The Effects of Eccentric Resistance Exercise on the Physical and Physiological Profile of the High Functioning Older Adult

Ashley Gluchowski

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Doctor of Philosophy (PhD)

Human Potential Centre
Primary Supervisor: Dr. Nigel Harris
Secondary Supervisor: Dr. Deborah Dulson

Abstract

The population is ageing in nearly every country in the world and New Zealand is no exception. In New Zealand, 14% of the total population is currently 65 years and older, compared to 12% in 2002 (Statistics NZ, 2012). The number of older adults has doubled since 1980 and this number is expected to double again by 2036 (Statistics NZ, 2012). However, populations of disabled and diseased older adults are of major social and economic concern.

Preventative efforts against the devastating yet predictable effects of ageing are likely to translate into significant reductions in this societal and economic burden (Goldman et al., 2013). Structured resistance exercise is increasingly acknowledged as a potent treatment of many of these effects that are commonly associated with ageing. Thus, the primary focus of this PhD was to conduct a series of cohesive investigations in order to answer the research question,

> What is the relative efficacy of eccentric-only resistance exercise and the more practically applicable eccentrically-biased resistance exercise when compared the more conventionally prescribed traditional resistance exercise with regards to changes in the physical and physiological profile of healthy, high functioning, resistance trained older adults?

This PhD thesis is constructed into several parts to organize the flow of investigation. The conclusion from our narrative literature review provides evidence in support of eccentric exercise for several outcomes of interest to older, healthy adults. Outcomes such as increased muscular strength and improved functional capacity are expected to occur following eccentric exercise. In addition, major muscular soreness that typically accompanies eccentric muscle actions can be avoided in this older population. Taken together, eccentric exercise proves to be at least as effective as other heavy training modalities as well as to be found safe to perform. Our acute crossover study describes novel physiological data not previously described for healthy, resistance trained older adults during eccentric resistance training. Thus, the exercise variables for the safe use of eccentric resistance exercise and the resulting physical and physiological outcomes from this acute study laid the groundwork for our subsequent chronic study. Consequent outcomes from our eight week intervention show no statistical differences between eccentric training modalities when compared to the more conventionally prescribed, traditional resistance exercise (when relative load is equated) for a number of outcomes including maximal muscular strength, functional capacity, body composition and metabolic biomarkers. Finally, outcomes from our follow-up qualitative study show that any modality of heavy resistance training is subjectively well tolerated and thoroughly enjoyed by healthy, older adults.

This thesis contributes to the World Health Organization's policy framework surrounding and supporting the action of a relatively new concept of 'active ageing.' The

implications and applications of this research will not only improve outcomes of interest to individual older adults themselves, but also lighten the societal and economic burden that typically accompanies sedentary ageing.

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Attestation of Authorship

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any degree or diploma of a university or other institution of higher learning.

Chapters 2, 3, 4 and 5 of this thesis represent 4 separate papers that have either been published or have been submitted to peer-reviewed journals for consideration for publication. My contribution and the contributions of the various co-authors to each of these papers are outlined at the beginning of this thesis (see ‘co-authored works’ section). All co-authors have approved the inclusion of the joint work in this doctoral thesis.

Ashley Gluchowski

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Co-Authored Works

Chapter	Contribution	Contribution	
Chapter 2	AG - Literature search, extraction and analysis, manuscript writing	AG	80%
	NH – Guidance and manuscript editing	NH	15%
	DD & JC – Manuscript review	DD	2.5%
		JC	2.5%
Chapter 3	AG – Data collection, analysis, writing	AG	80%
	NH – Manuscript editing	NH	17.5%
	DD - Manuscript review	DD	2.5%
Chapter 4	AG – Data collection, analysis, writing	AG	80%
	NH – Manuscript editing	NH	12.5%
	DD – Manuscript review	FM	2.5%
	FM – Sample processing	DD	2.5%
	LP – Laboratory use	LP	2.5%
Chapter 5	AG – Data transcription, analysis, writing	AG	80%
	IW – Data collection, manuscript editing	IW	10%
	TO – qualitative research guidance, manuscript editing	TO	7.5%
	NH – manuscript review	NH	2.5%

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First and foremost, I would like to acknowledge my primary academic supervisor, Dr. Nigel Harris. Nigel, you are the perfect example of what every postgraduate student visualizes of when asked to envision their ideal supervisor. I am beyond privileged and profoundly grateful to have had you on my side throughout this process. You certainly have gone above and beyond the call of duty. You knowingly took on an international student, who wanted to come to one of the most expensive cities in the world, who also needed to fund her own PhD, who wanted to switch from Medical Science to Exercise Science without any prior formal knowledge in the area, who wanted to push the boundaries in strength training for older adults, who wanted (needed!) to gain as much teaching experience while still studying, and as a result, a PhD student who is now well beyond her allotted three years. Needless to say, I attribute all my success in not only my PhD progression but also in my success at AUT as a whole. It was you who supported me when I wanted to go against popular advice and investigate very heavy load training in older adults. It was you, through your constant reminder to utilize tact when responding to the dreaded reviewer #2, whom probably has played the biggest part in me actually being a published researcher! It was you who managed to keep me afloat by knocking on (kicking in!) closed doors that led to employment (maybe they'll open up in February! Haha). It was you who turned my thoughts into reality when you endorsed the conception of my Active Ageing Clinics. AND it is you, who deserves a promotion just for the simple fact that I know what MBI stands for (and use it, no less!), when most times I think it would be easier to teach statistics to a fish! In all seriousness, Nigel, there are no combination of words I could string together that are meaningful enough to express my gratitude for all your time and effort as my supervisor. You have done everything you possibly could have done to get me to this point; I am and will be forever grateful.

To Dr. Deborah Dulson, my secondary supervisor and Professor John Cronin, my mentor, I appreciate you both for being part of my team. You have provided me with everything I ever needed or asked for and again, I am forever grateful for your contribution to the preparation of this PhD thesis.

Ethical Approval

Ethical approval for Chapters 3, 4 and 5 were granted by the Auckland University of Technology Ethics Committee (AUTEC). Reference: 15/229 Approved on 8 July 2015 (Appendix A)

Ethical approval for Chapter 6 was granted by the Auckland University of Technology Ethics Committee (AUTEC). Reference: 16/191 Approved on 13 May 2016 (Appendix B)

List of Abbreviations

Abbreviation	Definition
1RM	1 repetition maximum
1ERM	1 eccentric only repetition maximum
ACC	Accident Compensation Corporation
AUTEC	Auckland University of Technology Ethics Committee
BBS	Berg balance scale
BMC	Bone mineral content
CK	Creatine kinase
CORT	Cortisol
CRP	C reactive protein
DXA	Dual energy x-ray absorptiometry
EBRE	Eccentrically biased resistance exercise
ERE	Eccentric only resistance exercise
FAB Scale	Fullerton advanced balance scale
HbA1c	Glycated haemoglobin
HDL	High density lipoprotein
HGH	Human growth hormone
HR	Heart rate
LDL	Low density lipoprotein
N2O	Never2Old
RPE	Rating of perceived exertion
SBP	Systolic blood pressure
SORE	Visual soreness scale
SPSS	Statistical package for the social sciences
TEST	Testosterone
TG	Triglycerides
VO_2	Oxygen consumption

Chapter 1 Introduction

1.1 Rationale

According to United Nations, the older adult population (60 years and older) is projected to exceed the number of children for the first time by the year 2047 (UNdata, 2017). The population is aging in nearly every country in the world and New Zealand is no exception (UNdata, 2017). Even within the older adult population, the oldest old (80 years and older) are projected to reach 400 million by 2050 (www.un.org). Populations of disabled and diseased older adults are of major social and economic concern, however, preventative efforts are likely to translate into significant reductions in this overall burden (Goldman et al., 2013).

In New Zealand, 14% of the total population is currently 65 years and older, compared to 12% in 2002 (Statistics NZ, 2012). The number of older adults has doubled since 1980 and this number is expected to double again by 2036 (Statistics NZ, 2012). This is of importance as studies have shown the decrease in muscular power, muscular strength, muscle mass and functional capacity as early as 50 years of age (Marcus, LaStayo, Dibble, Hill, & McClain, 2009; Raj, Bird, Westfold, & Shield, 2012; Valour, Rouji, & Pousson, 2004). Of the 611,400 older adults in New Zealand, nearly 60% are disabled, with mobility and agility accounting for half of all reported disabilities (Statistics NZ, 2013). This means that over 40% of older adults in New Zealand are still living independently and free from any current physical disability.

Interestingly, the obesity rate has increased right alongside the increasing aging population, with well over one-third (39%) of New Zealanders in the 65 to 74 year old age bracket having a BMI of at least 30 kg/m^2(Statistics NZ, 2012). Not surprisingly then, diabetes has also increased with each increasing age bracket, affecting 15% of those 75 years and older (Statistics NZ, 2012). In terms of cardiovascular disease, half of those in the 75 years and older age bracket have high blood pressure and take medication to control their condition while one fifth have been diagnosed with ischemic heart disease (Statistics NZ, 2012). In addition, a third of the 65 years old and older population have high cholesterol and take medication to control that condition (Statistics NZ, 2012).

In addition to an increase in our disabled and diseased ageing population, the number of fatal falls in people 75 years and older has doubled from approximately 200 in the year 2000 to over 400 fatal falls occurring in 2010 (Statistics NZ, 2012). Non-fatal but serious falls occurred well over 3,000 times in that same year (Statistics NZ, 2012). The Accident Compensation Corporation (ACC) of New Zealand indicates that there were 130,000 accident claims for falls in adults over the age of 65 in 2013, costing ACC nearly 133 million dollars in that one year alone (ACC is funded by levies and taxation of working, non-earning and retired citizens) (ACC, personal communication).

Thus, as the population continues to rapidly and disproportionally age, we must intervene in an attempt to prevent, delay or at the very least attenuate these devastating physical and physiological effects of the aging older adult (Margolick & Ferrucci, 2015). From the irrefutable statistics, it is apparent that older adults (as well as society as a whole) would significantly benefit from the investigation of theoretically and practically promising preventative interventions (Slagboom et al., 2012). Arguably, our most effective preventative intervention is structured resistance exercise (Singh, 2002). Thus, global physical activity guidelines indicate that resistance exercise should take place on two or more days of the week (WHO, 2011). Unfortunately, physical activity as a whole begins to decline at age 45, with less than 40% of adults 75 years and older exercising regularly (New Zealand Ministry of Health, 2012-2013). With this decrease in physical activity, the aforementioned decrease in muscular strength, muscle mass, and functional capacity that accompanies the ageing process becomes nearly inevitable. In addition, sedentary ageing has also been shown to increase metabolic syndrome, chronic inflammation, cardiovascular disease and decrease anabolic signalling (Kawada, Otsuka, Endo, & Kon, 2011; Mendoza-Núñez et al., 2011; Rhoades et al., 2007; Swiecicka et al., 2017). Yet, structured resistance exercise has been shown to increase muscular power, muscular strength, functional capacity, exercise capacity, cardiovascular function, pulmonary function, nutritional capacity, improve body composition (decrease fat mass while increasing muscle mass and bone density), improve blood biomarkers of healthy ageing (fasting plasma glucose, insulin, low-density lipoprotein (LDL), C-reactive protein (CRP)), improve cognitive function, and significantly improve overall feelings of quality of life and well-being (Benton & Schlairet, 2012; Best, Chiu, Liang Hsu, Liu-Ambrose, & Nagamatsu, 2015; Hvid et al., 2016; Kemmler et al., 2010; Liu & Latham, 2009; Reeves, Maganaris, Longo, & Narici, 2009; Singh, 2002).

Structured resistance exercise can take the form of any number of unique modalities (traditional resistance exercise, eccentric exercise, isometric exercise, power/ballistic exercise, plyometric exercise/calisthenics, functional training, circuit/high intensity interval training) with even more distinctive variables of prescription (number of repetitions, number of sets, repetition tempo, rest period, relative/absolute load, frequency of training program, duration of training program). Based on the current research, it is still unclear even which general modality could potentially be the most effective for the older adult population.

Recently, there has been substantial interest in the literature into the investigation of the benefits of a particular modality of structured resistance exercise, namely, eccentric exercise, particularly for the older adult population. The inherent properties of eccentric muscle actions (low energy cost of doing negative work when compared to positive (concentric) work (Abbott, Bigland, & Ritchie, 1952), higher force production capability when compared to concentric or isometric muscle actions (Katz, 1939) and even the preservation of eccentric strength during the aging process, especially in females (Hortobágyi et al., 1995)) make eccentric exercise in this population particularly intriguing for investigators. To this point, most investigators have been particularly interested in the low energy cost of performing eccentric exercise and its benefits for the lower functioning older adult (older adults that have limited strength or aerobic capacity, such as those affected by sarcopenia, obesity, cardiovascular or pulmonary disease). However, eccentric exercise has also been found to have significant and superior benefits (a significant and superior increase in concentric and eccentric muscular strength, muscular power, muscle hypertrophy, vertical jump height and running speed) when compared to traditional resistance exercise in younger, athletic populations (Maroto-Izquierdo et al., 2017). Since these particular outcomes are also of interest to older adults, it would be prudent to also investigate eccentric exercise in the older adult population.

Unfortunately, another inherent characteristic of eccentric muscle action seems to be significant muscle damage, likely as a result of microtrama to the sarcomeres (Allen, Dumont, & MacIntyre, 2004). Thus, there has also been substantial interest in the literature investigating the possible muscle damaging effects of eccentric exercise on vulnerable populations such as older adults (Nogueira et al., 2014). Despite the substantial physical benefits eccentric exercise has in athletic populations as well as the possible muscular damage eccentric exercise may have in vulnerable populations, to the best of our knowledge, there has been no research as yet investigating eccentric resistance exercise in a resistance trained older adult population. Eccentric resistance exercise ought to be explored using a resistance trained, older adult population as it is possible that this modality could prove to be a powerful progressive tool for optimal muscular strength gain, muscle mass gain, and functional capacity improvement when compared to our conventionally prescribed traditional resistance exercise, just as eccentric resistance exercise has been shown to have these adaptations in a younger, athletic population (Maroto-Izquierdo et al., 2017).

Indeed, if evidence mounted in favour of eccentric resistance exercise as an effective modality for the outcomes of interest (that is, muscular strength, functional capacity, body composition, blood biomarkers for anabolic signalling) in a resistance trained older adult population, it is a possibility that through the translation of that research, we could begin to attenuate the devastating physical and physiological effects that customarily accompanies the ageing process. Thus, it is the primary focus of this PhD thesis to investigate and if appropriate, expand our structured resistance exercise programming options by exploring the relative efficacy of eccentric resistance exercise when compared to traditional resistance exercise in a healthy, high functioning, resistance trained older adult cohort.

1.2 Research Objectives

1.2.1 Overarching Research Question

What is the relative efficacy of eccentric-only resistance exercise (from here on out termed eccentric resistance exercise or ERE) and the more practically applicable eccentrically-biased resistance exercise (EBRE) when compared the more conventionally prescribed traditional resistance exercise (TRE) with regards to changes in the physical and physiological profile of healthy, high functioning, resistance trained older adults?

1.2.2 Overarching Research Aim

To explore the effects of eccentric resistance exercise on maximal muscular strength (primary outcome), functional capacity (secondary outcome), body composition (secondary outcome) and blood biomarkers of healthy ageing (secondary outcome) and compare this to the effects resulting from the more conventionally prescribed traditional resistance exercise in a cohort of older adults.

1.3 Specific Objectives

1. Review and critique the current literature surrounding eccentric exercise in the older adult (Narrative Literature Review, Chapter 2, published manuscript – Sports Medicine)
2. Investigate the acute physiological effects and subjective perspectives of performing ERE, EBRE and TRE (Acute Case Study, Chapter 3, submitted manuscript – International Journal of Sport Nutrition and Exercise Metabolism).
3. Investigate the chronic physical and physiological effects of ERE, EBRE and TRE (Intervention, Chapter 4, published manuscript – Experimental Gerontology)
4. Investigate the thoughts and feelings of particpants who have completed our very heavy load training program (Qualitative Study, Chapter 5, published manuscript – Qualitative Research in Sport, Exercise and Health)
5. Summarise, discuss and conclude the specific research objectives and overarching research aim. Suggest future research directions (Chapter 6).

Since Chapters 2, 3, 4, and 5 have been prepared for publication in distinct quality peer-reviewed journals, some repetition occurs throughout this thesis. Prefaces will introduce each Chapter; thereafter the Chapter will be similar to their published form. Chapter 6, the conclusion, is a synthesis of the research completed for this PhD and aims to provide implications for future work in the field of active ageing.

1.4 Candidate Contribution

This thesis fulfils the terms of an Auckland University of Technology Doctoral Degree through a significant, original contribution to knowledge regarding eccentric exercise and the older adult through critical appraisal of the existing literature and the completion of empirical studies.

The development of the research questions were solely undertaken by the candidate. Development of the research followed a review of the literature which identified both the strengths and the gaps in current understanding and practical programming of eccentric resistance exercise in the older adult.

The candidate was also involved in design and solely involved in the data collection phases. The candidate was also involved in the data analysis, write up, submission for publications and on-going dissemination phases.

Table 1. Research Publications and Conference Presentations

Chapter	Publication/Conference Presentation
Chapter 2	Gluchowski, A., Harris, N., Dulson, D., & Cronin, J. (2015). Chronic Eccentric Exercise and the Older Adult. *Sports Medicine,* 45(10), 1413-1430. Impact factor: 6.8 Gluchowski, A. (2015, November). Resistance training in the older adult – with a special emphasis on eccentric training. Invited presenter at the FitEx Conference, Auckland.
Chapter 3	Gluchowski, A., Harris, N., Dulson, D. (2017). The acute effects of eccentric exercise in resistance trained older adults. Ready to submit.
Chapter 4	Gluchowski, A., Dulson, D., Merien, F., Plank, L., & Harris N. (2017). Comparing the effects of two distinct eccentric modalities to traditional resistance training in resistance trained, high functioning older adults. *Experimental Gerontology*, 98, 224-229. Impact factor: 3.3 Gluchowski, A. (2016, September). *Very high load resistance training in older adults*. Poster presented at the New Zealand Association of Gerontology Annual Conference, Wellington.
Chapter 5	Gluchowski, A., Warbrick, I., Oldham, T., & Harris, N. (2018). “I have a renewed enthusiasm for going to the gym” What keeps resistance trained older adults coming back to the gym? *Qualitative Research in Sport, Exercise and Health* doi.org/10.1080/2159676X.2018.1431305. Impact factor: 2.0

Chapter 2 Chronic Eccentric Exercise and the Older Adult: A Review

Preface

The inherent properties of eccentric muscle actions (low energy cost of doing negative work when compared to positive (concentric) work (Abbott et al., 1952), higher force production capability when compared to concentric or isometric muscle actions (Katz, 1939) and even the preservation of eccentric strength during the aging process, especially in females (Hortobágyi et al., 1995)) make eccentric exercise in the older adult population particularly intriguing for investigators. However, most investigators have been particularly interested in the low energy cost of performing eccentric exercise and its benefits for the lower functioning older adult (older adults that have limited strength or aerobic capacity, such as those affected by sarcopenia, obesity, cardiovascular or pulmonary disease). On the other hand, eccentric resistance exercise may also prove to be a powerful progressive tool for optimal muscular strength, functional capacity and physiological improvements in the healthy, higher functioning, resistance trained older adult.

This review aimed to identify those original research papers that investigated a chronic eccentric exercise intervention in healthy, high functioning older adults. Unfortunately, there were no investigations on resistance trained older adult cohorts. Outcomes of interest from these interventions included the effect of eccentric exercise on muscular strength, functional capacity, body composition/muscle architecture, markers of muscle damage/immune system, the cardiovascular system, endocrine system and on the rating of perceived exertion. Our liberal inclusion of original research articles for this review still resulted in only 14 papers, thus a narrative review (and not a systematic review or meta-analysis) was determined to be best fit. I am exceedingly proud to state that this Chapter was accepted and published in Sports Medicine, a peer-reviewed journal with the highest impact factor and the number one choice for most researchers in the field of Sport and Exercise Science. Most importantly, as a result of this review, I was able to identify strengths in the design of the previous interventions as well as any remaining gaps in the current literature and apply both to my research design which investigated the chronic effects of eccentric resistance training modalities in resistance trained older adults (see Chapter 4).

Key Points

Chronic eccentric exercise leads to significant improvements in a variety of physical and physiological outcomes in the older adult population.

Chronic eccentric exercise should not be avoided due to the misconception of the older adult's inability to adapt to the mechanical stress and resulting muscle damage of eccentric muscle action.

Chronic eccentric exercise results in less stress on the cardiovascular system as well as lowered perceived exertion scores when compared to traditional resistance exercise, thus eccentric exercise may be a more appropriate modality for particular cohorts of the older adult population.

Abstract

Eccentric exercise has gained increasing attention as a suitable and promising intervention to delay or mitigate the known physical and physiological declines associated with aging. Determining the relative efficacy of eccentric exercise when compared to the more conventionally prescribed traditional resistance exercise will support evidence based prescription for the aging population. Thus, 14 original research studies incorporating chronic eccentric exercise interventions in the older adult population were included in this review. The effects of a range of eccentric exercise modalities on muscular strength, functional capacity, body composition, muscle architecture, markers of muscle damage, the immune system, cardiovascular system, endocrine system and rating of perceived exertion were all reviewed as outcomes of particular interest in the older adult. Muscular strength was found to increase most consistently when compared to traditional resistance exercise. Functional capacity and body composition showed significant improvements with eccentric endurance protocols, especially in older, frail or sedentary cohorts. Muscle damage was avoided with the gradual progression of novel eccentric exercise while muscle damage from intense acute bouts was significantly attenuated with repeated sessions. Eccentric exercise causes little cardiovascular stress, thus it may not generate the overload required to elicit cardiovascular adaptations. An anabolic state may be achievable following eccentric exercise while improvements to insulin sensitivity have not been found. Finally, rating of perceived exertion during eccentric exercise was often significantly lower than during traditional resistance exercise. Overall, evidence supports the prescription of eccentric exercise for the majority of outcomes of interest in the diverse cohorts of the older adult population.

2.1 Introduction

Eccentric exercise in the older adult has gained considerable attention within the last decade. The growing interest is conceivably attributable to the appropriateness and tolerability of eccentric exercise for older adults who might otherwise be limited by their diminished muscular strength and aerobic capacity. The unique properties of eccentric muscle action (low energy cost (Abbott et al., 1952), high force production (Katz, 1939) and the preservation of eccentric strength during the aging process, especially in females (Hortobágyi et al., 1995)) may make eccentric exercise a preferred option in some older adult cohorts. While eccentric muscle action is a well-defined phenomenon in the literature (Lindstedt, Reich, & LaStayo, 2001), eccentric exercise modalities are varied and often ambiguously described. Current research on eccentric exercise in the older adult has described body weight (Gault, Clements, & Willems, 2012; Theodorou et al., 2013), sub-maximal (Leszczak, Olson, Stafford, & Di Brezzo, 2013), maximal (Raj et al., 2012) and supra-maximal (Reeves et al., 2009) concentric one-repetition maximum (1RM) loads with a wide range of eccentric phase tempos (Jiménez-Jiménez et al., 2008; Leszczak et al., 2013). Some include (Raj et al., 2012) and others exclude (Reeves et al., 2009) concentric muscle actions. Furthermore, although it is known that traditional resistance training has significant effects on several physical and physiological outcomes (Liu & Latham, 2009; Singh, 2002), there has been little research on blood markers as an adaptation of eccentric training. Hence, for the purposes of this review, the term eccentric resistance exercise (ERE) will be used exclusively for studies that utilized a series of eccentric-only repetitions for the target muscle (deliberately excluding the concentric phase) in a structured resistance training intervention. Eccentric resistance exercise programs for instance, used isoinertial equipment alongside a partner who executed the concentric phase of the lift for the subject. Alternatively, ERE interventions may have used isokinetic devices programmed to passively return the subjects limbs to the start of the eccentric cycle upon completion of the eccentric muscle action. The term eccentrically biased resistance exercise (EBRE) will be used for resistance interventions that have attempted to emphasize the eccentric phase of the exercise yet the concentric phase was still performed. In EBRE, a partner has aided the subject with the concentric phase of the exercise, so that only a fraction of the load was lifted (common when using supra-maximal loads); the eccentric phase was then completed without any external assistance. Otherwise, subjects have lifted the load (that is, completed the concentric phase of the exercise) using two limbs and subsequently lowered the load with one limb, in an alternating limb fashion (common with machine based exercises such as the leg press). Finally, the term eccentric endurance exercise (EEE) will be used for interventions that have prescribed continuous eccentric muscle action (most often of the quadriceps muscle), on a staircase, stepper, treadmill or cycle ergometer. Research groups have implemented these eccentric exercise modalities in the older adult population in an attempt to determine their efficacy on muscular strength, functional capacity, body composition, muscle architecture, markers of muscular damage, the immune, cardiovascular and endocrine systems. Greater understanding of eccentric training induced adaptations on these outcomes would serve to underpin future research pathways as well as contribute to evidence based practice. Therefore, it is the objective of this paper to review the relative efficacy of eccentric exercise modalities on a range of outcome measures in the older adult population, in particular when compared to the conventional modality of traditional resistance exercise (TRE).

2.2 Methodology

A literature search was conducted to identify all original research articles that investigated a chronic ERE, EBRE or EEE intervention in the older adult population (for the purposes of this review, "older adult" was defined as a mean age of at least 55 years) and that included at least one outcome from the following areas of interest: muscular strength, functional capacity, body composition, muscle architecture, markers of muscular damage, the immune system, cardiovascular system, endocrine system and/or rating of perceived exertion. The electronic databases PubMed and SPORTDiscus were searched from their earliest records until July 2015. The following terms were used for the search, "eccentric" AND "older" OR "older adult*" OR "geriatric*" OR "senior*" OR "elderly" OR "age" OR "aged" OR "aging". Relevant articles from the references of included articles were also considered. Due to the limited number of studies investigating each of the main outcomes of interest compounded with the considerable differences in eccentric modalities used between those studies, quality of research was not systematically rated and a narrative review style was chosen. Detailed descriptions of each of the 14 studies are outlined in Table 2. In cases where multiple publications investigated the same population of subjects, the most appropriate publication was reviewed (P. LaStayo et al., 2007; P. C. LaStayo, Ewy, Lindstedt, Pierotti, & Johns, 2003; Melo et al., 2008; Matthias Mueller et al., 2011; M. Mueller et al., 2009; Takahashi, Melo, Quitério, Silva, & Catai, 2009). In all tables thereafter (Table 3, Table 4 and Table 5), relative efficacy of eccentric exercise will be described using percent change from baseline within groups. Relative efficacy of eccentric exercise when compared to TRE (or alternative comparison group) will be described using between group differences. Within and between group significance for percent change values are stated where reported within the original article.

