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EDITH COWAN UNIVERSITY

School of Medical & Health Sciences

The Efficacy of Periodized Resistance Training in Older Adults

Jennifer A. Conlon
BSc (Hons), MSc

A thesis submitted for the award of Doctor of Philosophy (Sports Science) from the School of Medical & Health Sciences, Edith Cowan University, Western Australia

Principal Supervisor: Assoc/Prof. Guy Gregory Haff (Edith Cowan University)
Co-Supervisor: Prof. Robert U. Newton (Edith Cowan University)

Submitted 29th August 2016

ABSTRACT

Sarcopenia describes the slow and inevitable age-related loss of skeletal muscle mass and consequent function. Fortunately, a continually growing body of research highlights the robust adaptability of the aging neuromuscular system in response to resistance training (RT). Yet, despite an abundance of research studies describing the benefits of RT in the elderly, there is a large variation in the type of training programs employed. Therefore, within the extensive range of beneficial RT stimuli, it is vital to confirm what organizational structure of acute program variables is most effective (i.e. the appropriate dose). The process of organizing a training program considering all of these factors is referred to as *periodization*.

Despite the well-recognized value of periodization in younger populations, the application of periodized RT has received little attention among the aged. Also, despite a great deal of focus on the application of the session rating of perceived exertion (sRPE) in the management of training stressors, this tool remains to be explored in older adults. Together, a greater understanding of periodized RT and training load in this setting, would ultimately aid in optimizing RT guidelines for maintaining the structure, QOL and health of the aging population. Therefore, this thesis is a presentation of a comprehensive investigation of the efficacy of periodized RT strategies, specifically block periodization (BP) and daily undulating periodization (DUP) on key neuromuscular, physiological and health-related outcomes in older adults, in comparison to a non-periodized (NP) training program. Secondary aims included the examination of training load indices, perceived enjoyment and tolerance, and the application of sRPE across the different RT models.

In conclusion, NP, BP and DUP RT models are equally effective for promoting significant improvements in key physical function, physiological, and neuromuscular adaptations among apparently healthy untrained older adults. Consequently, periodization strategies are not critical during the initial stages of RT among the elderly. Additionally, periodized RT does not appear to impact an elder's perceived tolerance or enjoyment of RT, yet may be important for the better management of training load, potentially reducing the risk of illness and injury beyond the initial stages of training. Finally, sRPE and related measures are not valid tools for RT monitoring purposes when compared to established methods.

The examination of periodization strategies among previously trained older

adults is warranted, with alternate training models such as weekly undulating periodization (WUP) proposed for consideration. Finally, the use of true repetition maximum (RM) sets to momentary concentric muscular failure is not advised over chronic training periods, with other means of resistance load prescription such as % one-repetition maximum (1RM) proposed. Yet, above all else, practitioners should focus on engaging older adults in RT, via feasible and efficacious interventions targeting long-term adherence in minimally supervised settings.

SIGNED DECLARATION

I certify that this thesis does not, to the best of my knowledge and belief:

i. Incorporate without acknowledgment any material previously submitted for a degree or diploma in any institution of higher education;
ii. Contain any material previously published or written by another person except where due reference is made in the text of this thesis; or
iii. Contain any defamatory material.

Signature: **Date:** 29th August 2016

Jennifer A. Conlon

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ABBREVIATED TERMINOLOGY

1RM	One repetition-maximum
ABC	Activities-Specific Balance Confidence Scale
ACSM	The American College of Sports Medicine
ADL	Activities of daily living
ANCOVA	Analysis of covariance
ANOVA	Analysis of variance
BF	Body fat
BF%	Body fat percentage
BM	Body mass
BMC	Bone mineral content
BMD	Bone mineral density
BMI	Body mass index
BP	Block periodization
CHAMPS	Community Health Activities Model Program for Seniors
CI	Confidence intervals
CMJ	Countermovement jump
CRP	C-reactive protein
CSA	Cross sectional area
CT	Computed tomography
DHA	Dehydroepiandrostedione
DEXA	Dual-energy x-ray absorptiometry
DUP	Daily undulating periodization
EMG	Electromyography
ES	Effect size
FM	Fat mass
GAS	General adaptation syndrome
GH	Growth hormone
HDL	High-density lipoprotein
HR	Heart rate
ICC	Intraclass correlation coefficient
IGF-I	Insulin-like growth factor

IL-1	Interleukin 1
IL-6	Interleukin 6
LBM	Lean body mass
LDL	Low density-lipoprotein
MHC	Myosin heavy chain
MPS	Muscle protein synthesis
MRI	Magnetic resonance imaging
mRNA	Messenger RNA
MU	Motor unit
MVIC	Maximal voluntary isometric contraction
mRF	Rectus femoris
mVL	Vastus lateralis
NP	Non-periodized
OMNI-RES	OMNI-Resistance Exercise Scale
QOL	Quality of life
RDA	Recommended daily allowance
RFD	Rate of force development
RM	Repetition maximum
RT	Resistance training
SD	Standard deviation
sRPE	Session rating of perceived exertion
TI	Training Intensity
TNF-α	Tumor necrosis factor alpha
VJ	Vertical jump
VL	Volume load
WHO	World health organization
WHR	Waist-to-hip-ratio
WUP	Weekly undulating periodization

RESEARCH OUTPUTS

Peer-reviewed journal articles, published or in review:

Chapter Three

Conlon JA, Newton RU, Tufano JJ, Banyard, HG, Hopper AJ, Ridge AJ, & Haff GG. Periodization Strategies in Older Adults: Impact on Physical Function and Health. *Medicine and Science in Sports and Exercise,* 48(12): 2426-36, 2016.

Chapter Four

Conlon JA, Newton RU, Tufano JJ, Banyard, HG, Hopper AJ, Ridge AJ, & Haff GG. Periodization Strategies for Older Adults: Impact on Neuromuscular Adaptations. *European Journal of Applied Physiology*, 2016 (in review).

Chapter Five

Conlon JA, Newton RU, Tufano JJ, & Haff GG. Training Load Indices, Perceived Tolerance and Enjoyment Among Different Models of Resistance Training in Older Adults. *Journal of Strength and Conditioning*, 2016 (in review).

Chapter Six

Conlon JA, Newton RU, Tufano JJ, & Haff GG. Application of Session RPE Among Different Models of Resistance Training in Older Adults. *Journal of Strength and Conditioning,* 29(12): 3439-46, 2016.

N.B. Please note the formatting/text within the following chapters does not coincide 100% with the published (or in review) manuscripts, as listed above. The reference styles and abbreviations may have been modified from the journals preferred styles to encourage consistency throughout this thesis. However, the main body of the text, tables and figures, and references have not been altered in any way.

Conference presentations:

Tufano JJ, Conlon JA, Newton RU, Banyard HG, Hopper AJ, McQuoid L, van Dordrecht RE, Haff GG. The effect of periodized versus non-periodized resistance training on muscle hypertrophy and physical function in older adults. *National Strength and Conditioning Association Annual Conference,* New Orleans, USA, July 2016.

Conlon JA, Tufano JJ, Hopper AJ, Banyard HG, Seitz LB, McQuoid LM, van Dordrecht RE, Newton RU, and Haff GG. The effect of periodized resistance training on maximal strength gains in older adults. *National Strength and Conditioning Association Annual Conference*, Orlando, USA, July 2015.

Additional conference presentations relevant to, but not forming part of, this thesis:

Ridge A, Devine A, Lyons-Wall P, Conlon JA, and Lo J. The effect of supplementing whey protein on dietary intakes in older adults over an 11-week exercise intervention. *Joint Annual Scientific Meeting of the Nutrition Society of New Zealand and Australia*, New Zealand, November 2015.

Ridge A, Devine A, Lyons-Wall P, Conlon JA, and Lo J. The possible benefits of supplementing whey protein in older adults undertaking an 11-week exercise intervention. *Dietitians Association of Australia National Conference*, Perth, Western Australia, May 2015.

CHAPTER ONE

General Introduction

1.1 Background

The developed world's population is growing older, with older adults projected to comprise approximately 20% of Australia's population by 2021 and more than 25% by 2051 (361). This growth of the aging population has profound implications, including inducing a significant economic burden on society via increasing health care expenditures. For instance, it is well documented that as one ages, there is an increase in clinical conditions that require extensive health care, including cardiovascular disease, type II diabetes, and osteoporosis, with these conditions often reducing independence, increasing disability, and ultimately lessening the quality of life (QOL) (186). A key component underlying many of these conditions is the slow and inevitable age-related loss of skeletal muscle mass and consequent function, known as sarcopenia (186).

Briefly, sarcopenia is a multi-faceted condition with several proposed contributing mechanisms, such as changes in protein metabolism and hormone levels, inflammatory status, and lifestyle behaviors (i.e. inadequate nutrition and physical inactivity). However, a reduction in the number of muscle fibers and/or size of muscle fibers (predominantly fast-twitch) is considered fundamental in the development and progression of sarcopenia. Therefore, considering the significant relationship between muscle cross-sectional area (CSA) and force production, a detrimental impact of aging on neuromuscular function is not surprising (146, 343). Specifically, functional capacity dramatically declines, particularly the ability to perform activities of daily living (ADL), thereby damaging an older person's independence and QOL.

