, they were moderately-highly active, meaning caution should be applied when generalising these findings to more sedentary older adults. Despite basing the decision to not assess in-task effective responses on the findings from study 3, it is possible that a relief effect was present and the affective rebound following exercise may have distorted any differences between exercise conditions. Lastly, it may have been useful to have assessed psychological states following a period of recovery, as psychological responses to exercise may have been obscured by the physiological responses to exercise.

6.5 Conclusion

In the present study, both supervised HVLL and LVHL whether performed once or twice-weekly, produced similar affective responses in a group of active older adults. LVHL conditions were perceived to have a greater workload and to be more fatiguing, but this did not negatively impact enjoyment. This may suggest that moderately-highly active older adults report similarly positive affective responses when performing higher or lower-intensity resistance exercise. As higher intensity resistance exercise has been suggested to be important for optimising strength and functional performance gains in older adults (Fisher et al. 2017), exercise professionals may maximise physiological benefits by utilising greater exercise intensities, without compromising enjoyment and adherence. However, as participants in the present study were moderately-highly active, caution should be applied when generalising these findings to more sedentary older adults. Future research should aim to better understand the role that supervision and habitual physical activity have on affective responses to such resistance exercise programmes in older adults.

Chapter 7: Study 5

Published in: European Journal of Sport Science.

Richardson, D. L., Duncan, M. J., Jimenez, A., Juris, P. M., and Clarke, N. D. (2018) 'Effects of Movement Velocity and Training Frequency of Resistance Exercise on Functional Performance in Older Adults: A Randomised Controlled Trial'. *European Journal of Sport Science,* 1-13

Data for this study was collected at the same time as study 4

Given that study 4 revealed that both HVLL and LVHL were enjoyed similarly, study 5 examined functional performance, maximal strength and body composition following a 10-week intervention using both HVLL and LVHL resistance exercise. Furthermore, the release of the systematic review by Byrne et al. (2016) informed the decision to investigate the impact of these types of resistance exercise when performed either, once or twice-weekly in order to investigate the minimal effective dose of resistance exercise.

7.1 Introduction

Exacerbated by physical inactivity (Doherty 2003), ageing is characterised by the progressive loss of muscle mass, muscle strength, and decline of functional performance (Barber et al. 2015). Reductions in functional performance are facilitated by physiological and structural alterations such as: type 2 myofibre atrophy, altered hormone status, protein synthesis and muscle architecture (Raj et al. 2010). Consequently, the ability to complete activities of daily living becomes impaired, reducing independence and quality of life (Doherty 2003). Given the global population of older adults is growing rapidly (He et al. 2016), the development of interventions that preserve physical function are vital.

Resistance exercise attenuates losses of strength, power, muscle mass and functional performance in older adults (Raj et al. 2010). As muscle power better predicts performance of activities of daily living than strength (Beltran Valls et al. 2014) and muscle power recedes faster than strength in older adults (de Vos et al. 2005), developing/maintaining peak power may be more important than strength for retaining function and independence (Bean et al. 2002). However, Fisher et al. (2017) recommended that explosive movements should be avoided during resistance exercise. A subsequent commentary by Cadore et al. (2018) strongly rebutted these claims, evidencing that despite a plethora of investigation, there is still no definitive recommendation for resistance exercise prescription in older adults. Furthermore, the heterogeneous nature of research in older adults (Barbalho et al. 2017) (e.g. training frequency, velocity, volume, load, intensity, rest etc.) has led to unclear conclusions as to whether power or strength training is most effective for improving physical function (Marsh et al. 2009). Although, a recent systematic review reported that 10/13 studies identified power training as superior for improving muscle power or functional performance compared to traditional strength training (Byrne et al. 2016), there was a bias towards the recruitment of female participants which may have skewed conclusions. Therefore, more studies should at least have equal number of male and female participants.

Physical activity guidelines in the United Kingdom (Bull et al. 2010) recommend that older adults perform whole-body strength training at least twice-weekly, despite little experimental evidence to support such a recommendation (Turpela et al. 2017). Commonly cited barriers to exercise for older adults are time and cost (Foley et al. 2011). Considering many older adults would need supervision, cost is a significant factor when performing resistance exercise at least twice-weekly. Therefore, it would be beneficial to understand the minimal effective dose of resistance exercise that facilitates physiological and functional benefits. Taaffe et al. (1999) demonstrated that once-weekly, progressive resistance exercise using 3 sets of 8 exercises at 80% one-repetition maximum (1RM), produced similar strength gains to twice or thrice-weekly. Foley et al. (2011) observed that once-weekly exercise was equally effective as twice-weekly in maintaining strength and functional outcomes, three months following a rehabilitation programme. Sousa et al. (2013) observed that resistance exercise once-weekly (3 sets of 8-12 repetitions on 7 exercises at 65-75% 1RM) for 32 weeks improved maximal strength and had beneficial effects on functional fitness. Turpela et al. (2017) concluded that resistance exercise 1-2 times weekly could elicit similar functional capacity improvements to thrice-weekly. Therefore, more focus on the differences between once and twice-weekly is needed to further ascertain the minimal effective training dose.

Foley et al. (2011) investigated the preference for frequency of exercise in a group of older adults, of the 94 participants who completed a 12-week community-based exercise referral programme, 66% preferred to exercise once-weekly, 26% preferred twice-weekly, 1% preferred thrice-weekly. This may mean that once-weekly resistance exercise could address common barriers like participant burden and cost, potentially improving long-term adherence (Foley et al. 2011). Furthermore, Byrne et al. (2016) advocated investigation into the minimal effective training dose of resistance exercise (training volumes and/or frequency), suggesting that the efficacy of once-weekly resistance exercise for improvements in muscle power and functional performance warrants further investigation. Therefore, the objectives of the present study were to investigate the effects that supervised programmes of HVLL (high-velocity, low-load) and LVHL (low-velocity, high-load) performed once or twice-weekly, have on indices of functional performance (Primary outcomes), maximal strength, and body composition (secondary outcomes). As Gentil et al. (2017) suggests that the use of heavy relative loads, performing exercise at high movement velocity, or training to momentary failure stimulates type II fibres, ultimately improving strength and the ability to carry out activities that require speed/power. It is hypothesised that: 1) HVLL and LVHL will similarly impact maximal strength and functional performance and 2) due to greater exercise volume, improvements will be enhanced in the twice-weekly, compared to the once-weekly conditions.

7.2 Methods

7.2.1 Design

A 10-week, randomised, controlled, multi-armed, parallel study was conducted to determine the effects of HVLL and LVHL, performed once or twice-weekly on functional performance, maximal strength and body composition. Participants were randomised (1:1 ratio) by an independent researcher using minimisation, to ensure small variances in sex and age between conditions. Participants and researchers were not blinded, as exercise conditions were apparent, and the same researcher carried out baseline, post-intervention testing and all intervention sessions. No methodological changes were made prior to commencement. Institutional ethics approval was obtained (Appendix A), and all participants were made aware of the exercise conditions before providing informed consent (Appendix B).

7.2.2 Participants

Through self-selection, 54 community-dwelling, Caucasian, males and females (Table 7.1) were recruited between March 2017 and November 2017 in Coventry, United Kingdom. The CONSORT diagram (Figure 7.1) shows 50 participants completed all assessments and were included in analyses. No data from participants that discontinued the intervention at any stage were used in any data analyses. Prior to randomising, each participant met the same inclusion criteria detailed in section 6.2.2. Medical conditions that did not violate the inclusion/ exclusion criteria were permitted. The most commonly medicated conditions were high blood pressure (28%) and acid reflux (14%). Minimisation was used to assign one of the following experimental conditions, after the first participant in each condition was truly, randomly allocated: (1) high-velocity, low-load once-weekly (HVLL1) (2) low-velocity, high-load once-weekly (LVHL1) (3) high-velocity, low-load twice-weekly (HVLL2) (4) low-velocity, high-load twice-weekly (LVHL2) (5) no exercise control condition (CON). All functional assessments took place in a private strength and conditioning suite and each exercise session in Coventry University gym.

Table 7.1. Participant characteristics

	HVLL1 (*n* = 10; 5m, 5f)	LVHL1 (*n* = 10; 5m, 5f)	HVLL2 (*n* = 10; 5m, 5f)	LVHL2 (*n* = 10; 5m, 5f)	CON (*n* = 10; 5m, 5f)
Age (years)	66 ± 5	67 ± 4	67 ± 6	66 ± 6	65 ± 5
Age Range (years)	60 – 74	60 – 72	60 – 78	60 – 79	61 – 76
Height (cm)	168.7 ± 7.4	167.2 ± 11.1	173.3 ± 9.7	166.8 ± 8.9	170.4 ± 9.5
Body Mass (kg)	80.0 ± 16.9	76.3 ± 11.8	83.2 ± 13.5	73.0 ± 13.4	71.4 ± 12.7
BMI (kg/m^2)	28 ± 5	28 ± 5	28 ± 5	26 ± 4	24 ± 3
Physical Activity (MET-min/week)	2919 (1771 – 4345)	3264 (2064 – 4067)	3095 (2381 – 4487)	2355 (1074 – 4026)	1767 (984 – 3428)
Daily Sitting (min)	330 (255 – 368)	195 (165 – 285)	240 (180 – 263)	360 (255 – 465)	300 (240 – 360)
Medical Conditions	1 ± 2	1 ± 1	1 ± 1	1 ± 1	1 ± 1
Number of Medications	2 ± 3	1 ± 1	1 ± 1	2 ± 2	1 ± 1
Most Commonly Medicated Condition(s)	High Blood Pressure (3/10)	Acid Reflux (2/10)	High Blood Pressure (2/10)	High Blood Pressure (5/10) Acid Reflux (2/10)	High Blood Pressure (4/10)
Most Common medication(s)	Simvastatin Atorvastatin	Omeprazole	Amlodipine Ramipril	Simvastatin Valsartan Omeprazole	Amlodipine Atenolol Atorvastatin
Daily Macronutrients					
Carbohydrate (g)	237 ± 83	231 ± 74	233 ± 72	245 ± 74	233 ± 64
Protein (g)	72 ± 21	75 ± 24	65 ± 22	67 ± 24	65 ± 23
Fat (g)	75 ± 38	67 ± 33	69 ± 27	68 ± 22	58 ± 26
Calories (Kcal)	1974 ± 609	1840 ± 571	1875 ± 507	1903 ± 509	1734 ± 471

Note: Values are mean ± SD except for weekly activity and sitting which are the median and interquartile ranges; m = male f = female; HVLL1 = High-velocity, low-load once-weekly; LVHL1 = Low-velocity, high-load once-weekly; HVLL2 = High-velocity, low-load twice-weekly; LVHL2 = Low-velocity, high-load twice-weekly; CON = Control condition

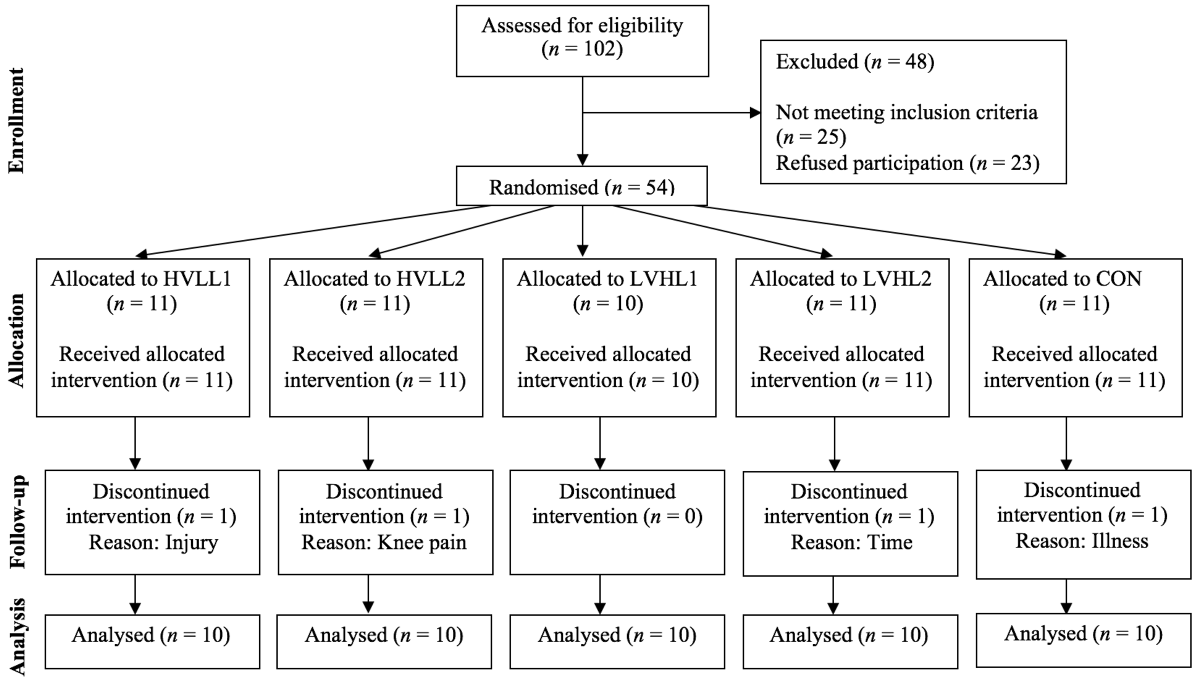

Figure 7.1. CONSORT flow diagram of progress through phases of the study

Note: HVLL1 = High-velocity, low-load once-weekly; LVHL1 = Low-velocity, high-load once-weekly; HVLL2 = High-velocity, low-load twice-weekly; LVHL2 = Low-velocity, high-load twice-weekly; CON = Control condition

7.2.3 Physical and physiological assessments

Firstly, blood pressure (Omron M3 Intellisense HEM-7200-E, Omron Matsusaka Co Ltd, Kyoto, Japan) was taken from the right arm, in the seated position, following 10 minutes quiet sitting, to rule out uncontrolled hypertension. Height (cm) was measured using a stadiometer (Seca Instruments, Hamburg, Germany). Body mass, body composition, fat free mass (FFM) and fat mass were analysed using a Tanita BC-418MA (Tanita Corporation, Tokyo, Japan) which uses a three-compartment model of body composition analysis. Body mass index (BMI) was calculated using height and body mass. The International physical activity questionnaire (IPAQ) (Craig et al. 2003) assessed habitual physical activity levels (Table 7.1) and are reported in accordance with the IPAQ website (www.ipaq.ki.se). The present study population were classified as moderately-highly active. The late-life function and disability instrument (LLFDI) (Haley et al. 2002; Jette et al. 2002) assessed perception of function and disability. Raw LLFDI scores were scaled (0-100) for easier clinical interpretation (LaPier 2012), with higher scores indicating less limitation, more frequency etc. Finally, a 7-day food diary was completed over consecutive days. The front page contained instructions, to ensure details of preparation and portion sizes of all foods and beverages were reported (Bingham et al. 1994).