Table 2. Characteristics of studies investigating eccentric exercise in the older adult population

Study	Population (characteristics, sex, age [y, mean ± SD])	Exercise Modality [exercise(s)]	Training duration (adherence rate)	Intervention (group size) [sets, reps, intensity, eccentric/concentric tempo, rest between sets]	Relative volume (sets x reps x load)[a]	Concentric muscle action performed?
Leszczak et al.	Healthy, currently active, community-dwelling Mixed sex 65-89 EBRE: 76±8 High velocity: 74±8	Pneumatic Leg Press Knee Extension Leg Curl	8 weeks 3x/week 90% of sessions completed	EBRE (n=10) 3 sets, 8-12 reps, 75% 1RM E 3-5s; C 1-2s No rest described High Velocity (n=9) 3 sets, 8-12 reps, 50% 1RM E 2-3s; C as fast as possible No rest described	1800 - 2700 1200 - 1800	Yes, with trainers help
Raj et al.	Community-dwelling Mixed sex 68±5	Isoinertial Leg press Toe press Pull-down Bench press	16 weeks 2x/week 95.9% of sessions completed for EBRE 95.8% for traditional resistance	EBRE (n=13) 3 sets, 10 reps, 50% 1RM No tempo described 3 min rest between sets Traditional resistance (n=12) 2 sets, 10 reps, 75% 1RM No tempo described 3 min rest between sets Control (n=13) Non-exercise waitlist	1500 1500	Yes, subject lifted load bilaterally, then lowered unilaterally, alternating between limbs
Reeves et al.	Moderately active, community-dwelling	Isoinertial Leg press	14 weeks 3x/week	ERE (n=10) 2 sets, 10 reps, 80% eccentric-only 5RM E 3s; C not performed	157,525±47,790[b]	No, the investigator performed the concentric action

Study	Population (characteristics, sex, age [y, mean ± SD])	Exercise Modality [exercise(s)]	Training duration (adherence rate)	Intervention (group size) [sets, reps, intensity, eccentric/concentric tempo, rest between sets]	Relative volume (sets x reps x load)[a]	Concentric muscle action performed?
Valour et al.	Physically active Females only 60-78 ERE: 65±6 Control: 68±7	Isoinertial Bicep curls	7 weeks 3x/week 92% of sessions completed	ERE (n=8) 5 sets, 6 reps, 100% 3RM No tempo described 3 min rest between sets Control (n=6) Maintained normal physical activities	3000	No, concentric muscle actions were not performed
Jimenez-Jimenez et al.	Healthy Males only 66-75 70	Isoinertial Leg press	8 weeks 2x/week No adherence described	ERE (n=11) 4 sets, 10-12 reps, 50% MVIC Lower load at the "most comfortable" velocity No rest described	2000 - 2400	No, two assistants raised the load
Symons et al.	Healthy, community-dwelling Mixed sex 65-87 ERE: 71±5 Concentric: 72±3 Isometric: 75±8	Isokinetic Knee extension	12 weeks 3x/week 90% of sessions completed (on average)	ERE (n=9) 3 sets, 10 reps, MVC at -90°s^{-1} 2 min rest between sets Concentric-only (n=10) 3 sets, 10 reps, MVC at 90°s^{-1} 2 min rest between sets Isometric-only (n=11) 3 sets, 10 reps, MVC at 0°s^{-1} for 5s 2 min rest between sets	3000 3000 3000	No, each subject performed only the muscle actions specific to their training group
Takahashi et al. **Melo et al.**	Healthy Males only 60-69 ERE: 62±2 Control: 64±4	Isokinetic Knee extension Knee flexion	12 weeks 2x/week No adherence described	ERE (n=9) 2-4 sets, 8-12 reps, 70-80% MIVC at 60°s^{-1} 2 min rest between sets Control (n=8) Non-exercise control group	1120 - 3840	No, subjects performed eccentric-only cycles

Study	Population (characteristics, sex, age [y, mean ± SD])	Exercise Modality [exercise(s)]	Training duration (adherence rate)	Intervention (group size) [sets, reps, intensity, eccentric/concentric tempo, rest between sets]	Relative volume (sets x reps x load)[a]	Concentric muscle action performed?
Porter et al.	Healthy, physically active Females only 68±5	Isokinetic Standing dorsiflexion (and standing plantar flexion)	8 weeks 2x/week 100% of sessions completed	ERE (n=15) 3 sets, 8 reps, 80-100% peak torque 30°s^{-1} 1 min rest between sets	1920 - 2400	No, subjects performed eccentric-only dorsiflexion (and concentric-only plantar flexion)
Theodorou et al.	Chronic heart failure Males only 60-70 EEE: 67±2 Stair ascending: 65±2	Stair descending	6 weeks 3x/week Sessions were 12 min each No adherence described	EEE (n=6) 4 sets, 3 min each, 55 steps/min 2 min rest between sets Stair ascending (n=6) 4 sets, 3 min each, 55 steps/min 2 min rest between sets	660 steps 660 steps	N/A
Gault et al.	Healthy, community-dwelling Mixed sex 67±4	Treadmill walking	12 weeks 3x/week Sessions were 30 min each No adherence described	EEE (n=13) Gradient: -10% Self-selected walking speed Level (n=11) Gradient: 0% Self-selected walking speed	Unable to determine	N/A

Study	Population (characteristics, sex, age [y, mean ± SD])	Exercise Modality [exercise(s)]	Training duration (adherence rate)	Intervention (group size) [sets, reps, intensity, eccentric/concentric tempo, rest between sets]	Relative volume (sets x reps x load)[a]	Concentric muscle action performed?
Mueller et al. 2011 **Mueller et al. 2009**	Stable health conditions and medications Mixed sex 71-89 EEE: 80 Traditional: 80 Cognitive: 82	Eccentric ergometer Leg press Leg curl Knee extension Hip extension	12 weeks 2x/week Sessions were 40 min each (including 10 min warm-up and 10 min cool-down) 89% of sessions completed (on average)	EEE (n=23) 20 min Loads started at 30W for females, 50W for males. Increased by 20% of individual maximum power output Traditional resistance (n=23) 2 sets, 8-10 reps Load was increased if subject was able to do 10 reps or more No tempo or rest described Cognitive (n=16) Non-exercise, computer guided cognitive training	Unable to determine Unable to determine	N/A
Marcus et al.	Inactive, overweight or obese, post-menopausal women with impaired glucose tolerance Females only 56±6	Eccentric ergometer	12 weeks 3x/week Sessions were 30 min each 100% of sessions completed	EEE (n=10) 30 min Target RPE from “very, very light” to “somewhat hard” Control (n=6) Non-exercise control group	Work increased from 20.3kJ to 229.7kJ	N/A

Study	Population (characteristics, sex, age [y, mean ± SD])	Exercise Modality [exercise(s)]	Training duration (adherence rate)	Intervention (group size) [sets, reps, intensity, eccentric/concentric tempo, rest between sets]	Relative volume (sets x reps x load)[a]	Concentric muscle action performed?
LaStayo et al. 2009	Moderately obese, 12 months post total knee arthroplasty Mixed sex 55-80 68	Eccentric stepper Leg press Leg curl Leg extension Calf raise	12 weeks, 3x/week Sessions were 30 min each (including 5-10 min warm-up) 89% of sessions completed	EEE (n=9) 20 min Self-selected, 15-25 rotations per min Target RPE from "fairly light" to "somewhat hard" Traditional resistance (n=8) 3 sets, 10-12 reps, 70% 1RM No tempo or rest described	Mean work increased from 44,003kJ to 86,480kJ 2100 - 2520	N/A
LaStayo et al. 2007 **LaStayo et al. 2003**	Frail, sarcopenic, high risk for falls, outpatient in cardio-pulmonary rehabilitation program Mixed sex 70-93 80	Eccentric ergometer Leg press Leg extension Mini squat	11 weeks 3x/week Sessions were 10-20 min each	EEE (n=11) 10-20 min Target RPE from "very, very light" to "somewhat hard" Traditional resistance (n=10) 10-20 min When 10-15 repetitions were considered "easy" the weight was increased No sets or loads described	For final 6 weeks, negative work increased from 70.3kJ to 232.4kJ Unable to determine	N/A

[a] Except where otherwise stated, [b] Absolute values, E eccentric tempo, EBRE eccentrically-biased resistance exercise, EEE eccentric endurance exercise, ERE eccentric resistance exercise, C concentric tempo, MVC maximal voluntary contraction, MVIC maximal voluntary isometric contraction, N/A not applicable, REP repetition, RM repetition maximum, RPE rating of perceived exertion, SD standard deviation

2.3 Results

This search lead to a total of 133 articles, fourteen of which were identified as chronic eccentric exercise interventions in the older adult population and thus detailed in this review. The majority of articles were excluded for the following reasons: interventions of less than two weeks (acute eccentric exercise often includes protocols not representative of practical training conditions; that is, intense interventions to investigate acute muscle damage mechanisms, multi-modal interventions (Jacobs, Marcus, Lastayo, & Morrell, 2014) and drug or supplementation studies (Fielding et al., 1991; Sacheck, Milbury, Cannon, Roubenoff, & Blumberg, 2003).

2.3.1 Effects of Eccentric Exercise on Muscular Strength

In a review investigating weakness in the older adult, a lack of strength was found to be a significant risk factor for falls (Masud & Morris, 2001). Falls have resulted in a significant cost to society (the US spent over $36 billion in 2012 on fall related injuries) and compromise the fundamental independence of older adults. As a result, improving muscular strength is a priority for studies investigating exercise in the older adult. As such, 13 of the 14 studies reviewed reported strength as an outcome of interest (see Table 3). Of those 13 studies, there was only one to have reported no significant improvement in strength following an eccentric exercise intervention (Gault et al., 2012). Using 24 healthy, community-dwelling subjects (67±4 years), this study was also the only one to have used downhill treadmill walking (-10% gradient) as an EEE modality. The active comparison group performed level treadmill walking (0% gradient). Subjects in both groups were permitted to select their own walking speed (which was re-assessed every four weeks) by choosing the speed they perceived to be able to maintain for the entire 30 min session. Subjects completed 30 min sessions, three times a week for 12 weeks. Strength was assessed with an isokinetic dynamometer measuring maximal eccentric and concentric knee flexion and extension torques. Torques were found to be similar in both groups with no significant change following the intervention (although the level walking group slightly declined (-4%, insignificant) from baseline strength). Treadmill walking may not be adequate to meet the intensity, gradient, velocity or volume threshold required to promote or even maintain strength in the healthy, community-dwelling older adult.

Table 3. Strength changes as a result of eccentric exercise in the older adult population

Study	Strength measurement	Eccentric baseline	Change (%)	Comparison baseline	Change (%)	Between group difference (%)	Between group significance
Leszczak et al.	Using estimated 1RM						
	Knee extension	29±12 kg	50*	26±8 kg	38*	12	All NS
	Leg press	164±59 kg	43*	132±50 kg	45*	-2	
	Leg curl	38±16 kg	37*	30±6 kg	28*	9	
Raj et al.	Using 1RM						
	Leg press	171±51 kg	23**	159±38 kg	23**	0	All NS
	Toe press	196±37 kg	35**	200±50 kg	32**	3	
	Bench press	37±14 kg	27**	36±13 kg	28**	-1	
	Latissimus dorsi pull-down	50±14 kg	22**	48±17 kg	21**	1	
	Maximal isokinetic						
	Knee extension at 0°.s^{-1}	175±38 Nm	7**	160±40 Nm	4	3	NS
	Knee extension at 60°.s^{-1}	129±30 Nm	6*	126±36 Nm	7*	-1	NS
	Knee extension at 120°.s^{-1}	101±24 Nm	7**	101±31 Nm	8**	-1	NS
	Knee extension at 240°.s^{-1}	74±21 Nm	5*	75±26 Nm	3	2	NS
	Knee extension at 360°.s^{-1}	56±16 Nm	11**	59±21 Nm	2	9	p<0.05
Reeves et al.	Using 5RM						
	Knee extension	69±23 kg	49	44±12 kg	11	38	All p<0.01
	Leg press	252±56 kg	42	178±45 kg	23	19	
Valour et al.	Maximal isokinetic						
	Elbow flexion at -60°.s^{-1}	None given	15±7*	None given	1±19	14	N/A
	Elbow flexion at -30°.s^{-1}		14±21*		3±15	11	
	Elbow flexion at 0°.s^{-1}		11±9*		3±21	8	
	Elbow flexion at 30°.s^{-1}		17±14*		1±15	16	
	Elbow flexion at 60°.s^{-1}		18±16*		-1±20	19	

Study	Strength measurement	Eccentric baseline	Change (%)	Comparison baseline	Change (%)	Between group difference (%)	Between group significance
				Isometric Group			
	Knee extension at -90°.s^{-1}	169±40 Nm	22**	151±46 Nm	17**	5	
	Knee extension at 0°.s^{-1}	142±40 Nm	24**	123±47 Nm	25**	-1	
	Knee extension at 90°.s^{-1}	108±31 Nm	7**	91±35 Nm	14**	-7	
Takahashi et al.	Peak isokinetic						
	Knee extension at -60°.s^{-1}	210±38 Nm	20*	203±33 Nm	6	14	p<0.05
	Knee flexion at -60°.s^{-1}	118±25 Nm	13*	126±20 Nm	7	6	p<0.05
	Isometric peak torque	178±25 Nm	10	172±27 Nm	2	8	NS
Porter et al.	Standing peak at 30°.s^{-1}						
	Dorsiflexion concentric	15±4 Nm	27**	N/A	N/A	N/A	N/A
	Dorsiflexion eccentric	30±4 Nm	17**				
	Plantar flexion concentric	71±14 Nm	4				
	Plantar flexion eccentric	103±24 Nm	1				
Theodorou et al.	Peak isokinetic						
	Knee extension at 0°.s^{-1}	143±10 Nm	9	135±11 Nm	6	3	p<0.001
	Knee extension at 60°.s^{-1}	125±15 Nm	8	119±14 Nm	10	-2	NS
	Knee extension at -60°.s^{-1}	156±10 Nm	12	148±12 Nm	7	5	NS
							Data mean±SE
Gault et al.	Maximal isokinetic						
	Knee extension at 60°.s^{-1}	122±40 Nm	-2	113±45 Nm	-2	0	All NS
	Knee extension at -60°.s^{-1}	165±55 Nm	1	154±61 Nm	5	-4	
	Knee flexion at 60°.s^{-1}	73±20 Nm	4	69±27 Nm	-3	7	
	Knee flexion at -60°.s^{-1}	116±29 Nm	-4	103±50 Nm	-4	0	
Muller et al. 2009	Maximal isometric Leg extension Relative to body weight	14.8 N/kg	8**	15.3 N/kg	2	6	NS
Marcus et al.	Knee extension 0°.s^{-1}	32±7 kg	29*	39±18 kg	-7	36	p=0.01
LaStayo et al. 2009	Knee extension 0°.s^{-1}	102±32 Nm	15**	113±42 Nm	3	12	NS
LaStayo et al. 2003	Knee extension 0°.s^{-1}	49±6 Nm	59**	46±5 Nm	15	44	p<0.05
							Data mean±SE

N/A data not available, NS non-significant, RM repetition maximum, SE standard error, * p<0.05, **p<0.01

In contrast, significant strength improvements were found in all 12 remaining studies. Considerable strength improvements were found in two studies in particular (Leszczak et al., 2013; Reeves et al., 2009). Leszczak et al. (2013) randomized 10 active, community-dwelling subjects (76±8 years) to EBRE. Subjects trained on the seated knee extension, leg curl and leg press every Wednesday and Friday for eight weeks (every Monday was reserved for strength re-assessment and week one was used as a familiarization period). A relative load of 75% 1RM for three sets of 8-12 repetitions was used. Subjects performed the concentric phase with the aid of a trainer followed by an unaided eccentric phase with a 3-5 s tempo. Dynamic strength changes were assessed with the estimated 1RM formula. All three (seated knee extension, leg curl and leg press) estimated 1RM values increased significantly from baseline (50, 37 and 43%, respectively) following the intervention. The nine remaining subjects were randomized into a high-velocity comparison group (using loads of 50% 1RM, completing the concentric phase "as fast as possible" and the eccentric phase in 2-3 s) and also significantly increased each of their estimated 1RM values (38, 28 and 45% for the knee extension, leg curl and leg press, respectively). No statistical difference was found between groups and therefore EBRE was found to be similarly effective to the high-velocity program. The authors did note that the short duration of their intervention might have preferentially compromised the improvement potential of the EBRE group as they were able to train and test with much higher loads (75% 1RM) when compared to the high-velocity group (50% 1RM). The greater mechanical stimulus assigned to the EBRE group may have led to significant long-term muscle adaptations. Another possible reason for the lack of eccentric exercise efficacy may be due to the failed attempt to utilize the force generation capacity of the lengthening muscle. At 75% 1RM, the eccentric phase was considerably under-loaded and thus, under-stimulated (1RM training loads are a limiting factor when used in eccentric exercise as they measure the load one can move concentrically only). Nevertheless, an earlier EBRE study supports these results (Raj et al., 2012). Raj et al. (2012) randomized 13 community-dwelling subjects (68±5 years) to EBRE two times per week for 16 weeks. Subjects trained on the leg press, toe press, latissimus dorsi pull-down and bench press. Although also categorized as an EBRE modality, this study is distinct from the previous EBRE study (Leszczak et al., 2013) as subjects lifted the load (50% 1RM) bilaterally during the concentric phase and lowered it unilaterally during the eccentric phase, in an alternating limb fashion. The TRE group (n=12; 68±5 years) performed each of the exercises bilaterally using 75% 1RM. Both groups performed 10 repetitions yet relative volume was precisely matched between the groups by differing the number of sets completed (3 and 2 for EBRE and TRE, respectively). Following the intervention, 1RM strength significantly improved independent of intervention, concluding that EBRE is similarly effective to TRE. At approximately 100% 1RM for each unilateral repetition, the load was higher and the intervention duration was double that used in the previous study (Leszczak et al., 2013), suggesting that the mere incorporation of concentric muscle action into eccentric exercise may yield adaptations similar to those of more conventional resistance programs (utilizing the stretch-shortening cycle) in the non-resistance trained older adult population. Alternatively, the results may indicate that the lengthening muscle was once again under-stimulated (subjects performed only one exercise for each major muscle group twice a week). However, since the subjects were untrained, increased exercise competence, coordination and neuromuscular adaptation may have considerably contributed to the overall strength improvement reported in this study, independent of intervention. The study did note a significant increase in isometric knee extension torque in the EBRE intervention that was not found in the TRE group (Raj et al., 2012). Significant improvements in maximal isokinetic knee extension concentric torque at all four velocities tested were also found (Raj et al., 2012). The TRE group improved in two of the slowest concentric velocities tested. Results from an earlier study also found significant improvements in maximal concentric and eccentric torque during isokinetic elbow flexion in all four velocities tested after a seven-week upper body isoinertial ERE intervention (Valour et al., 2004). Consequently, if improvements in power are required, ERE or EBRE programs (even at a moderate, 3-5s eccentric tempo) are recommended over TRE. Increased power output is especially important for the older adult in environments requiring high-speed contractions, such as recovering balance after a trip (Pereira et al., 2012).

In contrast, Reeves et al. (2009) found that ERE was more efficacious than TRE for strength improvement. Active, community-dwelling subjects were randomized to ERE (n=10, 67±2 years) or TRE (n=9, 74±3 years). Subjects trained using the seated knee extension and leg press exercises three times per week for 14 weeks (the first two weeks were used as a familiarization period). The ERE subjects used a load of 80% eccentric-only five-repetition maximum (ECC-5RM) for 2 sets of 10 repetitions. As an ERE modality, subjects did not perform the concentric phase but completed the eccentric phase using a 3 s tempo. The TRE group performed the same exercises using 80% 5RM for 2 sets of 10 repetitions with a 2s concentric phase followed by a 3 s eccentric phase. The ECC-5RM and the conventional dynamic 5RM were used to assess strength changes for the ERE and TRE groups, respectively. Both the knee extension and leg press were significantly improved in ERE only, leading to a significant difference between groups. Therefore, despite a much lower absolute volume, it was concluded that ERE was more effective than TRE. Completely excluding concentric muscle action from ERE training and testing as well as utilizing an intense eccentric-only load likely lead to the significant strength gains seen, which were twice as great when compared to the strength gains resulting from TRE. Altogether, this protocol offers support for eccentric exercise prescription when substantial improvement in strength is of importance. From these results, it would seem that ERE yields the greatest improvements in strength. However, if an ERE program cannot be implemented (as it does require a trainer to move the load during each concentric phase), either EBRE or TRE will provide significant but equal improvements in strength. In summary, any of the eccentric modalities (except treadmill walking) have empirical evidence for the development of strength in older adults.

Several studies reported significant improvements in isometric knee extension strength following an EEE intervention (P. C. LaStayo et al., 2003; P. C. Lastayo et al., 2009; M. Mueller et al., 2009; Theodorou et al., 2013); improvements were not found in any of the TRE groups (P. C. LaStayo et al., 2003; P. C. Lastayo et al., 2009; M. Mueller et al., 2009). Significant improvements in isometric strength provide considerable support for the use of EEE over TRE for the development of isometric muscle actions, which may be used to maintain posture and stability in the older adult. Only one study investigated eccentric or concentric strength following an EEE intervention (Theodorou et al., 2013). Two acute, isolated bouts of EEE were separated by a six-week EEE intervention in order to assess isokinetic eccentric, concentric and isometric peak torque of the knee extensors in older adult males (60-70 years) with chronic heart failure. The acute EEE bouts as well as the EEE intervention were both completed on an automatic escalator. The six subjects assigned to EEE descended the automatic escalator while the stairs continuously moved upwards. The remaining six subjects were assigned to the comparison group and ascended the escalator while the stairs continuously moved downwards. Both groups performed four sets of 3 min bouts of stair-descent or stair-ascent exercise interspersed with 2 min rest (the same protocol was used for the acute bouts as well as the intervention). Speed was set at 45 steps per min for the acute bouts and for the first two weeks of the intervention. Speed progressed to 50 and 55 steps per min for the next two and final two weeks of the six-week study, respectively. Isometric and eccentric (but not concentric) peak torque increased significantly following EEE while the stair-ascending (concentric-dominant action) group showed no significant changes in any of the isokinetic strength measurements.

Isokinetic strength training and assessment were used in three of the 14 studies (Porter & Vandervoort, 1997; Symons, Vandervoort, Rice, Overend, & Marsh, 2005; Takahashi et al., 2009). Eccentric-only training of the ankle dorsiflexors in an upright position produced significant improvements in eccentric ankle dorsiflexion peak torque (17%) after an eight-week intervention (Porter & Vandervoort, 1997). Interestingly, concentric ankle dorsiflexion peak torque increased to an even greater degree (27%) even though concentric muscle actions were not used during the intervention. Non-specific adaptations to the musculature (an increase in myofibril size rather than an increase of sarcomeres in series) due to the heavy mechanical load placed on the ankle may account for this non-specific strength adaptation (Fiatarone Singh et al., 1999). Unfortunately, muscle architecture was not investigated in this study in order to further explore causation. In another isokinetic study, knee extensors were exclusively trained with either concentric-only, eccentric-only or isometric-only muscle actions for 12 weeks (Symons et al., 2005). The concentric-only group significantly increased their concentric, eccentric and isometric strength (21%, 18%, 16%, respectively) with the greatest increase in strength occurring during the concentric assessment. The same phenomenon was reported for isometric-only training; that is, concentric, eccentric and isometric strength all increased significantly (14%, 17%, 25%, respectively) but isometric strength increased to the greatest extent. Lastly, the eccentric-only group also significantly increased their concentric, eccentric and isometric strength (7%, 22%, 24%, respectively) although the eccentric-only group experienced their greatest strength increase in the isometric assessment.

Of all studies reviewed, the greatest improvements in strength were made following an intervention utilizing the heaviest relative eccentric load while completely excluding concentric muscle actions (Reeves et al., 2009). The strength adaptations due to the heavy eccentric load were also found to be superior to the strength adaptations due to TRE. An exploration into a manipulation of volume (subjects in Reeves et al. (2009) performed just two sets of 10 repetitions in two lower body exercises) and/or velocity (subjects used a moderate 3 s eccentric tempo) in addition to this intense protocol of supra-maximal loads for eccentric-only repetitions and whether this would result in even greater strength improvements in the older adult would be warranted.

2.3.2 Effects of Eccentric Exercise on Functional Capacity

In the older adult, functional capacity is often measured against the ability to perform specified actions termed activities of daily living (ADL). Activities of daily living include basic self-care tasks (bathing, dressing, functional mobility etc.) as well as instrumental tasks required for independent living (housework, shopping, transportation within the community etc.). As indicated in Table 4, improving functional mobility was the ADL most often assessed following an intervention. Functional mobility, as well as the other ADL are essential for community-dwelling older adults and their quality of life hence the imperative to assess whether eccentric exercise may lead to functional capacity improvement. Eight of the 14 studies in this review assessed functional capacity in the older adult following an eccentric exercise intervention (see Table 4). Notable functional improvements were seen in the same (and only) study to have reported no significant strength improvement following an eccentric intervention (Gault et al., 2012). In addition to assessing strength, functional capacity was assessed with maximal walking speed, timed up-and-go and five-repetition sit-to-stand and all significantly improved independent of intervention. Prescription of a walking program, although ineffective for strength maintenance or improvement, may elicit significant improvements in functional capacity for healthy, independent older adults.

Table 4. Functional capacity changes as a result of eccentric exercise in the older adult population

Study	Functional measurement	Eccentric baseline	Change (%)	Comparison baseline	Change (%	Between group difference (%)	Between group significance
Leszczak et al.	Maximal walking speed	4.5±0.8 s	-4*	4.4±0.6 s	-7*	-3	All NS
	8-feet up & go	5.9±1 s	-5*	5.8±1 s	-7*	-2	
	Chair stand (in 30 s)	14±4.2	14*	14.8±3.9	17*	-3	
Raj et al.	6-minute fast walk	2.8±0.3 ms^{-1}	-7**	2.8±0.6 ms^{-1}	-4**	3	All NS
	Timed up & go	4.5±0.4 s	-2	4.6±0.8 s	-7**	-5	
	Stair climb power	433±138 W	5**	400±117 W	3	2	
	Stair descent power	366±105 W	4	376±83 W	4*	0	
Symons et al.	Step time	None given	-6	None given	Concentric: -7	-1	All NS
					Isometric: -7	-1	
Gault et al.	Maximal walking speed	2.4±0.3 ms^{-1}	-22**	2.4±0.4 ms^{-1}	-23**	-1	All NS
	5-rep sit to stand	8.5±1.5 s	-34**	8.5±1.2 s	-32**	2	
	Timed up & go	5.5±0.9 s	-22**	5.6±0.5 s	-22**	0	
Mueller et al. 2009	Timed up & go	None given	-8*	None given	-7*	1	All NS
	Berg balance scale		2		1	1	
Marcus et al.	6-minute walk	687±44 m	8*	696±75.5 m	0	8	p=0.02
	Steps/day	5949±2170	29	7873±778	4	25	NS
LaStayo et al. 2009	Timed up & go	8.5±2.7 s	-22**	7.7±1.7 s	-14**	8	NS
	6-minute walk	525±117 m	10*	523±142 m	9	1	NS
	Stair ascent	7.4±1.8 s	-24**	7.8±3.8 s	-17**	7	NS
	Stair descent	6.4±2 s	-23**	7±4 s	-7	16	p=0.04
LaStayo et al. 2003	Timed up & go	16.7±0.8 s	-28*	17.2±0.9 s	-9*	19	p<0.05
	Stair descent	25.3±2 s	-21*	21±2.3 s	7	28	p<0.05

Two other studies (P. C. LaStayo et al., 2003; P. C. Lastayo et al., 2009) also reported noteworthy functional improvements following an EEE intervention. An eccentric ergometer was utilized with 11 frail and balanced-impaired subjects (80 years) with a history of cardiovascular and/or peripheral vascular disease (P. C. LaStayo et al., 2003). The recumbent, high-force, leg cycle ergometer provided resistance by driving the pedals in a backward rotation while the subject attempted to slow the pedals, resulting in cyclic eccentric actions of the quadriceps muscle group. Subjects exercised for up to 20 min each session, three times a week for 11 weeks. The rating of perceived exertion (RPE) scale determined training intensity (Borg, 1982). Subjects began with a "very, very light" exertion level over the first three weeks (in an attempt to avoid any muscle damage that may occur with novel eccentric exercise), eventually reaching and maintaining an exertion level of "somewhat hard." Subjects were assessed using the timed up-and-go, stair descent and the Berg balance scale. The time taken to complete the timed up-and-go course was significantly reduced in both the EEE group (-28%) as well as in the TRE group (-9%) yet only the EEE group progressed from the high-risk category for falls (which is designated by a completion time of greater than 14 s) into the low-risk category. Furthermore, stair descent time (-17%) and the Berg balance score (7%) were significantly improved in the EEE group only. The TRE group actually worsened their stair descent time (10% increase although statistically insignificant) leading to a significant difference between the two groups. In a later study, a recumbent eccentric stepper (with pedals that drove up toward the subject) was used with nine moderately obese subjects (67±9 years, 32.2±4.4 kg/m^2) who underwent total knee replacement greater than 12 months prior to enrolling in the study (P. C. Lastayo et al., 2009). Subjects began with 5 min on the stepper and progressed to 20 min a day by the fourth week, completing three sessions per week for 12 weeks. The RPE progression was used as in the previous study (P. C. LaStayo et al., 2003). The six-minute walk, timed up-and-go, stair descent and stair ascent time were assessed following the intervention. The EEE group significantly improved in all four assessments while the TRE group (who performed three sets of 10-12 repetitions using 70% 1RM for four separate lower body exercises) significantly improved in the timed up-and-go and stair ascent assessments only. Again, a significant difference was noted in the stair descent assessment between the two groups.