Given the significant consequences of sarcopenia and current demographic trends, establishing the most effective interventions for prevention and treatment is paramount. Fortunately, there is a continually growing body of research highlighting the robust adaptability of the aging neuromuscular system in response to resistance training (RT), including both morphological and performance related changes. Equally important, RT is also considered the primary intervention for improving and maintaining functional independence among older adults (103-105, 132, 289, 362). Therefore, the implementation of safe, effective and sustainable RT programs is vital (293). Yet, despite an abundance of research studies describing the benefits of RT in the elderly, there is a large variation in the type of training programs employed.

For improvements in strength and hypertrophy among older adults, The American College of Sports Medicine (ACSM) recommend the use of free-weight

and machine, multiple- and single-joint exercises for one to three sets per exercise with 60-80% of one-repetition maximum (1RM) for 8-12 repetitions with 1-3 min of inter-set rest for 2-3 $d \cdot wk^{-1}$ (306). Yet, while progressive overload and variation are advocated, no guidelines are provided. Therefore, within the extensive range of beneficial RT stimuli, it is vital to confirm what organizational structure of acute program variables is most effective (i.e. the appropriate prescription of RT). The process of organizing a training program considering all of these factors is referred to as *periodization*.

Despite the well-recognized value of periodization in younger populations (354), the application of periodized RT has received little attention among the aged. Therefore, a comprehensive evaluation of periodization strategies on key neuromuscular, physiological and health-related outcomes among older adults is warranted. Additionally, although there has been a great deal of focus on the application of the session rating of perceived exertion (sRPE), and related measures, in the management of training stressors (240), this tool remains to be explored over a chronic RT period and among non-athletic populations, including older adults (96, 239). Together, a greater understanding of periodized RT and training load in this setting, would ultimately aid in optimizing RT guidelines for maintaining the QOL and health of the aging population.

1.2 Aims, Hypothesis and Research Questions

The central aim of this research was to investigate the efficacy of periodized RT strategies on key neuromuscular, physiological and health-related physical outcomes in older adults. Secondary aims include the examination of training load indices, perceived enjoyment and tolerance, and the application of sRPE in this setting. Overall, it is hypothesized that periodized RT will promote significantly greater improvements in training adaptations, induce greater ratings of enjoyment and tolerance to RT, superior to a non-periodized (NP) training model. Further, sRPE is hypothesized to be a valid measure of training load across the different models of RT, in this population.

Thus, the following research questions will be addressed:

1. Do periodization strategies promote greater improvements in physical function and health outcomes in older adults, in comparison to NP RT? (Chapter Three)

2. Do periodization strategies promote greater improvements in neuromuscular adaptations in older adults, in comparison to NP RT? (Chapter Four)

3. What is the relationship between training load indices, and the perceived enjoyment and tolerance of RT in older adults? (Chapter Five)

4. Is sRPE a valid tool for the quantification of RT in older adults? (Chapter Six)

1.3 Overview

This thesis consists of seven total chapters. To begin, an extensive literature review is presented (Chapter Two), encompassing the mechanisms and detrimental effects of sarcopenia, and the positive impact of RT, before finally discussing specific RT program considerations, including periodization. Thereafter, a series of four experimental studies are presented. Specifically, study one (Chapter Three) explores the impact of periodized RT on physical function and health outcomes, while study two (Chapter Four) further examines periodized RT on neuromuscular adaptations. Subsequently, study three (Chapter Five) assesses the relationship between training load indices, and the perceived enjoyment and tolerance of RT, and study four (Chapter Six) investigates the application of sRPE, and relation measures, among periodized and NP RT in older adults. Last, a final summary and conclusion is presented (Chapter 7), which ties together the entire body of research in this thesis, before outlining recommendations for future research.

CHAPTER TWO

Literature Review

2.1 The Aging Population

The developed world's population is growing older, with the fastest growing sub-population of western societies being adults aged ≥ 80 years (399). The number of persons aged >65 years is predicted to rise from 550 to 937 million worldwide between 2000 and 2030, representing an increase from 6.9% to 12% of the world population (365). Specifically within Australia, older adults are projected to comprise approximately 20% of the population by 2021 and more than 25% by 2051 (361). These demographic trends have profound implications, predominantly via increasing health care expenditures inducing a significant economic burden on society. It is well documented that as one ages there is an increase in clinical conditions such as cardiovascular disease, type II diabetes, rheumatoid- and osteo-arthritis, and osteoporosis that require extensive health care, with these conditions often reducing independence, increasing disability, and ultimately lessening the QOL (186). A key component central to many of these conditions is the slow and inevitable age-related loss of skeletal muscle mass and function, known as sarcopenia (186).

2.2 Sarcopenia

Sarcopenia is the literal Greek-derived meaning for "poverty of flesh" (316), and describes one of the major physiological processes associated with aging, defined as the age-associated loss of skeletal muscle mass and function (107). Accepted as a new geriatric syndrome, the understanding of sarcopenia has grown rapidly since its first introduction in 1989 by Rosenberg et al. (316). With muscle accounting for approximately 40% of body mass (271), the implication of sarcopenia is clearly substantial, and is distinct from muscle loss (cachexia) induced via inflammatory disease, or from the weight loss and consequent muscle wasting present in starvation or advanced disease (322). Briefly, the loss of muscle mass and function in sarcopenia has significant consequences for the elderly, including reduced physical capability, impaired cardiopulmonary performance, unfavorable metabolic effects, and increased risk of falls and disability (56). Strikingly, the degree of sarcopenia evident among the aged also serves as a significant predictor of all-cause mortality (68, 248). Thus affecting not only the quality, but also the quantity of life (68, 76).

Although considered an inevitable outcome of aging, the severity of sarcopenic progression is based on having a low whole body or appendicular fat free mass in combination with poor physical functioning (107). Generally, sarcopenia is

assessed and quantified with sophisticated imaging techniques, including; dual-energy X-ray absorptiometry (DEXA), computed tomography (CT) and magnetic resonance imaging (MRI) (318). In 2010, The European Working Group on Sarcopenia in Older People proposed an operational definition and diagnostic strategy for sarcopenia (66), becoming the most widely used worldwide (56). Specifically, measurements of muscle mass, muscle strength, and physical performance are required for a confirmed diagnosis. The reasoning for this criteria is that muscle strength does not depend solely on muscle mass, and the relationship between strength and mass is not linear (185). Thus, defining sarcopenia only in terms of muscle mass, not muscle strength, is too narrow and might be of limited clinical value (66, 393). Moreover, Fielding et al. (107) suggested that a gait speed >1 $m \cdot s^{-1}$ and an objectively measured low muscle mass (i.e. appendicular mass relative to height^2 that is ≤7.23 kg/m^2 in men and ≤5.67 kg/m^2 in women) are also consistent with a diagnosis of sarcopenia (107).

The prevalence of sarcopenia reported has varied significantly, reflecting the different population groups, methods used to quantify muscle mass, and the differences in the normative (young and healthy) data used to derive sarcopenia thresholds (394). Within the existing literature, the prevalence of sarcopenia in 60 to 70 year olds ranges between 5-13%, increasing to 11-50% among those aged ≥80 years (266). In their 2012 review, Wang and Bai (393) estimate that sarcopenia currently affects over 50 million individuals, and will affect more than 200 million older adults over the following 40 years, based on prevalence rates and the World Health Organisation (WHO) population data. Sarcopenia has also been noted as twice as high in males than females (126),yet as men have greater muscle mass and shorter survival rates, sarcopenia is potentially a greater public health concern among women (323). Thus, there is a gender difference in the trajectory of skeletal muscle mass decline through aging, where men demonstrate a gradual reduction and women experience a sudden drop following menopause (314).

Finally, many of the healthcare costs attributed to aging result from treatment of medical conditions associated with sarcopenia, with research consistently demonstrating a greater incidence of insulin resistance (35, 60), obesity (26, 91), and arthritis (319, 391) among those with sarcopenia. Further, as bone mineral density (BMD) is related to muscle mass and strength in older persons, sarcopenia is suggested to have a role in the development in osteopenia and its progression to

osteoporosis (59, 101).

In addition to its role in disease progression, the loss of muscle strength in sarcopenia also leaves older adults predisposed to a higher risk of falls and resultant injuries (123, 324). To highlight the substantial economic burden of sarcopenia on healthcare systems, the cost of treating hip fractures alone is projected to increase from $2 billion to ~$6 billion in the United States between the years 2000-2040 (333). Whereas, strikingly the total cost of sarcopenia in the American Health System was calculated at approximately $18.4 billion in 2004 (187).