MyNetDiary Pro (iPhone App Version 5.45) calculated average daily calories (Kcal), protein (g), carbohydrate (g) and fat (g) (Table 7.1).

7.2.4 Functional performance assessments

A warm-up consisting of five minutes cycling at a self-selected pace and five dynamic stretches was completed before all assessments and exercise sessions. The 30-sec chair stand, arm curl, 6-min walk, chair sit-&-reach, back scratch and 8-ft up-&-go assessments were administered in accordance with the senior fitness test (Rikli and Jones 1999) and balance tests with the short physical performance battery (SPPB) (Guralnik et al. 1994). Grip-strength was measured using a digital strain-gauge dynamometer (Takei TKK 5401, Takei Scientific Instruments, Tokyo, Japan) using instructions from the Groningen fitness test for the elderly (Lemmink et al. 2001). The least fatiguing assessments were performed first, and assessments that required more skilful movements were performed before more fatiguing assessments (Hoffman 2012). The techniques and procedures for each test were thoroughly explained and demonstrated. Participants then completed a familiarisation attempt, followed by two experimental attempts, with the best performance recorded. To avoid excessive fatigue, the 6-min walk, 30-sec chair stand and arm curl tests were performed once. The time of day that participants completed baseline testing was repeated post-intervention, to reduce variation in the physical and performance tests due to circadian variation.

7.2.5 One-repetition maximum assessments

The procedure for the prediction of 1RM's was identical as described in section 3.2.3.

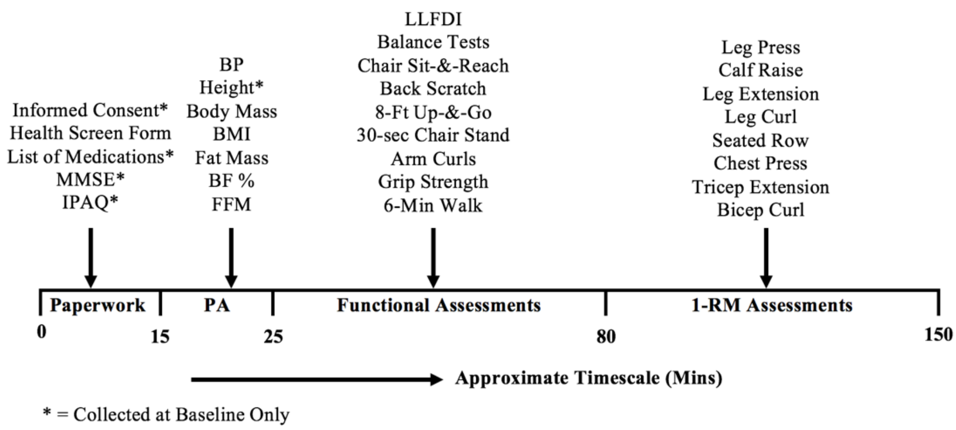

Figure 7.2. Schematic diagram of the baseline and post-intervention assessments

Note: MMSE = Mini-mental state examination; IPAQ = International physical activity questionnaire; LLFDI = Late-life function and disability instrument; BF% = Body fat percentage; FFM = Fat free mass; RHR = Resting heart rate; BP = Blood pressure; PA = Physical assessments; 1RM = One-repetition maximum

7.2.6 Resistance exercise conditions

The resistance exercise protocols were identical to those describe in section 6.2.10. Meanwhile, CON continued habitual activity and made no efforts to change daily habits. To ensure all scheduled sessions were completed, the intervention period was extended if sessions were missed, resulting in a maximum duration of 10 weeks and 6 days.

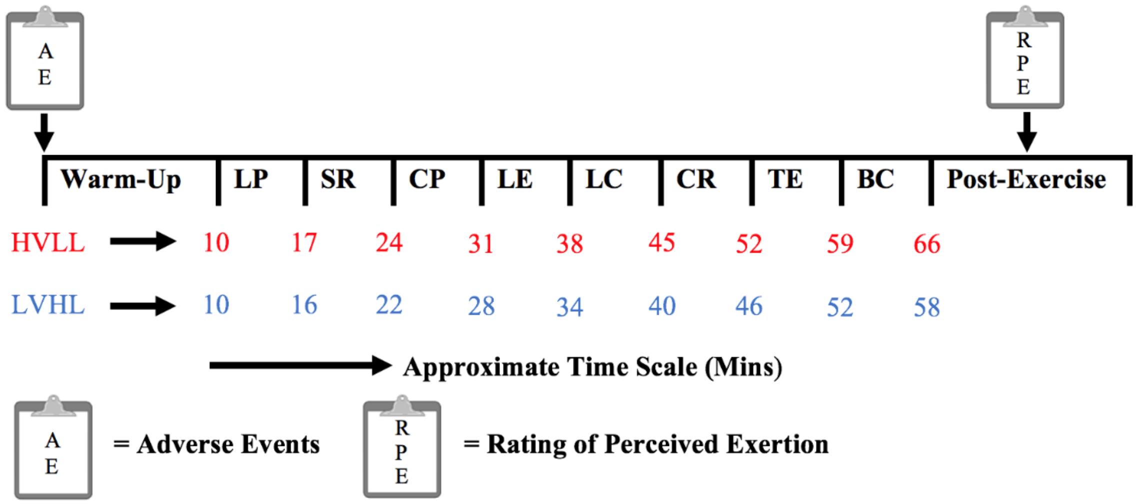

Figure 7.3. A schematic diagram of each resistance exercise session

Note: LP = Leg Press; SR = Seated Row; CP = Chest Press; LE = Leg Extension; LC = Leg Curl; CR = Calf Raise; TE = Tricep Extension; BC = Bicep Curl; HVLL = High-velocity, Low-load; LVHL = Low-velocity, High-load

7.2.7 Progression of programmes

Rating of perceived exertion (Borg 1982) was recorded (Appendix C5) immediately following each session and used to progress programmes as described in section 6.2.7. This method of progression, allows participants some control over progression of intensity, which may be important for enhancing exercise pleasure and adherence (Lind et al. 2008). One LVHL2 participant rated their 20th session RPE 10. Four HVLL1 participants rated sessions as RPE 10 in week 8 (*n*=2) and 9 (*n*=2), and two HVLL2 participants in weeks 4 and 7, there were zero ratings of RPE 10 in LVHL1.

7.2.8 Adverse events

Prior to each session, a self-report adverse events form was completed (Appendix C7), detailing adverse events since the previous session. Serious adverse events were defined as: deaths, prolonged hospital visits, significant incapacity or substantial disruptions in performing everyday tasks and minor adverse events were defined as any event causing minor discomfort or inconvenience (Goodrich et al. 2007).

7.2.9 Sample size

Based on analysis of covariance (ANCOVA), reported effect sizes from Liu and Latham (2009) revealed a sample size of 18 and 22 in each group is necessary to detect changes in strength and functional performance, ensuring, 1–β=0.80 for an alpha level of 0.05 (Walker et al. 2017). However, Taaffe et al. (1999) suggest that 11 per group is sufficient to detect strength differences and Seynnes et al. (2004) suggest 18 per group for functional performance differences in older adults. Therefore, despite great effort to recruit more participants, the sample size is low. To ameliorate this, ancillary analyses were conducted to strengthen the conclusions.

7.2.10 Statistical analysis

All data were analysed using IBM SPSS Statistics, Version 24.0 (Armonk, NY: IBM Corp) and descriptive statistics presented as mean ± SD, and 95% confidence intervals (95%CI). Normality of data was assessed using the Shapiro-Wilk test and manual analysis of the plotted data. Any scale data that was non-normally distributed was log transformed and reassessed for normality using the residuals (Kozak and Piepho 2018). Providing the data presented a normal distribution it was analysed with the appropriate parametric statistical test. One-way analysis of variance (ANOVA) compared baseline differences between conditions, including IPAQ scores and daily macronutrients. Analysis of covariance (ANCOVA), analysed between-condition differences, using baseline data as a covariate. Within-condition changes were analysed with Bonferroni corrected paired t-tests. Ancillary ANCOVA analyses were performed to compare the impact of movement velocity only [HVLL (n=20) vs. LVHL (n=20) vs. CON (n=10)] or frequency of exercise only [Once (n = 20) vs. twice weekly (n = 20) vs. CON (n=10)] and are only reported when significant. All Significance tests were two-tailed with an alpha level of 0.05 required for significance. All p-values are reported as exact values unless p<0.001. Partial eta squared was used to quantify the meaningfulness of any differences, and defined as trivial (<0.1), small (0.1-0.29), moderate (0.3-0.49) or large (≥0.5) (Hopkins et al. 2009). Hedges' g effect size estimates were selected as they allow correction for smaller sample sizes, and were calculated using the adjusted means and pooled SD. The interpretation of Hedges' g is similar to Cohens d e.g. small (0.2-0.49), moderate (0.5-0.79), and Large (≥0.8) (Balachandran et al. 2014).

7.3 Results

There were no significant baseline differences between conditions in any of the physical or physiological characteristics, IPAQ scores or daily macronutrients. However, 1RM's for HVLL2 were greater than CON for leg extension (Bonferroni p=0.027 95% CI 1.4, 37.1) and greater than LVHL1 for calf raise (Bonferroni p=0.017; 95% CI 4.9, 79.1). Finally, LVHL1 had greater chair sit-&-reach right-leg flexibility than CON (Bonferroni p=0.019; 95% CI: -33.0, -1.9).

7.3.1 Primary Outcomes

7.3.1.1 Balance assessments

The SPPB balance tests involve standing unsupported with the feet in 3 different positions (together, semi-tandem and full-tandem) for 10 s. All 50 participants successfully completed all balance assessments at baseline and post-intervention.

7.3.1.2 Flexibility assessments

There were trivial differences between conditions for chair sit-&-reach performance for both right ($F_{(4,44)}$=0.800; p=0.535; η_p^2 =0.07;Table 7.3) and left legs ($F_{(4,44)}$=0.427; p=0.788; η_p^2 =0.04) and back scratch right ($F_{(4,44)}$=0.537; p=0.683; η_p^2 =0.05;Table 3) and left arms ($F_{(4,44)}$=0.348; p=0.844; η_p^2 =0.03).

7.3.1.3 8-Ft Up-&-Go

Within-condition analysis revealed LVHL1 reduced their completion time by 7% (Bonferroni p=0.010; 95%CI: -0.69,-0.12; g=0.60) and HVLL2 by 8% (Bonferroni p=0.002; 95%CI:-0.62,-0.20; g=0.41). There were small differences between conditions ($F_{(4,44)}$=2.183; p=0.087; η_p^2 =0.17; Table 7.3). However, ancillary analyses indicated that there were small differences between velocity ($F_{(4,46)}$=3.214; p=0.049; η_p^2 =0.12) and frequency ($F_{(4,46)}$=3.243; p=0.048; η_p^2 =0.12). HVLL (Bonferroni p=0.050; 95%CI: -0.8, 0.0; g=0.38) and twice-weekly (Bonferroni p=0.048; 95%CI: -0.8, 0.0; g=0.52) reduced 8-Ft Up-&-Go times compared to CON.

7.3.1.4 Chair Stands

Within-condition analysis revealed HVLL1 increased the number of completed chair stands by 13% (Bonferroni p=0.012; 95%CI: 0.48,2.92; g=0.39), LVHL1 by 15% (Bonferroni p=0.012; 95%CI: 0.48,2.92; g=1.46), HVLL2 by 10% (Bonferroni p=0.048; 95%CI: 0.02,2.98; g=0.35) and LVHL2 by 20% (Bonferroni p=0.023; 95%CI: 0.46,4.94; g=0.76). There approached being significant differences between conditions ($F_{(4,44)}$=2.506; p=0.056; η_p^2 =0.19), only

LVHL2 improved performance compared to CON (Bonferroni p=0.035; 95%CI: 0.13,5.95; g=0.89; Table 7.3). Ancillary analyses indicated that there were small differences between velocities ($F_{(2,46)}$=3.937; p=0.026; η_p^2 =0.15) and frequency ($F_{(2,46)}$=4.584; p=0.015; η_p^2 =0.17). LVHL (Bonferroni p=0.027; 95%CI: 0.2, 4.5; g=0.75) and twice-weekly (Bonferroni p=0.012; 95%CI: 0.5, 4.7; g=0.70) improved chair stand performance compared to CON.

7.3.1.5 Arm Curls

Within-condition analysis revealed HVLL1 increased the number of completed arm curls by 25% (Bonferroni p=0.029; 95%CI:0.47,6.73; g=0.68), HVLL2 by 15% (Bonferroni p=0.026; 95%CI:0.42,5.18; g=0.41) and LVHL2 by 43% (Bonferroni p=0.002; 95%CI:2.86,9.34; g=1.54). There were also moderate differences between conditions ($F_{(4,44)}$=4.700; p=0.003; η_p^2 =0.30; Table 7.3), LVHL2 improved performance compared to LVHL1 (Bonferroni p=0.020; 95%CI: 0.57,10.82; g=1.51) and CON (Bonferroni p=0.011; 95%CI: 0.95,11.19; g=1.65). Ancillary analyses indicated that there were small differences between velocity ($F_{(2,46)}$=3.175; p=0.050; η_p^2 =0.12) and frequency ($F_{(2,46)}$=7.047; p=0.002; η_p^2 =0.24). HVLL improved performance compared to CON (Bonferroni p=0.050; 95%CI: -0.0, 8.3; g=0.84) and twice-weekly improved performance compared to both once-weekly (Bonferroni p=0.029; 95%CI: 0.3, 6.6; g=0.68). and CON (Bonferroni p=0.003; 95%CI: 1.6, 9.3; g=1.09).