The ability to safely descend a staircase is of utmost importance to the older adult in preventing the devastating consequences of a fall. The strength and functional coordination of the quadriceps both play a major role in this endeavour (Tiedemann, Sherrington, & Lord, 2007). EEE places emphasis on improving these precise variables (Purtsi, Vihko, Kankaanpää, & Havas, 2012). Not surprisingly then, both aforementioned studies were able to show significant stair descent improvements in the subjects who trained using EEE (P. C. LaStayo et al., 2003; P. C. Lastayo et al., 2009).

The eccentric modality and assessments chosen thereafter can both meaningfully influence a study's results and interpretation as seen throughout the studies in this review, especially influential when assessing functional capacity. Judicious selection of an appropriate assessment for a given intervention is important; specificity of training induced adaptations can be expected. For example, subjects who exercised via treadmill walking subsequently improved their maximal walking speed significantly (22%) (Gault et al., 2012). In turn, non-specific assessments may lead to insignificant findings. Subjects assigned to EBRE increased their maximal walking speed in another study by just 4% (Leszczak et al., 2013). However, a more specific assessment (to the EBRE intervention) showed significant improvement within these same subjects (sit to stand improved by 14%) (Leszczak et al., 2013). Therefore, prescribing eccentric exercise to older adults should be done only after the practitioner has determined the adaptation most crucial for their participant. That is, an older adult who scores poorly on a maximal walking assessment and whom routinely crosses at busy intersections would warrant inclusion of a treadmill walking program as opposed to EBRE. Alternatively, EBRE may be more appropriate for an independent, community-dwelling older adult who performs poorly during the sit-to-stand, given EBRE is more likely to improve their ability to lower safely into the bathtub or onto the toilet in their home. Participant characteristics will also influence a study's results as well as potentially limit translatability, which also is most noticeable during functional capacity assessment. Two studies (P. C. LaStayo et al., 2003; M. Mueller et al., 2009) randomized older adult subjects of the same mean age to an EEE intervention of similar duration. Subjects in both studies significantly improved their up-and-go time (28% and 8%, respectively). The discrepancy in percent change from baseline can be easily explained by the significant difference in physical conditioning of the subjects between studies. The same phenomenon was found for the Berg balance scale in which scores were increased insignificantly by 2% (M. Mueller et al., 2009) compared to a significant 7% (P. C. LaStayo et al., 2003). Thus, investigators utilizing high functioning older adult populations during their interventions must remain cognizant that the principle of diminishing returns may apply (Buchner, Larson, Wagner, Koepsell, & De Lateur, 1996a). The principle may be compounded when also utilizing a functional assessment tool with poor sensitivity for the high functioning cohort (for example, the Berg balance scale, which is best suited for use with a frail older adult cohort) (Berg, Wood-Dauphine, Williams, & Gayton, 1989).

In summary, the significant improvements described provide evidence in support of EEE for the increase of functional capacity in the older adult. Research support for EEE is especially strong for the improvement of specialized functional tasks required for independent daily living (P. C. LaStayo et al., 2003; M. Mueller et al., 2009). Conversely, just one of eight functional assessments following ERE or EBRE reported an advantage over TRE (Raj et al., 2012).

2.3.3 Effects of Eccentric Exercise on Body Composition and Muscle Architecture

Body composition describes the proportion of fat and fat-free mass of an individual while muscle composition describes the proportion of lean tissue, connective tissue and intramuscular adipose tissue as well as the underlying architecture, including fibre arrangement and fibre type. Aging and inactivity have been shown to have distinct effects on body and muscle composition including increases in intramuscular adipose tissue (Addison et al., 2014) and an increase in the loss of skeletal muscle mass characterized by the acceleration of type II fibre atrophy (Nilwik et al., 2013). Unfavourable changes to body and muscle composition may result in devastating secondary consequences for the older adult such as decreased power, decreased functional mobility and an increase in systemic inflammation (Visser et al., 2002). For practitioners, it is important to discern whether eccentric exercise can be expected to produce beneficial body and muscle composition changes or whether a complementary program must also be prescribed (that is, aerobic exercise).

Eight studies investigated body and muscle composition changes in the older adult (see Table 5). Significant changes in body composition occurred in ten inactive, overweight, post-menopausal women (56±6 years, 29.9±4.1 kg/m^2) with impaired glucose tolerance that were randomized to EEE utilizing an eccentric ergometer (Marcus et al., 2009). The sessions progressed from five to 30 min (to avoid muscle damage), three times a week for 12 weeks. The RPE scale was used, starting with an intensity of “very, very light” and progressing to “somewhat hard” by the third week where it remained for the subsequent nine weeks. The remaining six women were randomized to a non-exercise control group. Using dual energy x-ray absorptiometry (DEXA), leg muscle mass was found to significantly increase (7%) in the EEE group resulting in a significant difference between the two groups as the control group lost muscle mass (-2%) by the end of the intervention. A significant increase in leg muscle mass (6%) was also found in 11 frail older adults (78 years) with multiple cardiovascular diagnoses and co-morbidities assigned to 11 weeks of EEE (P. LaStayo et al., 2007). Leg muscle mass also significantly increased (3%) in 23 older adults (80 years) with stable medical conditions assigned to 12 weeks of EEE, although no significant differences were found between the EEE and TRE groups (M. Mueller et al., 2009). Thus, EEE can be expected to improve muscle mass in older adult cohorts that are currently inactive, overweight, frail and/or are living with chronic medical conditions.

While abdominal fat did not decrease as a result of EEE, abdominal fat was found to increase by 5% in a non-exercise control group (between group insignificant) (Marcus et al., 2009). However, in another study, significant reductions in total body fat (-5%) and thigh fat (-5%) occurred with EEE, with a significant difference from TRE noted (M. Mueller et al., 2009). Therefore, EEE can be expected to at least stabilize and even decrease adipose tissue in the older adult. The relative efficacy of EEE when compared to the more traditionally prescribed steady state aerobic exercise or to the more recently investigated high intensity interval training for adipose tissue loss in the older adult would be a timely and relevant area of future investigation.

Table 5. Body composition and muscle architecture changes as a result of eccentric exercise in the older adult population

Authors Year	Body composition measurement	Eccentric baseline	Change (%)	Comparison baseline	Change (%)	Between group difference (%)	Between group significance
Raj et al.	VL fascicle length	12.3±3.8 cm	5	11.1±2.6 cm	4	1	NS
	VL pennation angle	11.5±4.4 °	3	12.9±2.8 °	-8	11	NS
	VL site 1 thickness	4±0.6 cm	5*	3.9±0.5 cm	3	2	p<0.01
	VL site 2 thickness	4.5±0.5 cm	2	4.7±0.5 cm	0	2	NS
	GM fascicle length	5.7±0.8 cm	4	5.6±1 cm	-4	8	NS
	GM pennation angle	19.6±1.4 °	-4	19.9±3.6 °	4	-8	NS
	GM thickness	1.9±0.2 cm	0	1.9±0.3 cm	0	0	NS
Reeves et al.	VL fascicle length	79±9 mm	20**	72±8 mm	8*	12	p<0.05
	VL pennation angle	13.7±1.6 °	5	14.7±2.5 °	35**	-30	p<0.01
	VL thickness	18±4 mm	11*	18±3 mm	11*	0	NS
Takahashi et al.	Body mass index	25.4±1.9	2	N/A	N/A	N/A	N/A
Mueller et al. 2009, 2011	Body fat	17.6 kg	-5**	19.1 kg	-1	4	p=0.002
	Thigh fat	3.7 kg	-7**	4.3 kg	-3	4	p=0.03
	Thigh lean content	68.7 %	3**	67.4 %	2**	1	NS
	Intra-myocellular lipid	0.5±0.3	-40*	0.4±0.03	25	65	N/A
	Cross-sectional area per fibre	3,125±183	5	3,489±389	6	-1	N/A
	Type IIX/II muscle fibre ratio	0.22	-22*	0.28	-8	15	NS
Marcus et al.	Leg STLM	7.3±0.5 kg	6	8.5±1.1 kg	-3	9	p=0.03
	Abdominal fat	1.6±0.5 kg	-4	2±0.4 kg	3	7	NS
LaStayo et al. 2009	Quadriceps volume	979±255 cm^3	11**	1075±374 cm^3	3	8	p=0.01
LaStayo et al. 2007	Thigh muscle mass	None given	6*	N/A	N/A	N/A	N/A
LaStayo et al. 2003	VL fibre area	3295±366 μm^2	60*	2999±313 μm^2	41*	19	NS

Data mean±SE

Two studies used ultrasound imaging to measure the thickness of the vastus lateralis following eccentric exercise (Raj et al., 2012; Reeves et al., 2009). Both studies found eccentric exercise to be an effective method for inducing significant hypertrophy in the older adult population. When compared to TRE, two of three sites along the quadriceps muscle showed no difference between the eccentric and TRE groups, indicating both interventions were equally capable of increasing muscle size in the older adult. Regrettably, a control group showed significant reductions in the thickness of their vastus lateralis by the end of a 16-week period (-6%) (Raj et al., 2012). On a similar note, quadriceps volume was assessed in nine moderately obese, total knee arthroplasty subjects (68 years, 32.9 kg/m^2) by using magnetic resonance imaging (P. C. Lastayo et al., 2009). A significant increase in volume (11%) following 12 weeks of EEE was shown, a result not found in the TRE group. Cross-sectional area of the vastus lateralis was investigated in a subset of seven frail subjects, where biopsy was not contraindicated (P. C. LaStayo et al., 2003). Individual fibre cross-sectional area was significantly increased for both the EEE and TRE groups (60% and 41% respectively). The change in individual fibre area was noticeably greater for this particular study when compared to the other studies investigating muscle composition and architecture. As this was the only study to use muscle biopsy, it would be difficult to speculate however, the poor initial conditioning of the subjects may have partially accounted for the results seen.

The increase in vastus lateralis length was significantly greater in those subjects who trained using ERE when compared to subjects who trained using TRE as determined by ultrasound imaging *in vivo* at rest (Reeves et al., 2009). Yet, in another study, vastus lateralis length increased (also determined by ultrasound imaging), insignificantly, in both the EBRE and TRE subjects (Raj et al., 2012). The difference in findings may be due to the considerable difference in knee angle during measurement (10 and 90 degrees, respectively) or the distance along the femur used for the measurement site (50 and 62.5% from the superior patella to the anterior superior iliac spine, respectively).

Overall, evidence supports eccentric exercise prescription for a number of beneficial body and muscle adaptations in the older adult, although results indicating efficacy over TRE were mixed. Commencing eccentric exercise as early as the sixth decade would prove advantageous in order to prevent, delay or slow the rapid effects of aging and inactivity on body and muscle deterioration.

2.3.4 Effects of Eccentric Exercise on the Markers of Muscle Damage and the Immune System

Muscle damage following a novel bout of eccentric exercise can be measured both directly and indirectly. Direct measures are invasive but allow visualization of disturbances at the cellular or sub-cellular level. Indirect measures of muscle damage are more regularly employed and include decreased force production, reduced range of movement (ROM), delayed onset muscle soreness (DOMS), increases in muscle proteins within the blood and increases in inflammatory markers both locally and systemically. While muscle damage is consistently attenuated following a second bout of eccentric exercise, it is especially critical to monitor immune system responses to eccentric exercise as many disease states are associated with or exacerbated by chronic low-grade inflammation (Scrivo, Vasile, Bartosiewicz, & Valesini, 2011).

Only three studies examined muscle damage or immune system response following eccentric exercise in the older adult (Jiménez-Jiménez et al., 2008; P. LaStayo et al., 2007; Theodorou et al., 2013). Although inadequately investigated amongst current literature, the topic warrants discussion here. Muscle damage and immune system response in the older adult will allow for a greater understanding of the physical and physiological responses to eccentric exercise by the aging body. In turn, practitioners may then be cognizant of expected adverse events (and thus the safety of each modality), adherence rates and ultimately, the degree of achievement of adaptations from their eccentric exercise prescription.

Creatine kinase (CK, an indirect marker of muscle damage) and tumor necrosis factor alpha (TNFα, a pro-inflammatory marker) were measured in 11 high fall risk subjects (78 years) with existing cardiovascular disease (P. LaStayo et al., 2007). No significant increases in CK were observed at midway or at 48 hours following the final EEE session (18.5, 18.7 and 19.2 IU/ml, for baseline, midway and post-intervention respectively). TNFα began and remained well within normative values (0-4pg/ml, as specified by the enzyme linked immunosorbent assay kit manufacturer), also showing no significant changes throughout the intervention. At the very least, these results indicate that systemic increases in CK and TNFα do not necessarily occur as a result of novel eccentric exercise, especially when intensity is progressed gradually. Research investigating the optimal rate of intensity progression would allow for a more evidence-based approach to an important component of eccentric exercise prescription in the older adult. Whether other pro-inflammatory cytokines increase with eccentric exercise is still unknown, however, it is a question worth investigating as inflammatory burden is often contraindicated in specific older adult cohorts (for example, in patients with atherosclerosis).

Multiple markers of muscle damage were also assessed in older males (60-70 years) with chronic heart failure using two acute, isolated bouts of EEE separated by a six-week EEE intervention (Theodorou et al., 2013). Creatine kinase (80.3 to 913.3 U/L), eccentric (155.5 to 132.3 Nm), isometric (142.7 to 125.3 Nm) isokinetic strength loss, DOMS (1 to 3.2 on a 1-10 perceived soreness scale) and ROM (119.2 to 116.2°) all showed significant signs of muscle damage following the first acute bout of EEE. The subjects in the stair ascending comparison group experienced a significant change in CK (99.7 to 298.2 U/L) only. The difference between groups following the acute exercise bout clearly indicates that a greater degree of damage is caused by eccentric muscle actions. Yet, no significant signs of muscle damage were found following the second bout of acute exercise following the intervention for either group, confirming that older adult muscle retains the ability to adapt to such damaging muscle action (Nikolaidis et al., 2013). In a similar design, two acute, isolated bouts of ERE were separated by an eight-week ERE intervention to assess muscle damage in the healthy older adult

(Jiménez-Jiménez et al., 2008). Eleven men (71±4 years) performed acute, isolated bouts of ERE, one week before and one week after an ERE intervention. The acute isolated bouts consisted of 10 sets of 10 eccentric-only repetitions on the 45° incline leg press using 60% of the subject's maximal voluntary isometric contraction (MVIC). The intervention consisted of 4 sets of 10-12 eccentric-only repetitions at a load of 40-50% MVIC on that same leg press machine. Muscle damage was assessed immediately after each bout with measurements of CK, lactate dehydrogenase (LDH), interleukin-6 (IL-6), strength loss and soreness (using the 10 cm visual analogue scale). As in the previous study, all measures of muscle damage were significantly attenuated following the ERE intervention when compared to the acute ERE bout at baseline. These results imply that muscle damage resulting from novel eccentric exercise that has not been gradually introduced may be mitigated by regularly scheduled eccentric exercise. The concept of eccentric exercise prescription as an effective method for alleviating the chronic inflammatory process in the aging adult would be a worthwhile area of future research.

2.3.5 Effects of Eccentric Exercise on the Cardiovascular System

Ever since the early work by Abbott et al. (1952), it has been well accepted that oxygen consumption during eccentric muscle action is much less than that consumed during concentric muscle action. Researchers have now begun to fully appreciate the proposed benefit of this attenuated cardiovascular system response for those individuals who may otherwise lack the aerobic energy to perform exercise.

Two studies reported cardiovascular outcomes following eccentric exercise in the older adult. As expected, a lower mean heart rate was reported during the last minute of EEE when compared to a stair-ascending comparison group (98±5 and 139±7 beats/min, respectively) (Theodorou et al., 2013). Conversely, ERE in healthy men did not affect heart rate during a 60 s sub-maximal isometric hold (Takahashi et al., 2009). The short duration of individual training sessions (approximately 20 min per session), specificity of training (assessing ERE on the heart rate response to isometric exercise) or simply the fact that in its essence, eccentric muscle action elicits very little cardiovascular stress, may have been responsible for the lack of heart rate response cross-over or adaptation to isometric exercise following ERE. However, mean systolic blood pressure did significantly decrease during ERE (123.78±8.28 to 117.67±10.21 mmHg, -5%) in the healthy, normotensive men (Melo et al., 2008). Future research should look to confirm these promising blood pressure results in women as well as in the hypertensive.

2.3.6 Effects of Eccentric Exercise on the Endocrine System

Aging can cause significant changes within the endocrine system, usually affecting the available concentration of chemical messengers or the responsiveness of their target organ. Deviation from normal endocrine system function prompts muscular strength losses, functional capacity impairments, unfavourable body and muscular composition changes, declined immune system function and numerous disease states including cardiovascular disease and diabetes mellitus (Chahal & Drake, 2007).

Two studies measured endocrine system function following eccentric exercise in the older adult. Insulin like growth factor-1 (IGF-1, an anabolic factor) was measured in frail subjects diagnosed with cardiovascular disease following EEE (P. LaStayo et al., 2007). IGF-1 at baseline (~ 27 ng/mL) was lower than that of normal young adults however, IGF-1 increased by 65% (~ 47 ng/mL) by the end of the intervention (although slightly underpowered to see significance). Encouragingly, the increasing trend in IGF-1 was accompanied by a significant increase in muscle mass without significant muscle damage or inflammation. Further research should be conducted in order to confirm whether this increasing trend in IGF-1 would be clinically meaningful using a larger cohort as well as to delve deeper into the possible correlation between anabolic markers, muscle morphology and functional capacity.

Insulin sensitivity was measured following EEE in sedentary, overweight, post-menopausal women (56±6 years, 28.5±3.7 kg/m^2) with impaired glucose tolerance (Marcus et al., 2009). No significant differences between the EEE and inactive control groups were found at 72 hours following the intervention for fasting plasma insulin levels, fasting plasma glucose levels, or maximum glucose infusion rates. With no adverse side effects on insulin sensitivity, these results support the metabolically safe use of continuous eccentric muscle actions in a population afflicted with metabolic dysfunction in order to improve muscular strength, functional capacity and muscle mass. The authors did note that the deliberate timing of the post-intervention insulin sensitivity measurement might have interfered with their results (as they timed data collection in an attempt to ensure that the entire 12-week EEE intervention was being assessed rather than the last single training session). However, in a similar study, healthy, sedentary, slightly younger men and women (48.4±9.2 years) did significantly improve insulin resistance, fasting serum insulin and glucose tolerance 36 hours following an eight-week EEE intervention (Drexel et al., 2008). The timing of the post-intervention metabolic testing (36 versus 72 hours) is likely to be a significant factor as the improved population may have still been metabolically active. Also, the fact that the improved population included males and (assumingly) pre-menopausal women would make a significant difference in the amount of muscle mass between study populations, although body composition was not reported. Additionally, the techniques of measurement (oral glucose tolerance test versus hyperinsulinemic-euglycemic clamp test) may have also accounted for the differences seen between these studies. To confirm either way, future research is needed to determine whether an eccentric exercise intervention utilizing a greater proportion of muscle mass and/or one that imposes adaptations on body composition are necessary to see an improved sensitivity to insulin.

2.3.7 Rating of Perceived Exertion During Eccentric Exercise

The Borg rating of perceived exertion (RPE) scale is a subjective scale where an exercise subject can rate their exertion before, during or after exercise. The scale ranges from one (indicating “no exertion at all”) to 10 (indicating “maximal exertion”) (Borg, 1982). This rating can then be used to assess and adjust the intensity of the session if necessary.

Five studies reported the RPE of older adult subjects during an eccentric exercise intervention (Gault et al., 2012; P. LaStayo et al., 2007; Raj et al., 2012; Reeves et al., 2009; Theodorou et al., 2013). All five reported RPE during eccentric exercise to be equal to (Gault et al., 2012), lower than (Raj et al., 2012) or significantly lower (Reeves et al., 2009) than TRE. In one study, RPE was more than five points lower during EEE than during a concentric dominated modality (8.1±1.3 and 13.6±1.9, respectively) (Theodorou et al., 2013). Interestingly, RPE during eccentric exercise does not seem to increase with increasing exercise intensity, even when the total work triples (Gault et al., 2012; P. LaStayo et al., 2007; Raj et al., 2012). Additionally, RPE has also been shown to decrease over time, likely due to increased acclimatization with the modality (Raj et al., 2012; Reeves et al., 2009). Even frail cohorts with a history of cardiopulmonary disease have described eccentric exercise to be "easy and desirable" when compared to other modalities (P. LaStayo et al., 2007). Clearly, the perceived relative ease of eccentric exercise could be advantageous on exercise adherence.

2.4 Discussion

In order to provide the reader with a uniquely comprehensive review on the effects of eccentric exercise in the older adult, inadequately investigated outcomes were included in this manuscript. Although interpretation and application surrounding these areas are still quite limited, the current review does bring much needed attention to such outcomes that have, up to this point, lacked sufficient research support.

The application and practicality of eccentric exercise programs are somewhat of a challenge to incorporate into commercialized weight room settings, however, not impossible. While EEE often requires specialized equipment not (yet) found outside research settings, older adults can form pairs to provide each other with the assistance needed during the concentric phase of ERE and EBRE programs; EBRE may even be used alone, using two limbs to lift and one to lower the load. Research to date suggests careful consideration of the particular outcome(s) desired to determine the type of eccentric exercise (ERE, EBRE or EEE) that would be most appropriate and effective. An increase in muscular strength is by far the most potent outcome that can be expected from eccentric exercise although functional capacity and body composition may be meaningfully improved with particular modalities. In any case, with the incorporation of as little as two sets of 10 repetitions for two exercises, older adults can expect a substantial improvement from baseline strength in less than four months (Reeves et al., 2009). Convincing evidence for the increased prescription of eccentric exercise in the older adult exists; concentration on making eccentric modalities more accessible to the rapidly expanding older adult population would provide significant assistance to practitioners.

As eccentric muscle actions allow for significant loads at a fraction of the aerobic energy cost (Abbott et al., 1952) future research should investigate the implications of using supra-maximal eccentric-only loads in order to gain insight into the potential adaptations of this intensity on other practical outcomes of interest in the older adult. As already shown, using 80% of an eccentric-only 5RM does lead to a 49% increase in muscular strength from baseline

(Reeves et al., 2009) however, it is still unknown how training at this intensity might impact tasks of functional capacity, fat mass, the immune system, anabolic markers and insulin sensitivity.

The imperative in recognizing and implementing effective resistance exercise programs is highlighted by the substantial physical deteriorations of older adults randomized into passive control groups within the studies reviewed in this paper. For example, the relatively young (56±6 years) female cohort in one study declined in strength by more than 7% in 12 weeks (although statistically insignificant); an insignificant reduction in muscle mass (-3.2%) was also found (Marcus et al., 2009). In another study, maximal power of physically active older females (65±6 years) (randomized into the control group yet permitted to maintain all normal physical activity) declined by nearly 8% within seven weeks (also insignificant) (Valour et al., 2004). In yet another study, the basic six-minute fast walk significantly worsened (4%) following a 16-week wait period (Raj et al., 2012). Collectively, these results reinforce the need to get the older adult exercising, regardless of their current age, sex, activity level or disease-state.

Although each study included in this review investigated eccentric exercise in the older adult, modalities differed considerably. Modalities included escalators, treadmills, ergometers, steppers, dumbbells, weight-stacked machines and isokinetic devices. Intensities varied from 50% 1RM to 100% 3RM to 80% of an eccentric-only 5RM. Intensities were also captured using the RPE scale and one was self-selected. Eccentric tempos ranged from two to five seconds, to lowering the load at the "most comfortable" velocity to unreported and thus unknown tempos. Finally, concentric muscle actions were omitted in most eccentric interventions but not all. Despite the substantial differences between the modalities (over and above cohort differences, significantly limiting the ability to draw direct conclusions), there is sufficient support for eccentric exercise to be effective for a number of outcomes and cohorts within the older adult population. Muscular strength improved most consistently and to a greater extent when compared to TRE, not only in dynamic repetition maximum assessments but also during isometric, eccentric and high velocity concentric isokinetic assessments. Functional improvements generally occurred independent of intervention for the healthy, community-dwelling older adult. However, in the frail and disabled cohort, those assigned to EEE performed significantly better when compared to those assigned to TRE. Favourable body composition adaptations were greater for subjects assigned to EEE when compared to TRE. Muscle damage has been successfully avoided with gradual progression of eccentric exercise. In protocols containing acute bouts of intense eccentric exercise, signs of muscle damage were significantly attenuated following the occurrence of an eccentric intervention. As eccentric exercise imposes very little cardiovascular stress, it may be a poor stimulus for those seeking to obtain cardiovascular improvements, especially while performing dynamic (traditional resistance) or static (isometric) exercise. An increase in anabolic hormones may be obtainable for the older adult while insulin sensitivity has not been shown to improve with eccentric exercise.

To conclude, eccentric exercise and its numerous modalities have been shown to be an efficacious intervention in order to counteract the physical and physiological declines that occur with aging and inactivity in the older adult.

Compliance with Ethical Standards

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Conflicts of Interest

Ashley Gluchowski, Nigel Harris, Deborah Dulson and John Cronin declare that they have no conflicts of interest relevant to the content of this review.