2.3 Etiology and Pathophysiology of Sarcopenia

Based on a high degree of individual variability inherent in sarcopenia, and age only explaining 30% of the variance in strength among adults between the ages of 20–93 years (224), sarcopenia is not exclusively an outcome of aging (174). Specifically, the etiology underpinning sarcopenia is multifactorial, with a range of possible mechanisms and risk factors suggested to contribute to its development. Although the relative influences are not well understood, with each factor potentially contributing differently to the loss of muscle mass and function (315). Predominantly, sarcopenia is believed to be mediated by a reduction in the number of individual muscle fibers and/or size of muscle fibers, predominantly fast-twitch. Further proposed contributing mechanisms include denervation, changes in protein metabolism and hormone levels, and inflammatory status, with lifestyle behaviors including nutrition and physical inactivity also suggested to influence sarcopenia progression (Figure 2.1). Finally, although beyond the scope of this review, apoptosis, mitochondrial dysfunction and tendinous factors have also been considered (76, 229), while genetic susceptibility is believed to explain individual and group differences in rates of sarcopenia (314).

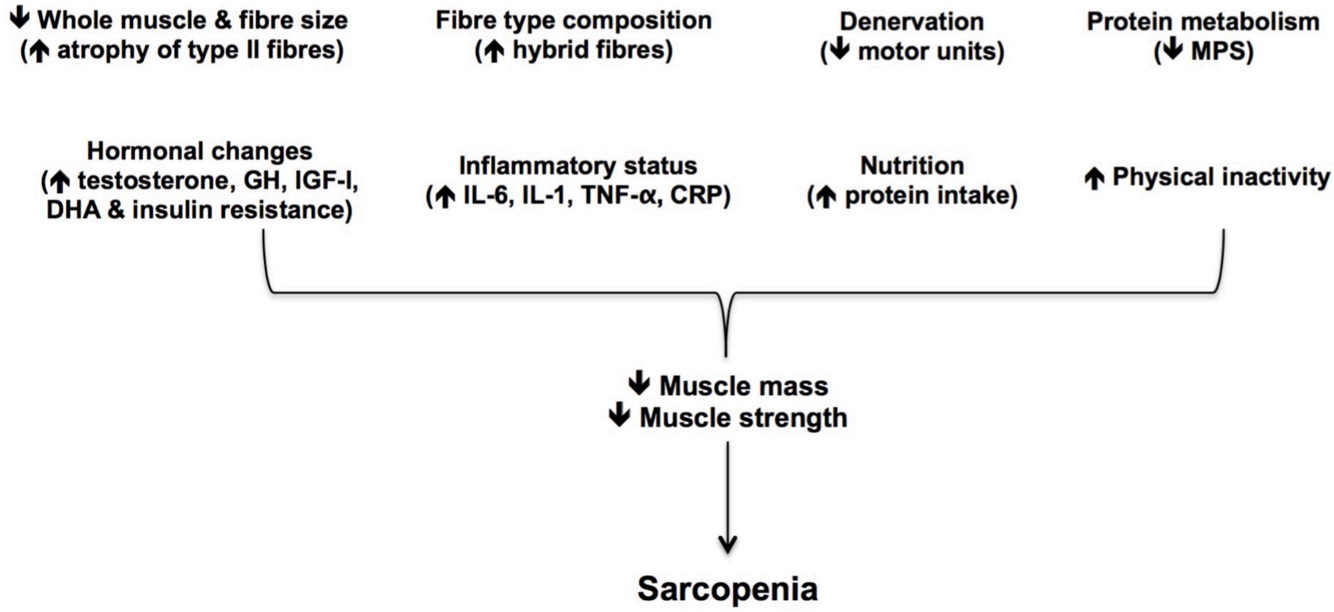

Figure 2.1. A summary of the key mechanisms underlying the development and progression of sarcopenia.

2.3.1 Whole Muscle and Fiber Size

Cross-sectional data estimates that total muscle mass, as well as whole muscle size, peaks around the age of 24 and displays a modest decrease of ~10% between 24-50 years of age (222). This rate then accelerates to a loss of ~1% per year above the age of 50 years (318), equating to ~30% between 50 and 80 years of age. More recent longitudinal data collected over a 12 year period, found that whole muscle mass is lost at an annual rate of 1.4%, as determined by CT (115). In addition to whole muscle size, there is also a concurrent reduction in the number of muscle fibers, occurring equally among type I (slow-twitch) and type II (fast-twitch) fibers (10, 196, 222, 329).

Despite a reduction in the number of muscle fibers predominantly explaining the age-related decline in muscle mass, evidence also suggests atrophy at the muscle fiber level (10, 172, 196, 222, 329). Whereas, in contrast to an equal overall decline in type I and II muscle fibers, cellular age-related atrophy is fiber-type specific (76). In detail, Lexell, et al. (222) reported a 26% loss in CSA of type II fibers between 20 and 80 year old adults, while there were no differences in type I fibers between the age-groups. Aging also appears to elicit preferential atrophy among type II fiber sub-types, with greater atrophy observed in type IIx (fast glycolytic) (~25%) muscle fibers in contrast to type IIa (fast oxidative) (~14%), over a 7 year period in aged men (10).

In support, type IIa and IIx fibers were 13% and 22% smaller in older men, respectively, when compared to younger counterparts (58). This was also found in elder women, with 24% and 30% atrophy in IIa and IIx fibers evident, respectively (58).

This selective atrophy of fiber types has been related to changes in genetic regulation of muscle, with more recent molecular biological approaches revealing a decrease in myosin messenger RNA (mRNA) content extracted from aged, compared with younger muscle (76). Yet, a decrease in specific myosin isoform concentration is considered most noteworthy (76), with senescent fibers showing a reduction in IIa mRNA, a greater reduction in IIx transcript, but no alteration in type I mRNA content, when normalized to young muscle (16). Additionally, Deschenes (76) also considers 'nuclear domains', which describes that each muscle fiber nucleus is responsible for the maintenance of a given area of cytoplasm within the fiber. Specifically, during unloading-induced fiber atrophy the nucleo-cytoplasmic relationship is maintained via a decrease in the number of nuclei within the fiber (4, 168). Recent evidence also suggests a decline in the number of myonuclei during atrophy of older fibers, consequently maintaining the size of nuclear domains (169). Together, these findings suggest that a reduction in the number of nuclear domains, rather than size, also contributes to the age-related decline in muscle CSA (76).

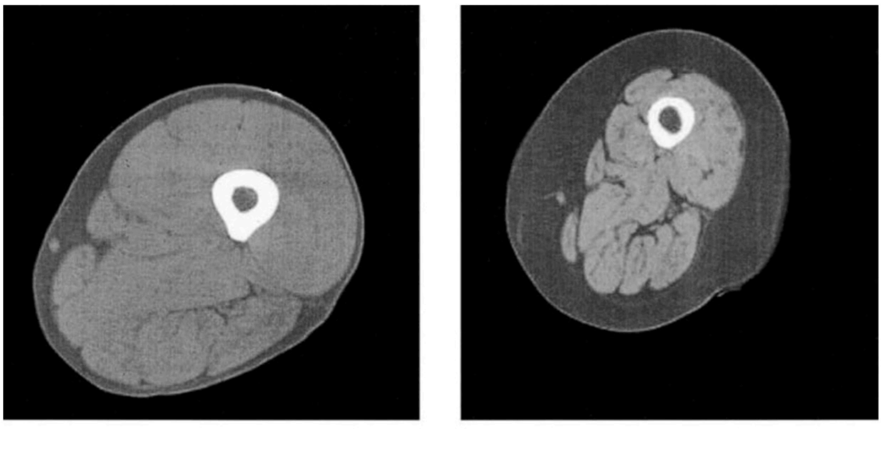

Figure 2.2. MRI images through the mid-thigh of a 25-year-old healthy adult (left) and a 75-year-old healthy adult (right). Note the smaller muscle mass (light grey), larger subcutaneous fat (dark grey), and increased intramuscular fat (dark grey lines) in the older adults upper leg (reproduced from Roubenoff (320) with permission from Oxford University Press).

2.3.2 Fiber Type Composition

Despite earlier research suggesting a selective loss of type II fibers through aging (215), a series of landmark studies by Lexell, et al. (219, 221, 222) later refuted this. Specifically, these studies involved the classification of individual fibers of the vastus lateralis (mVL) from whole muscle cross-sectional slices of 15 to 83-year-old autopsies. It was concluded that although the number of fibers declines with aging, this loss manifests equally among type I and II fibers, which was also later demonstrated in upper body musculature (329). Yet, the relative proportion of type I to type II muscle fibers, and the distribution of those fibers within the muscle has been found to change with aging (76). Unlike young muscle, where different fiber types are interspersed and have a 'mosaic' appearance, using histochemical staining of whole muscle sections, Lexell et al. (220) found that fiber types in older muscle are clustered together, resulting in a 'patchy' appearance (Figure 2.3).

Nevertheless, such conclusions were previously derived using histochemical staining of muscle cross-sections, whereas gel electrophoretic techniques been used more recently to determine myosin heavy chain (MHC) isoform expression within single muscle fibers. Using this technique, the proportion of 'hybrid' fibers which co-express more than one MHC isoform, opposed to 'pure' fibers that express a single isoform, have been found to increase with age (6, 197). Important to note, such 'hybrid' fibers do not alter histochemical staining to the same extent that the classification of the fiber type (I, IIa or IIx) would be affected since one isoform is usually predominant (5, 402). Therefore, previous data from studies using only histochemical staining techniques may be questioned due to not accurately detecting these 'hybrid' fibers.