7.3.1.6 Grip-Strength Dominant Hand

There were small differences between conditions ($F_{(4,44)}$=1.989; p=0.113; η_p^2 =0.15;Table 7.3). Ancillary analyses indicated that there were small differences between velocities ($F_{(2,46)}$=3.932; p=0.027; η_p^2 =0.15), LVHL improved grip-strength compared to CON (Bonferroni p=0.030; 95%CI: 0.3, 6.3; g=0.32).

7.3.1.7 Grip-Strength Non-Dominant Hand

Within-condition analysis revealed LVHL2 increased grip-strength by 10% (Bonferroni p=0.003; 95%CI: 1.1, 4.1; g=0.23). There were small differences between conditions ($F_{(4,44)}$=3.103; p=0.025; η_p^2 =0.22; Table 7.3), LVHL2 improved grip-strength compared to CON (Bonferroni p=0.015; 95%CI: 0.5,7.1; g=0.34). Ancillary analyses indicated that there were small differences between velocities ($F_{(2,46)}$=4.287; p=0.020; η_p^2 =0.16) and frequencies ($F_{(2,46)}$=4.750; p=0.013; η_p^2 =0.17). LVHL (Bonferroni p=0.018; 95%CI: 0.4, 5.3; g=0.29) and twice-weekly (Bonferroni *p*=0.012; 95%CI: 0.5, 5.4; *g*=0.26) improved grip-strength compared to CON.

7.3.1.8 6-Min Walk

Within-condition analysis revealed LVHL1 increased distance covered in the 6-min walk by 8% (Bonferroni *p*=0.007; 95%CI: 15.03,70.57; *g*=0.55), HVLL2 by 7% (Bonferroni *p*=0.002; 95%CI: 21.02,64.89; *g*=0.51) and LVHL2 by 7% (Bonferroni *p*=0.009; 95%CI: 12.82,68.38; *g*=0.39). There were small differences between conditions ($F_{(4,44)}$=1.811; *p*=0.144; η_p^2 =0.14;Table 7.3).

7.3.1.9 LLFDI

Within-condition analyses revealed that only self-reported limitation decreased by 11% in HVLL2 (Bonferroni *p*=0.047; 95%CI: 0.18,18.96; *g*=0.81). There were small differences between conditions for LLFDI function ($F_{(4,44)}$=1.268; *p*=0.297; η_p^2 =0.10; Table 7.5), LLFDI limitation ($F_{(4,44)}$=2.491; *p*=0.057; η_p^2 =0.19) and trivial differences for LLFDI frequency ($F_{(4,44)}$=0.657; *p*=0.625; η_p^2 =0.06). Ancillary analyses indicated that there were small differences between frequencies ($F_{(2,46)}$=4.327; *p*=0.019; η_p^2 =0.16), twice-weekly resulted in less self-reported limitation than once-weekly (Bonferroni *p*=0.022; 95%CI: 0.8, 12.8; *g*=0.65).

7.3.2 Secondary Outcomes

7.3.2.1 Leg press

Within-condition, LVHL1 improved strength by 20% (Bonferroni *p*=0.002; 95%CI: 10.1, 31.4; *g*=0.65) and LVHL2 by 25% (Bonferroni *p*=0.003; 95%CI: 12.7, 44.0; *g*=0.77). There approached significant differences between conditions ($F_{(4,44)}$=2.511; *p*=0.055; η_p^2 =0.19; Table 7.2). Pairwise comparisons revealed that only LVHL2 improved strength compared to CON (Bonferroni *p*=0.039; 95%CI: 0.9, 58.0; *g*=0.71). Ancillary analyses revealed small differences between velocity ($F_{(2,46)}$=4.778; *p*=0.013; η_p^2 =0.17) and frequency ($F_{(2,46)}$=3.953; *p*=0.026; η_p^2 =0.15). LVHL (Bonferroni *p*=0.011; 95%CI: 4.9, 45.6; *g*=0.66) and twice-weekly (Bonferroni *p*=0.025; 95%CI: 2.4, 45.5; *g*=0.58) improved strength compared to CON.

7.3.2.2 Calf Raise

Within-condition, HVLL1 improved strength by 17% (Bonferroni $p=0.015$; 95%CI: 4.7, 34.0; $g=0.73$), LVHL1 by 30% (Bonferroni $p<0.001$; 95%CI: 19.9, 38.6; $g=0.88$) and LVHL2 by 35% (Bonferroni $p<0.001$; 95%CI: 31.4, 50.8; $g=1.50$). There were moderate differences between conditions ($F_{(4,44)}=5.575$; $p=0.001$; $\eta_p^2=0.34$; Table 7.2). LVHL2 improved strength compared to HVLL2 (Bonferroni $p=0.009$; 95%CI: 5.3, 55.8; $g=1.00$) and CON ($p=0.001$; 95%CI: 10.1, 59.1; $g=1.05$). Ancillary analyses revealed small differences between velocity ($F_{(2,46)}=8.861$; $p=0.001$; $\eta_p^2=0.28$) and frequency ($F_{(2,46)}=3.565$; $p=0.036$; $\eta_p^2=0.13$). LVHL improved strength compared to both HVLL (Bonferroni $p=0.009$; 95%CI: 4.0, 35.1; $g=0.60$) and CON (Bonferroni $p=0.001$; 95%CI: 9.7, 45.9; $g=0.80$) and twice-weekly improved strength compared to CON (Bonferroni $p=0.037$; 95%CI: 1.0, 42.0; $g=0.66$).

7.3.2.3 Leg extension

Within-condition, LVHL1 improved strength by 25% (Bonferroni $p=0.002$; 95%CI: 4.9, 16.2; $g=0.68$), HVLL2 by 9% (Bonferroni $p=0.022$; 95%CI: 0.9, 9.0; $g=0.23$) and LVHL2 by 40% (Bonferroni $p<0.001$; 95%CI: 11.9, 22.4; $g=1.29$). There were also moderate differences between conditions ($F_{(4,44)}=5.961$; $p=0.001$; $\eta_p^2=0.35$; Table 7.2). LVHL2 improved strength compared to HVLL1 (Bonferroni $p=0.002$; 95%CI: 3.5, 22.7; $g=1.02$), HVLL2 (Bonferroni $p=0.013$; 95%CI: 1.6, 21.7; $g=0.65$). and CON (Bonferroni $p=0.003$; 95%CI: 3.2, 22.5; $g=0.98$). Ancillary analyses revealed small differences between velocities ($F_{(2,46)}=9.283$; $p<0.001$; $\eta_p^2=0.29$). LVHL improved strength compared to HVLL (Bonferroni $p=0.001$; 95%CI: 3.2, 15.1; $g=0.57$) and CON (Bonferroni $p=0.007$; 95%CI: 2.2, 16.7; $g=0.62$).

7.3.2.4 Leg curl

Within-condition, LVHL1 improved strength by 21% (Bonferroni $p=0.001$; $g=0.51$), HVLL2 by 10% (Bonferroni $p=0.020$; $g=0.25$) and LVHL2 by 28% (Bonferroni $p<0.001$; $g=0.87$). However, there were small differences between conditions ($F_{(4,44)}=1.883$; $p=0.130$; $\eta_p^2=0.15$; Table 7.2).

7.3.2.5 Seated row

Within-condition, HVLL1 improved strength by 7% (Bonferroni $p=0.044$; 95%CI: 0.1, 7.6; $g=0.28$), LVHL1 by 14% (Bonferroni $p=0.005$; 95%CI: 2.7, 11.3; $g=0.43$) and HVLL2 by 11% (Bonferroni $p=0.039$; 95%CI: 0.4, 12.8; $g=0.28$) and LVHL2 by 27% (Bonferroni $p<0.001$; 95%CI: 9.8, 17.9; $g=0.81$). There were moderate differences between conditions ($F_{(4,44)}=8.581$;

$p<0.001; \eta_p^2=0.44$; Table 7.2). LVHL1 (Bonferroni *p*=0.022; 95%CI: 0.8, 17.2; *g*=0.52), HVLL2 (Bonferroni *p*=0.040; 95%CI: 0.2, 16.7; *g*=0.40) LVHL2 (Bonferroni *p*<0.001; 95%CI: 7.7, 24.0; *g*=0.89) all improved strength compared to CON. LVHL2 also improved strength compared to HVLL1 (Bonferroni *p*=0.008; 95%CI: 1.8, 18.2; *g*=0.62). Ancillary analyses revealed moderate differences between velocities ($F_{(2,46)}=12.299$; $p<0.001; \eta_p^2=0.35$). Both HVLL (Bonferroni *p*=0.022; 95%CI: 0.8, 13.4; *g*=0.38) and LVHL (Bonferroni *p*<0.001; 95%CI: 6.1, 18.7; *g*=0.71) improved strength compared to CON. LVHL also improved strength compared to HVLL (Bonferroni *p*=0.043; 95%CI: 0.1, 10.5; *g*=0.29). Lastly, there were moderate differences between frequencies ($F_{(2,46)}=11.520$; $p<0.001; \eta_p^2=0.33$). Once (Bonferroni *p*=0.017; 95%CI: 1.1, 13.8; *g*=0.48). and twice-weekly (Bonferroni *p*<0.001; 95%CI: 5.9, 18.6; *g*=0.62) improved strength compared to CON.

7.3.2.6 Chest press

Within-condition, LVHL1 improved strength by 18% (Bonferroni *p*=0.001; 95%CI: 3.3, 8.2; *g*=0.27), HVLL2 by 12% (Bonferroni *p*=0.016; 95%CI: 1.2, 9.4; *g*=0.25) and LVHL2 by 24% (Bonferroni *p*<0.001; 95%CI: 5.6, 13.2; *g*=0.43). There were also moderate differences between conditions ($F_{(4,44)}=6.048$; $p=0.001; \eta_p^2=0.36$; Table 7.2). LVHL1 (Bonferroni *p*=0.027; 95%CI: 0.5, 13.9; *g*=0.36), HVLL2 (Bonferroni *p*=0.047; 95%CI: 0.1, 13.5; *g*=0.33) and LVHL2 (Bonferroni *p*<0.001; 95%CI: 4.2, 17.5; *g*=0.49) increased strength compared to CON. Ancillary analyses indicated moderate differences between velocity ($F_{(2,46)}=10.470$; $p<0.001; \eta_p^2=0.31$) and frequency ($F_{(2,46)}=9.860$; $p<0.001; \eta_p^2=0.30$). Both HVLL (Bonferroni *p*=0.010; 95%CI: 1.2, 11.0; *g*=0.31) and LVHL (Bonferroni *p*<0.001; 95%CI: 4.1, 13.9; *g*=0.43) improved strength compared to CON and both, once (Bonferroni *p*=0.008; 95%CI: 1.4, 11.3; *g*=0.34) and twice-weekly (Bonferroni *p*<0.001; 95%CI: 3.9, 13.8; *g*=0.42) improved strength compared to CON.

7.3.2.7 Tricep Extension

Within-condition, HVLL1 improved strength by 18% (Bonferroni *p*=0.018; 95%CI: 1.0, 8.1; *g*=0.49), LVHL1 by 24% (Bonferroni *p*=0.001; 95%CI: 3.0, 8.1; *g*=0.44), HVLL2 by 16% (Bonferroni *p*=0.001; 95%CI: 2.4,7.2; *g*=0.30) and LVHL2 by 33% (Bonferroni *p*<0.001; 95%CI: 4.8, 11.7; *g*=0.70). There were also small differences between conditions ($F_{(4,44)}=3.132$; $p=0.024; \eta_p^2=0.22$; Table 7.2). LVHL2 improved strength compared to CON (Bonferroni *p*=0.011; 95%CI: 1.0, 12.2; *g*=0.50). Ancillary analyses revealed small differences between velocity ($F_{(2,46)}$=4.957; *p*=0.011; η_p^2 =0.18) and frequency ($F_{(2,46)}$=4.892; *p*=0.012; η_p^2 =0.18). LVHL (Bonferroni *p*=0.009; 95%CI: 1.1, 9.2; *g*=0.41) and twice-weekly (Bonferroni *p*=0.009; 95%CI: 1.1, 9.3; *g*=0.38) improved strength compared to CON.

7.3.2.8 Bicep curl

Within-condition, LVHL1 improved strength by 25% (Bonferroni *p*=0.001; 95%CI: 2.7, 7.1; *g*=0.47), HVLL2 by 12% (Bonferroni *p*=0.003; 95%CI: 1.3, 4.9; *g*=0.25) and LVHL2 by 45% (Bonferroni *p*<0.001; 95%CI: 5.3, 12.5; *g*=0.72). There were also moderate differences between-conditions ($F_{(4,44)}$=5.026; *p*=0.002; η_p^2 =0.31; Table 7.2). LVHL2 improved strength compared to HVLL1 (Bonferroni *p*=0.010; 95%CI: 1.0, 11.2; *g*=0.52), HVLL2 (Bonferroni *p*=0.028; 95%CI: 0.4, 10.7; *g*=0.43) and CON (Bonferroni *p*=0.002; 95%CI:1.8, 12.0; *g*=0.53). Ancillary analyses indicated that there were small differences between velocity ($F_{(2,46)}$=6.744; *p*=0.003; η_p^2 =0.23) and frequency ($F_{(2,46)}$=3.599; *p*=0.035; η_p^2 =0.14). LVHL improved strength compared to HVLL (Bonferroni *p*=0.014; 95%CI: 0.6, 7.0; *g*=0.34) and CON (Bonferroni *p*=0.008; 95%CI: 1.0, 8.7; *g*=0.41) and twice-weekly improved strength compared to CON (Bonferroni *p*=0.040; 95%CI: 0.1, 8.3; *g*=0.34).