Chapter 3 The Acute Effects of Eccentric Resistance Exercise in Resistance Trained Older Adults

Preface

As a direct result of my literature review, I quickly realized that eccentric training variables were either not specifically investigated, comprehensively investigated or were not thoroughly described for the reader. In addition, the acute effect of important variables such as oxygen consumption, cardiovascular stress and perceived exertion as a result of performing eccentric resistance exercise have never been investigated nor described. Thus, I needed to investigate the appropriate eccentric loading prescription (as well as the appropriate number of repetitions, number of sets and length of the rest intervals) and its effects for the 45° linear, plate loaded leg press, which was to be used during the subsequent intervention. Loading prescription for eccentric-only muscle actions on the leg press has previously been investigated in only one study, with untrained, moderately active participants (Reeves et al., 2009). In addition to the protocol variables for the training intervention, there was no investigation into the acute physical (for example, muscle soreness) and physiological (for example, heart rate, blood pressure and oxygen consumption) effects that this loading prescription will have in a resistance trained yet eccentrically naïve older adult population. Thus, the information was critical to my chronic training intervention in terms of safety, adherence and expected physical and physiological outcomes. Only once I determined the safety and efficacy of our eccentric loads (and associated training variables and the expected outcomes), I began to execute our chronic eccentric resistance training intervention (see Chapter 4). Thus, this study used a crossover design to investigate the acute effects of ERE, EBRE and TRE on anabolic, metabolic and cardiovascular responses in six healthy, high functioning, resistance trained older adults. This Chapter will be submitted to an appropriate peer-reviewed journal.

Abstract

The purpose of this study was to describe the acute physiological responses to two distinct sessions of eccentric resistance exercise compared to traditional resistance exercise, in resistance trained older adults using a randomized, crossover design. Three male and three female resistance trained adults (71±5.3 years) performed 4 sets of 10 repetitions at 60% of their 1RM or 1-Eccentric-Only-RM using a plate loaded, 45° linear leg press. Participants performed this protocol using a different modality (eccentric only, eccentrically biased and traditional resistance exercise), with 3-5 days between sessions. Oxygen consumption (VO_2) was recorded throughout each session while systolic blood pressure (SBP), heart rate (HR), growth hormone (HGH), testosterone (TEST), cortisol (CORT), creatine kinase (CK) were measured pre and post-session only. Repetitions short of failure (SOF) was solicited post-session only, rating of perceived exertion for the session (session RPE) was recorded at 10 min post-session only, and soreness (SORE) at 10 min, 24, 48 and 72 hr post-session. Mean VO_2 for eccentric resistance exercise was 6.35-8.94 ml/min/kg, while mean VO_2 was 5.83 ml/min/kg for traditional resistance exercise. Cardiovascular increase was 20-21 SBP, 39-53 HR in the eccentric modalities. HGH produced increases in both eccentric modalities (2,454-3,376 pg/ml). No visible changes in TEST following any of the three modalities were observed. CORT decreased after traditional (-19 nmol/ml) and eccentric only (-15 nmol/ml) and increased after eccentrically biased resistance exercise (91 nmol/ml). There were no visible changes in CK following any of the three modalities. Small changes were found for RPE and SORE, yet SOF was reported as 2 after the eccentric modalities and 5 after the traditional modality. These findings produce novel descriptive data for eccentric resistance exercise in resistance trained older adults.

Keywords: oxygen consumption, anabolic, cardiovascular

3.1 Introduction

The exploration into the mechanisms of eccentric muscle action dates back to 1901 (Chauveau, 1901). During these early investigations, it was observed that an eccentric muscle action required less oxygen when compared to concentric muscle contraction (Chauveau, 1901). Later, Abbott et al. (1952) used two bicycle ergometers bound back to back to confirm the lowered systemic metabolic demand for oxygen during an eccentrically dominated movement (resisting backwards pedalling). In addition to finding that oxygen requirements were 2.4 to 5.2 times higher when pedalling forward (concentrically dominated) than resisting, it was also subjectively noted that the subject performing the eccentric muscle action was performing the movement with 'clearly less' effort (Abbott et al., 1952).

Since these early, aerobically based investigations, researchers investigating eccentric exercise have assumed this distinct modality requires the same quantity of oxygen to be consumed in their population of interest. Investigators exploring eccentric exercise working with a more vulnerable population, such as older adults, ought to be aware of how much energy is required to perform eccentric exercise. Yet, nearly all research on the acute effects of eccentric exercise in the older adult has prescribed and investigated a maximal or muscle 'damaging' protocol. Also, much of this research is concerned with comparing the magnitude of muscle damage as a result of maximal eccentric muscle actions to the magnitude of damage that occurs in the younger adult as a result of the same protocol. Other than muscle damage, the responses of other important blood variables are largely unknown. One study to our knowledge has compared an acute eccentric resistance exercise session to a traditional resistance exercise session in older adults without the intention of investigating muscle damage (Vallejo, Schroeder, Zheng, Jensky, & Sattler, 2006). Using smith machine squats, this study found eccentric resistance exercise produced less cardiovascular stress (Heart Rate (HR), Systolic Blood Pressure (SBP), cardiac index, expired ventilation), however, both their eccentric and concentric protocol was prescribed based off the concentric-limited 1 Repetition Maximum (1RM) (Vallejo et al., 2006).

Therefore, the aim of this study was to describe the acute anabolic, metabolic and cardiovascular responses and the subjective perceptions of performing two distinct eccentric resistance exercise modalities in resistance trained older adults. Secondarily, the current study was also the first to assess and describe 1RM and 1 Eccentric Only Repetition Maximum (1ERM) on the plate loaded, 45° linear leg press machine in this cohort.

3.2 Methods

3.2.1 Study Design

This was an acute, cross-over design that preluded an eight-week resistance training intervention (Ashley Gluchowski, Dulson, Merien, Plank, & Harris, 2017). Six participants performed three separate resistance exercise modalities on a plate loaded, 45° linear leg press, in a randomized order three to five days apart. Variables of interest were physiological and perceptive responses immediately post exercise.

3.2.2 Subjects

Three males (age: 71±5.3 years, body mass: 66.3±12.23 kg, height: 165±6.9 cm) and three females (age: 71±5.3 years, body mass: 66.3±12.23 kg, height: 165±6.9 cm), all resistance trained (participating in resistance training at least two times per week for the last three months) older adults who were also participants in our subsequent training study (Ashley Gluchowski et al., 2017) volunteered to first partake in this acute study. The institution's ethics board approved this study. All participants were informed of both the benefits and the risks of the investigation prior to providing written informed consent on an institutionally approved informed consent document.

3.2.3 Procedures

Each participant completed five sessions in total. During the first familiarization visit, individual settings on the leg press machine were determined (110° knee flexion at the bottom of the movement to near full knee extension, 170° following the concentric phase of the exercise, as determined by a goniometer). Each participant was familiarized with each of the three modalities. One session was to be performed with eccentric muscle actions only (ERE), one performed with a focus on eccentric muscle actions (EBRE), and one conventional, traditional resistance exercise (TRE), involving both concentric and eccentric muscle actions with the right leg only (Ashley Gluchowski et al., 2017). Also, repetitions short of failure (SOF) (0+, where 0 was reported when the participant subjectively felt that no further repetitions could have been successfully completed) (Zourdos et al., 2016), RPE for the session (6-20, 6 representing no exertion, 20 representing maximal exertion) (Borg, 1982) and the subjective soreness (SORE) scale (1-10, 1 representing no passive soreness, 10 representing maximal possible passive soreness) (Hawker, Mian, Kendzerska, & French, 2011) were introduced. During the second visit, lower body maximal muscular strength was determined using the 1RM for both the concentric (1RM) and eccentric (1ERM) phase using the same plate-loaded, 45° leg press machine (Life Fitness, USA). The testing protocol used for this study is further detailed in our training study (Ashley Gluchowski et al., 2017). Following the familiarization and strength assessment visits, participants completed each of the three modalities, in their pre-determined but randomized order. Each session took place 3-5 days following the previous session (once SORE was back to baseline) and at the same time of the day (all participants completed their sessions between 3pm and 6pm) in an attempt to account for standardisation of diurnal variation in outcome measures. Participants were instructed not to perform any exercise outside of the study as well as not to ingest any food or drink (other than water) at least one hour before their session time.

Each of the three sessions included a resting SBP and HR reading (POLAR H10, Finland), blood collection (drawn from the antecubital vein) and SORE rating. A portable oxygen consumption device (metalyzer 3B, CORTEX, Germany) acquired a breath-by-breath measurement of gas exchange from a mask (connected to a turbine) that was placed around the participant's nose and mouth and remained on the participant's face for the entire session. The analyser was warmed and calibrated using known gas concentrations and volume according to the manufacture's specifications prior to each use. The participant was instructed to remain seated, as still as possible without talking. Five minutes of baseline oxygen consumption was collected before initiating any exercise. Each of the three acute sessions were equated for relative volume at four sets of 10 repetitions at 60% of their pre-determined 1RM (for TRE and EBRE) or 60% of their pre-determined 1ERM (for ERE) as well as for total set time, with a two-minute rest between sets. The load did not change throughout the session (that is, the same load was used for both the eccentric and concentric phases of the movement). TRE required participants to concentrically lift and eccentrically lower the sled bilaterally. For ERE, participants bilaterally lowered the sled only. For EBRE, participants lifted the load bilaterally but lowered the load unilaterally (using their right leg only) (Ashley Gluchowski et al., 2017). Immediately after all four sets were completed, SBP, HR, SOF and a second blood sample were collected. Ten minutes following the session's last repetition, SORE and session RPE were collected and gas analysis was terminated. The participants' 24, 48 and 72-hour passive, subjective SORE ratings were recorded via email. Following blood collection, serum was separated by centrifugation at 1500 *g* for 10 minutes at 4°C and stored at -80°C until further analyses. Samples were subsequently thawed and analysed using specific commercial assays on a Roche Modular E170 at AUT-Roche Diagnostic Laboratory.

3.2.4 Statistical Analyses

All descriptive values are presented as means ± standard deviation (SD). Data within the manuscript are presented by group (TRE, ERE, EBRE). Data within the tables are presented by sex (male and female) and by group. Due to small sample size (n=6), between group statistics were not calculated.

3.3 Results

Descriptive results are shown in Table 6. Individual variances for blood biomarkers are shown in Figure 1, Figure 2, Figure 3 and Figure 4. Individual variances for oxygen consumption are shown in Figure 5.

Table 6. The acute physiological responses and subjective perspectives following TRE, ERE and EBRE (n=6, mean±SD)

	TRE		ERE		EBRE	
	Pre	Post	Pre	Post	Pre	Post
SBP (mmHg)	141±6	156±23	152±21	172±25	157±23	178±36
HR (bpm)	67±7	97±10	67±5.0	106±13	71±11	124±16
HGH (pg/mL)	708±970	928±727	292±215	2746±1282	241±200	3617±2928
TEST (ng/mL)	1.24±1.31	1.32±1.41	0.98±1.12	0.71±1.08	1.18±1.51	1.25±1.56
CORT (nmol/L)	189±82	170±66	265±53	250±69	235±70	326±118
CK (U/L)	156±104	158±104	164±99	158±135	109±61	111±55
VO_2 (ml/min/kg)		5.83±2.30		6.35±2.92		8.94±3.12
Session RPE (6-20)		13±0.8		14±1.8		14±1.2
SOF (0+)		5±1.9		2±1.9		2±1.2
SORE 0 hr (1-10)		0.2±0.4		0.2±0.4		1±1.7
SORE 24 hr (1-10)		0±0		1.3±2		2±1.9
SORE 48 hr (1-10)		0.2±0.4		1.3±1.8		1.3±1.2
SORE 72 hr (1-10)		0±0		0.2±0.4		0.6±0.5

CK creatine kinase, CORT cortisol, HGH human growth hormone, HR heart rate, RPE rating of percieved exertion, SBP systolic blood pressure, SOF short of failure, SORE soreness scale, TEST testosterone, VO2 maximal oxygen consumption

1ERM was 138% (129-149%) greater than 1RM. The mean SBP increased by 15 mmHg from resting to immediately post-exercise in TRE. The mean SBP increased by approximately 20 mmHg following both eccentric modalities. The HR increase from resting to immediately post-exercise was 30 bpm in TRE, 39 bpm in ERE and 53 bpm in EBRE. HGH increased by a mean of 220 pg/ml after TRE, and by 2,454 and 3,376 pg/ml in ERE and EBRE, respectively. One participant had a particularly exaggerated HGH response to EBRE (See Figure 1). All participants except for one (and only after their TRE session) showed an increase in HGH. TEST changes immediately following each of the three acute sessions were negligible (See Figure 2). Mean CORT decreased in ERE (15 nmol/L), TRE (19 nmol/L), and in EBRE (91 nmol/L) although inter-individual nuances may be observed in Figure 3. CK changes immediately following each of the three acute sessions were negligible (See Figure 4).

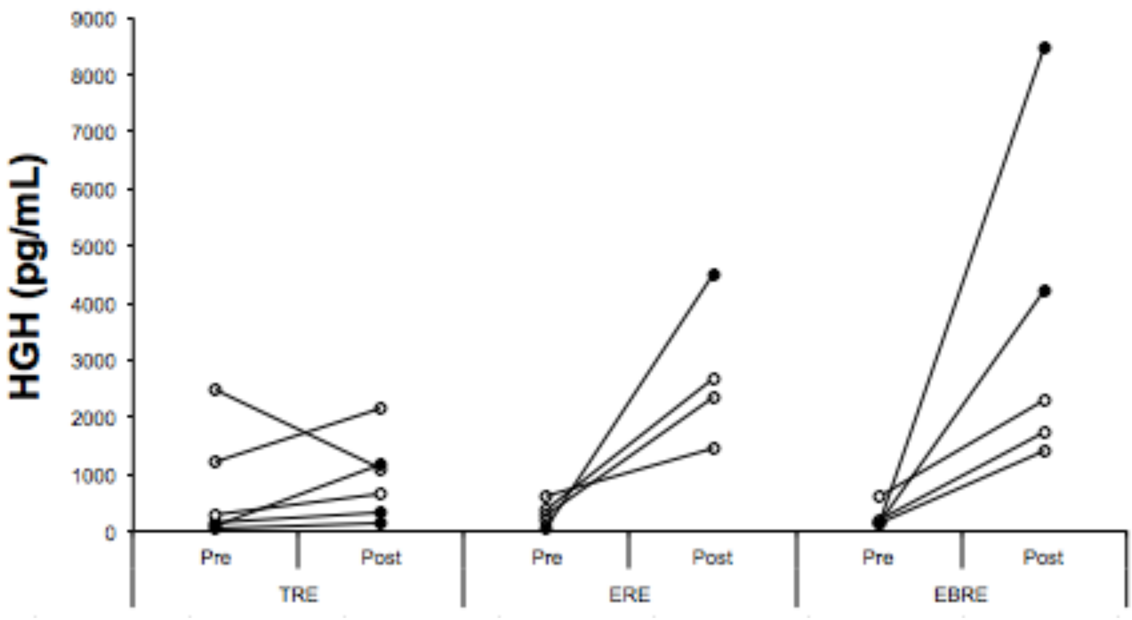

Figure 1. Individual changes in Human Growth Hormone from pre to post acute leg press session for TRE, ERE and EBRE. Solid data points () represent male; Open data points (¢) represent female participants.

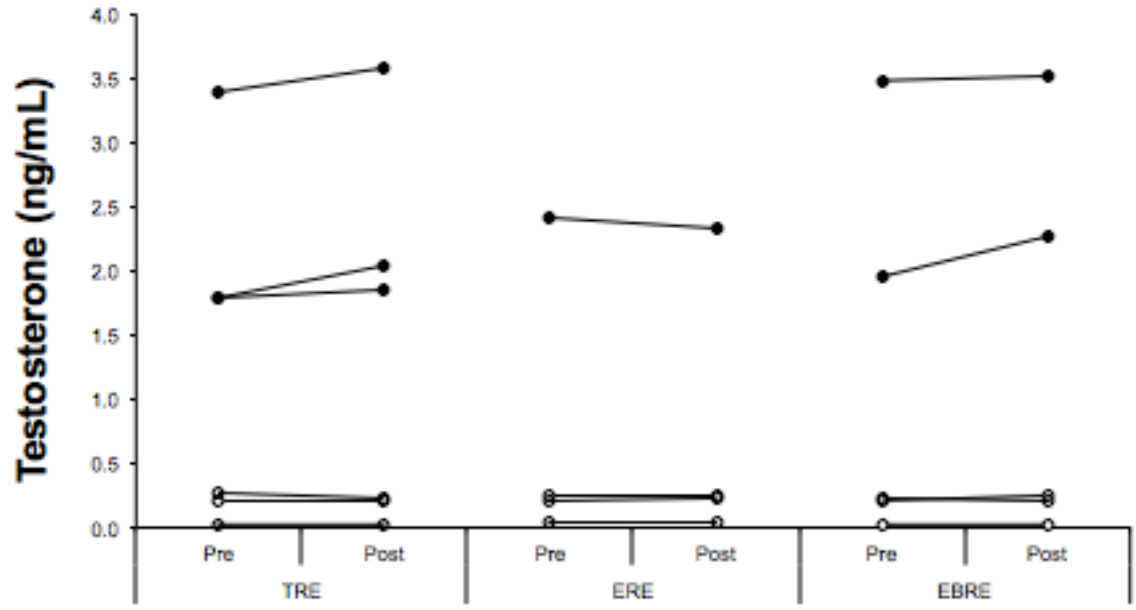

Figure 2. Individual changes in Testosterone from pre to post acute leg press session for TRE, ERE and EBRE. Solid data points (•) represent male; Open data points (**O**) represent female participants.

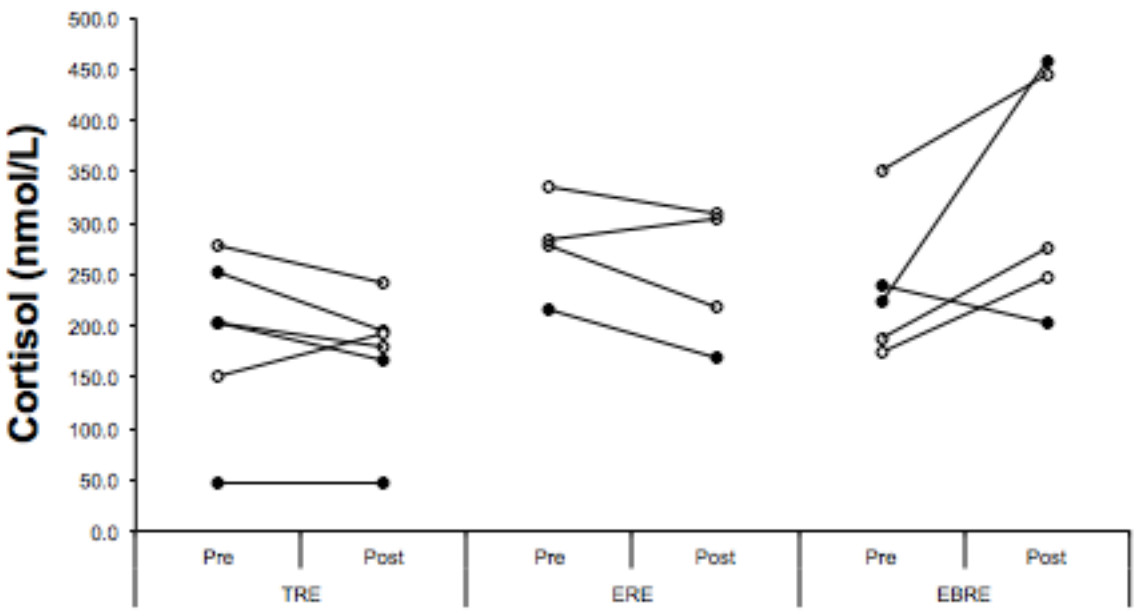

Figure 3. Individual changes in Cortisol from pre to post acute leg press session for TRE, ERE and EBRE. Solid data points (•) represent male; Open data points (**O**) represent female participants.

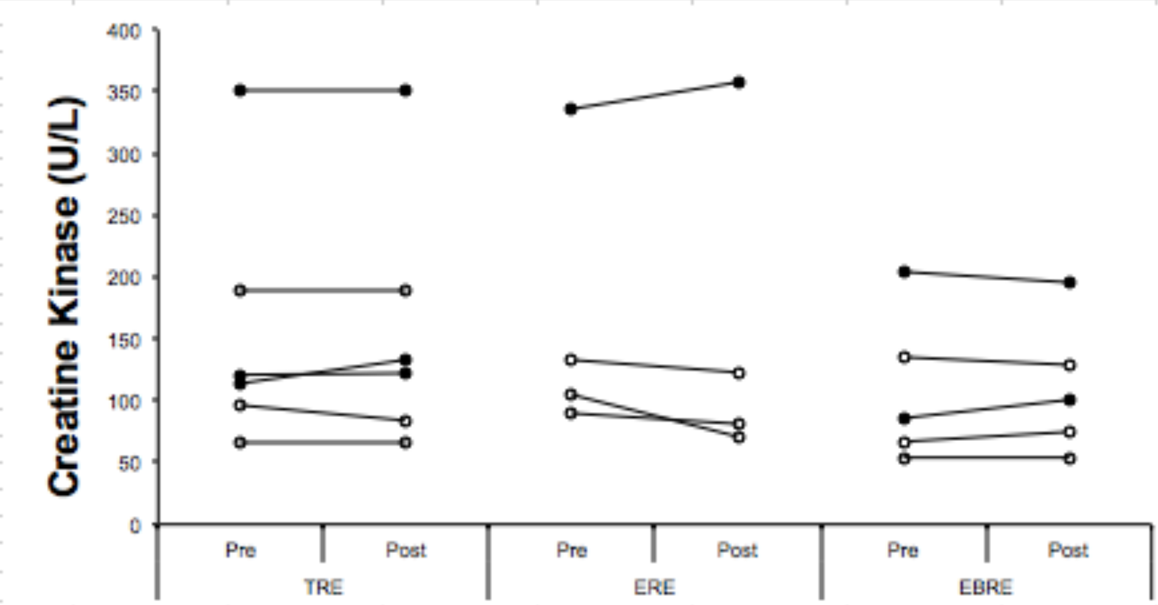

Figure 4. Individual changes in Creatine Kinase from pre to post acute leg press session for TRE, ERE and EBRE. Solid data points (•) represent male; Open data points (**O**) represent female participants.

Mean oxygen consumption (ml/kg/min) for the duration of the session (from the beginning of the first set to the end of the fourth set) was 5.8 in TRE, 6.4 in ERE, and nearly 9 ml/min/kg in EBRE. There were two participants (participants 2 and 5, see Figure 5) who did not follow this pattern and in these cases, ERE was either below or slightly above the distinctive pattern of oxygen consumption seen in the other 4 participants (that is, TRE<ERE<EBRE).

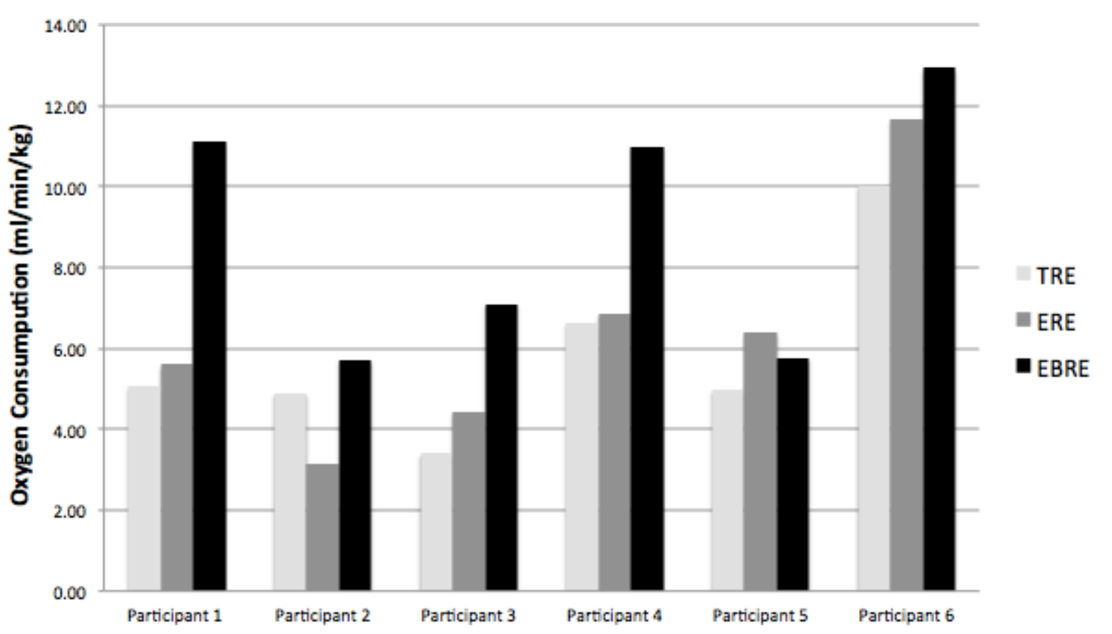

Figure 5. Individual oxygen consumption values for performing an acute session (4 sets of 10 repetitions at 60% 1RM/1ERM) of TRE, ERE and EBRE on the 45° linear leg press machine

The mean session RPE 10 min following the session was 14 of 20 in both ERE and EBRE while session RPE was 13 of 20 following TRE. Correspondingly, the mean repetitions

SOF were reported as 2 in the eccentric modalities and 5 SOF in TRE. Mean SORE increased to a maximum value of 2 out of 10 (EBRE only), occurring at 24 hours post session and fell back to 0 out of 10 by 72 hours post session for all groups.

3.4 Discussion

The present study is the first to investigate and describe the physiological and perceptive responses to two distinct eccentric modalities, using traditional resistance exercise as a reference point, in resistance trained older adults. Also, to our knowledge, this is the first time older adults have been tested for both 1RM and 1ERM using isoinertial methods. This is important, as investigators have hitherto, used the concentric limited 1RM to program their eccentric training programs.

When work is equated, the local metabolic demand on the systemic circulatory system from eccentric muscle action results in reduced oxygen consumption when compared to concentric contractions (Dufour et al., 2007; Perrey, Betik, Candau, Rouillon, & Hughson, 2001). This reduced consumption, measured at a pulmonary level, is partly a result of less hydrolysis or turnover of adenosine triphosphate (Dufour et al., 2007; Perrey et al., 2001). However, in a practical, traditional resistance exercise setting with isoloads, and in fact to be a true eccentric modality, the forces required to perform eccentric and concentric actions are rarely equated. In our study, there was an increase in VO_2 from TRE to ERE. Only relative loads were equated (60% 1RM for TRE and 60% 1ERM for ERE), thus, our participants lifted heavier absolute loads with a slower eccentric contraction velocity in ERE compared to TRE. This increased mechanical tension and eccentric time under tension in ERE likely caused this increased VO_2 (Vincent et al., 2014). Our participants used a 4 s eccentric tempo in ERE, which still used a lower VO_2 than EBRE (in which the eccentric action was performed in 2 s). Of the two (mechanical tension and velocity), it is likely that mechanical load played a larger role in our findings as oxygen consumption has been shown to increase with increasing loads (Buitrago, Wirtz, Yue, Kleinöder, & Mester, 2012) as well as suggesting that VO_{2max} is no different between eccentric velocities (Okamoto, Masuhara, & Ikuta, 2005).