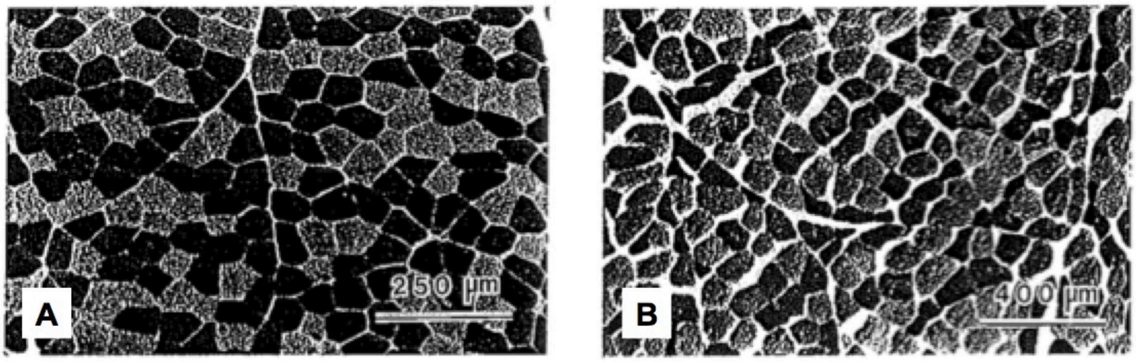

Figure 2.3. Images of whole cross-sectioned mVL, showing type I (lightly stained) and type II (dark stained) fibers in young (A) and old (B) muscle. Note the tightly packed muscle fibers and well preserved fascicles in (A), and the variation in fiber size and shape in (B), in groups of various sizes or sometimes isolated (reproduced from Lexell et al. (222) with permission from Elsevier).

2.3.3 Denervation

As a result of reduced muscle mass, a consequent decline in reduced excitable or 'functionally active' muscle, is also considered in the etiology of sarcopenia, with the muscle fiber and the innervating motor neuron together referred to as the motor unit (MU). Briefly, an age-related reduction in the number of MUs was initially described based on surface electromyography (EMG) recordings over 40 years ago (45). Specifically, a 25% reduction in the number of functional MUs (347), alongside a simultaneous decrease in the size of the remaining MUs has been observed among the aged (346). Therefore, each motor neuron innervating older muscle is associated with a greater number of muscle fibers (76). Consequently, an age-related denervation of muscle has been proposed, in that the normal cycling of denervation-re-innervation of younger muscle is impaired through aging, with evidence of this phenomenon within the spinal cord and the peripheral nervous system (76).

2.3.4 Protein Metabolism

Data support that early-phase sarcopenia (between the ages of 50 and 60 years) is related to changes in muscle protein metabolism (171). Yet, this age-related decrement in muscle protein is not associated with greater protein degradation, but rather a decreased rate of muscle protein synthesis (MPS), accounting for slower overall rates of muscle protein turnover (15, 171, 397, 398). In a comparison of

young, middle-aged and elderly subjects, mixed, as well as fractional rates of MPS declined significantly by ~50 years of age and continued to decrease into old age (15). More recently, reduced MPS has been associated with diminished mRNA transcript content for myosin heavy chain, thereby suggesting a genetic component (16, 396). The net-effect of age-related disturbances in protein metabolism is that older individuals demonstrate a reduced muscle to body mass ratio, and as this ratio declines, the percentage of body fat (BF) increases, resulting in what is termed sarcopenic obesity.

2.3.5 Hormonal Changes

Aging is associated with changes in anabolic hormone production and sensitivity, including testosterone, growth hormone (GH), insulin-like growth factor (IGF-I) and dehydroepiandrostedione (DHA). Between 20 and 80 years of age, total testosterone has been shown to decline by 35%, while unbound testosterone drops 50% (382). Moreover, the normal circadian variation in testosterone levels noted in young men was found to be blunted in elder males (338). Similarly, circulating levels of GH progressively decline by ~50% between 20 and 70 years of age between both genders (381), significant due to the belief that GH is the primary blood-borne muscle-building agent in women (76). Specifically, GH levels are reduced by ~50% between 20 and 70 years of age in both genders (381). Further, despite failing to indicate associations between IGF-1 and markers of body composition, aging is also associated with decreased IGF-1 (162), with individuals displaying the lowest IGF-1 values also exhibiting the lowest strength, walking speed and mobility (52). Regarding DHA, blood concentrations drop dramatically with age and are significantly lower in old men when compared to younger counterparts (130). However, in contrast to the negative decline in major muscle-building hormones, cortisol levels appear to remain unaffected through aging (25, 201), which is encouraging due to being considered the primary catabolic hormone of the human endocrine system (76).

An increased risk of insulin resistance is also associated with a progressive increase in BF in sarcopenia, and even more so in sarcopenic obesity (242). Yet, the anabolic effect of insulin on MPS remains controversial, and whether this effect is impaired through aging is unclear (314). However, insulin selectively stimulates skeletal MPS (36), and the MPS response to insulin appears impaired in the aged

muscle cell (137), with older adults displaying lower MPS rates following glucose and amino acid ingestion in contrast to younger counterparts (388). Moreover, vitamin D levels fall longitudinally with age (290), with an independent association between sarcopenia with low serum vitamin D (< 30 ng/ml) and parathyroid hormone previously noted (265, 385).

2.3.6 Inflammatory Status

Moderately strong evidence suggests that aging is associated with immune senescence (318), with a potential association between sarcopenia and a chronic low-grade pro-inflammatory state (336). In detail, aging muscle exhibits oxidative damage to DNA, protein and lipids, which is associated with muscle atrophy, and the loss of muscle fibers and consequent function (189). Additionally, muscle is highly sensitive to catabolic cytokines, and an age-related increase in several pro-inflammatory cytokines has been proposed to trigger muscle atrophy, including interleukin-6 (IL-6) (100) and interleukin-1 (IL-1) (321). Such cytokines are catabolic in nature primarily via increasing myofibrillar protein degradation and decreasing MPS. For instance, IL-1 and tumor necrosis factor-α (TNF- α) modulate the production of both anabolic and catabolic hormones resulting in a negative nitrogen balance, indicative of protein breakdown (76). Elevated cytokines may also result in a decline of muscle mass through increased activation of the ubiquitine-protease pathway (85) and lower IGF-1 production (314).

An inverse relationship between both muscle mass and strength, and blood levels of TNF- α, IL-6 and C-reactive protein (CRP) has been reported (54, 331, 387), while IL-6 is proposed to be a significant predictor of sarcopenia in women (287). Therefore, a chronic elevation of pro-inflammatory cytokines or other pro-inflammatory proteins may increase an individual's susceptibility to sarcopenia (99, 323). However, the role of IL-6 in sarcopenia remains conflicting due to being both a pro-inflammatory and anti-inflammatory cytokine, with recommendations for blood Il-6 to be differentiated from the muscle-derived form, which is able to inhibit TNF-α (161). Therefore, while TNF- α stimulates muscle loss through the activation of the apoptosis pathway (405), the effect of IL-6 depends on its form and localization (314).

2.3.7 Nutrition

It is well recognized that aging is associated with a decline in food intake, with this ‘anorexia of aging’ considered a significant factor in sarcopenia (263, 268). Briefly, anorexia increases the risk of developing severe muscle wasting, possibly manifesting during illness or other potential catabolic states, for instance following a hip fracture (79). If severe, such wasting can lead to cachexia and consequent progressive functional decline (262, 263). A range of complex mechanisms and interactions leading to decreased food intake are proposed with aging, including early satiety, decreased relaxation of the fundus, increased cholecystokinin release following fat intake, increased leptin levels, likely due in part to increased BF, and the effects of neurotransmitters such as opioids and neuropeptides (264).

It remains unclear whether this physiological anorexia contributes to sarcopenia due to inadequate protein intake for the maintenance of muscle mass, or because the intake of essential dietary nutrients, including creatine, is reduced (79). Considering protein, 15% of those aged >60 years consume less than 75% of the recommended dietary allowance (RDA) of 0.8 $g \cdot kg^{-1} \cdot day^{-1}$ (323). What’s more, the extent to which the RDA for protein is sufficient for the elderly remains in question, with authors challenging the one-size-fits all recommendation failing to consider age-related protein metabolism and hormonal changes (23). Therefore, dietary protein recommendations greater than the current RDA for older adults have been proposed (23).

2.3.8 Physical Inactivity

A substantial proportion of the neuromuscular function lost through aging is mediated by decreases in physical activity, although whether physical inactivity is a cause or the effect has been questioned (158). Specifically, among the multiple factors independent of age that influence sarcopenia, physical inactivity accelerates greater muscle loss than demonstrated by physically active elders (318). Low levels of physical activity also results in muscle weakness that, in turn, increases the risk of falls and fractures, and further reduces activity levels, loss of muscle mass and muscle strength, thus resulting in a positive feedback loop, further exacerbating sarcopenia progression (314). Interrupting this feedback loop is considered a vital step toward maintaining the QOL and health of the aging population (174).