7.3.3 Physical Assessments

There were small differences between conditions for BMI ($F_{(4,44)}$=2.111; *p*=0.096; η_p^2 =0.16; Table 7.4) and body mass ($F_{(4,44)}$=2.537; *p*=0.053; η_p^2 =0.19; Table 4). However, both BMI (Bonferroni *p*=0.047; 95%CI: -0.7,-0.0; *g*=0.09; Table 3) and body mass (Bonferroni *p*=0.037; 95%CI: -2.0,-0.1; *g*=0.07) decreased significantly in HVLL2. Pairwise comparisons revealed a significant decrease in HVLL compared to CON for both BMI (Bonferroni *p*=0.045; 95%CI: -0.8, -0.0; *g*=0.10) and body mass (Bonferroni *p*=0.017; 95%CI: -2.4, -0.2; *g*=0.09). Furthermore, there were small differences between conditions for body fat percentage ($F_{(4,44)}$=2.290; *p*=0.075; η_p^2 =0.17; Table 7.4) and fat mass ($F_{(4,44)}$=1.957; *p*=0.118; η_p^2 =0.15; Table 7.4). Within-condition analyses revealed that both body fat percentage (Bonferroni *p*=0.002; 95%CI:0.7,2.2; *g*=0.23) and fat mass (Bonferroni *p*=0.001; 95%CI:0.7,1.9; *g*=0.24) increased in CON. Finally, there were small differences between conditions in FFM ($F_{(4,44)}$=2.909; *p*=0.032; η_p^2 =0.21; Table 7.4). Increases in FFM were significantly greater in LVHL1 compared to HVLL2 (Bonferroni *p*=0.040; 95%CI: 0.04,3.11; *g*=0.16) as HVLL2 experienced losses of FFM (Bonferroni *p*=0.009; 95%CI:-1.95,-0.37; *g*=0.10).

7.3.4 Adverse Events

No serious adverse events were reported in any exercise condition. One HVLL2 participant withdrew with knee pain (causation unclear), and one HVLL1 participant with an abdominal hernia in week 2 (causation unclear). One LVHL2 participant withdrew in week 1 citing "lack of time", and a CON participant withdrew with Ramsay Hunt syndrome (unassociated with study). An injury occurred (unassociated with study) in LVHL1 causing one missed session. Minor adverse events are reported as number of participants affected (p) and number of reports (*n*). There were incidences of mild joint discomfort: HVLL1 (p=3: *n*=5), LVHL1(p=2: *n*=3) HVLL2 (p=3: *n*=3) LVHL2 (p=2: *n*=3) and muscle soreness: HVLL1 (p=3: *n*=8), LVHL1 (p=5: *n*=13) HVLL2 (p=3: *n*=3) LVHL2 (p=4: *n*=12), that did not affect participation.

Table 7.2. Predicted 1RM data (Brzycki 1993) baseline and post-intervention

	HVLL1 (*n* = 10; 5m, 5f)			LVHL1 (*n* = 10; 5m, 5f)			HVLL2 (*n* = 10; 5m, 5f)			LVHL2 (*n* = 10; 5m, 5f)			CON (*n* = 10; 5m, 5f)		
	Mean ± SD	95% CI	ES	Mean ± SD	95% CI	ES	Mean ± SD	95% CI	ES	Mean ± SD	95% CI	ES	Mean ± SD	95% CI	ES
Leg press (kg)															
Baseline	103 ± 23	86.1 – 119.0	–	104 ± 29	83.3 – 125.4	–	135 ± 39	107.0 – 162.9	–	114 ± 28	94.1 – 134.8	–	95 ± 39	67.6 – 123.0	–
Post-intervention	117 ± 29	96.6 – 138.0	0.59	125 ± 32*	102.3 – 147.9	0.65	150 ± 44	118.4 – 181.3	0.34	143 ± 41*#	113.5 – 172.2	0.77	95 ± 38	68.0 – 122.3	0.00
Calf Raise (kg)															
Baseline	116 ± 21	101.1 – 131.6	–	97 ± 31	74.7 – 119.5	–	139 ± 31	117.0 – 161.2	–	117 ± 26	97.8 – 135.3	–	107 ± 30	86.2 – 128.7	–
Post-intervention	136 ± 29*	114.8 – 156.5	0.73	126 ± 32*	103.2 – 149.5	0.88	148 ± 32	124.7 – 170.4	0.26	158 ± 26*#¥	138.8 – 176.5	1.50	115 ± 36	88.8 – 140.7	0.21
Leg Extension (kg)															
Baseline	41 ± 8	35.9 – 46.9	–	42 ± 14	31.3 – 52.0	–	55 ± 21	39.8 – 70.4	–	42 ± 10	35.4 – 49.5	–	36 ± 10	29.2 – 43.0	–
Post-intervention	45 ± 9	39.3 – 51.6	0.48	52 ± 15*	41.2 – 63.2	0.68	60 ± 19*	46.3 – 73.8	0.23	60 ± 15*#¥†	48.8 – 70.3	1.29	41 ± 14	30.6 – 50.6	0.36
Leg Curl (kg)															
Baseline	40 ± 12	31.0 – 48.8	–	37 ± 12	28.2 – 46.1	–	48 ± 17	35.8 – 60.2	–	41 ± 11	33.3 – 48.9	–	36 ± 10	29.4 – 43.5	–
Post-intervention	45 ± 6	40.5 – 49.5	0.49	45 ± 17*	33.1 – 56.8	0.51	53 ± 20*	38.6 – 67.1	0.25	53 ± 14*	42.4 – 62.6	0.87	40 ± 14	29.9 – 50.6	0.29
Seated Row (kg)															
Baseline	53 ± 14	43.3 – 62.6	–	51 ± 15	40.4 – 61.2	–	59 ± 21	43.9 – 73.5	–	51 ± 15	40.2 – 61.7	–	51 ± 19	37.8 – 64.5	–
Post-intervention	57 ± 13*	47.8 – 65.8	0.28	58 ± 17*#	45.7 – 70.0	0.43	65 ± 24*#	48.1 – 82.5	0.28	65 ± 18*#†	52.1 – 77.5	0.81	49 ± 16	37.5 – 60.9	-0.11
Chest Press (kg)															
Baseline	35 ± 14	25.2 – 45.5	–	33 ± 21	17.4 – 47.9	–	44 ± 21	29.6 –59.0	–	38 ± 19	25.0 – 51.9	–	37 ± 19	23.1 – 50.9	–
Post-intervention	39 ± 16	28.2 – 50.6	0.26	38 ± 20*#	24.3 – 52.5	0.27	50 ± 20*#	35.2 – 63.9	0.25	48 ± 23*#	31.5 – 64.2	0.43	36 ± 19	21.9 – 49.3	-0.07
Tricep Extension (kg)															
Baseline	25 ± 10	17.8 – 31.7	–	23 ± 12	14.0 – 31.6	–	30 ± 16	18.2 – 41.4	–	25 ± 10	18.0 – 32.1	–	23 ± 14	12.6 – 32.4	–
Post-intervention	29 ± 8*	23.7 – 34.8	0.49	28 ± 12*	19.9 – 36.9	0.44	35 ± 15*	24.0 – 45.3	0.30	33 ± 12*#	24.4 – 42.2	0.70	24 ± 13	15.1 – 33.6	0.13
Bicep Curl (kg)															
Baseline	20 ± 10	12.8 – 27.7	–	20 ± 10	12.5 – 26.6	–	26 ± 12	16.8 – 34.4	–	20 ± 10	12.5 – 27.3	–	19 ± 12	10.6 – 27.7	–
Post-intervention	23 ± 9	16.9 – 29.3	0.28	24 ± 10*	17.3 – 31.6	0.47	29 ± 11*	20.6 – 36.9	0.25	29 ± 13*#¥†	19.4 – 38.2	0.72	21 ± 12	12.6 – 29.8	0.16

Note: m = male f = female; HVLL1 = High-velocity, low-load once-weekly; LVHL1 = Low-velocity, high-load once-weekly; HVLL2 = High-velocity, low-load twice-weekly; LVHL2 = Low-velocity, high-load twice-weekly; CON = Control condition; ES = Cohens *d* within-condition effect size

***** = Significantly different from baseline; **†** = Significantly greater than HVLL1; **¥** = Significantly greater than HVLL2; # = Significantly greater than CON ($p \leq 0.05$) as determined by Bonferroni correction

Table 7.3. Functional performance changes across the intervention period

	HVLL1 (*n* = 10; 5m, 5f)			LVHL1 (*n* = 10; 5m, 5f)			HVLL2 (*n* = 10; 5m, 5f)			LVHL2 (*n* = 10; 5m, 5f)			CON (*n* = 10; 5m, 5f)		
	Mean ± SD	95% CI	ES	Mean ± SD	95% CI	ES	Mean ± SD	95% CI	ES	Mean ± SD	95% CI	ES	Mean ± SD	95% CI	ES
Chair Sit-&-Reach (cm) Right															
Baseline	-6 ± 14	-15.6 – 3.8	–	-18 ± 14	-28.3 – -8.5	–	-8 ± 9	-14.8 – -1.3	–	-9 ± 11	-17.1 – -1.8	–	-1 ± 11	-8.7 – 6.8	–
Post-intervention	-7 ± 15	-17.5 – 3.6	-0.07	-16 ± 12	-24.6 – -7.8	0.16	-5 ± 9	-11.1 – 1.7	0.35	-9 ± 14	-18.5 – 1.0	0.06	-4 ± 13	-12.9 – 5.5	-0.22
Chair Sit-&-Reach (cm) Left															
Baseline	-6 ± 12	-15.0 – 2.7	–	-17 ± 15	-27.8 – -7.0	–	-7 ± 11	-15.2 – 1.1	–	-10 ± 11	-17.6 – -1.8	–	-2 ± 12	-10.5 – 7.0	–
Post-intervention	-8 ± 14	-17.5 – 2.3	-0.11	-15 ± 13	-24.4 – -5.5	0.17	-5 ± 10	-12.1 – 2.4	0.20	-9 ± 13	-17.7 – 0.4	0.08	-1 ± 11	-9.2 – 6.5	0.03
Back Scratch (cm) Right															
Baseline	-9 ± 12	-17.9 – -0.3	–	-16 ± 10	-23.5 – -8.6	–	-12 ± 12	-20.8 – -3.3	–	-9 ± 10	-16.5 – -2.3	–	-7 ± 11	-14.2 – 0.8	–
Post-intervention	-12 ± 12	-20.4 – -3.0	-0.21	-14 ± 9	-20.9 – -8.0	0.16	-13 ± 12	-21.1 – -4.0	0.04	-10 ± 10	-17.4 – -2.8	-0.07	-8 ± 10	-14.7 – -1.1	-0.11
Back Scratch (cm) Left															
Baseline	-15 ± 13	-24.7 – -5.6	–	-18 ± 10	-25.6 – -11.2	–	-16 ± 14	-25.9 – -5.8	–	-12 ± 9	-18.1 – -5.9	–	-12 ± 10	-18.5 – -4.6	–
Post-intervention	-15 ± 12	-24.2 – -6.4	-0.01	-19 ± 11	-27.1 – -11.0	0.06	-18 ± 15	-28.4 – -6.8	0.12	-12 ± 9	-17.7 – -5.6	0.04	-13 ± 14	-23.5 – -3.0	-0.13
8-Ft Up-&-Go (s)															
Baseline	5.7 ± 1.4	4.72 – 6.66	–	6.0 ± 0.7	5.46 – 6.45	–	5.1 ± 1.1	4.30 – 5.80	–	5.6 ± 0.8	5.05 – 6.23	–	5.3 ± 0.6	4.86 – 5.71	–
Post-intervention	5.4 ± 1.4	4.43 – 6.46	0.17	5.6 ± 0.6*	5.12 – 5.98	0.60	4.6 ± 0.9*	4.01 – 5.27	0.41	5.4 ± 0.5	5.02 – 5.78	0.34	5.4 ± 0.7	4.86 – 5.92	-0.15
Chair Stands (no. of stands)															
Baseline	13 ± 5	9.4 – 16.0	–	11 ± 1	10.3 – 12.1	–	15 ± 4	12.0 – 17.6	–	14 ± 3	11.6 – 15.6	–	13 ± 2	11.7 – 15.1	–
Post-intervention	14 ± 4*	11.5 – 17.3	0.39	13 ± 1*	12.2 – 13.6	1.46	16 ± 4*	13.2 – 19.4	0.35	16 ± 4 *#	13.5 – 19.1	0.76	13 ± 2	11.4 – 14.8	-0.12
Arm Curls (repetitions)															
Baseline	14 ± 5	10.6 – 18.0	–	15 ± 2	13.2 – 16.6	–	19 ± 6	14.1 – 22.9	–	14 ± 3	11.9 – 16.5	–	15 ± 4	11.4 – 17.7	–
Post-intervention	18 ± 5*	14.3 – 21.5	0.68	15 ± 3	13.0 – 17.0	0.04	21 ± 7*	16.4 – 26.2	0.41	20 ± 4 *‡#	17.2 – 23.4	1.54	14 ± 3	12.6 – 16.2	-0.03
GS (kg) Dominant Hand															
Baseline	28 ± 9	21.5 – 34.6	–	24 ± 6	20.4 – 28.3	–	36 ± 12	27.4 – 44.5	–	28 ± 11	20.4 – 36.2	–	29 ± 11	21.6 – 37.0	–
Post-intervention	28 ± 6	23.0 – 32.5	-0.03	26 ± 6	21.6 – 30.4	0.26	36 ± 12	27.3 – 43.8	-0.03	30 ± 11	22.4 – 38.6	0.19	28 ± 12	19.2 – 36.2	-0.13
GS (kg) Non-Dominant Hand															
Baseline	27 ± 8	21.7 – 32.9	–	24 ± 6	19.7 – 28.6	–	33 ± 13	23.8 – 42.8	–	28 ± 11	19.6 – 35.7	–	27 ± 10	20.1 – 34.4	–
Post-intervention	27 ± 6	22.8 – 31.8	0.00	25 ± 6	20.9 – 29.6	0.16	34 ± 12	25.3 – 42.1	0.03	30 ± 11*#	22.3 – 38.3	0.23	26 ± 10	18.7 – 33.5	-0.10
6-Min Walk (m)															
Baseline	535 ± 100	464 – 607	–	514 ± 76	460 – 569	–	617 ± 79	561 – 673	–	554 ± 108	477 – 631	–	527 ± 92	462 – 593	–
Post-intervention	560 ± 112	481 – 640	0.23	557 ± 74*	504 – 610	0.55	660 ± 84*	600 – 720	0.51	595 ± 93*	528 – 661	0.39	542 ± 65	495 – 589	0.18