In our study, the same relative loads (60% 1RM and 60% 1ERM) used in all three modalities lead to absolute loads that were different enough (for example, 100 kg 1RM and a 138 kg 1ERM) to discern the patterns of recruitment of the oxygen inefficient, type II fibres that are required during high force production (Henneman, Somjen, & Carpenter, 1965). In support of the difference that absolute loading can make, our participants reported they were still 3-8 repetitions SOF for TRE and only 1-6 repetitions SOF for ERE following the fourth and final set of the acute session. Of note, participants reported 0-3 SOF following the EBRE session (which was prescribed based off 1RM but lowered unilaterally), which also happened to yield the greatest VO_2.

Our participants consumed approximately 35% more oxygen during the EBRE session than when they performed TRE even though both conditions lifted the same relative and absolute load (60% 1RM). In the present study, the VO_2 difference between EBRE and TRE cannot be attributed to a greater usage of muscle mass since EBRE was performed with only one lower limb (Farinatti, Castinheiras Neto, & Amorim, 2016). However, the difference may have resulted from an increased utilization of stabilizer muscles to secure the hips into the seat of the 45° linear leg press machine while performing the unilateral eccentric muscle actions in EBRE (Pedersen, Sorensen, Jensen, Johansen, & Levin, 2002). The difference in VO_2 could also be due to the increased neuromuscular activity of coordinating limbs during the 2-up-1-down (EBRE) modality (Dufour et al., 2007; He, Bottinelli, Pellegrino, Ferenczi, & Reggiani, 2000). Neither of these proposed explanations were assessed in the current study.

In our study, an increase in HGH was found in EBRE and ERE when compared to TRE. In a previous study, HGH has also been found to increase in a resistance-trained population (Calixto et al., 2014). In that study Calixto et al. (2014), HGH was shown to increase in the group who performed an isoinertial eccentric bench press at a slower tempo (3 s) when compared to those prescribed a faster eccentric tempo (0.5 s). In another study utilizing non-resistance trained women, HGH also increased significantly immediately following an elbow flexor session on an isokinetic dynamometer completed at a slow angular velocity when compared to a fast angular velocity (Libardi et al., 2013). This same study also found no differences for CORT and TEST between the conditions (Libardi et al.). Thus, we can confirm that while performing ERE with a slower, 4 s eccentric tempo elicited greater HGH elevations than the 2 s eccentric tempo in TRE. This same 4 s eccentric tempo in ERE did not elicit greater HGH elevations when compared to the 2 s eccentric tempo in the EBRE modality.

In our study, acute CORT decreased in both TRE and ERE but increased in EBRE. A rise in CORT is expected, especially after an intense strength training session (Shaner et al., 2014). A decline in CORT could mean that our intensity was under loaded, which is likely at 60% 1RM/1ERM (Goto et al., 2009). CORT may have organically decreased due to the circadian rhythm (Beaven, Gill, Ingram, & Hopkins, 2011), although all participants completed all sessions between 3pm - 6pm and pre and post blood samples were only approximately 45 min apart.

We have shown negligible change in CK for any of our modalities, similarly to previous studies utilizing trained individuals (Hather, Dudley, Buchanan, & Tesch, 1991; Nosaka & Clarkson, 1995). However, there is evidence of both normal and high CK responders in the older adult population (Tajra et al., 2014). Tajra et al. (2014) found that approximately 10% of older adults are high CK responders following eccentric exercise (Tajra et al.). With such a small sample size, it is possible that we did not recruit from this cohort of high CK responders although one participant (male) did show signs of being a higher responder. There is also evidence that CK increases significantly when eccentric muscle actions continue until muscle fatigue (Hody, Rogister, Leprince, Wang, & Croisier, 2013). As our SOF results show, our participants felt they were still on average at least 2-5 repetitions SOF following their TRE, ERE and EBRE sessions. CK, together with our subjective SORE scale (which was never reported higher than 5 out of 10), demonstrates the likeliness that our protocol did not cause significant micro-trauma to the musculature. Consequently, our protocol could indicate a safe loading and volume prescription for eccentrically naïve older adults.

The strength of this study is in the practicality of its protocol. It is unlikely that older adults would train with an accentuated load during the eccentric phase (in order to equate work), train to failure, or train on an isokinetic device as most studies exploring acute metabolic, cardiovascular and anabolic outcomes have previously investigated (Denis, Bringard, & Perrey, 2011; Dolezal, Potteiger, Jacobsen, & Benedict, 2000). Thus, having an eccentric modality that is relatively easy to execute alongside a stronger trainer (ERE) or even to have an option of training alone (2-up-1-down modality, EBRE), are more likely relevant to real world scenarios. Thus, our study provides a practical example of the acute responses to different modalities in a commonly utilised exercise.

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Conflicts of interest: none

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Chapter 4 Comparing the Effects of Two Distinct Eccentric Modalities to Traditional Resistance Training in Resistance Trained, Higher Functioning Older Adults

Preface

Based on the design of previous eccentric exercise investigations and the subsequently identified research gaps from my literature review in Chapter 2, I developed the outcome measures of interest for this Chapter. Using my experimental knowledge from my acute crossover study in Chapter 3, I identified the training variables believed to be safe and effective in our population of interest.

In this Chapter, I present the main study of my PhD thesis. I set out to investigate the chronic effects of two distinct eccentric resistance exercise modalities when compared to the effects that occur following our conventionally prescribed, traditional resistance exercise. For this study, I was able to recruit 33 healthy, high functioning, resistance trained older adults, whilst reporting only one dropout (unrelated to the study) over the course of the 10-week research duration. As a result of this study, I successfully reported an unprecedented number of outcomes (especially for a PhD timeline and budget, no less) for an exceptionally comprehensive examination of the physical and physiological adaptations resulting from an eight-week chronic eccentric resistance exercise program. My exceptional adherence rate (94%) consequently directed the ad hoc design of a follow-up qualitative study (Chapter 5). I am incredibly proud that this particular Chapter was quite quickly accepted and published in my first choice of journal due to its suitability, the high impact factor, peer-reviewed journal, Experimental Gerontology.

Abstract

Background. The effects of eccentric resistance exercise are of interest in the older adult cohort, but to our knowledge, there is no research on the relative effects of different eccentric modalities on a range of outcomes (maximal muscular strength, functional capacity, body composition and blood biomarkers) in higher functioning, resistance trained older adults.

Methods. 33 resistance-trained older adults (aged 67±4.5 years) were randomized into one of three supervised training groups: traditional (TRE), eccentric only (ERE) or eccentrically biased resistance exercise (EBRE) on a 45°, plate-loaded leg press machine. Participants trained twice per week with primary outcome of maximal strength, and secondary outcomes of functional capacity, body composition and blood biomarkers measured before and after the eight-week intervention.

Results. Both eccentric and concentric strength, and important functional tasks for independent living significantly improved independent of group ($p>0.05$). Body composition and blood biomarkers were found to significantly improve ($p<0.05$) in the EBRE group only however, no statistical differences were found between groups ($p>0.05$).

Conclusion. Compared to traditional resistance training, the two eccentric modalities investigated here were equally effective for improvements in maximum muscular strength, functional capacity, body composition and metabolic biomarkers. When training the resistance trained older adult, very heavy isoinertial external loads (at least 70% of one repetition maximum) are effective irrespective of contraction mode. With heavy load strength training, resistance trained older adults can continue to expect improvements in health and function.

Key Words: strength, function, body composition, high functioning, very heavy load, exercise

4.1 Introduction

Older adults with chronic disability or disease are of major social and economic concern (Salomon et al., 2012). However, even the smallest of early, preventative efforts are likely to translate into significant reductions in this overall burden (Viña, Rodriguez-Mañas, Salvador-Pascual, Tarazona-Santabalbina, & Gomez-Cabrera, 2016). It is estimated that for every one dollar spent in encouraging physical activity, $3.20 is saved in medical costs (US Centers for Disease Control, 1999). Physical activity and structured exercise are regarded as our most effective interventions to prevent, delay or attenuate the devastating physical and physiological effects of ageing (Viña et al., 2016). Thus, older adults and society as a whole would benefit from the meticulous investigation of theoretically and practically promising exercise interventions.

To this point, investigators have been particularly intrigued by eccentric muscle action and its characteristics (higher force production, relative preservation of eccentric strength, lower aerobic cost and even a lower rating of perceived exertion, RPE). The characteristics of eccentric exercise seem to allow even the lowest functioning older adult (those with limited strength or aerobic capacity, such as sedentary individuals or those affected by sarcopenia, obesity, cardiovascular or pulmonary disease) to participate in exercise by allowing them to utilize their remaining capacities (for instance, their preserved eccentric strength). As a consequence, eccentric exercise has been studied only on those particular older adults with no recent structured exercise history (A Gluchowski, Harris, Dulson, & Cronin, 2015). However, research has shown that the implementation of most exercise modalities will elicit significant benefits to an untrained or detrained population (Churchward-Venne et al., 2015; Conlon et al., 2016). Thus, the limitation with using an untrained population is that we are likely investigating the well-known neuromuscular adaptations that come with initiating any structured exercise program, rather than the adaptations that may or may not develop from the unique modality itself. In addition, we need to investigate whether each theoretically promising exercise modality provides physical or physiological benefit above and beyond the adaptations from a participant’s current training.

As such, eccentric exercise may prove to be a powerful progressive tool for continued physical and physiological improvement for the resistance trained older adult. Evidence is readily available for the chronic adaptations due to traditional resistance exercise in older adults yet, we are unaware of any studies that have used a trained, older adult population to investigate the effects of chronic eccentric exercise (A Gluchowski et al., 2015). Especially true in ageing biomarkers as a result of chronic eccentric exercise, this study will serve to explore this area of interest. As a result, it is the aim of this research to investigate and if appropriate, expand our exercise programming options by exploring the relative efficacy of eccentric-only exercise (no concentric muscle action performed, from here on out termed eccentric resistance exercise or ERE) and the more practically applicable eccentrically-biased resistance exercise (an attempt to emphasize the eccentric muscle action but concentric muscle action is also performed by the participant, EBRE) when compared to the more conventionally prescribed traditional (both concentric and eccentric muscle action performed, TRE) resistance exercise in a population of resistance trained older adults. We hypothesized that due to the characteristics of eccentric muscle actions, the ERE group would inevitably train with greater absolute loads thus the additional mechanical tension would lead to significant improvements in maximal eccentric strength, lean muscle mass and bone mineral content compared to the EBRE and TRE groups. Furthermore, the increase in maximal strength would not likely lead to any further improvements of functional capacity or blood biomarkers for this healthy, high-functioning cohort.

4.2 Methods

4.2.1 Participants

Thirty-three resistance trained older adults (21 females and 12 males, mean±SD age 67±4.5 yr, weight 75±15.3 kg, height 169±8.6 cm) participated in this trial. Participants were recruited by referal from a resistance training program for older adults, from posters placed in the institution's public gym and by word of mouth. Participants were excluded if they were not at least 60 years of age, were not participating in structured resistance exercise for at least the last three months, had any musculoskeletal issues that prevented the safe use of the required exercise loads, or were taking any performance or body composition enhancing supplements. The Institutional Ethics Committee approved this study and participants were made aware of both the risks and possible benefits before providing written informed consent. This study was not registered with clinicaltrials.gov.

4.2.2 Study Design

This was a randomized, controlled, eight-week intervention comparing the effects of TRE, ERE and EBRE on lower body maximal muscular strength, functional capacity, body composition, and blood biomarkers.

Participants were fixed block stratified by baseline concentric strength on a 45° leg press machine and then randomly assigned (using an equal allocation ratio of 1:1:1) to one of the three training groups: ERE (n=11, 6 females), EBRE (n=11, 8 females) or TRE (n=11, 7 females, control group) using opaque envelopes. Blinding of the particpants, trainer or assessor was not possible in this trial. Participants were asked to put their current resistance training on hold and replace it with that of the current study but encouraged to continue with their regular aerobic programming (which typically included recreational walking, jogging and hiking as well as both recreational and competitive sprinting, cycling and swimming). Participants were also asked not to alter their normal nutritional or habitual physical activity habits during the study.

4.2.3 Testing Procedures

Baseline and post-intervention testing procedures included strength, function, body composition and blood biomarkers. Both testing and training took place in our institution's strength and conditioning laboratory. Lower body maximal muscular strength (kg) was assessed with the same leg press machine used in training (Life Fitness, Rosemont, IL). Adjustable mechanical brakes were used to fix the stop-start position at 110° knee angle (using a goniometer centred at the lateral epicondyle of the knee and aligned to the lateral malleolus and greater trochanter). Foot position was self-selected by participants but standardized to within 5 cm between all participants. The traditional 1RM (assessing concentric muscle strength in order to push the load from 110° of knee flexion) was performed first. Following a five-minute rest, an eccentric-only 1RM (1ERM) was performed (in which an assistant performed the concentric phase, the participant then took and lowered the load in a slow controlled manner back to the start-stop position from approximately 170° degrees knee flexion). A successful 1ERM attempt was one in which the participant was able to lower the load slowly (in approximately 2 s) while coming to a stop 'softly' on the blocks. No more than five attempts were needed to determine 1RM or 1ERM. Maximal strength was also assessed mid-way through the intervention (week four) to re-inform relative training load.

Functional capacity was assessed using sit to stand (Rikli & Jones, 1999), stair descent (Oh-Park, Wang, & Verghese, 2011), rise from ground (Alexander, Ulbrich, Raheja, & Channer, 1997) and the 6 m fast walk (Rikli & Jones, 1999). All four were assessed through timed performance (s) in an attempt to avoid any ceiling effect that can occur with fixed maximum score based assessments (such as the Berg Balance Scale or the Fullerton Advanced Balance (FAB) scale) in a high functioning cohort. However, the FAB scale was used solely to ensure our participants were objectively classified as high functioning older adults. The five-repetition sit to stand (5STS) measured how quickly a participant (with their arms folded across their chest) could sit and stand from a box height of 40 cm, five times. The stair descent (SD) measured how quickly a participant could descend a 14-step staircase (height 17 cm, length 30 cm). Time began with participants' initiation of first step and stopped when both feet were on the landing. The rise from ground (RFG) assessment measured how quickly a participant could stand from a supine position. Time began with the word "go" and stopped when the participant was in an upright position. The 6 m fast walk (6FW) measured how quickly a participant could walk (without running) six metres. The 10 m track included two metres both preceding and following the timed six metres to allow for maximum acceleration and deceleration. Time began when the participant crossed the two-metre mark and stopped when they broke the eight-metre mark.

Body composition was assessed using whole-body Dual-energy X-ray Absorptiometry (DXA) scanning (GE-Lunar iDXA, GE Healthcare, Madison, WI). GE-Lunar enCORETM software (version 15) was used to determine lower limb (LL) lean mass (g), total bone mineral content (BMC) (g), total fat mass (g) and estimated visceral adipose tissue (VAT) (g). Height (wall stadiometer to nearest 0.1 cm, baseline only) and weight (to nearest 0.01 kg) were also taken.

Blood samples were collected through venipuncture of the anticubital vein on the morning (from 08:00 to 09:00 h) after a 12-hour fasting period. Serum was isolated by centrifugation at 1500 *g* at 4°C for 10 min and frozen at -80°C until further analyses. Samples were subsequently thawed and analysed using specific commercial assays on a Roche Modular E170 at AUT-Roche Diagnostic Laboratory. Blood biomarkers assessed included metabolic biomarkers (HbA1c (mM/M), Glucose (mmol/L), Insulin (pmol/L)), cardiovascular biomarkers (low-density lipoprotein (LDL) (mmol/L), high-density lipoprotein (HDL) (mmol/L), Triglycerides (mmol/L)) and an inflammatory biomarker (high-sensitivity C reactive protein (hs-CRP) (mg/L)).

4.2.4 Familiarization Sessions

Two familiarization sessions took place the week between baseline testing and the intervention. Familiarization allowed each participant to acquaint themselves with their respective leg press training modality (ERE, EBRE or TRE), as well as the remaining upper body and core exercises and their respective loads to be used in the training study.

4.2.5 Training Intervention

All training sessions were conducted in a circuit format in groups of up to six participants per session. The TRE group performed both the concentric and eccentric phase on the leg press bilaterally at a tempo of 2 s to lift the load (concentric phase), a 1 s pause at the end of the concentric phase, then a 2 s lowering (eccentric) phase (2-1-2) for consecutive repetitions. The EBRE group performed the concentric phase bilaterally in the same manner as the TRE group, but the eccentric phase was performed unilaterally (using their preferred leg, which did not change throughout the study) with the same 2-1-2 tempo. Those in the ERE group performed only the eccentric phase, bilaterally; the concentric phase was performed exclusively by an assistant. Repetitions, sets and loads used are detailed in Table 7. Supplementary upper body and core exercises completed the training programme, as presented in Table 8.

Table 7. Leg Press Exercise Prescription Between Groups

	TRE (n=11)	EBRE (n=11)	ERE (n=11)
Limb Involvement and Muscle Action	**Bilateral ECC Bilateral CON**	**Unilateral ECC Bilateral CON**	**Bilateral ECC CON not performed**
Reps	10	10	10
Sets	4	4	4
Relative Intensity	70% 1RM	70% 1RM	70% 1ERM
Relative Volume	2,800	2,800	2,800
Tempo	2021	2021	2--1
Rest	60s	60s	60s
Set TUT	50s	50s	30s
Total TUT	200s	200s	120s

ECC eccentric, CON concentric, TUT time under tension

Table 8. Supplementary Exercise Prescription for all Groups

Weeks 1-4	Weeks 5-8
Shoulder Press	Push Up
Bicep Curl	Side Plank
Bent Over Row	Lateral Raise
Plank	Triceps Kickback
Chest Press	Lat Pulldown

Participants began the circuit at a designated station for the first session and subsequently rotated their starting station each session in an attempt to account for exercise order effect over the duration of the intervention. An audible timer was used throughout each training session to provide distinguishing ‘beeps’ for the requisite tempo, number of repetitions, the start and end of rest periods and progression to the next exercise.

Each session began with a standardised warm-up consisting of three minutes on the treadmill, upright or recumbent bike (Life Fitness, Rosemont, IL) at a 9 on the 6 – 20 RPE scale followed by dynamic stretching (Borg, 1982). Each session ended with a cool-down involving static stretching with a focus on the lower body. After each training session, participants were prompted to provide overall session RPE on the same 6 - 20 RPE scale.

Perceived repetitions short of failure (SOF) were recorded for all exercises at the immediate conclusion of the final set. If, after the final set of each exercise, participants reported that they were two or more SOF for two consecutive sessions, the weight was increased by 20 kg on the leg press or to the next available increment for all other exercises.

4.2.6 Statistical Analysis

Sample size was determined using a power of 90% and a statistical significance of 5%, based on the study by Reeves et al. (Reeves et al., 2009) which found a 42% increase in muscular strength using 10 moderately active participants over 14 weeks. All descriptive values are presented as means ± standard deviation (SD), unless otherwise stated. In SPSS (IBM SPSS Statistics), Shapiro-Wilk was used to determine normality of the data. Equivalence between groups at baseline was assessed with ANOVA within group pre and post intervention mean values; effect size (ES) and p-values for each outcome are presented in Table 9, Table 10 and Table 11.

Between group significance was determined using one-way ANOVA for three independent groups with a post hoc Tukey test.

4.3 Results

A total of 33 participants were recruited for the study. One participant (male, TRE) later withdrew from the study owing to knee soreness prohibiting further training or testing (reportedly unrelated to study protocols). Additionally, four male participants (1 from TRE, 2 from ERE and 1 from EBRE) were excluded from the strength analysis (1RM and 1ERM) as their required loads during the mid-way (week four) strength assessment time point exceeded the loading restrictions on our leg press machine. The four male participants are included in all other analyses (functional capacity, body composition and blood markers). Overall, adherence to the training sessions was 94% (with participants attending on average 15 out of a total of 16 training sessions, with a range of 14 out of 16 to 16 out of 16 training sessions attended). Within group pre and post-intervention testing results as well as between group differences on maximum muscular strength, functional capacity, body composition and blood biomarkers are presented in Table 9, Table 10 and Table 11. Figure 6 and Figure 7 are presented as change score (pre-post) with black bars representing median change and data points indicating female (open) and male (solid) participants.

Table 9. Within Group Differences for TRE

	Traditional (n=10)							
	Pre			Post				
	Mean	±	SD	Mean	±	SD	%Δ	ES
1RM (kg)	222	±	87.0	317	±	95.6**	43	1.1
1ERM (kg)	308	±	118.7	410	±	125.3**	33	0.9
Rise from Ground (s)	2.83	±	0.66	2.32	±	0.45**	-18	-0.8
Stair Descent (s)	4.30	±	0.48	3.68	±	0.49**	-15	-1.3
5 Rep Sit-to-Stand (s)	8.11	±	1.32	6.19	±	1.94**	-24	-1.5
6m Fast Walk (s)	2.63	±	0.37	2.37	±	0.20*	-10	-0.7
Total Fat Mass (g)	23355	±	9539	23132	±	9484	-1	0
Estimated VAT (g)	823	±	683	857	±	607	4.2	0.1
LL Lean Mass (g)	15635	±	3337	15565	±	3305	-0.4	0
Total BMC (g)	2477	±	557	2472	±	549	-0.2	0
HbA1c (mM/M)	34.4	±	3.5	37.4	±	2.7*	8.6	0.9
Glucose (mmol/L)	5.3	±	2	5.1	±	0.5	-4.9	-0.1
Insulin (pmol/L)	58.1	±	48.7	46.5	±	31.4	-19.9	-0.2
LDL (mmol/L)	3.4	±	1.2	3.4	±	0.6	1.4	0
HDL (mmol/L)	1.6	±	0.6	1.3	±	0.3	-15.7	-0.4
TG (mmol/L)	1	±	0.3	0.8	±	0.1	-15.8	-0.5
CRP (mg/L)	1.4	±	1.8	1.5	±	1	5.4	0

%Δ percent change
ES effect size
LL lower limb

* within group p<0.05
** within group p<0.01
# between group significance

Table 10. Within Group Differences for ERE

	Eccentric-Only (n=11)							
	Pre			Post				
	Mean	±	SD	Mean	±	SD	%Δ	ES
1RM (kg)	219	±	58.0	296	±	48.2**	35	1.3
1ERM (kg)	259	±	93.5	424	±	57.9**	63	1.8
Rise from Ground (s)	3.62	±	1.64	3.11	±	1.38*	-14	-0.3
Stair Descent (s)	4.93	±	0.84	4.19	±	0.81**	-15	-0.9
5 Rep Sit-to-Stand (s)	10.29	±	2.67	7.52	±	2.67*	-27	-1.0
6m Fast Walk (s)	2.81	±	0.28	2.50	±	0.24*	-11	-1.1
Total Fat Mass (g)	28218	±	11294	27616	±	11059	-2.1	-0.1
Estimated VAT (g)	1499	±	1070	1488	±	1073	-0.7	0
LL Lean Mass (g)	16357	±	3221	16478	±	3013	0.7	0
Total BMC (g)	2624	±	425	2621	±	422	-0.1	0
HbA1c (mM/M)	37.7	±	4.1	38.2	±	3.5	1.5	0.1
Glucose (mmol/L)	5.8	±	0.8	4.6	±	1.9	-19.8	-1.5
Insulin (pmol/L)	81.8	±	95.3	61.3	±	28.6	-25	-0.2
LDL (mmol/L)	3.7	±	0.9	3.2	±	1.1	-13.9	-0.6
HDL (mmol/L)	1.5	±	0.4	1.3	±	0.6	-15.2	-0.5
TG (mmol/L)	1.4	±	0.8	1.2	±	1.2	-15.8	-0.3
CRP (mg/L)	2.1	±	1.6	1.7	±	1.3	-18.2	-0.2

%Δ percent change
ES effect size
LL lower limb

* within group p<0.05
** within group p<0.01
# between group significance

Table 11. Within Group Differences for EBRE

	Eccentrically-Biased (n=11)							
	Pre			Post				
	Mean	±	SD	Mean	±	SD	%Δ	ES
1RM (kg)	251	±	94.3	330	±	87.1**	31	0.8
1ERM (kg)	339	±	125.1	458	±	106.7**	35	0.9
Rise from Ground (s)	3.00	±	0.56	2.54	±	0.57**	-15	-0.8
Stair Descent (s)	4.60	±	0.76	4.11	±	0.56**	-11	-0.7
5 Rep Sit-to-Stand (s)	7.01	±	1.20	5.62	±	0.92**	-20	-1.2
6m Fast Walk (s)	2.60	±	0.57	2.47	±	0.28	-5	-0.2
Total Fat Mass (g)	27362	±	7224	26847	±	7026*	-1.9	-0.1
Estimated VAT (g)	1093	±	964	1017	±	880	-7	-0.1
LL Lean Mass (g)	15038	±	4557	15174	±	4507	0.9	0
Total BMC (g)	2348	±	678	2323	±	657*	-1.1	0
HbA1c (mM/M)	37.8	±	3.3	39.3	±	4.0**	4	0.5
Glucose (mmol/L)	6.1	±	1.2	5.1	±	1.0**	-16.2	-0.8
Insulin (pmol/L)	84.6	±	52.2	63	±	49.1*	-25.4	-0.4
LDL (mmol/L)	4.2	±	1.2	3.4	±	0.7**	-19	-0.7
HDL (mmol/L)	1.7	±	0.7	1.4	±	0.6**	-17.5	-0.5
TG (mmol/L)	1.1	±	0.4	0.9	±	0.6	-17.1	-0.4
CRP (mg/L)	2.1	±	1.6	1.3	±	1.0	-39	-0.5

%Δ percent change
ES effect size
LL lower limb

* within group p<0.05
** within group p<0.01
# between group significance

4.3.1 Maximal Strength

Both concentric and eccentric maximal strength significantly increased following the intervention independent of training group (all p<0.01). There were no significant differences between the groups.

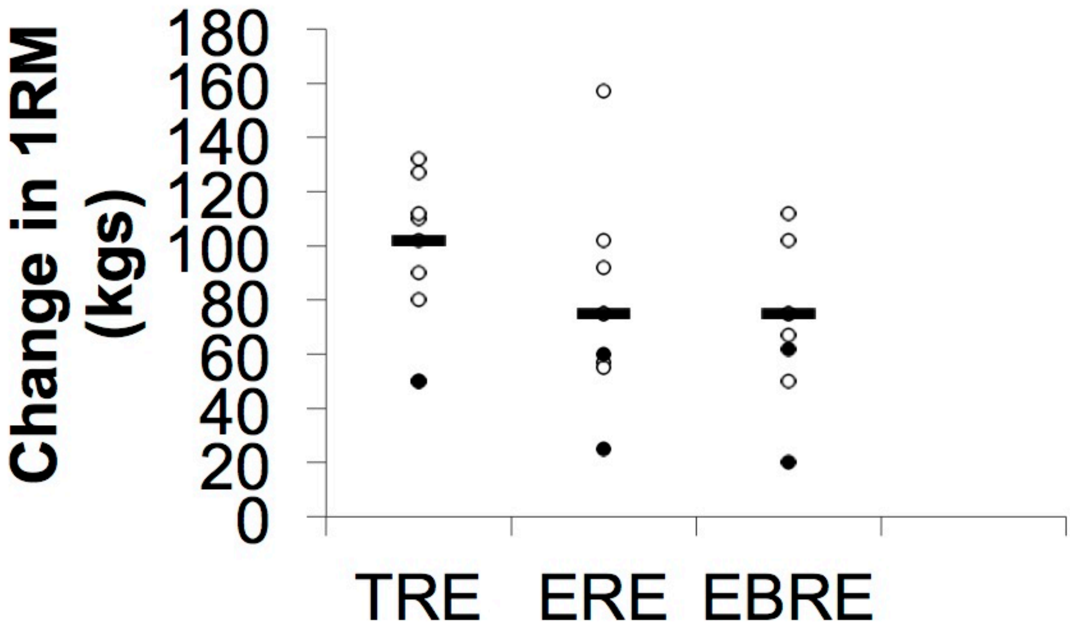

Figure 6. Change in 1RM

Individual and group change for maximal muscular concentric strength on the leg press from pre-post intervention. Black bars represent the median change while females are indicated with open and male with solid circles.