However, sarcopenia has been reported in master athletes, proving that it is not

solely a manifestation of disuse and inactivity (318). Nevertheless, the consistent finding that locomotor muscles are more susceptible to age-related declines in muscle function than non-locomotor muscles, supports the hypothesis that declining muscle function is predominantly mediated by decreases in physical activity (173, 212). Therefore, considering the overwhelming rise in physical inactivity with advancing aging, it is not surprising that older individuals who are less physical active have less skeletal muscle mass and an increased prevalence of disability (90, 92, 93, 323).

2.4 Sarcopenic Obesity

Sarcopenic obesity is characterized by a loss of muscle mass and a parallel increase in fat mass (FM) representing a significant health risk, predominantly expressed in older adults (286, 319). Common among obese older adults (268, 319) and considered to have even greater negative health consequences than sarcopenia alone (392), sarcopenic obesity is particularly challenging due to changes in body composition being easily be masked when increases in one type of tissue are compensated for by decreases in another (31). For example, substantial increases in BF percentage (BF%) and reductions in lean body mass (LBM) are not always evident if a relatively stable body weight is maintained. As a result, obesity is not diagnosed until FM increases to such an extent that total body mass is increased (31). For instance, despite an overall decrease in body weight that may appear reassuring to the clinician, the relative amount of FM actually increases in contrast to LBM, a critical step in the development of the condition (31).

Although sarcopenia occurs regardless of changes in adiposity, in the obese elderly it may be associated with visceral adiposity and a state of low chronic inflammation, consequently further accelerating muscle loss and increasing the risk of developing sarcopenic obesity (314). In evidence, sarcopenic obesity is associated with high inflammation which preferentially mobilizes muscle over fat, thereby further contributing to the erosion of muscle mass (189). Additionally, IL-6 and CRP are positively associated with body mass index (BMI) and total FM, and inversely associated with appendicular LBM (54). As obesity remains significantly associated with elevated IL-6 and CRP, even after adjustments for sarcopenia, obesity-related inflammation is suggested to have a role in age-related sarcopenia (189).

The consequences of sarcopenic obesity was demonstrated in the Health, Aging, and Body Composition Study (386), where despite having a higher leg muscle

mass, functional capacity was worse in elderly subjects with a higher proportion of infiltrated intramuscular fat Moreover, intramuscular fat was independent of total body fat as well as total muscle area. Thus, interventions to combat sarcopenia and sarcopenic obesity should not only target increasing muscle mass, but should also target reductions in FM or the maintenance of a healthy BF%.

2.5 Impact on Neuromuscular Function

As noted, sarcopenia not only describes the age-related loss of muscle mass, but also the consequent decline in neuromuscular function that ensues (186). Yet, despite being a multi-faceted condition, the reduction in whole muscle and fiber size is clearly fundamental in sarcopenia. Considering and the significant relationship between muscle CSA and force production, a detrimental impact of aging on neuromuscular function is not surprising (146, 343). Therefore, the loss of muscle quantity through aging is matched by a loss of 'muscle quality'. Specifically, there is a strong body of evidence showing significant age-related reductions in maximal strength, power, rate of force development (RFD) and neural factors. Ultimately, this decline in neuromuscular function is substantially detrimental to the functional capacity and overall QOL in the elderly.

2.5.1 Strength

It is well established that strength (the maximal amount of force exerted in a single effort) is diminished in older muscle, and has been proposed as more important than muscle quantity in estimating mortality risk (275). Based on cross-sectional data, strength peaks at approximately 30 years of age and is well maintained through the 50^{th} year of life (213). Thereafter, strength steadily declines between the ages of 50 and 60 years, with the rate of loss significantly accelerating above the age of 60 years (155, 213). Strength loss assessed via isokinetic peak torque occurs at a rate of ~12-14% per decade after approximately 50 years of age (224, 228, 246), yet longitudinal data suggest the magnitude the decline to be even greater, ranging between 2.5-5% per year (9, 10, 115).

Direct comparisons between groups of young and older individuals have shown that the quadriceps muscle group of the elderly (~70 years of age) display on average ~60% of the force generating ability of younger counterparts (20–30 years) (118, 146, 196, 407, 408). Short and Nair (340) also note that the decline of muscle

function in the whole population may be even greater than that reported, due to older individuals commonly being excluded from research studies for the presence of disease.

Age-related strength loss is true in both men and women (116, 376, 407, 408), and although evident in upper and lower-body musculature (228), strength loss is most notable in weight-bearing proximal lower-limb muscle groups (183, 212), likely due to greater reductions in the usage of lower compared with upper limb muscles (116, 228). Also, although all forms of strength expression (i.e. concentric, eccentric and isometric) are affected, eccentric strength appears to be more resistant to the detrimental impact of aging (295, 375). Nevertheless, a decrease in isometric and concentric strength is considered more significant than eccentric strength (374).

More than 90% of age-related strength loss is considered to be accounted for directly by sarcopenia (115), which although minor, implies that there are other contributing factors. Briefly, in addition to neural factors, to be discussed, several studies have also examined muscle quality (force per unit of muscle) or specific tension (force produced as a function of a given unit of contracting muscle), with conflicting findings. For instance, while many authors have reported that specific tension is unaffected by age (193, 247), there is also evidence that muscle quality is compromised through aging (224, 228). Moreover, even within a single study it has been reported that aging may, or may not, alter muscle quality depending upon whether upper or lower extremities are assessed, and whether males or females are examined (228).

This equivocal nature of the literature has been attributed to the broad range of methodological approaches, with specific tension quantified at the whole muscle or single fiber level, and force being related to unit of muscle mass, total muscle mass or as whole muscle CSA or average fiber CSA (76). However, Frontera, et al. (118) assessed muscle quality as force produced relative to whole muscle CSA, as well as tension generated by isolated single fibers when normalized to that fiber's CSA. The findings showed no significant differences in whole muscle specific tension between young and aged subjects during maximal voluntary contraction isometric (MVIC) of the knee extensors. Conversely, both type I and type II fibers isolated from the quadriceps of older adults demonstrated a ~30% reduction in specific tension when compared to the younger fibers, thereby confirming a age-related impairment of specific tension. This deficit is suggested to be potentially related to the reduced

number of myosin cross-bridges within aged muscle (44).

2.5.2 Power

As muscular strength is fundamental in the expression of power (power = force x velocity), a decline in power with advancing age is similarly well evidenced (22, 71, 97). Specifically, a loss of muscular power, i.e. the rate of performing mechanical work, is first evident at ~40 years of age and displays a more rapid decline than that of strength (183, 245, 343). For instance, Skelton, et al. (406) reported an annual decline of 3-4% and 1-2% of power and isometric strength, respectively, between the age of 65-89 years. Consistent with strength, this loss of power is evident in in lower and upper body musculature (181), and both genders (245).

Loss of power generating capacity has severe implications, with a direct relationship between power and number of falls experienced among the elderly (344). Further, very old adults who require the use of aids to perform functional tasks, e.g. stair climbing and rising from a chair, express 42-54% lower leg power than similar aged subjects who do not require the use of an aid (22). A positive association between ankle flexor power and functional limitations in community-dwelling older women was also reported (358), while diminished knee extensor power is considered a key predictor of mobility restrictions (303).

As muscular power is the product of force and velocity, any factor affecting force production or muscle shortening velocity will also impact power (229). Therefore, all of the factors considered to explain the age-induced strength loss are also relevant for the loss of power (229). In evidence, significant age-related differences in the EMG characteristics of single motor units have been noted (373), with a shift towards slower firing motor units during MVIC of older individuals. Specifically, as fast-twitch muscle fibers produce greater power expression than type I fibers, the selective atrophy of type II fibers through aging is fundamental to the reduced power observed (88, 222). Likewise, the increase in 'hybrid' fibers (6, 197), and both type I and type IIA fibers displaying lower specific tension and maximum shortening velocity in older persons (119, 214), there is a shift towards a 'slower' or less powerful muscle with aging (229).

Moreover, there is a possible impairment of the basic excitation-coupling mechanism within aged fibers, specifically via attenuation in the amount of calcium released from the sarcoplasmic reticulum (74). Other factors, including a reduced

maximal shortening velocity in aged muscle fibers (210), suggesting that the contractile apparatus itself within the fiber is altered, consequently reducing muscular power.

2.5.3 Rate of Force Development

Many ADL require a rapid development of force in a limited amount of time (<200 ms), such as maintaining balance to prevent falling, standing on a bus or train when it changes speed, or stopping at a crosswalk to avoid a car (174). This is significantly less time than what is required to achieve maximal force production (~300-600 ms) for the elbow flexors (357) and knee extensors (366). Consequently, the ability to develop a rapid rise in muscle force and subsequently large impulse (or "momentum") under such time restrictions, i.e. RFD (Δforce/ Δtime), is suggested to be more important than both maximal muscle force and power production in the aged (355). In other words, RFD is suggested to be a major determinant of the maximal force and velocity that can be achieved during fast limb movements (1).