Note: m = male f = female; HVLL1 = High-velocity, low-load once-weekly; LVHL1 = Low-velocity, high-load once-weekly; HVLL2 = High-velocity, low-load twice-weekly; LVHL2 = Low-velocity, high-load twice-weekly; CON = Control condition; GS = Grip-strength; ES = Hedges' *g* within-condition effect size estimate

***** = Significantly different from baseline; **‡** = Significantly greater than LVHL1; # = Significantly greater than CON ($p \leq 0.05$) as determined by Bonferroni correction

Table 7.4. Physical and Physiological changes from baseline to post-intervention

	HVLL1 (*n* = 10; 5m, 5f)			LVHL1 (*n* = 10; 5m, 5f)			HVLL2 (*n* = 10; 5m, 5f)			LVHL2 (*n* = 10; 5m, 5f)			CON (*n* = 10; 5m, 5f)		
	Mean ± SD	95% CI	ES	Mean ± SD	95% CI	ES	Mean ± SD	95% CI	ES	Mean ± SD	95% CI	ES	Mean ± SD	95% CI	ES
BMI (kg/m^2)															
Baseline	28 ± 5	24.3 – 31.6	-	28 ± 5	23.9 – 31.0	-	28 ± 5	24.5 – 30.9	-	26 ± 4	23.1 – 29.4	-	24 ± 3	22.6 – 26.1	-
Post-intervention	28 ± 5	24.0 – 31.5	0.04	27 ± 5	24.1 – 30.8	0.00	27 ± 4*	24.2 – 30.4	0.09	26 ± 4	23.2 – 29.4	0.00	25 ± 3	22.7 – 26.4	0.06
Body Mass (kg)															
Baseline	80.0 ± 16.9	67.9 – 92.1	-	76.3 ± 11.8	67.8 – 84.7	-	83.2 ± 13.5	73.5 – 92.8	-	73.0 ± 13.4	63.4 – 82.6	-	71.4 ± 12.7	62.3 – 80.5	-
Post-intervention	79.4 ± 17.6	66.8 – 92.0	0.03	76.3 ± 11.2	68.3 – 84.2	0.00	82.2 ± 13.5*	72.5 – 91.8	0.07	73.1 ± 13.5	63.4 – 82.7	0.01	71.9 ± 12.6	63.0 – 80.9	0.04
BF (%)															
Baseline	30.9 ± 9.0	24.5 – 37.3	-	34.1 ± 8.6	28.0 – 40.2	-	31.2 ± 8.4	25.2 – 37.2	-	28.9 ± 11.2	20.9 – 36.9	-	27.5 ± 5.9	23.2 – 31.7	-
Post-intervention	30.2 ± 9.3	23.5 – 36.9	0.07	33.6 ± 8.2	27.7 – 39.4	0.06	31.7 ± 8.0	26.0 – 37.5	0.06	29.3 ± 11.6	21.0 – 37.6	0.04	28.9 ± 6.0*	24.6 – 33.2	0.23
Fat Mass (kg)															
Baseline	25.0 ± 9.6	18.1 – 31.9	-	26.3 ± 8.9	19.9 – 32.7	-	26.1 ± 9.7	19.2 – 33.0	-	21.3 ± 9.1	14.8 – 27.8	-	19.5 ± 4.8	16.0 – 22.9	-
Post-intervention	24.5 ± 10.2	17.2 – 31.8	0.05	25.7 ± 8.1	19.9 – 31.5	0.06	26.2 ± 9.3	19.6 – 32.9	0.01	21.6 ± 9.2	15.0 – 28.2	0.03	20.7 ± 5.3*	16.9 – 24.5	0.24
Fat Free Mass (kg)															
Baseline	55.0 ± 12.1	46.3 – 63.6	-	50.0 ± 9.0	43.5 – 56.5	-	57.1 ± 11.1	49.2 – 65.0	-	51.7 ± 11.7	43.3 – 60.0	-	52.0 ± 11.3	43.9 – 60.0	-
Post-intervention	54.9 ± 11.8	46.4 – 63.4	0.00	50.5 ± 9.2¥	43.9 – 57.1	0.05	55.9 ± 10.8*	48.2 – 63.7	0.10	51.5 ± 12.2	42.7 – 60.2	0.02	51.2 ± 10.5	43.7 – 58.7	0.07

Note: m = male f = female; HVLL1 = High-velocity, low-load once-weekly; LVHL1 = Low-velocity, high-load once-weekly; HVLL2 = High-velocity, low-load twice-weekly; LVHL2 = Low-velocity, high-load twice-weekly; CON = Control condition; RHR = Resting heart rate; SBP = Systolic blood pressure; DBP = Diastolic blood pressure; MAP = Mean arterial pressure; RPP = Rate pressure product; BMI = Body mass index; BF% = Body fat percentage; ES = Hedges' *g* within-condition effect size estimate
***** = Significantly different from baseline; ¥ = Significantly greater than HVLL2 ($p \leq 0.05$) as determined by Bonferroni correction

Table 7.5. LLFDI responses at baseline and post-intervention

	HVLL1 (*n* = 10; 5m, 5f)			LVHL1 (*n* = 10; 5m, 5f)			HVLL2 (*n* = 10; 5m, 5f)			LVHL2 (*n* = 10; 5m, 5f)			CON (*n* = 10; 5m, 5f)		
	Mean ±	95% CI	ES	Mean ±	95% CI	ES	Mean ±	95% CI	ES	Mean ±	95% CI	ES	Mean ±	95% CI	ES
LLDI Function															
Baseline	70 ± 9	62.8 – 76.2	–	74 ± 12	65.1 – 82.0	–	81 ± 11	72.9 – 88.5	–	82 ± 14	72.3 – 92.2	–	73 ± 13	63.4 – 81.8	–
Post-intervention	69 ± 9	62.9 – 75.8	-0.02	73 ± 11	64.8 – 81.1	-0.05	84 ± 13	75.0 – 93.4	0.29	84 ± 13	74.5 – 93.4	0.12	73 ± 12	64.6 – 82.3	0.06
LLFDI Frequency															
Baseline	58 ± 5	55.3 – 61.7	–	69 ± 16	57.7 – 80.4	–	64 ± 10	57.1 – 70.8	–	63 ± 15	52.1 – 73.0	–	56 ± 5	53.2 – 59.7	–
Post-intervention	58 ± 5	54.7 – 61.2	-0.12	65 ± 12	56.4 – 74.0	-0.26	64 ± 8	58.0 – 70.0	-0.01	62 ± 7	56.7 – 66.6	-0.08	56 ± 4	53.3 – 59.5	-0.01
LLFDI Limitation															
Baseline	82 ± 13	72.2 – 91.5	–	91 ± 12	82.7 – 100.0	–	87 ± 13	77.1 – 96.1	–	90 ± 13	80.9 – 99.4	–	89 ± 13	79.8 – 97.9	–
Post-intervention	85 ± 12	75.9 – 93.3	0.20	93 ± 12	84.4 – 101.8	0.14	96 ± 9*****	89.8 – 102.6	0.81	97 ± 5	93.1 – 100.5	0.65	91 ± 8	85.0 – 96.8	0.18

Note: Values are mean ± SD; LLFDI = Late-life function and disability instrument HVLL1 = High-velocity, low-load once-weekly; LVHL1 = Low-velocity, high-load once-weekly; HVLL2 = High-velocity, low-load twice-weekly; LVHL2 = Low-velocity, high-load twice-weekly; CON = Control condition; ES = Cohens *d* within-condition effect size
***** = Significantly different from baseline ($p \leq 0.05$) as determined by Bonferroni correction

Table 7.6. Functional assessment results for females with normal ranges and risk zones.

	HVLL1 (*n* = 5)		LVHL1 (*n* = 5)		HVLL2 (*n* = 5)		LVHL2 (*n* = 5)		CON (*n* = 5)			
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Normal Range	Risk Zones
Chair Sit-&-Reach (cm) Right	1.0 ± 14.2	0.7 ± 13.3	-9.5 ± 13.5	-8.6 ± 11.7	-6.5 ± 11.8	-2.5 ± 6.9	-7.8 ± 8.7	-8.8 ± 14.6	0.1 ± 11.9	-1.0 ± 13.2	-1.3 – +11.4	>-5.1
Chair Sit-&-Reach (cm) Left	0.1 ± 12.3	-0.3 ± 11.6	-9.0 ± 13.7	-6.9 ± 12.0	-5.1 ± 15.3	-1.6 ± 7.9	-8.7 ± 7.9	-8.6 ± 12.5	-0.3± 13.1	1.3 ± 11.8	-1.3 – +11.4	>-5.1
Back Scratch (cm) Right	-2.7 ± 10.5	-5.3 ± 10.5	-9.2 ± 7.3	-9.4 ± 5.5	-12.0 ± 11.2	-10.6 ± 9.7	-10.2 ± 12.3	-9.4 ± 12.5	-5.2 ± 15.0	-6.9 ± 13.6	-8.9– +3.8	>-5.1
Back Scratch (cm) Left	-4.9 ± 7.9	-6.2 ± 9.8	-12.8 ± 7.4	-13.8 ± 7.0	-19.4 ± 13.5	-19.9 ± 15.5	-7.6 ± 8.1	-5.7 ± 4.4	-10.0 ± 13.3	-14.5 ± 21.2	-8.9– +3.8	>-5.1
8-Ft Up-&-Go (s)	5.2 ± 0.5	4.7 ± 0.6	6.1 ± 0.9	5.8 ± 0.7	5.0 ± 0.5	4.5 ± 0.4	5.9 ± 1.0	5.5 ± 0.5	5.6 ± 0.7	5.6 ± 0.8	6.4 – 4.8	>9
Chair Stands (no. of stands)	15 ± 5	16 ± 3	12 ± 1	13 ± 1	15 ± 4	16 ± 3	13 ± 4	15 ± 3	13 ± 2	13 ± 3	11 – 16	<8
Arm Curls (repetitions)	16 ± 6	20 ± 5	15 ± 3	14 ± 2	16 ± 5	20 ± 5	13 ± 4	18 ± 4	15 ± 6	14 ± 3	12 – 18	<11
6-Min Walk (m)	558 ± 59	599 ± 67	461 ± 62	508 ± 67	576 ± 30	635 ± 28	494 ± 99	529 ± 71	475 ± 97	501 ± 59	457 – 581	<320

Note: Values are mean ± SD; HVLL1 = High-velocity, low-load once-weekly; LVHL1 = Low-velocity, high-load once-weekly; HVLL2 = High-velocity, low-load twice-weekly; LVHL2 = Low-velocity, high-load twice-weekly; CON = Control condition; Normal ranges and risk zones are from (Rikli and Jones 1999)

Table 7.7. Functional assessment results for males with normal ranges and risk zones

	HVLL1 (*n* = 5)		LVHL1 (*n* = 5)		HVLL2 (*n* = 5)		LVHL2 (*n* = 5)		CON (*n* = 5)			
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Normal Range	Risk Zones
Chair Sit-&-Reach (cm) Right	-12.8 ± 9.7	-14.6 ± 12.8	-27.3 ± 7.2	-23.8 ± 5.6	-9.6 ± 7.3	-6.9 ± 11.0	-11.1 ± 13.2	-8.7 ± 14.4	-2.0 ± 11.0	-6.4 ± 13.4	-7.6 – +7.6	>-10.2
Chair Sit-&-Reach (cm) Left	-12.4 ± 9.8	-14.9 ± 12.7	-25.8 ± 10.5	-23.0 ± 9.4	-9.0 ± 7.2	-8.1 ± 12.	-10.6 ± 14.4	-8.7 ± 14.4	-3.2 ± 12.7	-4.0 ± 10.8	-7.6 – +7.6	>-10.2
Back Scratch (cm) Right	-15.5 ± 11.3	-18.1 ± 10.9	-22.9 ± 8.7	-19.5 ± 9.4	-12.1 ± 14.6	-14.5 ± 14.7	-8.6 ± 8.3	-10.8 ± 8.8	-8.2 ± 4.3	-8.9 ± 4.0	-19.1– -2.5	>-10.2
Back Scratch (cm) Left	-24.5 ± 8.5	-24.3 ± 6.9	-24.0 ± 9.9	-24.3 ± 12.9	-12.3 ± 15.1	-15.3 ± 16.0	-16.4 ± 7.1	-17.6 ± 7.4	-13.1 ± 5.5	-12.0 ± 3.2	-19.1– -2.5	>-10.2
8-Ft Up-&-Go (s)	6.2 ± 1.6	6.2 ± 1.5	5.8 ± 0.4	5.3 ± 0.4	5.1 ± 1.3	4.7 ± 1.1	5.4 ± 0.5	5.3 ± 0.5	5.0 ± 0.1	5.1 ± 0.5	5.7 – 4.3	>9
Chair Stands (no. of stands)	11 ± 4	12 ± 4	11 ± 1	13 ± 1	14 ± 4	16 ± 6	14 ± 2	18 ± 5	14 ± 3	14 ± 2	12 – 18	<8
Arm Curls (repetitions)	12 ± 4	15 ± 4	14 ± 2	16 ± 4	21 ± 7	22 ± 9	16 ± 1	22 ± 4	14 ± 3	15 ± 2	15 – 21	<11
6-Min Walk (m)	513 ± 134	522 ± 141	568 ± 43	606 ± 44	658 ± 94	685 ± 115	613 ± 87	660 ± 62	580 ± 53	585 ± 43	512 – 640	<320

Note: Values are mean ± SD; HVLL1 = High-velocity, low-load once-weekly; LVHL1 = Low-velocity, high-load once-weekly; HVLL2 = High-velocity, low-load twice-weekly; LVHL2 = Low-velocity, high-load twice-weekly; CON = Control Condition; Normal ranges and risk zones are from (Rikli and Jones 1999)

7.4 Discussion

The aim of this study was to investigate the impact that HVLL and LVHL performed once or twice-weekly, have on indices of functional performance, maximal strength and body composition. The main finding was that LVHL2 elicited the greatest magnitudes of improvements in more tests of strength and functional performance than any other condition, compared to CON. However, within-condition analyses revealed that HVLL and LVHL performed once or twice-weekly improved some aspects of strength and functional performance. Supported by the ancillary analyses, hypothesis 1 must be rejected as there were greater benefits to performing volume-load matched LVHL compared to HVLL and hypothesis 2 is confirmed following more/greater benefits in the twice-weekly compared to once-weekly conditions.