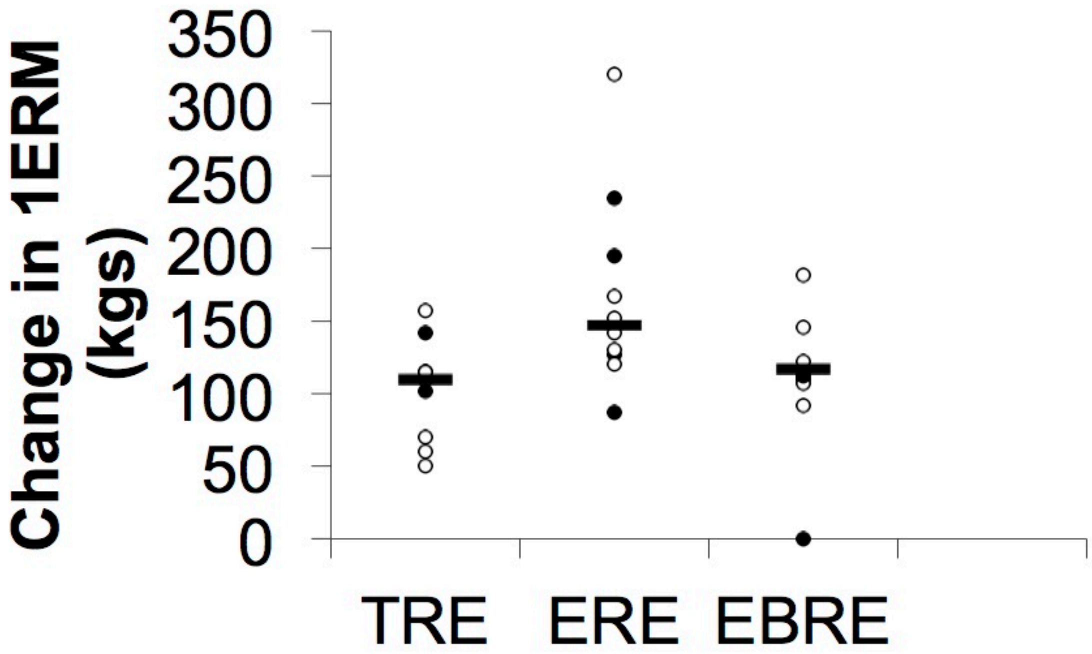

Figure 7. Change in 1ERM

Individual and group change for maximal muscular eccentric strength on the leg press from pre-post intervention. Black bars represent the median change while females are indicated with open and male with solid circles.

4.3.2 Functional Capacity Assessments

An average baseline score of 37 on the FAB scale confirmed our participants were high functioning (scores >25 indicate high functioning). The lowest score at baseline was 28, while the next lowest score was 33, scored by two participants. The highest scores at baseline included three 39 scores while six people scored the maximum possible 40. Post-intervention, the average score on the FAB scale improved two points to 39. Of note, the lowest score following the intervention was 35 with fourteen scores of 40.

All four functional capacity assessments significantly improved ($p<0.050$) within all groups except for the 6FW in the EBRE participants ($p=0.360$). There were no significant differences between the groups following the intervention.

4.3.3 Body Composition

The only significant pre to post changes in body composition were observed within the EBRE group (total body BMC ($p=0.040$), decrease in total body fat mass ($p=0.030$)). There were no significant differences between the groups following the intervention.

4.3.4 Blood Biomarkers

The only significant pre to post changes in blood biomarkers were observed within the EBRE group (decrease in glucose (p=0.010), insulin (p=0.015), LDL (p=0.004) and HDL (p=0.008)). Both the TRE (p=0.037) and EBRE (p=0.004) groups experienced an increase in HbA1c following the intervention, albeit within the normal reference ranges. There were no significant differences between the groups following the intervention.

4.4 Discussion

This is the first study to compare two distinct eccentric modalities to traditional resistance exercise in resistance trained, higher functioning older adults. Also, to our knowledge, this is the first time older adults have been tested for both 1RM and 1ERM using isoinertial methods. There are several key findings from this study. All three groups (ERE, EBRE, TRE) significantly increased both their concentric (1RM) and eccentric (1ERM) maximal strength (p<0.01) with no differences in concentric or eccentric strength gain between the groups. Thus, we have shown that simply training with very heavy loads, regardless of modality type, will result in significant strength gain of both muscle actions.

The only protocol difference between EBRE and TRE was that the 70% 1RM external load was lowered unilaterally during the eccentric phase in EBRE. The only protocol difference between ERE and TRE was the absolute load. It appears that utilizing 70% 1RM loads (or an average absolute load of 231 kg) lowered unilaterally (as in EBRE) offers no significant advantage to the eccentric strength enhancements as utilizing 70% 1ERM loads (average absolute load of 297 kg) lowered bilaterally (as in ERE). Thus, for older adults requiring strength development we would suggest that training load is sufficiently heavy and modality is chosen using personal preference. Ultimately, our ERE group increased their eccentric strength on the leg press by 63% compared to 43% (Leszczak et al.), 42% (Reeves et al.) and 23% increases (Raj et al.) reported in previous studies. The difference in strength gained between these studies indicates that resistance trained, high functioning older adults certainly benefit from novel and intense training. However, we unfortunately cannot comment on our participant's strength relative to the baseline and post-intervention strength of participants in these previous studies as these investigations either did not directly measure 1RM or 1ERM (Leszczak et al.; Reeves et al.) or did not include leg press range of movement (ROM) information for direct comparison (Raj et al.). Future studies should measure and provide the reader with 1RM and 1ERM pre and post-intervention values, percentages of 1ERM for eccentric training prescription, ROM (or other applicable exercise methodology) as well as strength relative to body mass, which would be necessary in order to make more thorough cohort and modality comparisons. As far as maximal concentric strength, we have confirmed the results from several previous studies that have shown that eccentric only training (ERE) leads to significant increases in concentric strength even when loaded concentric actions are avoided (Raj et al.; Reeves et al.; Valour et al., 2004).

A second key finding was a significant increase in functional capacity in this high functioning, resistance trained population. Although it has been previously reported that an increase in strength does not translate into improvements in relevant functional tasks (Buchner, Larson, Wagner, Koepsell, & De Lateur, 1996b; P. C. LaStayo et al., 2003; P. C. Lastayo et al., 2009; Matthias Mueller et al., 2011; Raj et al.), we trust there is a reasonable explanation for this difference. Regrettably, the assessments commonly employed to measure functional capacity in older adults (Berg Balance Scale (BBS), FAB Scale, Short Physical Performance Battery (SPPB), Timed Up and Go (TUG)) are not sensitive to training induced adaptations in healthy, independent older adults, particularly those with some structured resistance exercise training history. For instance, in the eight studies investigating the effects of eccentric exercise on functional capacity, six studies assessed function with the TUG (A Gluchowski et al., 2015). Of note, the recommended cut off indicating normal functional capacity for the TUG is 12 s (Bischoff et al.). While one study did not provide any baseline TUG values (Matthias Mueller et al., 2011), most other studies provided TUG values far below 12 s: 5.9 s (Leszczak et al.), 5.5 s (Gault et al.) and 4.5 s (Raj et al.) leaving little room to capture statistically significant or meaningful functional improvements that likely occurred following the interventions. Thus, our findings are likely resultant from simply applying a more appropriate set of assessments for this healthy, independent, high functioning and resistance-trained population. The appropriate measurement and explicitly stated functional capacity characteristics of the cohort in question should be detailed to not only allow for cohort specific comparisons between studies but especially to avoid the ceiling effect found in even unhealthy but medically stable older adults (M. Mueller et al.). Based on available data, our participants were likely higher functioning and stronger at baseline than participants in other studies (Leszczak et al.; Raj et al.). We have nevertheless shown that prescribing very heavy load training (at least 70% 1RM/1ERM) increases strength and consequently improves functional performance outcomes, again, regardless of modality.

A third key finding was that body composition (total fat mass and BMC) changes following the intervention were only significant for the EBRE group. However, there were no differences between the three groups for any of the body composition outcomes investigated. EBRE participants lowered 70% 1RM (an average absolute load of 231 kg) unilaterally during training and this very heavy unilateral overload may have been the stimulus required to overcome the proposed anabolic resistance that has been reported with ageing (Biolo et al., 2016; Doering, Reaburn, Phillips, & Jenkins, 2016; Katsanos, Kobayashi, Sheffield-Moore, Aarsland, & Wolfe, 2005; Koopman, Saris, Wagenmakers, & van Loon, 2007). Training in this way (also known as the ‘two up, one down’ modality) may be a more practical way of incorporating eccentric overload independently. As conditions such as sarcopenia, sarcopenic obesity, and dynapenia become more prevalent, investigating exercise modalities that can avoid, delay or attenuate these conditions is compelling. Two studies have investigated EBRE as an eccentric modality. One study used a much lighter intensity (50% v. 70% 1RM in the current study) (Raj et al.) while the other used a specific EBRE variation which applied a slower tempo (3-5 v. 2 s) during the eccentric phase of the exercise (Leszczak et al.), which has been previously shown to result in no additional beneficial adaptations in strength or function for older adults when compared to TRE (Dias et al., 2015). In fact, there is evidence that increasing the speed of eccentric muscle action provides a greater stimulus for muscle hypertrophy (Farthing & Chilibeck). Nevertheless, of these two EBRE studies, only one study investigated body composition outcomes (quantified using ultrasound techniques) reporting a significant increase in vastus lateralis thickness (Raj et al.) while in the present study we utilized DXA, making comparisons difficult. It is likely that our study did not reach the external load or perhaps even the velocity required to see the significant differences between groups in lower limb lean mass or bone mass changes as expected with high load training (Beck, Daly, Singh, & Taaffe, 2016). Our participants were permitted to continue with their regular aerobic activity throughout the study, which may have influenced the body composition (especially total body fat) results presented here. Additionally, dietary (specifically protein) information was not collected from the participants during this study but we speculate that increased protein intake was influential (perhaps more so than modality type) in our body composition findings (Koopman et al., 2007). Future investigation should apply these modalities in addition to a well-controlled and sufficient protein intake.

The fourth key finding of this study was that blood biomarker (glucose, insulin, LDL, HDL) changes following the intervention were only significant after EBRE. Still, there were no differences found between the three groups for any of the blood biomarkers investigated. It may be that the frequency of sessions or the duration of our intervention was insufficient to see more favourable biomarker changes, especially in our healthy, high functioning, active and resistance-trained cohort. The data available in this area is scant, however, a recent study has described greater functional capacity, insulin sensitivity and improvements in blood lipid markers after the completion of an eccentric-only training intervention when compared to concentric-only training (Chen et al., 2017). Then again, this study used a cohort of men who had not trained in at least five years (Chen et al., 2017). We speculate that particularly the decrease in fasting plasma glucose found in the EBRE group may be due to the 1.9% increase in total body lean mass in that group, when compared to the 1.0% increase in total body lean mass following TRE. Also, the decrease in LDL in EBRE could have been the result of their decrease in total body fat (Oda, 2017). Nevertheless, the results from our study suggest that it is possible that healthy, high functioning and resistance trained older adults can continue to show significant improvement in key biomarkers with increased training age. It is likely though, that a longer, more frequent or more intense intervention is required for this cohort (A. S. Ribeiro et al., 2015).

4.4.1 Study Strengths and Limitations

Strengths of this study include a comparison of two eccentric modalities to an active control group performing the common traditional resistance exercise modality, all three equated for relative volume. We used highly active, resistance trained older adults to account for the known neuromuscular effects that occur with beginning any training program. Limitations of this study include the possibility that a longer duration (>8 weeks), higher frequency (>2 sessions/week) and increased load (>70% 1RM/1ERM) may have been required to see meaningful improvements in body composition (especially lean and bone mass) and blood biomarkers in this cohort of trained older adults. It is quite possible that our intervention may not have been a significant progression in training from our participants' training programs immediately prior to commencing our study. In addition, our participants were permitted to continue with their usual aerobic activities throughout this study, making some interpretation of our results (most notably, body composition) difficult to distinguish from our intervention. Inclusion of nutritional data and analysis may have clarified the body composition results of this study.

4.5 Conclusion

Training with very heavy loads (≥70% 1RM or 1ERM) can be used as a tool to elicit critical progressions in strength, function, body composition and blood biomarkers for healthy ageing. Researchers in this area need to be cognizant when designing their investigations into the various modalities of exercise on their outcomes for the diverse cohorts of the older adult population. From this study, it would seem that external loading prescription should prevail over contraction type for healthy, high functioning, resistance trained older adults. Our study confirms that 70% 1ERM (or 1RM) for 10 repetitions is safe and leaves repetitions in reserve thus, continued investigation into loads greater than 70% 1ERM (or 1RM) on high functioning, resistance trained older adults is warranted. As there is considerable evidence for both concentric and eccentric strength improvements following eccentric exercise, other outcomes of interest for the older adult population should be carefully considered and included. Functional capacity assessments should be appropriate for the level of functioning of the cohort in order to avoid any unwarranted ceiling effects. Outcomes of research interest should include muscle and bone mass measurements (perhaps concurrently with an appropriately monitored daily protein intake) and markers of the immune, inflammatory, hormonal and metabolic system, which are all still ripe for investigation in this cohort.

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Chapter 5 'I have a renewed enthusiasm for going to the gym': What Keeps Resistance Trained Older Adults Coming Back to the Gym?

Preface

Quite unexpectedly, while collecting quantitative data during my main PhD study (Chapter 4), I was inspired to design a follow-up focus group qualitative study. This mixed methods approach was utilized in order to not only capture the feel good stories my participants had regarding their on-going participation in the intense, very heavy load, resistance training intervention but also any suggestions they had in order to improve the protocol for implimentation into the community. As these stories overwhelmingly poured in, my curiosity and overall research objectives bowed toward exploring this phenomenon. I quickly realized that for this population in particular, it was not only important for us, as researchers to ensure physical and physiological improvement but that our participants' subjective feelings regarding improvement in their overall quality of life and well-being were as important, if not more so, to their (long-term) participation and adherence to resistance exercise. As exercise professionals, we are cognizant that even the most immaculately designed resistance-training program is only as effective as the adherence to it.

The aim of this study was to authentically illustrate my participant's (n=21) feelings and perceptions regarding their participation in the intense, very heavy load resistance-training program. These feelings and perceptions were shared with Dr. Isaac Warbrick during a one-hour small group discussion. Furthermore, it is my expectation that this qualitative study will help inform the successful translation and application of such research by other exercise professionals who also specialize in resistance training with the older adult population.

Designing a qualitative study, and analysing qualitative data in addition to performing a qualitative literature search for the background and support of my findings as well as writing this Chapter for a pure qualitative research journal and their expert qualitative reviewers was a completely new journey for me. Therefore, I am thrilled to have this particular Chapter be accepted into the peer-reviewed journal, Qualitative Research in Sport, Exercise and Health. I am even more honoured, as this journal has one of the higher impacts in the field.

Abstract

The purpose of this study was to identify the factors that were responsible for the feelings of satisfaction and the behaviours of adherence to an intense exercise intervention recently completed by resistance trained older adults. A total of 21 healthy, high functioning, resistance trained older adults (aged 60-77 years) participated in one of four focus group discussions where qualitative data was collected. Our study utilized a convenience sample of participants who had just completed an eight-week very heavy load resistance training study. As a result of our small focus groups, we found that our cohort of older adults enjoyed training

with an expert, enthusiastic trainer who provided a challenging program and appropriate, timely fitness assessments in a small group setting of like-minded peers. Our findings suggest that high intensity resistance training is well tolerated and enjoyed by healthy older adults, while also impacting positively on subjective markers of health including improved feelings of strength and functional capacity.

Keywords: high functioning; ageing; exercise; resistance training; adherence

5.1 Introduction

As our population ages, the absolute number of older adults living with one or more chronic conditions has the possibility to overwhelm our social and economic infrastructure (Salomon et al., 2012). Initiating and subsequently maintaining a recommended level of physical activity has been shown to reduce the risk of living with chronic disability and disease, enhance functional capacity and improve quality of life in older adults (Albuquerque, Borges-Silva, da Silva Borges, Pereira, & Dantas, 2016; Duncan, Wright, & Minatto, 2016; Jefferis, Whincup, Lennon, Papacosta, & Goya Wannamethee, 2014). Thus, it is likely that even small, early and sustained efforts to promote an active lifestyle will translate into significant reductions in social and economic burden (Viña et al., 2016).

Structured resistance exercise specifically has been shown to significantly benefit a number of physical, physiological and cognitive domains. Increases in muscular strength as a result of structured resistance training is expected, especially for those with little to no training history, and is associated with a decrease in all-cause mortality (Kraschnewski et al., 2016). The beneficial effects of resistance training have also been found for bone density, frailty, falls and fall risk (Giangregorio et al.). Resistance training also benefits both the metabolic and cardiovascular systems (Alex S. Ribeiro et al., 2016; Steele, Fisher, McGuff, Bruce-Low, & Smith, 2012). Improved mental health and increased cognitive function have also been shown as a result of resistance training (Kimura, Ohki, Nakagawa, & Ikegami, 2014; Mavros et al., 2017). Thus, there are numerous benefits of initiating and maintaining a structured resistance exercise program among older adults both at an individual and societal level.

Although the positive impact of resistance training on clinical markers of physical and physiological health are well known (Shaw, Shaw, & Brown, 2015), the effectiveness of this modality as shown in a research setting may not translate into more accessible, ‘real-life’ settings, such as within a private home or in a commercial gym (Kyrdalen, Moen, Røysland, & Helbostad, 2014). Indeed, many promising clinical exercise studies do not account for the complexities and intricacies of the beliefs, attitudes, preferences and underlying driving behaviours of participants, and the impact of such on adherence to particular exercise modalities.

Considering the global importance of maintaining adequate physical activity throughout the ageing process, the translation of findings from research to a ‘real life’ setting should be a priority during the study design process. An important step in translating findings into meaningful outcomes is understanding the preferences of older adults toward exercise – structured resistance exercise in particular. Thus, in this study, we explore the thoughts and perspectives of older adults at the completion of a highly structured, very heavy-load, resistance training intervention.

5.2 Methods

This study is pragmatic in its approach (Bourgeault, Dingwall, & De Vries, 2010). While the experiences of those participating in the intervention are their own, they are being reported on by researchers with an interest in understanding the processes that underpin health and well-being. Thus, the intent of the study is problem focussed, reporting data that is of value in facilitating similar interventions and understanding adherence. As such, a relatively unsophisticated research question can be approached using Qualitative Descriptive Methods, designed to capture as Neergaard et al. (2009) puts it, the "why, how and what" of human behaviour. Furthermore, this study is not designed to develop theory or interrogate particular meanings that may be attributed to actions in the world, which positions the work outside the scope of Grounded Theory or Phenomenology. Ontologically speaking, those involved in the study are able to contribute their own perspective on the shared experience of a successful exercise programme and speak to it on their own terms (Neergaard et al., 2009). Consequently, the role of researchers in this case is to best present themes drawn from the data that are of interest to a relevant audience. With this in mind a simple presentation of data is offered with context placed in the introduction and discussion.

5.2.1 Positioning

The broad purpose of this study is to capture the experiences of participants in an exercise intervention that resulted in unexpectedly high rates of adherence and satisfaction. The original intention of the study from which this data is drawn was to compare three distinct resistance exercise modalities: traditional, eccentric only and eccentrically biased, in healthy, high-functioning, resistance-trained, older adults (Ashley Gluchowski et al., 2017). While seeking to be effective in this regard, the intervention was not explicitly designed to examine the efficacy of any given model or theory of adherence. During the training intervention, participants frequently reported their enjoyment and satisfaction with the highly structured and intense training sessions. This daily, and often overwhelming anecdotal evidence, along with a high adherence rate (94%) emphasised the need for a deliberate qualitative assessment. The two authors (AG and IW) who undertook the thematic analysis are respectively specialists in medical science and holistic aspects of well-being. All authors maintain first hand, experienced views with respect to what might constitute a successful exercise intervention and are familiar with the culture surrounding prescribed exercise programmes.

Focus groups were conducted in order to allow not only the capture of experiences, but the collective sharing and recall of said experiences. In this way participants engaged in a constructive interrogation of their experiences that built on each other's knowledge and was able to span the extended time-period over which the study was conducted. The focus groups were drawn from a convenience sample of the first 25 participants who completed the intervention. Wilkinson (1998) argues that focus groups are a particularly good choice when one wants to elicit people's opinions and views in their own 'naturalistic' way, which mimics 'structured eavesdropping', rather than speaking directly to and being influenced by a researcher. Our focus groups also supported capture of the shared experiences and outcomes that were most important to our participants and allowed us to listen to their shared ways of making sense of those outcomes and experiences (Wilkinson, 1998). The strength of creating focus groups immediately following our exercise intervention (2 – 3 weeks after the completion of the intervention) provided vivid and compelling data on their recent participation in an intense, structured, very heavy load resistance training program. During our focus groups, our participants (who had come to know each other throughout the previous eight weeks) were able to recall common experiences, bring back forgotten experiences or outcomes in one another, and even defend or challenge their fellow participants (Wilkinson, 1998).

5.2.2 Participants

Participants (aged 67 ± 4.5 years) who completed the eight-week training intervention (consisting of two, one hour sessions per week) were invited to take part in focus group discussions. The first 25 participants to complete the training intervention were invited to be involved in the focus group discussions. Four were unable to participate, due to prior travel commitments or were otherwise unavailable during the set dates/times. All participants were independent, community-dwelling (Auckland, New Zealand) adults over the age of 60. All our participants were also healthy, high functioning, physically active and resistance-trained. All participants gave their informed consent prior to being contacted to arrange the small group discussions. The University's Research Ethics Committee approved this study.

5.2.3 Procedures

A total of four small group interviews (n = 7, 4, 6 and 4 respectively) were conducted in a small conference room. The focus group discussions were all conducted by the second author (who had no contact with the participants prior to the interviews) and each lasted approximately one hour. The following questions were used as a guide for the semi-structured discussions:

- What was your expectation prior to starting the intervention? Why did you respond to the invitation?
- How did you feel about being pushed hard?
- How important is it to have others to exercise with?
- How did the intervention impact on your health, strength, or any other aspects of your life?
- What did you enjoy/not enjoy about the exercises or the program as a whole?

- Now that the study is finished, what would you like to see happen going forward? What do you want to see being done with the results?

A flexible approach was used and participants were encouraged to speak freely. Following preliminary analysis at the completion of the fourth group discussion, it was determined that data saturation (that is, each theme was observed multiple times by the end of the fourth focus group session), had been reached and as a result, data collection ceased (van Rijnsoever, 2017).

5.2.4 Data Analysis

Interviews were digitally recorded, transcribed verbatim by Gluchowski and then coded and analysed using inductive thematic analysis (Clarke & Braun, 2013). Although the search for patterns within language does not necessarily require a specific framework (Clark and Braun,2013), researcher interests and experiences have inherently shaped the analysis processes and the interpretation of data. Analysis of data used the six steps of thematic analysis outlined by Clarke and Braun (2013) consistent with a qualitative descriptive approach (Neergaard et al. 2009). Following several readings of the transcripts, authors independently coded the data, identifying themes and subthemes that occurred most frequently. Once coding was completed, the authors came together to discuss and review the themes and sub-themes identified and agreed on five dominant themes that emerged from the raw data. It is realized that inter-rater reliability will always be influenced by theoretical proclivities and specifically, power, age, gender, nationality and academic training all were significantly different between coders in the present study, which has most likely influenced the coding (Smith & McGannon, 2017). However, we agree with Smith and McGannon (2017) that reliability is of little concern with qualitative data collection, as qualitative researchers, we do not aim to reproduce the data, as this would be counterintuitive to our aim of collecting rich, personal stories as a result of our small focus groups. Finally, the themes were named and raw data extracts were included in the manuscript to give the reader a persuasive story regarding our participants' thoughts and feelings on completing such an intense training program.

5.3 Results

The five themes were each assigned representative phrases: 'Expert Enthusiastic Instructors', 'Appropriate Assessments for Real Life Results', 'Craving Challenge and Savouring Success', 'Accountability To A Cause' and 'Exercise Environment.' Sub-themes fell under one or more of these primary themes. Of note, the five identified themes are not entirely independent of one another nor must they occur in particular sequence or occupy discernible hierarchy.

5.3.1 Expert, Enthusiastic Instructors

The most prominent theme to emerge from the data collected during focus group discussions detailed particular characteristics of a trainer believed to be ideal when working with the older adult cohort. When asked to comment on the characteristics they thought were most important, participants commented that it was important for the trainer to have exceptional understanding of anatomy, exercise science and even biogerontology. One participant noted how important it was for the trainer to *'explain the technicalities [of each exercise], the benefits of each exercise and which part of the body is affected.'*

Taking the time to explain and reinforce musculature and exercise form was beneficial as participants learned to translate this new information into their everyday activities outside of the gym –

> *'…the other thing I've learned [from the trainer], is to [contract] your core, when lifting. I have learnt how to lift and engage [my muscles] properly, I found that very helpful, 'cause I have a bit of a funny back.'*

Providing education during the training sessions appeared to provide additional motivation and continued adherence to lifelong exercise –

> *'I have a renewed enthusiasm for going to the gym, I was just going through the motions, and now I've learnt something [from the trainer], a lot more [than I would have doing it alone].'*

In addition to having an expert trainer who provided education, enthusiasm and genuineness were also discussed as ideal characteristics. Enthusiasm for exercise in particular becomes contagious and may cultivate adherence, *'I think we are very fortunate to have a person like [our trainer] to be so focused and enthusiastic about her subject and it rubbed off on all of us.'*

Our older adults felt that a genuine interest in each participant's personal safety was essential from their trainer,

> *'I felt safe, you knew that if you tried as hard as you could, [our trainer] wouldn't let you do anything that would cause you damage. She is watching all the time and has the experience that makes you feel safe. You feel confident to push yourself to the limit. I noticed that trying to do exercises at home it is so hard compared to here.'*

A fine line does exist between an encouraging push out of a comfort zone and feeling threatened. One participant explains,

> *'[Our trainer] is not a pushy person; she doesn't push you but encourages you in an intelligent way…you need a person who encourages you to go a little farther without feeling threatened. Because at the start, I was afraid of the leg press, but [was comfortable after] having her assistance.'*

Ultimately, during our discussions, participants confirm the importance of this theme (characteristics of an ideal trainer) with comments similar to that below.

> *For me, the big thing was just [our trainer], I don't think the results would be as stunning as they were if not for [our trainer]. [Our trainer is a] force of*

nature person who not only has the personality but also the knowledge. Her manner of dealing with people was extraordinary. I've had Personal Trainers in the past, a series of them but bar none she was the best I've ever worked with. Because she, part of it her energy, demeanour with us, you never thought she thought you were over 60, that's important if you are going to work with certain people. You never thought you were over 60. So you didn't think you were old. You never thought you were over 60. That's one of the reasons everyone got better.