The RFD has been shown to be reduced among elderly individuals in comparison to younger counterparts (183), with an age-related drop in RFD evident when express in absolute terms (19, 53, 181, 241) or normalized to body mass (195). Additionally, a notable age induced reduction has also been reported when RFD is normalized to maximal isometric or dynamic strength (181, 195). Primary causative factors considered central in this decline include neural activation levels, muscle size and fiber-type composition (2).

2.5.4 Functional Capacity

Most functional tasks are of relatively short in duration and are therefore not significantly related to aerobic or even anaerobic capacity, but instead are strongly related to strength (11, 42, 102, 103), and possibly even more so, power (27, 110, 183, 343) and RFD (355). Therefore, neuromuscular deconditioning as one ages is directly associated with a decline in functional capacity (Figure 2.4), particularly lower extremity performance (135), e.g. the ability to climb stairs and rise from a chair unassisted. No doubt maintaining function is what matters the most to the elderly, without even considering recreational activities that add joy to life.

For instance, a large proportion of individuals >55 years of age have difficulty walking 0.4 km or carrying 11 kg (339), while 57% and 75% of men and women,

respectively, are unable to complete heavy housework by the age of 80 years (339). Strikingly, the average 80-year-old no longer retains the capacity to rise unassisted from a chair (68). Further, the age-related decline in neuromuscular performance also results in an increased risk of falls (123), with approximately 20% of those who experience hip fractures do not regain their ability to walk (252). Therefore, along with an increasing difficulty to perform ADL, independence declines through aging, while the risk of falls, disability, hospitalization and mortality increases, overall negatively influencing QOL.

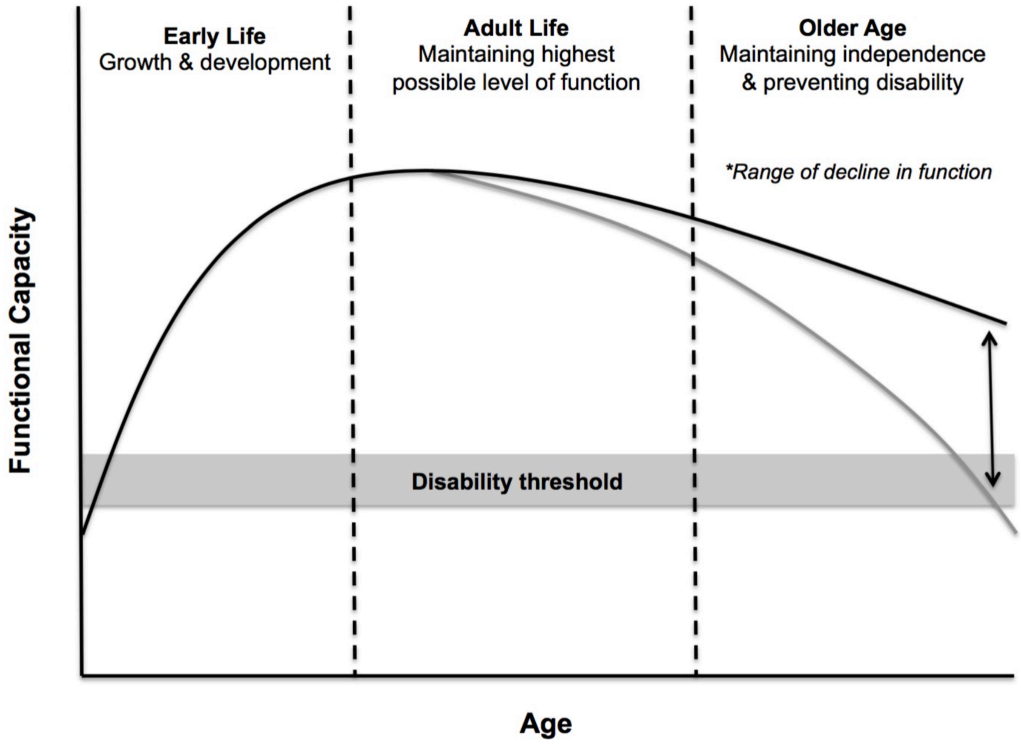

Figure 2.4. Functional capacity over the life course, increasing in childhood, peaking in adulthood, eventually followed by a decline throughout older age which may reach a disability threshold (dependent on individual variability and the influence of factors such physical activity levels and diet) (adapted from (281)).

2.5.5 Neural Factors

An age-related denervation of muscle has been considered as a potential causal factor in sarcopenia, describing a reduction in the number and size of functional MUs, thus further affecting the capacity of skeletal muscle to produce force (46, 80, 81). Therefore, in addition to the age-related muscle morphological changes (i.e. reduced

size and number of muscle fibers), neural mechanisms also contribute to this cascade of neuromuscular decline. Alternatively, such neural factors are commonly discussed as a detrimental outcome of aging and sarcopenia, and will therefore also be considered in this context within the present review.

Briefly, using a twitch interpolation technique (a method based on delivering a series of electrical stimuli to the muscle fibers during MVIC), researchers have demonstrated that older adults are unable to maximally activate a muscle or muscle group (32, 157), Conversely, a superimposed stimulus, in the form of a single twitch or short tetanus, added minimal or nothing to the volitional force of older individuals, indicating the maintenance of central drive (184, 193, 330). Moreover, activation capacity could be muscle specific, potentially preserved in distal muscles of both upper and lower extremities (376).

Using EMG, a reduction in the maximal voluntary activation of the agonist muscles and/or a greater degree of antagonist muscle co-activation (or co-contraction) during maximal muscle contraction in aged muscle has been confirmed (145, 148). However, subcutaneous fat between the muscle and the recording electrodes has a filtering effect on the EMG signal (70). Therefore, although absolute EMG measures, such as amplitude, are lower in older adults as compared to young or middle-aged counterparts (87, 145, 148, 244), the physiological meaning of this difference is questionable. Therefore, lower EMG amplitude among older subjects (~70 years of age) may not only be reflective of different MU firing rates but may also be influenced by age-related changes in the thickness or conductivity of the tissue between the muscle and the recording electrodes (87, 244).

Yet, the influence of tissue can be discounted in measures of antagonist co-activation, although cross-talk from nearby muscles may interfere with the EMG signal, therefore reducing its validity (95). However, the co-activation is deemed significant as it may serve to protect and stabilize the joint during forceful contractions. Therefore, greater antagonist co-activation observed in older adults, compared to younger and middle-aged individuals likely contributes to the age-related decline in force production (149, 183, 230). Simply put, the net force exerted about the knee joint during knee extension, would be reduced in older people due to the greater simultaneous activation of the hamstring muscles exerting a torque in the opposite direction of the movement (229).

Nevertheless, the lower EMG amplitude in older adults has been attributed to

either a smaller number of recruited MUs or a decreased firing rate of individual MUs, with the possibility of a decreased MU synchronization also considered (230). However, a limitation of EMG is its inability to determine the relative contributing roles of MU recruitment, MU firing rate and synchronization of individual MUs. Further, a lower rate of decline in median power frequency and mean power frequency parameters of the power spectrum, in relation to muscular fatigue, has also been observed among the elderly in comparison to younger individuals (33, 244). This data further supports the 'fatigue-paradox' which has been explained by selective atrophy of type II fibers, slowing in the contractile properties, and lower MU firing rates of the older muscle (229, 272). Conversely, other studies have reported no significant differences between younger and older individuals in the decline of EMG spectral parameters during sustained contractions (refs). The influence of ischemia, specifically stronger muscle contraction in the young and smaller capillary bed in older subjects (156), and electrode placement (244) have both been considered in the interpretation of these findings.

2.6 Intervention

Given the severity of the consequences of sarcopenia and the demographic trends observed among western societies, it is imperative for research to continue to unravel a thorough understanding of the effect of aging on skeletal muscle. Yet, above all else, establishing and communicating the most effective interventions for the prevention and treatment of sarcopenia are vital. Considerable evidence suggests that sarcopenia is a reversible cause of disability and dramatically benefits from structured countermeasures, particularly during the early stages of its progression (93, 314, 317).

Due to the complex and multifactorial nature of sarcopenia, various pharmacological and nutritional interventions have been explored, including anabolic hormone administration (e.g. testosterone and GH) (266, 314), with selective androgen receptor modulators most preferable due to providing an anabolic effect without any negative side-effects (223, 269). Vitamin D, calcium and creatine supplementation are further proposed interventions (266, 314), with evidence also supporting the use of angiotensin II converting enzyme inhibitors in combatting sarcopenia (259, 280). Also, anti-inflammatory agents including anti-TNF-α antibodies and fish oil-derived omega-3 fatty acids, as well as antioxidants may hold promise as treatments (189, 266, 314). Less examined drug therapies include estrogen

and tibolone, myostatin antibodies and the nerve growth promoter, topiramate (266, 314). However, the risk-benefit ratio and long-term efficacy of many of these pharmacological and nutritional interventions remains unknown.