Arguably the most important aspect of a resistance training programme for older adults, is its ability to enhance functional performance (Stec et al. 2017). Aside from flexibility, which was generally poor, participants exhibited sufficient pre-existing levels of functional fitness by meeting or exceeding normal range values (Rikli and Jones 1999) at baseline (Tables 7.6 and 7.7). All participants completed the SPPB balance tests at baseline and post-intervention, meaning a clear ceiling effect was present. Given the high levels of pre-existing functional fitness, a more challenging balance test may have been more appropriate. The present study did not include flexibility training and contrary to findings in younger participants, resistance exercise alone did not improve flexibility (Morton et al. 2011). As flexibility reduces with ageing (Medeiros et al. 2013), future exercise programmes may wish to include specific activities to maintain/improve flexibility in older adults.

Although only LVHL2 significantly improved functional performance compared to CON in the present study, paradoxically, self-reported LLFDI limitation only significantly decreased in HVLL2. However, ancillary analyses revealed HVLL enhanced both arm curl and 8-ft-up-&-go performance compared to CON. Whereas, the LVHL conditions enhanced chair stands and grip-strength performance compared to CON. It is also important to highlight that within-condition changes revealed that HVLL1 improved chair stand and arm curl performance, and LVHL1 improved 8-ft-up-&-go, chair stand and 6-min walk performance compared to baseline. Therefore, the present study revealed some benefits to once-weekly resistance exercise in moderately-highly active, older adults, in as little as ~10 hours over 10-weeks with little progression of intensity.

Maximal strength increased in all exercise conditions, which over short interventions, is commonly attributed to neuromuscular adaptations (Barbalho et al. 2017). The greatest magnitudes of strength improvements were observed in LVHL2, with 7/8 exercises significantly improving compared to CON, compared to 2/8 in both HVLL2 and LVHL1. It is expected that the increased loading (80% 1RM), in the LVHL conditions meant participants exercised at closer proximity to momentary failure, creating a greater stimulus for strength gains (Gentil et al. 2017). Indeed, the LVHL conditions produced failure on multiple exercises in the first 4-6 weeks, whereas the HVLL conditions did not cause failure on any exercise, except the bicep curl. As low intensity resistance exercise needs to be performed to failure to gain the same strength gains as high-intensity resistance exercise (Nobrega and Libardi 2016), it may explain why HVLL did not illustrate the same magnitudes of strength increases as LVHL. Furthermore, the LVHL conditions may have experienced greater increases in strength than HVLL, as maximum strength testing was more similar to the exercise performed by the LVHL conditions (Buckner et al. 2017).

The present study appears to contradict previous studies, where power training has produced similar improvements in muscular strength (Nogueira et al. 2009), and greater improvements in functional performance (Bottaro et al. 2007) compared to strength training. These differences may be explained by the loading used, both previous studies used 60% 1RM for both strength and power training, meaning these protocols were better matched for intensity of effort compared to the present study. Furthermore, many power training studies that have observed greater functional outcomes compared with strength training, have used greater percentages of 1RM than the present study (Byrne et al. 2016). The findings of the present suggest that LVHL is more beneficial to strength and functional performance in older adults when exercise is volume-load matched against HVLL, which may suggest that the intensity of resistance exercise is more important than its movement velocity.

Body mass and BMI decreased in HVLL2 beneficially, as BMI classifications indicated they were overweight. However, FFM also decreased in HVLL2, possibly due to low mean protein intake (0.78g/kg/day), which is significantly lower than the 1–1.3g/kg/day recommended for older adults while resistance training for attenuating age-related losses in muscle mass and improving functional performance (Nowson and O'Connell 2015). Similar to the present study, inadequate protein consumption during an exercise intervention, has demonstrated both losses in body mass and lean body mass (Bopp et al. 2008). As protein requirements are higher for older adults who exercise (Bauer et al. 2013), low protein intake combined with increased exercise may have exacerbated losses of FFM. It is unclear why CON increased fat mass by 1.2kg over the short intervention period in the present study. Based on self-reported habitual activity levels and calorific intake, such a gain is unlikely. As bioelectrical impedance is low cost, easy to use, and is readily available, it has been recommended as a good portable alternative to dual-energy X-ray absorptiometry (DEXA) (Cruz-Jentoft et al. 2010). However, measurement error can be high (Balachandran et al. 2014) and the under-reporting of macronutrients is also a feasible explanation (Garriguet 2008).

Furthermore, there were no other positive effects on body composition in any exercise condition. This is unsurprising as studies that have observed positive changes in body composition, trained thrice-weekly (Campbell et al. 1994; Nichols et al. 1993) controlled diet (Avila et al. 2010; Campbell et al. 1994; Treuth et al. 1994) or had longer intervention periods (Nichols et al. 1993; Treuth et al. 1994) etc. Shorter-term (15-weeks) resistance exercise interventions, even when performed on obese sarcopenic women have shown no change in body fat percentage (Balachandran et al. 2014).

7.4.1 Limitations

Both functional and 1RM assessments were conducted on the same day, meaning some assessments may have been affected by fatigue. To attenuate this, all assessments were performed in the same order with appropriate rest times. Secondly, the same researcher conducted the baseline and post-intervention assessment sessions and all sessions in the 10-week programme, meaning they were not blinded to condition assignment. Potential bias was counteracted by providing identical assessment procedures and motivation to all participants (Miszko et al. 2003). In addition to testing maximal strength, assessing muscle power would have been useful to observe and compare training specificity effects. Matching the number of repetitions used by participants to predict their 1RM at baseline and post-intervention was not attempted. Therefore, given the error in the prediction equation, this may have affected the ability to distinguish between exercise conditions. However, the Brzycki equation has previously produced valid estimations of 1RM on multiple machine based exercises in older adults (Knutzen et al. 1999). Lastly, the sample size was small, possibly increasing the risk of type 2 errors. Therefore, ancillary analyses were conducted to support the conclusions.

7.4.2 Conclusion

The present study indicates that 10-week programmes of LVHL, performed twice-weekly are most beneficial for already moderately-highly active older adults in improving strength and functional performance. It is speculated that the greater intensity of effort required in the LVHL conditions compared to HVLL, provided participants with a greater stimulus to facilitate these improvements. The ancillary analyses revealed that LVHL was more beneficial for strength and functional performance than HVLL, and twice-weekly was more beneficial than once-weekly. Despite this, within-condition changes indicated that all conditions improved some aspects of maximal strength and functional performance from baseline. Therefore, the volume-load matched protocols, suggest that the intensity of effort resistance exercise is performed at, may be more important for enhancement of strength and functional performance than movement velocity in older adults. Furthermore, superior benefits were observed from performing these resistance exercise protocols with greater weekly volume (twice-weekly vs. once-weekly). Therefore, whether utilising HVLL or LVHL, exercise professionals should ensure that programmes contain sufficient weekly volume and intensity of effort to maximise functional performance and strength gains in older adults. In agreement with Fisher et al. (2017), exercise professionals may elect to begin with a minimal dose/intensity of supervised resistance exercise and progress programmes through manipulation of volume and/or load when participants show adequate progression.

Chapter 8: Synthesis of findings

8.1 Synthesis of findings

The initial studies described in this thesis aimed to distinguish the differences in physiological and affective responses to commonly employed methods of resistance exercise in older adults. These findings then informed the design of a 10-week intervention study that further investigated the differences between high-velocity, low-load (HVLL) and low-velocity, high-load (LVHL) resistance exercise. The first study ensured that a command and metronome-based protocol delivered appreciable differences in exercise movement velocity between HVLL and LVHL. Study 2 and 3 examined the acute physiological and affective responses to HVLL and LVHL. Based on these findings, a training intervention study was designed to assess functional performance and affective responses to both HVLL and LVHL over a 10-week period. The first of these intervention studies (study 4) used the same metrics as study 3 to examine affective responses and enjoyment over a 10-week intervention period, to monitor if the acute observations in study 3, persisted in a larger sample size, over a longer period of time. Finally, as maintaining/improving functional performance is of key importance to the ageing population, study 5 examined changes in functional performance, maximal strength and body composition over the same 10-week intervention period when performing either HVLL or LVHL, once or twice-weekly. Therefore, the original contributions of this thesis include: 1) Validating a method of manipulating exercise velocity in older adults. 2) Examining the acute physiological and affective responses to different resistance exercise protocols in older adults. 3) Comparing the effects that these protocols have on important outcome measures such as changes in maximal strength, body composition and functional performance when performed either once or twice-weekly.

Figure 8.1 displays a schematic diagram which combines the observations of studies 2,3,4, and 5 to aid in summarising the main findings of this thesis. As volume-loads were matched, study 2 revealed that both HVLL and LVHL increased heart rate and blood lactate similarly. These findings are consistent with those of Nitzsche et al. (2017) who observed similar blood lactate and heart rate responses following different resistance exercise protocols that varied in load, repetitions, number of sets and rest times. Although, others have observed that lifting heavier loads results in greater lactate accumulation than lower loads (Lagally et al. 2002) and slower movement velocities also stimulate greater lactate production than faster velocities (Arazi et al. 2014), this was not observed in study 2. It is possible that the rest times given in study 2, allowed sufficient passive metabolic clearance (Ratel et al. 2002) allowing blood lactate values to be similar when measured at the end of the session.

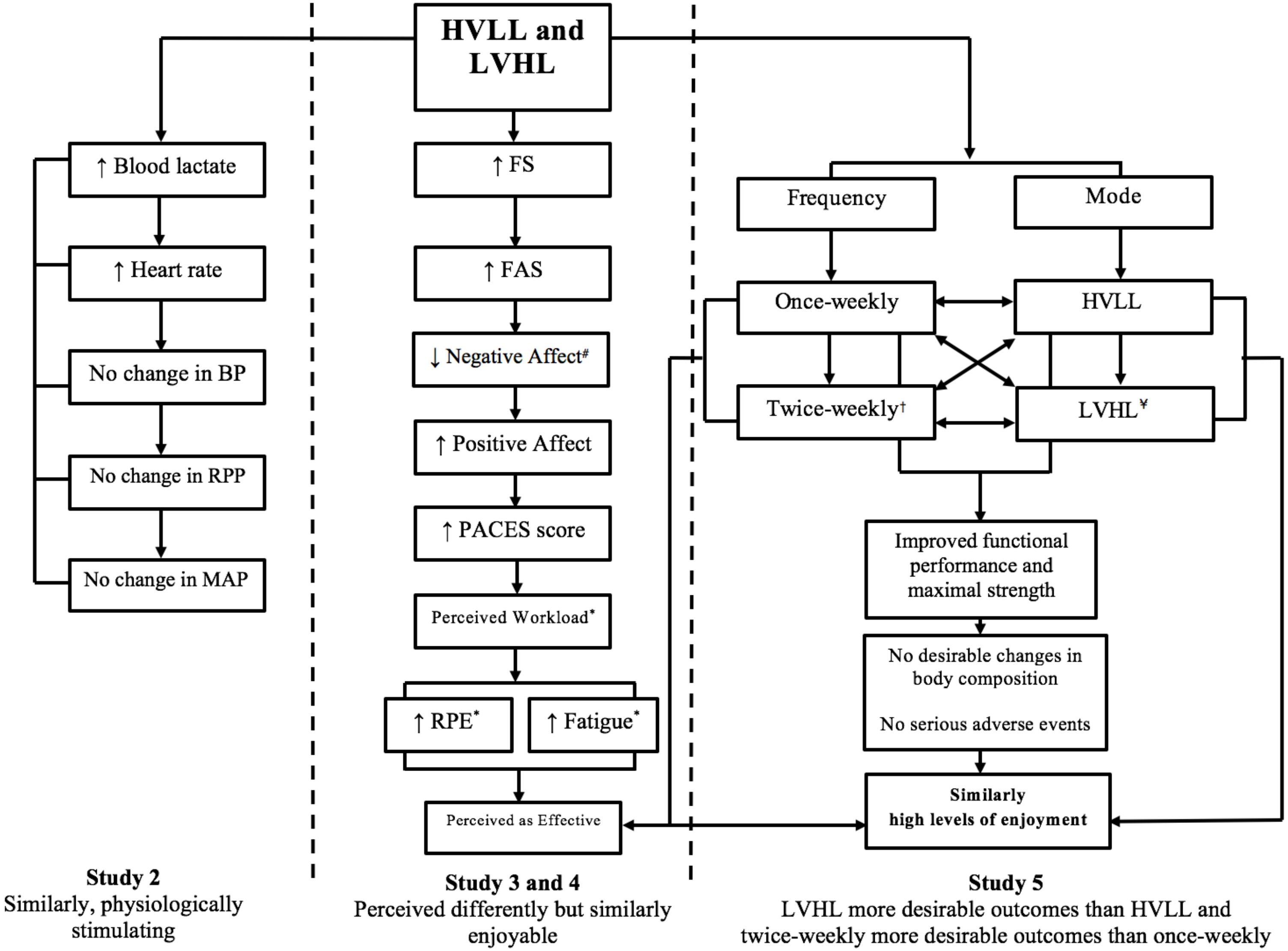

Figure 8.1. Schematic diagram of the interaction between the key variables investigated in this thesis
* = LVHL significantly greater than HVLL; # = HVLL significantly greater than LVHL; † = More significant improvements than once-weekly; ¥ = More significant improvements than HVLL

Note: HVLL = High-velocity low-load, LVHL = Low-velocity high-load; FAS = Felt arousal scale; FS = Feeling scale; PACES = Physical activity enjoyment scale; BP = Blood pressure; RPP = Rate pressure product; RPE = Rating of perceived exertion; MAP = Mean arterial pressure

Furthermore, there were no differences between HVLL and LVHL in post-exercise blood pressure, rate pressure product or mean arterial pressure. As the participants in study 2 were normotensive, this may explain why no differences were observed from performing resistance exercise, as the greatest post-exercise hypotensive effects occur in individuals with elevated blood pressure (Cardoso et al. 2010). There can be large increases in blood pressure immediately following sets of resistance exercise (da Silva et al. 2007). However, study 2 only measured pre- and post-exercise blood pressure, meaning these potential in-exercise changes were not measured. Overall, figure 8.1 displays the conclusions from study 2, that HVLL and LVHL, when volume-load matched stimulate similar physiological responses in older adults.