5.3.2 Appropriate Assessments for Real Life Results

Another main theme that emerged from our focus group discussions was how appropriate and relevant the outcomes of the study were to our participants in their everyday life. Many female participants spoke of improving their bone mass content,

'I've had bone density scans because I had the condition for a long time and I'm thrilled to bits, first time ever, it increased, not a lot but it did increase. That's been the biggest thing for me, really exciting.'

Avoiding pharmaceutical intervention appeared to contribute to their personal health goals and overall feelings of fitness and well-being,

'My bone density has increased. I'm now out of that slow decline, that has been the biggest 'coo' of all and I've filled out my skin as well (laughing). The weights have been fantastic but it's the health benefits that come along with it.'

Another result relevant to our older adult's everyday life was the significant increase in muscular strength gained during the eight-week study. However, the translation of that strength into improvements in such things as lifting and moving heavy household objects, gardening and grocery shopping all had noticeably improved in this cohort. An improved functional ability came as a surprise to our older adults as they have been told and fully expected to get weaker (not stronger) as they got older.

'Most of us are quite a bit stronger [as a result of the intervention], lifting a chair up, and all these other things, as we get a bit older, you generally lose your fitness and strength.'

As a result of their improved strength and functional ability, our older adults had a new found confidence, a feeling not experienced in some time for some – *'I feel more confident, I can lift that, and I've been shifting some damn heavy boxes that I never would have touched a couple years ago and I did.'*

Our oldest female participant (75 years old), an avid gardener and traveller describes, '*I feel stronger in the garden, lifting heavy pots and all my tools. Lugging heavy cases while travelling is so much easier too*.'

It appeared that the intervention also improved chronic injuries. One participant who suffered chronic low back pain commented,

> *[The training intervention] improved your overall wellbeing. That you feel better all around, even more cheerful, as well as enjoying life more because you haven't got aches and pains. You just felt good about coming and doing it. It wasn't "oh no, I have to go to the gym today."*

With another noting that prior injuries appeared to improve,

> *'I'm a jogger, for 10-15 years I've been troubled with Achilles and calf problems, and since I've been doing this [training intervention], I have had no issues, absolutely no issues.'*

Our study also showed significant improvements when descending stairs (Ashley Gluchowski et al., 2017), a common activity required for independent living. *'Going down the stairs, I can instantly adjust and stop myself from falling.'* In fact, one married couple in the study took their stair navigation confidence to 'the extreme' and tackled what is known as the "Devil's staircase."

> *I booked to do the Tongariro crossing, the only time we could do it was half way through the program, I think she, my wife [who is also a part of the training intervention] would still be up there if we hadn't done this program. It's 36,000 steps, on 300 flights of stairs, that's just the ones you go up. We just did it, it was hard but we did it.*

5.3.3 Accountability to the Cause

An unexpected cause of motivation to participate in the training intervention emerged through our discussions. When asked for a reason behind consenting to our exercise intervention, our older adults spoke how they felt the need to 'give back.'

> *This [training intervention] was an opportunity to give something back, [the trainer] was here to do a study and research and with a view to getting her PhD. I thought 'well, why not give something back?' And that was my main motivation to get in at the start of it and for me it seems to have gone on forever, I've enjoyed it.*

Another participant confirms,

> *I was very conscious I wasn't there for myself, it was research, and we were participants in that research, if there was some benefit out of it, then fantastic. I was surprised as a guinea pig, how beneficial it ended up being, and how personal it did become, so I have found it a fantastic experience. To be part of something. I found it fantastic.*

Several other participants confirmed that 'giving back' was their main motivation to initial participation, 'it looked so interesting, you want to help people do these studies well and it's a two-way thing' and 'the fact that she's doing PhD, I want to help her.' Finally, 'anything to help students, and I wanted a challenge'

Participants felt that continued assessment and reporting of their results would be a major factor in keeping them coming back to the gym. Again, most women discussed being motivated with continued body composition assessment. The men were more motivated by having their strength continuously measured and compared to their previous value(s). One woman commented that a promise of further regular and appropriate assessments would keep her optimally motivated to adhere to any future training schedule,

> *'I'd like to be measured again at the end of the next eight weeks, the measurement part is a huge motivator, puts meaning into what we are doing every day… having a professional to measure us and encourage us, but we knew it was up to us. Having everything measured, it made more sense. Can see the logic in it, not meaningless exercise.'*

One gentleman, who visibly struggled to get up for the early morning sessions even used our assessments as motivation to continue to force himself out of bed on those early mornings, *'regular check-ups [motivate me], knowing that I will have another performance measurement in 2 or 3 weeks, I feel obligated to train regularly.'*

Thereafter, motivation shifted into a compelling sense of accountability and commitment to the other group members. One avid jogger in the group uses jogging as an analogy,

> *'If you go for a jog on your own, you'll take shortcuts if you've had enough. It's that phrase 'any obligation to yourself you'll break, any obligation to others you'll fulfil.''*

Another participant simply states, '*with social groups, you a feel a commitment to turn up. They will be there if we are there. They are doing what we are doing*.' While another comments, '*I found coming to the class, even if there's not much talk, just doing it with a group, it's an extra bit of commitment to make sure you get there*.'

The sense of commitment our older adults had towards their peers was also directed towards their trainer. Their commitment to the trainer however, does seem to be connected to our first theme, indicating their commitment is correlated with the trainer's personality, *'[our trainer] has a manner that encourages you to be there.'* Another commented that *'We're keen to do better, and improve on yourself, to please her.'*

5.3.4 Craving Challenge and Savouring Success

During our discussions, participants reported a feeling of disappointment knowing they had not reached this level of success sooner. Some of our participants admitted that, in hindsight, they didn't push themselves sufficiently and had become quite complacent with their training.

> *'I found what we've done in the research, it's much more effective. I joined gyms all my life, but that initial workout you were given, it's almost like [personal trainers] don't expect too much from you. I was throwing 2, 3 kilos around and not making much difference. It's quite light, and you get bored. This program pushed me to test my own strength…I surprised myself; I've always been athletic, from a fit healthy family. I had cancer and after chemo and radiation, my strength disappeared, and thought 'I guess I'm just old now.' They tell you to exercise, but you're so exhausted. I've rebuilt my health, having this program, to realize I can get a level of strength back, that*

> *I don't even think I had before the cancer, it's been really amazing and encouraging.'*

Another participant confirms his complacency when training with his long-time personal trainer,

> *Having done weight training for 10 years, I wanted to see if what I was doing was the best that I can do, because you get apathetic, with doing the same thing all the time, and over the course you get an injury and stop doing that, stop doing that and then to come along and get the enthusiasm [trainer] puts into it.*

Another participant, also with a longstanding personal trainer, confirms her craving for a more challenging program,

> *'You don't want to be on lots of machines, you want to be on stuff that challenges you. The free weights nearly killed me and I consider myself strong but it's the [tempo].'*

In the end, our challenging program led to an increased sense of pride and accomplishment,

> *[Our trainer] said, I haven't got any more weights, so she [increased the range of motion on the leg press] to make it harder for me. I was bringing down over 510 kg or something like that.*

Our participants were quite fond of the strict and challenging program, '*we had to exercise to a tempo, 4 [sets] of 10 [repetitions], it was very rigid, but it was good*', 'I actually look forward to those sessions, even though they're hard work.' The challenge afforded by the intervention appeared to be related to competitiveness as well,

> *We, myself and one other gentlemen in the study, both pushed more weight than the leg press could hold. I had to then lift the weight with two legs, and lower with one, it was torture. But come to the last training session, I did the full sets. [Our trainer] always asked how many [more repetitions] you can do, instead of saying I could do two more [repetitions], I did them. I improved incredibly.*

Issues of ageism, both covertly and overtly, were evident from our discussions and presented quite a different form of challenge for our high functioning older adults. During the study, participants had begun to bring cameras to take 'evidence' of what they had accomplished to prove to their family and friends who were sceptical of their results.

> *I didn't expect changes because of what I was already doing [at the gym]. We ran out of room on the leg press for more weights. We had to take a photo! There was no way my sons would believe me. My sons said, literally, 'there's no way Mom you could push that weight!'*

Even participants themselves were in disbelief of the loads they were moving. One participant (67 years old), who had worked with the same personal trainer for over ten years, went back to his trainer's notes and found he lifted more during our intervention then he had when he was a decade younger.

> *'Having done weight training for a number of years, we went back to our trainer, the interesting thing is that he pulled out what I was leg pressing 10 years ago, which was 115 kg and on Wednesday I did 340 kg.'*

More overtly, from the very beginning, it quickly became apparent that some participants were greatly offended with the use of words such as 'ageing' and 'old.' 'Elderly' gathered responses akin to profanity. Some participants even alluded to the fact that they had second thoughts about participating in a research intervention in which those terms were used. One woman (66 years old) was particularly offended,

> *What's wrong with [just] saying 60 plus? Cause that's what we are. When you say 'elderly', [our trainer] is fighting that much more to bring us in [to participate in the training intervention]. Don't call us 'elderly', I find that quite insulting, demeaning. In our heads we are still 20.*

5.3.5 Exercise Environment

Our participants enjoyed how our training intervention was carried out in small groups (1 - 6 participants) rather than one-on-one or with a much larger group. As previously discussed, group training led to a feeling of accountability and commitment to the group as well as to the trainer. Thus, our small group training provided extra motivation our cohort may not have felt or experienced if the training sessions were one-on-one. On the other hand, some participants who never had the luxury of affording a personal trainer loved the attention of small group training, *'I've never had a personal trainer, I felt like I had one with such a small group.'*

In addition to the small group, our participants enjoyed training with the same group each week over the eight-week intervention. This small group dynamic not only caused strong feelings of accountability, commitment and motivation but also made the challenging sessions a little more appealing, '*I find [training] incredibly boring [by myself], but when you're doing it with 3 or 4 other people, the hour goes like that.'* A number of participants expressed similar feelings, '*if there's a social aspect, [training's] not the same chore.*' These feelings are further enhanced when the group possesses a similar enthusiasm for exercise, '*it's a huge part, I'd be long gone if it wasn't social. We've had a lot of fun. [Our trainer] has a wonderful sense of humour*.' Another participant echoes, '*the social thing in our lives is important. [Training] has to have an element of enjoyment.'*

On the other hand, the oldest gentleman in our study was previously a member of a large group program and provides his perspective,

> *I think [a large, local program for older adults] err on the side of caution far more than what we've been doing [in the training intervention]. We have been monitored [during the training intervention], therefore we could do more, we could challenge ourselves more, because of our situation [small*

> *group lead by an experienced trainer]. Whereas [with the large program] there are so many people, the programs are on the cautious side.*

Finally, the dedicated training environment provided to our participants was found to be a key feature of the program. One participant simply stated, *'the area was a luxury.'* Having their own training space with equipment they were familiar with, without music or other users was a certain advantage. One of our female participant confirms*, 'having that gym to ourselves makes a difference also, you don't have 20 year olds watching. Was such a relief to get away from the grunting and groaning.'*

5.4 Discussion

As a result of our small group discussions with 21 older adults following a very heavy load resistance training intervention, five themes emerged: 'Expert Enthusiastic Instructors', 'Appropriate Assessments for Real Life Results', 'Craving Challenge and Savouring Success', 'Accountability To A Cause' and 'Exercise Environment.' Of the five themes, the trainer's characteristics appeared to be the most regularly cited factor contributing to satisfaction and subsequently adherence to our eight-week resistance training intervention. For real world, sustainability purposes, exercise programs for older adults have been recently leaning towards sessions that are led by a peer (Modra & Black, 1999). In a 2010 study, moderately active participants were intentionally paired up with a student volunteer to complete a resistance training intervention (Dionigi & Lyons, 2010). Those older adult participants noted that they '*needed young people around them….because [older adults] put confines on themselves and young people get them away from that*.' Despite this, the age of our trainer was never mentioned in our group discussions. Instead, we can confirm that the presence of a trainer who has the personality to push, encourage and motivate older adults out of their 'confines' is key to exercise satisfaction. In addition, as discussed and corroborated by Bundon et al. (2011), there is also value in having a trainer who is an expert in effective resistance training modalities and assessment strategies specifically targeted for strength and functional capacity adaptation (Bundon, Clarke, & Miller, 2011). Furthermore, in a study that recruited older adults with a varying level of physical activity, a theme entitled 'factors that support sustainability of physical exercise' was related closely to the findings in our study (Janssen & Stube, 2014). One sub-theme in particular from that study also indicated personable and expert trainers as vital for exercise adherence (Janssen & Stube, 2014). One participant indicated that their ideal trainer needs to be an *'excitable person…and a likable person who makes exercise fun'* and another, similar to our findings, listed the importance of the opportunity to learn about physical activity (Janssen & Stube, 2014). Having an expert trainer seems particularly important when working with older adults living with health conditions, such as osteoarthritis (Fisken, Waters, Hing, & Keogh, 2016). As one older participant from Fisken et al. (2016) states, '*Perhaps it could be recommended within this study that aqua-aerobics instructors be more attuned to older people and their needs…or specific ones that will help people with arthritis*.'

The negative connotations surrounding the ageing discourse can be challenged with the encouragement of a supportive trainer, as the last quote in our theme ‘Expert, Enthusiastic Instructors’ demonstrates. Self-perception, especially exercise-identity and thus, well-being, has been shown to be driven by external factors (that is, by society or by a trainer) (Whaley & Ebbeck, 2002). Much of our society still subscribes to the notion that ageing is implicitly degenerative, yet, our trainer does not. Additionally, the first quote in our theme ‘Craving Challenge and Savouring Success’ left our participant with feelings of inadequacy when she previously tried to challenge this degenerative discourse. Unfortunately, these attempts went unsupported by her previous trainers. Trainers that nurture positive self-schemas for exercise, foster a greater sense of self-determination, feelings of competence (Cross & Markus, 1994), autonomy and perhaps adherence. Alternatively, it is possible that our participants have adhered to such an intense training program simply to rebel against societies degenerative expectations.

In a study by Dionigi and Cannon (2009), healthy and moderately active yet previously untrained older adults (n=9) provided many similar insights following a resistance training intervention to those found in our study, especially surrounding our second theme, ‘Appropriate Assessments for Real Life Results.’ Their untrained participants were surprised by their strength gain for reasons also found in our trained participants (because both set of participants were physically active, they doubted they could increase their strength any further). Dionigi and Cannon (2009) also noted that their participants doubted they could increase their strength because of their advanced age. It is at these critical moments of uncertainty and insecurity that trainers must instil a sense of confidence in abilities, rather than limit the older adult any further. It is unacceptable that chronological age remains a barrier that older adults cite for their lack of physical activity (Grant, 2008). Nevertheless, similarities between the studies included the increase in strength that translated to performing every day activities with greater ease, improved energy, confidence, increased motivation and resulted in a strong sense of achievement (Dionigi & Cannon, 2009). As the benefits of exercise for older adults become increasingly convincing, more and more adults are looking to maintain their exercise programs as they age. As our older adult population is rapidly increasing, it is important to continue to enable this active cohort by instilling confidence and providing effective and relevant exercise programming that maximizes long term adherence.

Importantly, even older adults reporting a high quality of life prior to training, found benefits from resistance training (Dionigi & Cannon, 2009). Dionigi et al. (2009) also notes that positive strength and body composition changes contribute to increased self-esteem. Increased self-esteem in turn, motivated many to continue training independently following their study (Dionigi & Cannon, 2009). We also had several participants mention an increase in confidence during our group discussions and even more continued training with our author in a small group setting following the conclusion of data collection. Thus, improved self-esteem via physical changes seems to be a contributing factor to continued exercise adherence. Continued adherence, in turn, allows older adults to extend their disability-free life expectancy (Bélanger, Martel, Berthelot, & Wilkins, 2002). Extending the years spent functionally independent allow older adults to continue to pursue activities of enjoyment which improves overall quality of life and reduces the risk of depression and loneliness (Aartsen & Jylhä, 2011).

In a study by Janssen and Stube (2014), participants support our conjecture of providing an exercise program that is challenging yet achievable; exercise that is not so easy as to be boring but not so hard as to be frustrating. Masters cyclists take our theme 'Craving Challenge and Savouring Success' to the upmost level of competition, '*You have to test yourself a smidgeon every now and then and I guess I'm not afraid to test it more than a smidgeon* (Appleby & Dieffenbach, 2016).' Exercise programs offering insufficient vigorous options have even been cited as a barrier to adherence amongst a female cohort in their early seventies (Biedenweg et al.). Our research contributes to this body of evidence suggesting prescription of challenging programming for able-bodied cohorts through both our unusually high adherence rate and our qualitative findings presented here. However, older adults with osteoarthritis found that aqua exercise was too challenging and thus, cited it as a barrier to continued adherence, *'I found it was going too fast for me and I didn't like that, I couldn't keep up* (Fisken et al., 2016).' Of course, practitioners need to be wary of the capabilities of their particular cohort, as either end of the challenge spectrum may lead to cessation of exercise adherence.

In an endorsement of our 'Accountability to a Cause' theme, a study by Biedenweg et al. (2013) found that exercise programs promoting accountability were one of the most frequently cited motivating factors for exercise participation. One participant justified, '*I can exercise in the living room easily but I'm also not very disciplined…so, yes, having a class that you had to go to…*' (Biedenweg et al.). Masters cyclists also feel the need to have coach and team for continued training adherence, '*If I didn't have a team, I don't know if I would have been racing this long. To be an unattached rider and not have camaraderie and friends as a team and just go to a race by myself, I don't think I'd be doing this* (Appleby & Dieffenbach, 2016).' Thus, it seems exercise adherence is strongest when older adults are held accountable to their trainer, peers or team. Conversely, one-on-one and home-based programs remain suboptimal for long term exercise adherence (Simek, McPhate, & Haines, 2012).

Suggestions on how to optimally market exercise programs to older adults have mentioned and confirm our results described in the 'Exercise Environment' theme. Older adults prefer to have a place and time when the gym is opened only to their cohort (Biedenweg et al.; Fisken et al., 2016). Additionally, group exercise has been identified as an important motivational factor for continued exercise adherence in several studies, including ours, with cohorts ranging from healthy yet sedentary, older adults with morbidity, to masters athletes (Appleby & Dieffenbach, 2016; Biedenweg et al.; Fisken et al., 2016). Group exercise has also been shown to increase self-efficacy, which related to increased positive feelings of well-being while simultaneously decreasing psychological stress (McAuley, Blissmer, Katula, & Duncan, 2000). Our research contributes to this body of evidence indicting small group training (2-6 people) leads to high levels of motivation and adherence (Ashley Gluchowski et al., 2017).

Exercising alone, on the other hand, was shown to significantly decrease feelings of well-being while increasing psychological distress (McAuley et al., 2000).

Our study adds to the growing body of literature on the keys to exercise satisfaction by extending the previous findings from active yet untrained older adults to our cohort of high functioning, resistance trained older adults. Our results intensify the evidence in areas such as prescribing and performing challenging programming in small groups rather than prescribing less challenging programs to complete either one-on-one with the trainer, or even worse still, alone. Interestingly, in our study, the modality of resistance exercise (in our case, traditional, eccentric only and eccentrically biased) did not seem to play a critical role in the perceived benefit of resistance training or continued adherence. That is, adherence was maintained equally across all three of our investigated modalities (94%)(Ashley Gluchowski et al., 2017). Findings from our study and that of Dionigi and Cannon (2009) suggest that active older adults are motivated to exercise and perceive many of the same benefits regardless of previous training status.

5.4.1 Limitations

The recruitment of a small sample of high functioning, resistance trained older adults somewhat limits the statistical probabilistic generalization of these findings, but it does not limit the naturalistic generalizability for those older adults who have also experienced very heavy load training (Smith, 2018). In addition, this study may even provide inferential generalization (or transferability) to practitioners who may wish to apply this research and its findings to their own practice (Smith, 2018). It is also possible that the insights and perspectives described in this study would vary considerably if we would have recruited an untrained or clinical population into our intense, highly structured, very heavy load exercise intervention. However, Dionigi and Cannon (2009) revealed similar insights and perspectives to a training intervention with their untrained yet moderately active participants (Dionigi & Cannon, 2009). It is also possible that our participants felt uncomfortable with disclosing more intimate or negative details regarding their participation in the study, perhaps due to the close relationship that developed between themselves and the lead researcher (who was also their trainer). As with qualitative research, the interviewers and authors own backgrounds and worldviews may influence the collection and interpretation of data. However, as discussed, our methods were selected to reduce researcher bias and our results have been supported by several previous investigations (Bundon et al., 2011; Dionigi & Cannon, 2009; Dionigi & Lyons, 2010; Franke, Tong, Ashe, McKay, & Sims-Gould, 2013; Janssen & Stube, 2014).

5.4.2 Implications

Because exercise is most effective when performed regularly, it is important to identify prior to designing an initiative, the factors which influence adherence to and relevance of prescribed training programs. Thus, the following points are summarised from our results as practical suggestions and considerations for trainers and coaches working with older populations.

- The characteristics of a trainer appear to be of upmost importance to older adults. It is important that the trainer is an expert in the field of active ageing and who is able to push them past their comfort zone.
- Use evidence-based exercise prescription. When older adults have experience in resistance exercise, continue to challenge them and despite the importance of safe training practices, don't avoid going heavy simply because of their chronological age.
- Fitness assessments are key for recruiting, motivating and encouraging continued adherence. Older adults, like every other age group, want to see positive outcomes as a result of their effort, whether improved strength, functional capacity, body composition or blood biomarkers.
- Keep goals connected to activities that are relevant to everyday life. Make the connection between strength and function, functional ability and independence, body composition and health, and health and quality of life.
- Most enjoy the social aspects of exercise, so look for opportunities to train in small groups (ideally, two to six participants per trainer).
- Use a strength based approach that highlights the capabilities and potential of the individual rather than the perceived barriers or weaknesses associated with older age. This includes doing too much for participants (setting up equipment), prescribing significant restrictions in their training without reasonable cause or explanation or simply naming your program using 'offensive' wording such as 'exercise for the elderly.' It is necessary that researchers and trainers be cognizant of both their verbal and non-verbal communication.

5.5 Conclusion

During the reading and re-reading of the verbatim transcripts, our author and trainer rediscovered much of what participants had informally discussed with her during the training sessions. The themes presented here provide a deeper understanding of the thoughts and perspectives from older adults on participating in an intense, very heavy load resistance training program. We identified a few key factors that keep high functioning, resistance trained older adults satisfied with their exercise program; factors which likely contribute to long-term exercise adherence. The findings from this study provide researchers and practitioners with important factors to consider when designing and implementing very heavy load training programs for older adults. This study, alongside our quantitative study (Ashley Gluchowski et al., 2017), may also be used to directly inform older adults of the multitude of benefits of very heavy load training.

Conflicts of interest: none

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Chapter 6 Discussion

Summary of Research

The research completed for this PhD thesis makes several important contributions and findings. First, practitioners now have an all-encompassing review article in which to refer when contemplating eccentric exercise as a prescription for older adults. Practitioners can quickly determine the benefits of each type of eccentric modality on each outcome of interest to their patient or client, cohort or population. Second, important findings from our acute study show that although eccentric exercise is well known and often avoided due to its muscle damaging properties, when the protocol is ramped appropriately, high functioning, resistance trained yet eccentric-naive older adults are able to avoid functionally limiting muscle damage. Thirdly, findings from our training study fail to show significant differences between eccentric modalities and traditional resistance exercise, suggesting that the load itself, rather than the modality, is most important when prescribing resistance exercise to older adults. Finally, our qualitative study complements our training study to show that eccentric exercise is safe and is thoroughly enjoyed by older adults.

The research completed for this PhD thesis also makes a significant contribution to the relatively new area of active ageing. Active ageing, according to the World Health Organization, 'is the process of optimizing opportunities to health, participation and security in order to enhance quality of life as people age.' Accordingly, the World Health Organization has put together a policy framework to formulate action plans that promote active ageing. Active ageing aims to extend the healthy life expectancy and quality of life for people as they age.

Auckland University of Technology (North Shore campus) founded and continues to offer a gym-based resistance exercise program for adults 60 years and older, appropriately titled, Never2Old (N2O). The goal of N2O is to help the physically and physiologically diverse older adult population achieve a healthy, active and independent lifestyle by providing them with a traditional resistance exercise program, tailored to their specific needs and goals. For sedentary older adults who are on the physical and physiological decline (and whom N2O often encounter), and whom in which there has been substantial research attention focusing on curing their physical and physiological ailments, the implementation of any modality of structured resistance exercise has been continuously and consistently shown to elicit significant benefits (P. C. LaStayo et al., 2003; P. C. Lastayo et al., 2009; Theodorou et al., 2013; Williams et al., 2011). Yet, there are approximately 40% of older adults who are free from disease and disability and it is increasingly likely that these older adults are currently engaged and perhaps even excelling in either physical activity and/or in a structured resistance exercise program. Until now, this resistance-trained cohort of older adults has been completely overlooked by investigators, as not one study has investigated eccentric resistance exercise in a trained older adult population (A Gluchowski et al., 2015).

From preventative measures, to maximizing or optimizing outcomes, to fostering lifelong adherence, to investigating eccentric muscle actions rather than the novelty of neuromuscular effects that accompany any modality of resistance training for previously sedentary older adults, there is a need to use a resistance trained older adult cohort in eccentric resistance exercise research. We know that for these healthy, high functioning, resistance trained older adults, a more precise and intense variable scheme and modality type will most likely be needed in order to see significant physical and/or physiological improvements from their already high baseline levels of strength, function and overall health. In fact, I have shown that for resistance trained older adults, the loading scheme seems to take precedence over modality type. However, most importantly, it is simply an intense and/or challenging program that seems to be critical for the World Health Organization's definition of active ageing, specifically, continuing to optimize health and participation (that is, adherence). While these particular older adults are still physically independent, community-dwelling and perceived as physiologically free from disease, they should not be excluded from our preventative resistance exercise interventions. In the first instance, if these older adults do not continue to progress their physical activity or exercise, they too are at risk of plateauing and regressing in physical and physiological health. Second, these older adults have been shown to benefit psychologically from the stimulus of a new and more challenging structured resistance exercise program, and as we have shown, this challenge fosters adherence. Lastly, one in three older adults will still experience at least one fall per year, regardless of health status (Rubenstein, Vivrette, Harker, Stevens, & Kramer, 2011; Verghese, Holtzer, Lipton, & Wang, 2012). Preventing falls (and the subsequent consequences) alone should be enough reason to ensure we continue to target both healthy, high functioning as well as lower functioning older adults into our training interventions and ensure the successful translation of that research into community programming.

In conclusion, I have shown with this PhD thesis that even physically and physiologically healthy, high functioning older adults who have resistance training history are able to significantly improve their physical and physiological health, participation and overall quality of life with an intense, very heavy load resistance training prescription. Increases in maximal muscular strength (concentric and eccentric), functional capacity (getting up off the floor, getting up and down stairs, getting up off chairs without the use of their hands, and increasing their walking speed), body composition (total fat mass, visceral adipose tissue, muscle mass, bone mass), numerous blood biomarkers of healthy ageing and subjective feelings of well-being and quality of life can and do improve with the proper progression of loading schemes, all without injury or otherwise compromising safety in any way.