Nevertheless, Wang and Bai (393) note that although new pharmacological medicine may radically alter the therapeutic approach to sarcopenia and substantially reduce the functional decline in older adults, no drug is as successful as physical exercise and nutritional intervention (i.e. adequate protein and energy intake). Specifically, to-date, no single pharmacological or behavioral intervention has been proven to counteract sarcopenia as effectively as RT (314). Further, a multifaceted strategy combining RT and dietary protein supplementation provides an even greater anabolic response among the elderly than RT alone (40, 267).

2.7 Protein Supplementation

To properly understand the role of dietary protein intake in aging, greater efforts are required to direct and integrate research design and data acquisition from various disciplines (282). Nevertheless, at present, concurrent RT and protein supplementation is considered the gold standard for maximizing the anabolic environment in senescent muscle (40), ultimately promoting skeletal muscle hypertrophy and consequent neuromuscular adaptations.

Briefly, daily muscle protein turnover, ~1–2 %, is regulated in large part by nutrition, with protein intake increasing MPS rates, thereby promoting net muscle protein accretion (309). Also, although to a lesser extent, protein ingestion inhibits muscle protein breakdown (390). As noted, basal rates of MPS and muscle protein breakdown are unchanged with advancing healthy age, but aged muscle is resistant to normally robust anabolic stimuli such as protein or RT (40, 390). The most compelling evidence for higher than usually recommended protein intakes in the elderly is presented in the 10 year longitudinal New Mexico Aging Process Study (378), where older persons consuming higher protein intakes (1.2-1.8 $g \cdot kg^{-1} . day^{-1}$) had fewer adverse health events.

2.7.1 Type and Amount

Despite both animal and plant-based proteins able to provide the required essential amino acids for health, animal proteins generally have a higher proportion of the amino acid leucine (282). Specifically, leucine is considered significant due to

stimulating translation initiation and muscle protein anabolism, and has received a great deal of focus in ongoing research (283). For instance, a bolus intake of a leucine-enriched whey protein stimulated acute postprandial MPS in both healthy and sarcopenic elderly (283).

Recent recommendations state that daily protein intakes that should be a minimum of 1.0-1.2 $g \cdot kg^{-1}.d^{-1}$ for healthy older people, and 1.2-1.5 $g \cdot kg^{-1}.d^{-1}$ among those with acute and chronic disease (23, 77). Further, given the blunted sensitivity of older muscles to protein, in order to optimally stimulate MPS, protein should be appropriately distributed to at least 25-30 g of high-quality protein per meal containing approximately 2.5-2.8 g of leucine (23). Therefore, protein supplementation may assist in preventing the onset or progression of sarcopenia, particularly significant among individuals unable to exercise (24).

2.7.2 Protein Ingestion and Resistance Training

Aside from food intake, muscle contraction represents the main physiological stimulus controlling muscle protein turnover (390). Consequently, RT coupled with protein supplementation better combats this 'anabolic resistance' primarily via enhanced MPS (40). The positive synergistic anabolic effect of RT in combination with protein ingestion is well documented in the aging population (41, 86, 249, 360). Further, whey protein promotes greater protein accretion than equivalent amounts of casein and soy proteins following RT (401). Yet, RT–induced improvements in muscle strength, size and physical functioning are not enhanced when older people who habitually consume adequate dietary protein (in excess of the RDA 0.8 $g \cdot kg^{-1}.d^{-1}$) further increase their protein intake (51, 134, 216, 233, 353, 379). Thus, adequate dietary intake may be all that is necessary from a nutritional perspective to maximize skeletal muscle responses to RT in the aged.

Nevertheless, the current RDA for protein is likely insufficient among the elderly (23), and a large proportion of this population fail to meet this inadequate guideline (323). Also, no major adverse effects have been reported for long-term protein supplementation in healthy older adults, specifically in renal function or 24 h nitrogen balance (380). Therefore, with only minor gastrointestinal disturbances observed in few individuals (254), the benefit-to-risk factor is not a concern. Thus, consuming an adequate amount of high-quality protein at each meal, in combination with RT, represents a promising strategy to prevent or delay the onset of sarcopenia

(282).

2.7.3 Timing of Protein Ingestion

The optimal timing of protein intake remains unclear, with some research suggesting that small and regular protein intake, i.e. four feedings of ~20 g across the day, increases MPS greater than less frequent but larger protein ingestion, i.e. two ~40 g servings (12). With regards to RT, protein intake prior to (367, 368), during (30), immediately after (257, 305), or 4 hours following (305) elicits similar increase in MPS. Therefore, a specific and narrow 'window of opportunity' may not be as vital as previously suggested, yet protein consumption in close temporal proximity to RT is clearly an important factor for maximizing the anabolic response (390).

2.8 Resistance Training

Through inducing skeletal muscle hypertrophy and subsequent improvements in body composition, RT is classified as the most effective intervention for preventing the onset and counteracting sarcopenia, while also reducing the risk of developing sarcopenic obesity (31, 40, 314, 361). Equally significant, RT is considered the primary intervention for improving and maintaining functional independence in the aging population (103-105, 132, 289, 362). Generally, studies have examined apparently healthy untrained older adults (~60-80 y), however the efficacy of RT has also been explored in the very elderly (80-97 y) (53, 157) and following long-term disuse (355). Moreover, a recent study highlighted that RT consistent with recommended guidelines is significantly associated with decreased overall mortality in older persons (209). Therefore, RT drives adaptations that have an important impact on the QOL of the elderly and subsequently reduces the economic burden on healthcare. Yet unfortunately, cross-sectional data indicate that only 4.4% of US adults aged ≥65 years participate in muscle-strengthening activities (227).

2.9 Neuromuscular System Adaptation

A continually growing body of research highlights the robust adaptability of the aging neuromuscular system in response to RT, including both morphological and performance related changes. Briefly, marked increases in muscle CSA, maximal strength, power, RFD, functional capacity and muscle activation, have been reported following RT. These findings fuel the ongoing debate over the degree to which

sarcopenia is attributable to biological aging versus chronic physical inactivity. While both factors certainly play a role, older muscle is consistently proven adaptable to RT (174), even to the extent that similar gains in muscle size were noted in younger and older men following the same RT program (148).

2.9.1 Muscle Morphology

Skeletal muscle is a highly plastic tissue influenced by changes in loading patterns (174). During progressive RT, strength development includes a considerable contribution of muscle hypertrophy in older adults, refuting earlier claims that strength gains were solely due to neurological factors (261). Specifically, RT-induced muscle fiber area increases of 20-40% have been reported using muscle biopsy sampling techniques (86, 117, 148, 167, 199, 356), including very old individuals (>80 years) (211). Also, muscle fiber hypertrophy is evident in all fiber types (235, 301), with fiber type transitions also reported (148).

High intensity RT, i.e. >70% 1RM, across 10-14 weeks has produced 5-12% gains in muscle CSA and volume among the elderly, as measured via MRI or CT (86, 98, 117, 149, 308, 355). Thus demonstrating a reversal of 5-12 years of age-induced muscle loss in only 2-3 months of intervention (318). Previously the magnitude of CSA in response to RT has been described as minor in comparison to neural and strength changes among previously untrained older adults (145, 149). However, studies demonstrating hypertrophic adaptation over short-term RT challenge this notion, with recent reports of a 7.1% increase in mVL CSA following only 9 weeks of RT (18 sessions) (225).

2.9.2 Strength

A strong pool of evidence shows that RT produces substantial maximal strength improvements in older adults across both genders (53, 145, 148, 149, 154, 362), generally above what would be typically expected by the increases in muscle mass (17, 180, 369). Further, greater strength ability is associated with a reduced cardiovascular and metabolic risk profile, irrespective of normal-weight or class I obesity weight classification (312), significant in saropenic obesity.

A landmark study by Frontera, et al. (117) reported maximal 1RM strength gains between 107-226% for the knee extensors and flexors in healthy untrained elderly men (60-72 years), following a 12 week RT period. These data amount to an

average improvement of 5% per training day, based on an RT frequency of 3 d·wk^{-1}. In the same study, 1RM strength gains were ~10 times greater than those measured using isokinetic apparatus, therefore the nature of the specific adaptation to RT appears, as within younger counterparts, to be highly specific to the mode of training, and suggests adaptation in the actual skill of performing the lifting task (157). Thus, many factors should be considered in assessing strength improvements between studies due to differences in methodologies, particularly RT prescription (training volume and loading patterns) and exercise modality (dynamic, isokinetic, isometric, etc.).

For instance, Lemmer, et al. (217) found that 1RM performance increased ~30% following 9 weeks of RT in older adults. Nevertheless, this lower figure still represents counteracting 6-12 years of age-related strength loss, based on longitudinal data demonstrating an annual 2.5-5% reduction in strength with aging (9, 10, 115). Or considering strength loss at a rate of ~12-14% per decade after approximately 50 years of age (224, 228, 246), this would translate to as little as 9 weeks of RT reversing almost two decades of strength reduction.