As observed in study 4, both HVLL and LVHL exercise elicited significant and similar increases in FAS and FS values, which replicated the acute findings of study 3 in this thesis, and other exercise studies that have measured Feeling Scale (FS) (Focht et al. 2015) and Felt Arousal Scale (FAS) (Kilpatrick et al. 2007). These findings are unsurprising as resistance exercise has been shown to enhance mood in older adults (Cassilhas et al. 2007) which can be explained by the monamine hypothesis (Morgan and O'Connor 1988). This hypothesis suggests that neurotransmitters in the brain linked to mood constructs such as depression and anxiety are positively altered through both acute and chronic exercise in older adults (Arent et al. 2000). It is proposed that positive ratings of affective valence (combined FAS and FS) occur below ventilatory threshold, and once intensity increases, affective valence begins to decrease (Ekkekakis et al. 2004). Therefore, it is surprising that despite the greater intensity of the LVHL conditions, affective valence remained similarly as high as HVLL. Possible reasons for this are discussed later.

Studies 3 and 4 also highlighted that both types of exercise improved positive exercise affect and decreased negative exercise affect, assessed using the physical activity affect scale (PAAS). Although differences were not significant, the decrease in negative affect was more pronounced following HVLL. Although physiological variables were similar between the volume-load matched protocols, a possible reason for the differences in affective responses, were the differing intensities between HVLL and LVHL e.g. LVHL lifted the same total load over a shorter period of time. The greater intensity of LVHL meant that perceived workload was significantly greater, which also led rating of perceived exertion (RPE) and perception of fatigue to be greater in LVHL. Previously, a meta-analytic review by Arent et al. (2000) highlighted that low-moderate intensity exercise achieved the most consistent improvements in mood. The current thesis may reflect these observations with negative exercise affect significantly reducing in the lower intensity form of exercise (HVLL). Arent et al. (2000) also eluded to the fact that less frequency of exercise also elicited the greatest improvements in mood. However, although no indices were measured directly to monitor this, there appeared to be no differences in affective responses between once or twice-weekly.

Despite the greater perceived workload and exertion in LVHL, both HVLL and LVHL were perceived as similarly effective by older adults. Furthermore, both HVLL and LVHL elicited similarly, very high scores for the physical activity enjoyment scale (PACES), meaning that both HVLL and LVHL were similarly enjoyable to older adults despite clear differences in perception of difficulty and exertion. Greater exercise intensities have previously been associated with increased displeasure during physical activity (Ekkekakis and Petruzzello 1999). Humans possess a basic action tendency to avoid unpleasant events whilst embracing more pleasurable ones (Cacioppo and Berntson 1999). Therefore, it is somewhat surprising that despite significant differences in perceived workload and exertion, affective responses were similar between HVLL and LVHL. This may be explained by the activity status of the participants recruited in the present thesis. The international physical activity questionnaire (IPAQ) data show that many of the participants were already meeting or greatly exceeding recommended amounts of exercise. McAuley et al. (2003) suggests that those who exercise more frequently, report a more positive exercise experience and high enjoyment of physical tasks are correlated with high levels of physical activity (Salmon et al. 2003). It is probable that the active nature of participants in the present studies meant that exercise was enjoyed regardless of the intensity/ frequency it was performed at. Therefore, it is important to consider that the patterns of high enjoyment observed in the present thesis, may not be replicated in more sedentary older adults. Lastly, it is important to acknowledge that information on what actually makes exercise interventions enjoyable is scarce, and it is hard to distinguish if social interaction, session structure or supervision influences enjoyment more strongly than the exercise itself (Hagberg et al. 2009). This should be considered when trying to generalise the findings of this thesis to other groups of older adults.

Although the present intervention did not explicitly manipulate the constructs of self-determination theory, examining the principles of this theory may help to explain how the study design and supervision has elicited similarly positive affective responses despite clear differences in perception of effort. Self-determination theory suggests that humans need relatedness, competence and autonomy to motivate physical exertion and behaviour adherence (Ryan and Deci 2000). For example, in the present study, positive reinforcement and feedback was provided to the participants which may have increased self-perceived competence (Jekauc 2015). Furthermore, allowing participants control over the progression of their programmes has also been shown to positively influence affective responses (Williams and Raynor 2013). Therefore, several of these factors may have clouded the ability to distinguish between the different protocols. However, this may also suggest that a combination of social interaction and positive reinforcement can make greater intensity exercise similarly enjoyable to older adults. As there were greater benefits from performing exercise with greater intensity of effort, understanding the role of social interaction and supervision in such exercise interventions is important for exercise professionals so that programmes can be effectively progressed. However, this is evidently an area that has received little research attention and warrants further investigation.

The observations of study 5 show that within-condition changes following HVLL and LVHL whether performed once or twice-weekly, improved some aspects of maximal strength and/or functional performance. Although HVLL and LVHL performed just once-weekly did not improve functional performance compared to the control condition, within-condition analysis revealed some significant improvements. This is an important observation of the present thesis and is in agreement with others (Foley et al. 2011; Sousa et al. 2013; Taaffe et al. 1999) that once-weekly resistance exercise can elicit gains in maximal strength and functional performance. Therefore, the minimal effective dose of resistance exercise needs further investigation to provide conclusive evidence that would warrant an 'update' to the current recommendations provided by the physical activity guidelines.

None of the conditions performed either once or twice-weekly had a significant positive effect on lean body mass. Some previous resistance exercise studies have observed modest increases in lean body mass when measured using highly accurate methods such as dual-energy X-ray absorptiometry (DEXA) (Nichols et al. 1993; Taaffe et al. 1999). The most likely proposed mechanism for this increase in lean body mass is an increase in muscle protein synthesis following exercise that exceeds that of muscle protein breakdown (Yarasheski 2003). However, similar to the findings of the present thesis, many exercise studies in older adults have observed no changes in body composition (Balachandran et al. 2014; Brochu et al. 2002; Henwood and Taaffe 2005). It is possible that the stimulus provided in this study was not great enough or performed over a long enough period of time to elicit positive changes in body composition. As discussed in study 5, studies that have observed positive changes in body composition, have employed training three times per week (Campbell et al. 1994; Nichols et al. 1993), controlled diet (Avila et al. 2010; Campbell et al. 1994; Treuth et al. 1994) or had longer interventions (Nichols et al. 1993; Treuth et al. 1994) etc.

Adverse events or 'harms' have previously been underreported in exercise studies involving older adults (Latham et al. 2004), but the CONSORT guidelines in 2010 included the need to report harms in their checklist, which has since improved reporting in randomised controlled trials. From the findings of study 5, both HVLL and LVHL were both considered safe for older adults as there were no serious adverse events reported in any condition, and there were similarly low numbers of minor adverse events. Similar resistance exercise interventions on older adults have also found no serious adverse events (Fiatarone Singh et al. 2014; Singh et al. 2012; Winters-Stone et al. 2012) suggesting that these types of exercise are well-tolerated by older adults.

The findings of study 5 suggest that there were more improvements in both maximal strength and functional performance when resistance exercise was performed twice-weekly rather than once-weekly. Furthermore, LVHL stimulated a greater number of improvements in maximal strength and functional performance than HVLL for both once and twice-weekly. Overall, despite the limitations of the study discussed in section 7.4, analysis using analysis of covariance (ANCOVA) made it clear that LVHL2 was superior at delivering improvements in both maximal strength gains and functional performance. This is consistent with the meta-analysis by Peterson et al. (2010) which highlighted that higher intensity resistance exercise programmes are superior for gains in strength than lower intensity programmes. Some of the suggested mechanisms for this improvement in strength in older adults include: adaptations of the neuromuscular system; increases in muscle mass; and intra and intermuscular muscle coordination (Mayer et al. 2011); and a shift in myosin heavy chain (MHC) isoform composition from MHC I to MHC IIA (Peterson et al. 2010). However, some studies have reported that maximal strength has been shown to increase similarly when training at higher velocities at a lower percentage of 1RM compared to a greater percentage of 1RM at lower movement velocities (Fielding et al. 2002; Henwood and Taaffe 2006). Yet, this was not observed in the present thesis. Some explanations for this may be found in repetition range and loading used in the HVLL conditions. For example, it has been demonstrated that once a reduction in training velocity is achieved (from fatigue), additional repetitions do not elicit further strength gains (Pareja-Blanco et al. 2017). The HVLL conditions employed in this thesis were performed at 40% 1RM for 14 repetitions which may have caused significant drop off in velocity, either by fatigue or lack of engagement. Furthermore, 40% 1RM may have been insufficient loading, as other studies that have carried out high-velocity exercise have used higher loads. E.g. 50-80% 1RM (Balachandran et al. 2014) and 60% 1RM (Bottaro et al. 2007). Finally, it has been suggested that to elicit similar hypertrophic gains to lifting heavier loads, lighter loads need to be lifted to failure (Mitchell et al. 2012a). The lower intensity nature of HVLL meant momentary failure was rarely reached whereas, the LVHL conditions frequently stimulated momentary failure on multiple exercises, possibly explaining the greater strength gains observed in LVHL.

8.2 Recommendations

Based on the observations of the present thesis and also evidence provided by the extant literature, some practical recommendations are offered. Although LVHL twice-weekly was the only condition to significantly improve functional performance compared to the control condition, both HVLL and LVHL were enjoyed similarly and positively influenced aspects of maximal strength and functional performance whether performed once or twice-weekly. Therefore, in agreement with Papa et al. (2017) the adage "doing something is better than doing nothing" applies here, and resistance exercise participation should be viewed as a continuum, with "no activity" at one end, and "recommended daily amounts" at the other. Getting older adults onto this continuum is important, and progression along it, would likely provide additional benefits to the individual.

As discussed in chapter 2, various programmes of both strength and power training have improved aspects of maximal strength, functional performance and various other health outcomes. Findings from study 5, revealed that LVHL resistance exercise performed twice-weekly was the most beneficial to maximal strength and functional performance. As strength underpins power, it has been suggested that beginners to resistance exercise, may benefit more from strength training before progressing to power training (Cormie et al. 2010). Once a solid foundation of strength has been established, participants should be allowed a choice of either, or a combination of HVLL and LVHL depending upon their preference. Based on the observations of this thesis, power training may need to have sufficient intensity of effort to elicit functional improvements and strength gains similar, or superior to strength training.

As there have been shown to be increased benefits of supervised resistance exercise (Ramirez-Campillo et al. 2017) and many older adults may have a reduced capacity to effectively exercise unsupervised (Fennell et al. 2016), it is recommended that older adults complete these programmes supervised. As concluded in study 3, preference of intensity is individual and therefore exercise practitioners should allow older adults involvement in the selection of intensity of resistance exercise. If inflicting higher intensities/ frequencies of exercise on older adults achieves greater results, but ultimately reduces adherence and enjoyment, then the long-term benefits of resistance exercise will not be realised. Therefore, progression of intensity should be encouraged, but not forced upon individuals. The RPE based system of progression used in studies 4 and 5 revealed that sufficient progress can be made in 10-weeks, only progressing the programme when participants are finding it "too easy". Exercise professionals should encourage older adults to perform resistance exercise more than once per week if possible, but it should not be specified that twice-weekly is the absolute minimum.

Therefore, to reiterate the practical applications made in study 5, the volume-load matched protocols investigated in this thesis, suggest that the intensity of effort that resistance exercise is performed at, may be more important for the enhancement of strength and functional performance than movement velocity in older adults. Superior benefits were observed from performing resistance exercise with greater weekly volume (twice-weekly vs. once-weekly) and so greater weekly volume should be encouraged. As many other studies have shown adequate and even superior benefits when using power training (Byrne et al. 2016), whether utilising HVLL or LVHL, exercise professionals should ensure that programmes contain sufficient weekly volume and intensity of effort in order to maximise functional performance and strength gains in older adults. In agreement with Fisher et al. (2017), exercise professionals may elect to begin with a minimal dose/intensity of supervised resistance exercise and progress programmes through manipulation of volume and/or load when participants show adequate improvements and a willingness to progress.