6.1 Implications and Practical Application

The strength of this research is that the implications and practical applications are closely aligned. Muscular strength remains one of the most researched outcomes in older adult exercise or training studies. One would be hard pressed to find a manuscript that does not show an increase in strength following an exercise intervention. However, this must be interpreted and translated with caution, as untrained populations will gain muscular strength from the addition of many training modalities. The strength gain in this population is unlikely to be caused by the modality itself but rather various initial neuromuscular adaptations. It was the aim of this study to be able to detect differences between the groups as a result of the modality, rather than measure these initial strength gains due to neuromuscular changes. However, I too have shown that with 11 participants per group, no statistical differences in maximal muscular strength gain between any of the three groups of resistance trained older adults. Thus, the study was underpowered to provide statistical evidence for or against the superiority of eccentric resistance exercise. However, the raw absolute increases in maximal muscular strength certainly favor ERE for eccentric strength gain and TRE for concentric strength. The implication (and practical application) here is twofold. One, if an older adult requires significant overall improvement in muscular strength, the addition of a heavy load program will ensure this outcome, seemingly regardless of training history. Secondly, if they lack specific concentric or eccentric strength, it is likely that training with the respective modality will be most effective in achieving this goal.

Justifiably, gerontologists seem to be most concerned with improving or maintaining functional capacity and independence in older adults as they age. From my review in Chapter 2, I suggest that future investigations using older adults as a study population be cognizant of the ceiling effect many current, conventional functional capacity assessments exhibit. Also, when designing and reporting on outcome measures surrounding functional capacity, investigators and readers alike, need to be aware of false negative reports due only to poor choice in testing battery rather than actual functional changes as result of exercise interventions. Healthy cohorts require a more advanced testing battery (or at the very least, a timed scale rather than a finite one) than the BBS or the FAB scale can provide. Both through my literature review and practically with my eight-week resistance training intervention, I have shown that statistically significant functional improvements are possible even in already high functioning older adults when timed individual assessments are used and again, occur independent of training modality. Although individual functional capacity assessments will only evaluate one aspect of functional capacity, several can be complied to meet the needs of the participant or the research outcomes.

Implications and practical applications from body composition outcomes are not as clear. I have shown a decrease in total body fat mass and BMC with EBRE over the eight-week intervention. No other within or between group significances for body composition measures were found. However, I strongly suspect that nutrition has played a considerable role here, much more so than the training modality. Discussing nutrition, specifically protein intake, with our participants after the intervention, it is clear that they are not obtaining the recommended daily intake of the macronutrient (Dawson, Taylor, & Favaloro, 2008). This is important as there have been several recent studies showing the importance of an increase in protein dose for older adults following resistance training for improvements in body composition outcomes (namely, increase in muscle and bone mass) (Verlaan et al., 2017).

Again, EBRE was the only group to show any significant pre to post changes in the blood biomarkers measured as a result of the eight-week resistance training intervention. A decrease in fasting plasma glucose, insulin, LDL and HDL found might have simply resulted from the decrease in fat mass that also occurred in this group. Results that lead me back to the question of whether the decrease in total fat mass occurred as a result of the EBRE modality, nutritional intake or outside physical activity changes. Once again, these variables make implications and practical applications unclear for blood biomarker outcomes of interest in the healthy, high functioning, resistance trained older adult.

Eccentric muscle actions have specific characteristics that make eccentric modalities of interest to those in gerontology research. However, the implications from my acute study (Chapter 3) suggest that although technically an eccentric modality, EBRE requires 35% more oxygen to preform than TRE, when loads and volumes are equated. The cardiovascular stress (SBP, HR) was also higher in eccentric resistance modalities when compared to traditional resistance exercise. Furthermore, repetitions SOF were less with both ERE and EBRE compared to TRE, indicating at least an increase in subjective physical (or mental) fatigue. Practitioners need to be cognizant that eccentric modalities do not necessarily require less energy to preform and may in fact, be more demanding than traditional resistance exercise. On the other hand, eccentric muscle actions are also known to cause significant muscle damage. I found that eccentrically naïve older adults could perform eccentric muscle actions without significant rise in CK while keeping the average soreness rating a two or less on a 1-10 visual analog scale. Thus, it seems likely that our knowledge on eccentric muscle actions, which has been based on antiquated aerobic studies, needs to be carefully re-examined before translating to resistance training prescription in resistance trained older adults.

The implications from our main training study (Chapter 5) as a whole suggest that the particular exercise modality may not play a major role in most outcomes of interest for an older adult population, at least until the other variables are optimized. Perhaps only once loading is optimal and has periodized over several mesocycles can modality then be trained and specific adaptations can be distinguished from other modalities. This study has important practical implications suggesting that healthy, high functioning, resistance trained older adults can continue to see improvements in their physical and physiological health with increased loads during their training. Most of all, my participants enjoyed the research program so much that they demanded I continue to train them following the conclusion of the study. I continue to train well over 20 of my original research participants twice a week to this day, a testament to how enjoyable, effective and practical this research truly was. In order to execute this program, one needs nothing more than a space with a few common pieces of exercise equipment, and a smartphone app with a set of speakers.

My qualitative study (Chapter 5) has led to several implications and practical applications for understanding the innermost thoughts, feelings and perspectives from older adults participating in an intense, very heavy load resistance training intervention. From their discussions, it is evident that the ideal trainer for a higher functioning older adult cohort should be an expert in the field of active ageing who strategically challenges older adults with resistance training history by pushing them beyond their comfort zone. Practitioners should continue to use fitness assessments to measure baseline and post-program outcomes as they would in any younger population. Older adults are just as, if not more so, interested in their progress (and certainly in their decline) in key outcomes such as strength, functional capacity, body composition and blood biomarkers of healthy ageing. Knowing these values also gives the practitioner leverage for retaining the client should the practitioner show successful progress in these outcomes of interest to the older adult through their effective programing. On the other hand, the practitioner must be mindful that some older adults just simply enjoy the social aspects of group training, which is one of the biggest implications and practical applications that keep our older adults adhering to structured resistance exercise. Finally, any practitioner that is interested in working with the older adult population must use a strength-based approach that highlights the potential rather than the weaknesses typically associated with old age. I had several participants indicate that their participation in the program continued because they never felt discriminated against. Equally, I have had participants express their complete and utter dissatisfaction when any inkling of ageism was perceived. In summary, participation and adherence can be incredibly high if practitioners understand the thoughts, perceptions and goals behind this particular cohort.

6.2 Study Limitations and Future Research Directions

My study also has several limitations. I was unable to clearly answer our overarching research question regarding the effectiveness of eccentric resistance exercise when compared to traditional resistance exercise. Although I recruited a relatively large number of participants for a three-armed exercise intervention and had only one drop out, my research was underpowered to reveal significant differences between the groups using conventional statistical methods.

Although I was able to personally train six of the 33 participants, finding additional older adults who had resistance training history in a relatively high loading scheme immediately prior to commencing the intervention proved time consuming. Alternately, a longer study duration or a longer familiarization period could have ensured all participants were training with very heavy loads prior to investigating (and attempting to distinguish) modality. I also could have incorporated an additional inclusion criterion, as this would have ensured all participants had an above average level of baseline strength for their age and stature. Additionally, I was unable to fully control for outside aerobic activity. Although I did request stability in their habitual aerobic routine throughout the study, our healthy, high functioning, resistance trained participants were participating in a number of high intensity aerobic activities (some at the Masters level), which may have played a bigger role in body composition outcomes than anticipated. Furthermore, I suspect nutrition, particularly if I had ensured optimal protein consumption, concurrently with this highly effective resistance training program, I would have revealed even more impressive outcomes for my population. Speculating, based on personal communications with my participants following their participation in my eight-week interneuron, my participants were not taking nearly the recommended protein for their age and activity level, thus perhaps negatively influencing particularly the body composition outcomes. Quantifying macronutrient (especially protein) intake (perhaps through the inclusion of food diary use during my intervention) would have provided objective evidence for this speculation and would have added valuable evidence for the gerontology community. On the other hand, my research may indicate that it may simply be the case of identifying the outcome of interest most important to the individual older adult and prescribing their resistance training modality accordingly (rather than the existence of an overall optimal exercise modality).

Future directions for this line of research include the continued dissemination of these particular research findings, to educate older adults and practitioners alike on the benefits of lifting heavy loads during structured resistance exercise. I have shown that it is safe, effective and even enjoyable to lift loads on the leg press in the range of 70% 1REM/1ERM twice a week and to test maximal muscular strength (1RM/1ERM) every four weeks. I have hopefully presented the evidence to advocate to practitioners that have, up to this point, avoided prescribing heavy loads for their older adult clients, solely based on chronological age. Overcoming this particular age-old ageism barrier is one I've personally had to defend several times during my PhD journey. Also, although I did not intend to delve into qualitative research, the rich stories I captured as a result of this study illustrates several key themes important for enjoyment and ultimately adherence when designing such an intense, very heavy load intervention in the future.

The underlying aspiration of this PhD research was to ensure that the program design was less clinical and laboratory in nature and more practical and easy to implement in real world resistance training settings. Obviously, expanding the precise blueprint of this intense, very heavy load, resistance-training program into the community is an important future direction for the promotion of active ageing. Additionally, I would also like to investigate the influence or impact of this particular resistance-training program in conjunction with the recommended daily intake of protein for the older adult. As research has shown and experts agree, there are additive effects of protein when combined with an effective resistance-training program (Calder et al.; Verreijen et al.). However, no investigations as yet describe the effect of eccentric resistance exercise in resistance trained older adults who objectively intake optimal protein dose following twice a week sessions. I would expect to see impressive synergistic results, especially in the body composition measures and perhaps downstream, giving rise to greater improvement in the blood biomarkers of healthy ageing.

6.3 Conclusion

This PhD thesis outlines the effects of eccentric resistance exercise on the physical and physiological profile of the high functioning older adult. Particularly, this thesis details the importance of providing a very heavy load resistance-training program for improvements in maximal muscular strength, functional capacity and overall quality of life to those healthy, high functioning, resistance trained older adults. My narrative review has shown that although eccentric exercise has been a hot topic of late and the research is strong in areas of strength development and functional capacity, the research is severely lacking in other such areas as body composition, cardiovascular, immune and endocrine adaptations as a result of chronic eccentric resistance exercise. As practitioners, we must appreciate that there are major gaps in our knowledge surrounding the outcomes of interest to older adults as a result of prescribing the various eccentric resistance exercise modalities.

My investigation into the acute effects of eccentric resistance exercise shows our current understanding of eccentric muscle actions, based on antiquated aerobic based studies may not be representative of the acute effects that occur in eccentric resistance exercise, in trained individuals or in the older adult population. I have shown that practitioners cannot subscribe to this notion that eccentric muscle action always requires less energy, causes less cardiovascular stress and can be completed with far less effort. In fact, when eccentric muscle actions are performed as eccentric resistance exercise (or eccentrically biased resistance exercise), in loads prescribed from 1ERM (or 1RM) and all else being equal (that is, repetitions, sets, relative load and time under tension), these programs appear to require more energy, cause more stress and require more effort to perform than traditional resistance exercise.

My investigation into the chronic adaptations due to eccentric resistance exercise has shown that eccentric resistance exercise may not be more effective than traditional resistance exercise, at least not for eccentrically naïve, resistance trained older adults in an eight week training period. However, healthy, high functioning, resistance trained older adults can most certainly expect maximal muscular strength and functional capacity improvements with heavy loads, regardless of the modality they are lifted with. Notably, the quantitative physical and physiological benefits seen with very heavy load training translate into more subjective but equally as important areas such as increased feelings of confidence, well-being and quality of life.

Unfortunately, physical activity as a whole begins to decline at around 45 years of age, with less than 40% of adults 75 years and older exercising regularly (New Zealand Ministry of Health, 2012-2013). Of utmost importance, community exercise programs are needed that not only recruit older adults before any substantial decline in physical activity level occur but also before the decline in physical and physiological health becomes significant and potentially irreversible. I am confident that this PhD research and its findings will contribute to future research in the area of active ageing as well as enlighten practitioners who specialize in the older adult, in how to practically engage and foster adherence to very heavy load resistance training programs in their older adult populations.

In conclusion, by describing the physical and physiological effects of eccentric resistance exercise in healthy, high functioning, resistance trained older adults, this body of research makes a significant contribution to the area of active ageing in the older adult. The implications from this research help to determine effective program prescription for the higher functioning older adult cohort with resistance training history. Through practical applications of this research, we can begin to prevent much of the societal and economic burden that typically results from the devastating physical and physiological effects of the typical ageing process.

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Appendices

Appendix A: AUTEC approval for the quantitative studies

AUTEC Secretariat

Auckland University of Technology
D-89, WA505F Level 5 WA Building City Campus
T: +64 9 921 9999 ext. 8316
E: ethics@aut.ac.nz
www.aut.ac.nz/researchethics

8 July 2015

Nigel Harris
Faculty of Health and Environmental Sciences

Dear Nigel

Ethics Application: **15/229 The effects of eccentric resistance exercise on the physical and physiological profile of the older adult.**

Thank you for submitting your application for ethical review. I am pleased to confirm that the Auckland University of Technology Ethics Committee (AUTEC) has approved your ethics application for three years until 6 July 2018.

The Consent Form requires another tick box indicating that participants agree to be x-rayed.

AUTEC suggests reflection on the possibility that it might be appropriate to either contribute to travel costs (e.g. University of Auckland for xray, appointment charge for doctor's visit)or offer koha.

As part of the ethics approval process, you are required to submit the following to AUTEC:

- A brief annual progress report using form EA2, which is available online through http://www.aut.ac.nz/researchethics. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 6 July 2018;
- A brief report on the status of the project using form EA3, which is available online through http://www.aut.ac.nz/researchethics. This report is to be submitted either when the approval expires on 6 July 2018 or on completion of the project;

It is a condition of approval that AUTEC is notified of any adverse events or if the research does not commence. AUTEC approval needs to be sought for any alteration to the research, including any alteration of or addition to any documents that are provided to participants. You are responsible for ensuring that research undertaken under this approval occurs within the parameters outlined in the approved application.

AUTEC grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to obtain this.

To enable us to provide you with efficient service, we ask that you use the application number and study title in all correspondence with us. If you have any enquiries about this application, or anything else, please do contact us at ethics@aut.ac.nz.

All the very best with your research,

Kate O'Connor
Executive Secretary
Auckland University of Technology Ethics Committee

Cc: Ashley Gluchowski agluchow@aut.ac.nz

Appendix B: AUTEC approval for the qualitative study

AUTEC Secretariat

Auckland University of Technology
D-88, WU406 Level 4 WU Building City Campus
T: +64 9 921 9999 ext. 8316
E: ethics@aut.ac.nz
www.aut.ac.nz/researchethics

13 May 2016

Isaac Warbrick
Faculty of Health and Environmental Sciences

Dear Isaac

Re Ethics Application: **16/191 The perspectives and experiences of older adults at the completion of a resistance exercise program.**

Thank you for providing evidence as requested, which satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC).

Your ethics application has been approved for three years until 13 May 2019.

As part of the ethics approval process, you are required to submit the following to AUTEC:

- A brief annual progress report using form EA2, which is available online through http://www.aut.ac.nz/researchethics. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 13 May 2019;
- A brief report on the status of the project using form EA3, which is available online through http://www.aut.ac.nz/researchethics. This report is to be submitted either when the approval expires on 13 May 2019 or on completion of the project.

It is a condition of approval that AUTEC is notified of any adverse events or if the research does not commence. AUTEC approval needs to be sought for any alteration to the research, including any alteration of or addition to any documents that are provided to participants. You are responsible for ensuring that research undertaken under this approval occurs within the parameters outlined in the approved application.

AUTEC grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to obtain this.

To enable us to provide you with efficient service, please use the application number and study title in all correspondence with us. If you have any enquiries about this application, or anything else, please do contact us at ethics@aut.ac.nz.

All the very best with your research,

Kate O'Connor
Executive Secretary
Auckland University of Technology Ethics Committee

Cc: Nigel Harris; Ashley Gluchowski

Appendix C: Participant information sheet – quantitative

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Participant Information Sheet

Date Information Sheet Produced:

July 8, 2015

Project Title:

The Effects of Eccentric Resistance Exercise on the Physical and Physiolgocial Profile of the Older Adult

An Invitation:

Hello, I am Ashley Gluchowski, a PhD student investigating the effects of three different types of resistance exercise (using weight machines) in older adults. This study may contribute to the completion of my PhD degree at AUT University. The results of this study may also result in journal publications or academic presentations.

As an independent, active adult over the age of 60, I would like to invite you to participate in my research study. Please take the time to read through this information sheet carefully before making your decision. Your participation is voluntary and you may even decide to withdraw at any time. If you choose not to participate, you may still continue with your regularly scheduled exercise program with no negative consequences.

What is the purpose of this research?

It is recommended that older adults participate in resistance exercise in order to prevent the declines in strength and muscle mass that occurs with aging. New research shows that a particular type of resistance exercise, termed "eccentric" resistance exercise, may provide even greater benefits than the traditional type of resistance exercise.

How was I identified and why am I being invited to participate in this research?

You have been given this information sheet to decide whether or not you are interested in participating in this research study. I am looking for adults 60 years old and older, independent (living alone or with a significant other) and physically active (participating in an exercise program).

If after reading this information sheet, you would like to discuss your potential participation in this research further, please email me directly (agluchow@aut.ac.nz) with your preferred method of contact (email or phone number). I will then contact you to answer any further questions you may have.

You may not be able to participate in this research if you currently have medical conditions preventing you from participating in resistance exercise, are a current smoker or have frequent changes to your medications.

What will happen in this research?

As a participant in this research, you will be required to participate in one of three different types of resistance exercise programs at AUT Millennium. Each session will run for approximately one hour, two times per week for 10 weeks in total.

The type of exercise you will perform will be chosen at random. You will have a 33% chance of participating in the traditional type of resistance exercise and a 66% chance in participating in the "eccentric" type of resistance exercise.

To measure the effects of exercise, you will be required to perform functional balance tests, provide blood samples and travel to Auckland University for body composition measurements using dual-energy x-ray absorptiometry (DXA). DXA is a scanning or imaging method, which provides a quick and non-invasive

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measure of body composition (bone, fat, lean tissue). The scan takes about 10 minutes. You lie quietly on an open bed (you are not inside a 'tube' as you are for MRI scanning) and a scanning arm passes quickly over the top of you. You have to lie quietly without moving, but it is not an unpleasant measurement. As the scanning arm passes over you it emits very low dose x-rays, similar to the radiation dose that you would receive if you took a 1 hour flight – perhaps between Auckland and Wellington. At the end of the scan we will print a picture of you showing an image of the bone, fat and lean tissue in your body both before and after the exercise intervention.

What are the discomforts and risks?

You may experience slight discomfort or soreness in the days following resistance exercise. Additionally, providing blood samples may also result in some discomfort.

How will these discomforts and risks be alleviated?

The discomfort or soreness you may experience from resistance exercise is expected to diminish on its own. I will make sure you are comfortable and cater to your needs at every stage of the intervention. I will personally deliver the exercise sessions and prioritise your safety. Experienced professionals will be involved in taking blood and body measurements to ensure comfort and safety at all times.

What are the benefits?

As a result of this research you may experience increased strength, improvements in your performance of everyday activities, decreased fat tissue, increased muscle tissue, increased heart and lung health, decreased fear of falling and overall quality of life. You will be provided with a detailed report of your physical and physiological health after your completion of the exercise study.

The findings from this study could also benefit many individuals worldwide through employment of the most effective resistance exercise for health benefits in the older adult population.

What compensation is available for injury or negligence?

In the unlikely event of a physical injury as a result of your participation in this study, rehabilitation and compensation for injury by accident may be available from the Accident Compensation Corporation, providing the incident details satisfy the requirements of the law and the Corporation's regulations.

How will my privacy be protected?

Due to the nature of the research your colleagues will know that you are participating in the research. However, your data will be kept private and will not be shared with them. No names or contact details will be stored with the dataset.

What are the costs of participating in this research?

The costs of participating in this research include approximately two hours per week of your time, transportation to and from each of the testing and exercise training sessions.

What opportunity do I have to consider this invitation?

This research will recruiting participants on a first come, first served basis until we reach our target number of participants.

How do I agree to participate in this research?

If you agree to participate in this research, you will need to complete a consent form and obtain a note from your general practitioner (GP) stating that it is safe for you to participate in resistance exercise.

Consent forms may be obtained from me, following your email indicating your expression of interest.

Appendix D: Participant information sheet – qualitative

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Participant Information Sheet

AUT UNIVERSITY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

Date Information Sheet Produced:

July 8, 2015

Project Title:

The Effects of Eccentric Resistance Exercise on the Physical and Physiolgocial Profile of the Older Adult –

Thoughts and Perspectives

An Invitation:

Hello, I am Ashley Gluchowski, a PhD student investigating the effects of three different types of resistance exercise (using weight machines) in older adults. This study may contribute to the completion of my PhD degree at AUT University. The results of this study may also result in journal publications or academic presentations.

As an independent, active adult over the age of 60, who has participated in my research, I would like to invite you to participate in focus group discussions with Dr. Isaac Warbrick.

Please take the time to read through this information sheet carefully before making your decision. Your participation is voluntary and you may even decide to withdraw at any time. If you choose not to participate, there are no negative consequences.

What is the purpose of this research?

To gain an understanding of your thoughts and perspectives surrounding your participation in eccentric resistance exercise.

How was I identified and why am I being invited to participate in this research?

You have been given this information sheet to decide whether or not you are interested in participating in this research study. I am looking for adults who have just completed my research study.

If after reading this information sheet, you would like to discuss your potential participation in this research further, please email me directly (agluchow@aut.ac.nz) with your preferred method of contact (email or phone number). Dr. Isaac Warbrick will then contact you to answer any further questions you may have.

What will happen in this research?

As a participant in this research, you will be required to focus group discussions with others from your

What are the discomforts and risks?

Isaac, what do you normally put here?

How will these discomforts and risks be alleviated?

What are the benefits?

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How will my privacy be protected?

Due to the nature of the research your colleagues will know that you are participating in the research. However, your data will be kept private and will not be shared with them. No names or contact details will be stored with the dataset.

What are the costs of participating in this research?

The costs of participating in this research include your time, transportation to and from the focus group sessions.

What opportunity do I have to consider this invitation?

This research will recruiting participants on a first come, first served basis until we reach our target number of participants.

How do I agree to participate in this research?

If you agree to participate in this research, you will need to complete a consent form.

Consent forms may be obtained from me, following your email indicating your expression of interest.

Will I receive feedback on the results of this research?

If the results are published, you will also receive notice of that.

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Nigel Harris, nharris@aut.ac.nz, 921 9999 ext 7301.

Concerns regarding the conduct of the research should be notified to the Executive Secretary of AUTEC, Kate O'Connor, *ethics@aut.ac.nz* , 921 9999 ext 6038.

Whom do I contact for further information about this research?

Primary Researcher Contact Details:

Ashley Gluchowski, agluchow@aut.ac.nz

Approved by the Auckland University of Technology Ethics Committee on *8/7/15*, AUTEC Reference number *15/229*.

Appendix E: Consent form – quantitative

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Consent Form

AUT UNIVERSITY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

Project title: ***The Effects of Eccentric Resistance Exercise on the Physical and Physiological Profile of the Older Adult***

Project Supervisor: *Nigel Harris*

Researcher: *Ashley Gluchowski*

- ○ I have read and understood the information provided about this research project in the Information Sheet dated 08 July 2015.
- ○ I have had an opportunity to ask questions and to have them answered.
- ○ I understand that I may withdraw myself or any information that I have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.
- ○ I am not suffering from any illness or injury that impairs my physical performance.
- ○ I agree to provide blood samples.
- ○ I agree to be x-rayed at Auckland Hospital
- ○ I agree to take part in this research.
- ○ I wish to receive a copy of the report from the research (please tick one): Yes○ No○
- ○ I wish to have my blood samples returned to me in accordance with right 7 (9) of the *Code of Health and Disability Services Consumers' Rights* (please tick one): Yes○ No○

Participant's signature: ....

Participant's name: ....

Participant's Contact Details:

....

....

....

....

Date:

Approved by the Auckland University of Technology Ethics Committee on 8/7/15 AUTEC Reference number 15/229

Note: The Participant should retain a copy of this form

Appendix F: Consent form – qualitative

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Consent Form

AUT UNIVERSITY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

Project title: ***The Perspectives and experiences of older adults at the completion of a resistance exercise program***

Project Supervisor: *Dr. Isaac Warbrick*

Researcher: *Ashley Gluchowski*

○ I have understood the information provided about this research project by Dr. Isaac Warbrick.

○ I have had an opportunity to ask questions and to have them answered.

○ I understand that I may withdraw myself or any information that I have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.

○ I agree to take part in this research.

○ I wish to receive a copy of the report from the research before it is published (please tick one): Yes○ No○

Participant's signature: ....

Participant's name: ....

Participant's Contact Details:

....

....

....

....

Date:

Approved by the Auckland University of Technology Ethics Committee on 8/7/15 AUTEC Reference number 15/229

Note: The Participant should retain a copy of this form

Appendix G: Application for embargo

POSTGRADUATE

AUT

FORM PGR16 APPLICATION FOR EMBARGO

PLEASE NOTE

- *This form must be typed. Handwritten forms will not be accepted.*
- *Double clicking on the check boxes enables you to change them from not-checked to checked.*
- *The completed form, signed by the student and the primary supervisor, should be submitted to the appropriate Faculty Postgraduate Office when the thesis/exegesis is lodged for examination. If the application is approved by the Faculty Postgraduate Committee, the form will be signed by the Dean and sent to the Graduate Research School for insertion into the print copies deposited. For more information consult the Postgraduate Handbook.*

Student ID No	1313440	**Name**	Ashley Gluchowski
Faculty	HE	**School/Dept**	HS
Programme	PhD	**Date of submission for examination**	Jan 2018
Research Output	**Thesis** ☒ **Dissertation** ☐	**Exegesis** ☐	**Points Value** 360
Research Title	The Effects of Eccentric Exercise in the Resistance Trained Older Adult		

EMBARGO TIMEFRAME

An embargo is requested on the public availability of the print and digital copies of the above thesis/exegesis from when the thesis is lodged in the Library (maximum normally 36). 18 **months**

EMBARGO CATEGORIES

The thesis/dissertation/exegesis contains confidential or sensitive information which if publicly available may *(Tick all that apply)*

☒ Jeopardise the future intellectual property rights of the author (e.g. a patent application or publication)

☐ Breach a prior contractual arrangement with an external organisation *(Please attach a copy of the relevant agreement(s))*

☐ Infringe or endanger the right to privacy or cultural respect of an individual or group

The embargo would apply to

☒ The complete thesis/dissertation/exegesis

☐ A portion of the work (specify) :

Signatures

Student	Ashley Gluchowski	**Signature**	[signature]	**Date**	20 Oct 2017
Primary Supervisor	Dr. Nigel Harris	**Signature**	[signature]	**Date**	20 Oct 2017
Secondary Supervisor	Deborah Dulson	**Signature**	[signature]	**Date**	20 Oct 2017
Additional Supervisor		**Signature**		**Date**	

RESTRICTED ACCESS APPROVED BY FACULTY DEAN(or delegate)

Signature **Date**

OFFICE USE **RELEASE DATE**