8.3 Limitations

A significant limitation of the present thesis is that the participants that volunteered for participation, were moderately-highly active (classified through IPAQ). The thesis findings show that both HVLL and LVHL, despite having significantly different perceived workloads were enjoyed similarly. However, because of the high habitual activity levels of the older adults that participated in this research, caution should be taken when applying these findings to the wider population of more sedentary older adults.

As analysed earlier in the thesis, a limitation of many other studies is the recruitment of a greater number of female participants than males. This may have skewed the conclusions made by authors on the efficacy of power training, as females have been shown to adapt more favourably to low resistance training than males (Glenn et al. 2015). Although studies in the present thesis did recruit equal numbers of males and females, they did not have sufficient statistical power to make comparisons between males and females. In general, larger sample sizes would have been desirable, as identified in study 5, ancillary analyses were needed to support the conclusions as the sample size was low. Every effort was made to recruit more participants, but given the timescale of the project, this was not possible.

There are numerous studies that have examined resistance exercise over short interventions such as the one carried out in studies 4 and 5. Therefore, longer interventions that span 6 months - 1 year and beyond are needed to observe progression of such programmes past the initial first few months. This was an issue identified at the beginning of this thesis, but was not possible due to the timescale needed to collect such data.

All resistance exercise throughout the thesis was performed in a sports centre under supervision. It has been reported that there are significant benefits to measured outcomes of exercise, when supervision is given (Ramirez-Campillo et al. 2017; Wind and Koelemay 2007). Therefore, it is likely that the programmes carried out in this thesis would need to be carried out with supervision in order to gain the substantial benefits observed. The provision for such supervision is limited in the United Kingdom without substantial cost to the individual, making it highly probable there would be a minority of older adults willing to incur these costs. The benefits of supervision, but lack of provision is a significant problem in improving public health.

8.4 General Conclusions

The overall conclusions of this thesis are:

1. The command and metronome-based protocols used in this thesis, elicit significantly different movement velocities in older adults and are an easy, cost effective way to differentiate between high and low velocity resistance exercise.
2. When volume-loads are matched, there are no significant acute physiological differences in heart rate, blood pressure and blood lactate between HVLL and LVHL resistance exercise.
3. Both HVLL and LVHL have similar affective responses in already active older adults despite LVHL being perceived as more fatiguing and having a greater rating of perceived exertion.
4. The Physical Activity Enjoyment Scale and visual analogue scale for enjoyment suggest that both HVLL and LVHL were largely and similarly enjoyable to already active older adults.
5. The visual analogue scales for fatigue and perceived workload were significantly greater following LVHL exercise.
6. Given the positive affective responses, based on hedonic theory, it is practical to conclude that both HVLL and LVHL would have a positive impact on continued exercise behaviour.
7. Both HVLL and LVHL whether performed once or twice-weekly, significantly improved some aspects of maximal strength and functional performance in moderate-highly active older adults.
8. Increases in maximal strength were greatest in those that performed LVHL.
9. Only LVHL performed twice-weekly improved aspects of functional performance significantly compared to the control condition.
10. The intensity of effort that resistance exercise is performed at may be more important than its velocity, for making gains in maximal strength and functional performance in older adults.

8.5 Recommendations for future research

After conducting the studies presented in this thesis and further examining the wider literature, the following recommendations for future research are presented:

- All of the studies in this thesis were conducted in a sports centre under supervision. It is unlikely that there will be the provision for such supervised programmes for the majority of older adults in the near future. Therefore, more investigations should be carried out with minimal equipment e.g. dumbbells, resistance bands, possibly at home. This would more closely resemble a more likely training environment, as many older adults do not have the ability or motivation to participate in supervised facility-based programmes (Cohen-Mansfield et al. 2003).

- The role that exercise programme supervision has on functional improvements, adverse events and affective responses observed in this thesis and many other studies, warrants further investigation.

- The training interventions in this thesis and the wider literature are often conducted over short intervention periods. It would be beneficial if more studies continued these types of resistance exercise programmes over a longer period e.g. years instead of weeks or months. Measuring affective and physiological responses over this time frame would aid in providing superior recommendations.

- Further investigation into the minimal effective dose of resistance exercise is also warranted. Study 5 investigated the minimal effective amount of weekly sessions, but there are many variables in the session which could also be manipulated. For example, changing the number of exercises, sets, time under tension and repetitions etc.

- As highlighted in the thesis, many studies conducted thus far, appear to have used more female participants. As females have been shown to respond more favourably to low-load resistance exercise than males, this may have skewed conclusions in favour of HVLL. In study 5 an equal number of male and female participants were used, and HVLL was not more effective than LVHL. Therefore, more studies should be conducted with male participants or at least with equal numbers of male and female participants. This would help to establish if the same resistance exercise programmes should be prescribed to both older males and females.

- The heterogeneity of study designs makes it difficult to compare the findings of one study to another. Future research would benefit from employing similar protocols and procedures to ensure comparability across studies e.g. tests and methods of testing, in order to establish clearer conclusions on resistance exercise recommendations for older adults.

- The participants that took part in the studies within this thesis were resistance exercise naïve but also moderately to highly active (as categorised by the IPAQ). Research has shown that those who are more physically active are likely to have more positive affective responses to exercise. This represents an unavoidable bias, as those who are interested in exercise or have already realised the benefits, are the ones who volunteer for such research. Therefore, it would be beneficial to conduct this type of research in more sedentary older adults, possibly in a clinical setting, where this type of exercise is offered to older adults as part of their treatment. This would likely be more representative of the wider sedentary population.

- Within-condition analyses in study 5 lends support to the fact that once-weekly resistance exercise may improve aspects of maximal strength and functional performance. Further investigations substantiating the efficacy of once-weekly resistance exercise are needed, so that updates can be made to the physical activity guidelines if needed.

- There is a wealth of literature testifying to the usefulness of resistance exercise in improving health and functional outcomes in older adults. The challenge now is how to integrate resistance exercise in to the lives of older adults, considering factors such as: safety; effectiveness; cost; adherence and equipment. More research should be focused on how to get older adults to do something, as opposed to nothing.

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Appendices

Appendix A: Ethical approval certificates

Certificate of Ethical Approval

Applicant:

Darren Richardson

Project Title:

A Reliability Study to Demonstrate the Amount of Familiarisation Needed to Achieve Consistent Speed of Movement during High and Low Velocity Exercise

This is to certify that the above named applicant has completed the Coventry University Ethical Approval process and their project has been confirmed and approved as Medium Risk

Date of approval:

14 March 2016

Project Reference Number:

P40329

Certificate of Ethical Approval

Applicant:

Darren Richardson

Project Title:

The efficacy of high and low velocity resistance exercise performed once or twice weekly on improvements in functional performance in older adults

This is to certify that the above named applicant has completed the Coventry University Ethical Approval process and their project has been confirmed and approved as Medium Risk

Date of approval:

10 February 2017

Project Reference Number:

P51432

Appendix B: Example participant information sheet and Informed Consent form

PARTICIPANT INFORMATION SHEET
UNDERGRADUATE AND TAUGHT POST GRADUATE STUDENT PROJECTS
DEPARTMENT OF BIOMOLECULAR AND SPORT SCIENCES

A copy of this sheet must be given to all participants for them to keep

PROJECT TITLE: The efficacy of high and low velocity resistance exercise performed once or twice weekly on improvements in functional performance in older adults.

NAME OF STUDENT: Darren Richardson

Thank you for considering helping one of our students with their research work. This form explains what you will be asked to do. If you have any questions about this please ask the student.

By signing this form you agree to take part in the study. However, please note that you are free to stop taking part at any time.

Information about the project/Purpose of the project Many studies that have previously examined high and low velocity resistance training in older adults have not reached a firm conclusion on which is more effective at improving functional performance (ability to complete everyday tasks). Programmes of exercise used in these studies have done so, training two or three times weekly. This may not be a desirable or sustainable programme of exercise for many older adults to complete. This study aims to find out if training just once per week is enough to make significant improvements in functional performance compared to twice per week and secondly, does training with high or low movement velocity make a difference to any improvements.
Why have I been chosen? You have been selected to participate in this study because you are a healthy adult, aged 60 and over who is unfamiliar with resistance exercise. Who does NOT display any of the following exclusion criteria: acute or terminal illness, cognitive impairment, had a heart attack, had a lower extremity bone fracture in the previous six months, symptomatic coronary artery disease, congestive heart failure, high blood pressure (>150/90 mm Hg), neuromuscular disease, or hormone replacement therapy and has not done weight training more than once per week in the last 6 months.
Do I have to take part? You do not have to take part in this research project if you do not want to and you do not need to give any reason if you decide not to take part

What do I have to do?
It is also important that you fit the inclusion criteria for this study which includes the absence of several conditions and illnesses (listed above) whilst also being unfamiliar with resistance exercise. Before testing you will be asked to fill out an informed consent form and a health questionnaire before every session. You will also be asked to refrain from any other exercise or strenuous physical activity in 24 hours prior to attending each testing session. Physical details will be collected that include your age, height, mass, blood pressure, body fat and muscle mass information using a Tanita machine. You will attend a preliminary session where you will complete: 8ft Timed up and go, chair sit and reach, arm curls, back scratch, 6-minute walk test, Grip strength, (SPPB balance tests, gait speed, chair stand) Minnesota manual dexterity test. Following these tests, you will be asked to perform a maximum of 10 repetitions on each exercise for an estimation of the maximal weight you can lift on each exercise (1RM test) to be made, the complete session should take in the region of 90-120 minutes to complete. These weights will then be used as a baseline for your training programme. You will then be allocated one of the groups; fast weight training once weekly, fast weight training twice weekly, slow weight training once weekly, slow weight training twice weekly or a no exercise control group. At the start and end of the intervention you will be required to complete questionnaires that will assess your enjoyment and perception of the training programme. During each session, we will monitor your heart rate and blood pressure and enjoyment. You will complete a late life function and disability instrument questionnaire before and following the 10-week training intervention period. Following each training session, you will complete a 24-hour dietary recall form that details what you ate in the 24 hours after each training session.
What are the risks associated with this project?
- There is a possibility of you getting muscle soreness from performing the exercises. This soreness will subside after 48-72 hours. This will be minimised by following a structured and specific warm up and cool down protocol. - There is a chance you may pull muscles from lifting heavy weights (80% 1RM), however a sufficient warm up will significantly reduce this possibility. - You may experience some light headedness from lifting weights but this will be managed with the teaching of correct lifting and breathing techniques. -
What are the benefits of taking part?
Upon completion of the 10-week training intervention you will receive £20 in love2shop vouchers
Withdrawal options
You are free to stop taking part in this study at any time and you do not have to give any reason for this
Data protection & confidentiality
Procedures for handling, processing, storage and destruction of their data match the Caldicott principles and the Data Protection Act 1998. All data gathered will be anonymous and treated in strictest confidence. It will only be used for the purposes

described above and only the principal researcher will have access to the data. Once the research has been completed the data will be destroyed.
Who should you talk to if you have questions or you wish to make a complaint? If you have any questions or queries Darren Richardson will be happy to answer them. If they cannot help you can speak to Neil Clarke If you have any questions about your rights as a participant or feel you have been placed at risk you can contact Neil Clarke
What will happen with the results of the study? Any data/ results from your participation in the study will be used by Darren Richardson as part of their PhD. The data will also be available to Neil Clarke. It may also be published in scientific works, but your name or identity will not be revealed.
Who has reviewed this study? This study has ethical approval from Coventry University

Content removed on data protection grounds

INFORMED CONSENT FORM
UNDERGRADUATE AND TAUGHT POST GRADUATE STUDENT PROJECTS
DEPARTMENT OF BIOMOLECULAR AND SPORT SCIENCES

PROJECT TITLE: The efficacy of high and low velocity resistance exercise performed once or twice weekly on improvements in functional performance in older adults.

NAME OF STUDENT: Darren Richardson

SUMMARY OF PROJECT

Many studies that have previously examined high and low velocity resistance training in older adults have not reached a firm conclusion on which is more effective at improving functional performance (ability to complete everyday tasks). Programmes of exercise used in these studies have done so, training two or three times weekly. This may not be a desirable or sustainable programme of exercise for many older adults to complete. This study aims to find out if training just once per week is enough to make significant improvements in functional performance compared to twice per week and secondly, does training with high or low movement velocity make a difference to any improvements.

	Please initial
1. I confirm that I have read and understood the participant information sheet for the above study and have had the opportunity to ask questions	
2. I understand that my participation is voluntary and that I am free to withdraw at anytime without giving a reason	
3. I understand that all the information I provide will be treated in confidence and only disclosed to people detailed on the Participant Information Sheet	
4. I agree to take part in the research project	

Name of participant: ____________________ Signature of participant: _________________________

Date: _____________

Name of Researcher:_________________________ Signature of researcher: ___________________________

Date:____________________________

A CONSENT FORM MUST BE SIGNED BY ALL PARTICIPANTS BEFORE THEY TAKE PART IN THE STUDY AND THE SIGNED FOMRS MUST BE SUBMITTED BY STUDENTS AT THE END OF THEIR PROJECT

Appendix C: Scales and forms used throughout this thesis

Appendix C1 - Physical Activity Affect Scale (PAAS) (Lox et al. 2000)

Note. Subscales and corresponding items are as follows: Positive Affect (1, 3, 11); Negative Affect (6, 10, 12); Fatigue (4, 7, 9); Tranquility (2, 5, 8).

Appendix C2 - Felt Arousal Scale (FAS)

(Svebak and Murgatroyd 1985)

Appendix C3 - The Feeling Scale (FS)

(Hardy and Rejeski 1989)

Appendix C4 - RPE Scale (Borg 1982)

Appendix C5 - Visual Analogue Scales (VAS) (Kuys et al. 2011)

Appendix C6 - Modified PACES (Graves et al. 2010)

Appendix C7 - Adverse Events Report Form

ADVERSE EVENTS
Please indicate below any side-effects you have experienced
These may include events such as:
Muscle aches and pains
Joint aches and pains
Dizziness, sickness, pulled muscles
Or any other side-effects you have experienced during the exercise programme