2.9.3 Power

Despite the majority of studies incorporating high-intensity, slow velocity RT with aim to increase strength, many authors have reported a positive improvement in power production following RT in older adults (39, 53, 83, 98, 106, 145, 152, 255, 276, 343, 345), including very old individuals (up to 90 years) (345). These improvements in power are also apparent at the muscle fiber level (164, 370).

Briefly, 10 weeks of progressive RT enhanced muscle power by 28% in very old and frail nursing-home residents (104). De Vos, et al. (72) also demonstrated that explosive RT using low (20% 1RM), moderate (50% 1RM) and heavy loads (80% 1RM) produced similar gains in peak muscle power (~14.5%) among healthy older adults. The authors concluded that explosive high-intensity RT is the best strategy for simultaneous improvements in whole-body peak power, strength and local muscular endurance in aging individuals (72). What's more, due to all groups performing the concentric portion of exercises with maximal velocity, these findings support the notion that the intention to move quickly is the most important factor in increasing power and RFD, regardless of the load (270).

Training-induced power adaptations are significant due to the positive

association with ADL performance among the elderly (27, 28), and may be a greater indicator of functional status than strength (27, 28, 82, 89, 110). Muscular power is also related to dynamic balance (27) and postural sway (181), and may be a more valid predictor of falls risk than strength (344).

2.9.4 Rate of Force Development

A concurrent increase in isometric force and RFD in the initial and early phase of the isometric torque-time curve have been noted in the elderly post-RT (2, 53, 148, 355). Strikingly, after only 12 weeks of 'explosive-type heavy RT', RFD improved by 51% in very old subjects (80-89 years), calculated as the mean tangential slope of the force–time curve in the initial 200 ms of contraction (53). Conversely, Walker, et al. (389) failed to observe an improvement in RFD following 20 weeks of 'hypertrophic' medium-load, high-volume RT in healthy older men. However, subjects performed repetitions in a slow and controlled manner, thereby supporting that the concentric portion of exercises be performed with maximal velocity to optimize RFD adaptations (270). Nevertheless, muscle activation is a major limiting factor influence the expression of RFD (34, 111, 195) irrespective of age (3), with the ability to produce force rapidly proposed to depend predominantly on the increase of muscle activation at the onset of the contraction (232).

2.9.5 Functional Capacity

Multiple studies have displayed a positive relationship between strength and functional capacity (102, 103, 127, 175, 384), most evident among the weakest individuals (55). Hunter et al. (174) propose that RT is the optimal form of exercise for improving functional capacity, and is supported by several studies demonstrating improved ADL performance following RT in older adults (103, 104, 175, 177, 238, 273, 342, 345, 362). These findings are apparent across a vast range of functional capacity assessments including repeated chair rise, stair climbing, walking, and dynamic balance performance. Additionally, authors have also reported that very older adults (~90 years of age) rely less on mobility aids such as walkers and canes, following 8-10 weeks of RT (102, 103).

It is postulated that a threshold exists above which further strength and power improvements will yield only small improvements (127), with strength and power ability above this threshold referred to as 'reserve capacity' (47). However, this

reserve provides a critical safety margin for maintaining function after periods of deconditioning/inactivity resulting from illness or surgery (304), thereby prolonging independence. This threshold is also likely responsible for a lack of improvement in functional task performance in healthy and highly functioning older adults following 12 weeks of RT, despite a 22% increase in strength and peak power (83).

2.9.6 Neural Factors

Previously untrained young individuals display greater initial increases in strength during the first few weeks of RT, predominantly attributed to enhanced neural adaptations, whereas muscle hypertrophy contributes to strength development more-so during the subsequent phases of RT (150, 151, 198, 260, 328). Despite, recent data demonstrating significant hypertrophic adaptation over short-term RT (9 weeks) refuting this idea (225), some authors also consider this concept true in older populations, based on data showing minor increases in CSA when compared to the magnitude of neural adaptations (145, 148, 149, 152).

An increase in muscle activity is brought about by greater MU recruitment or a higher rate of MU firing (rate coding), with ample studies showing increased maximal EMG activity of trained muscles in response to RT among aged subjects (2, 19, 145, 148, 149, 152, 153, 355). There is also a significant reduction in the co-activation of antagonist muscles (145, 149), particularly in older women (152). In contrast, there was no increase in muscle activity following a 12-week RT intervention among the elderly (157). However, knee extensor muscle activity was assessed during isometric contraction yet training was comprised entirely of dynamic actions, thus further supporting the specificity of adaptation to RT. Nevertheless, neural adaptations played a much greater role than morphological changes in explaining large strength and power gains in older adults following 24 weeks of RT (149).

2.10 Other Physiological & Metabolic Adaptive Changes

In addition to the substantial impact on key neuromuscular and physical function, there is also strong evidence to support the benefit of RT on other risk factors for age-related diseases and disabilities. For the purpose of this review, these topics will be limited to body composition, bone tissue and cardiovascular health.

2.10.1 Body Composition

Changes in LBM favoring the promotion or retention of skeletal muscle is a further benefit of RT, predominantly due to an increase in MPS with the rate of synthesis after a training bout being greater than that for muscle protein breakdown (404). A simultaneous loss in FM is also advantageous, primarily due to being a source of inflammatory cytokines (288). Specifically, a reduction in visceral fat following RT has been demonstrated (371), significant in reducing the risk of sarcopenic obesity, type 2 diabetes and metabolic syndrome.

Studies among the elderly, commonly using DEXA, have demonstrated reductions in total FM and parallel increases in LBM following RT, with no consequent significant change in total body mass (18, 127, 176, 218, 362). For instance, Hunter, et al. (176) reported an average 2 kg increase in LBM and 2.7 kg loss in FM among older adults (61-77 years), following 25 weeks of RT. However, another study demonstrated that only 12 weeks of RT produced a 4 kg reduction in BF and 2.9 kg increase in LBM among older adults (400). It is apparent that variability in RT interventions and methodologies can impact the magnitude of body composition responses. For instance, consistently performing RT to momentary muscular failure may contribute to greater body composition adaptations (400).

2.10.2 Bone Tissue

Reduced BMD is a major risk factor for hip fracture, therefore the maintenance or enhancement of bone health in older persons is a major public health concern, particularly in older women (178). Beneficial changes in bone parameters are notable following RT, yet are much lower in magnitude in comparison to neuromuscular adaptations. For instance, in the same study by Hunter, et al. (176), there was an average increase in bone mineral content (BMC) of 37 g following RT. It was also demonstrated that heavy RT essentially maintained BMD (~1% increase) at the femoral neck and lumbar spine among 70-year-old women, compared to reductions of 2.5% and 1.8% in the control group, respectively (273), and increased femoral neck BMD in older men (50-70 years old) following 16 weeks of heavy RT (243, 327).

Importantly, it appears that RT loading is an important factor among the elderly, as a significant increase (1.96%) in BMD of the femoral neck was evident following high-intensity RT (80% 1RM), but not low-intensity RT (50% 1RM) (383).

Although, 6 months of moderate RT loading, specifically 12-15RM (equating to ~65-67% 1RM) (13), resulted in significant increases in femoral neck and greater trochanter BMD, ward's triangle, leg BMC, and total body BMC in older adults (325).

Nonetheless, if RT simply prevents further age-induced decline in bone tissue, this alone is advantageous and significant for reducing the risk osteopenia and osteoporosis. Also, as BMD increases >20% are estimated as necessary for protection against bone fracture in falls (63), and considering most RT studies report increases <5% in BMD, RT is probably more important as a preventative tool against falls rather than reducing the risk of fracture during falls (178).

2.10.3 Cardiovascular Health

Contrary to earlier belief, there is now convincing evidence showing the benefits of RT for cardiovascular health. In their systematic review, Tambalis, et al. (364) demonstrated that RT had a positive effect on lowering low-density lipoprotein (LDL) and a tendency to increase high-density lipoprotein (HDL). Several studies also support RT-induced improvements in blood lipid profile in older individuals (94, 143, 236, 364). For example, 16 weeks of RT significantly reduced heart rate (HR), blood pressure and rate pressure product, as an index of myocardial oxygen uptake, during a weight-loaded submaximal treadmill walking test in elderly women (285). What's more, high-volume heavy RT reduced resting blood pressure in older adults (234). Possible mechanisms for such cardiovascular adaptations include a greater rate of fiber type recruitment, less occlusion of blood flow and increased lactate threshold, but require further examination (178).

2.10.4 Other Benefits

The examination of RT on further important health outcomes is somewhat limited in the aging population, with most studies conducted in young and middle-aged subjects (178). Nevertheless despite some conflicting data, there is evidence to support RT-induced improvements in inflammatory status (136, 279, 292) and glucose metabolism in older persons (64, 191, 253). Additionally, several studies have demonstrated an increase is time un in response to RT among the elderly (50, 297, 326). Resistance training may also have value in increasing energy expenditure and lipid oxidation rates, ultimate improving the metabolic health profile (176).

2.11 Program Considerations

Considering the role of RT in counteracting sarcopenia, inducing a considerable positive impact on the neuromuscular system, functional capacity, and a vast range of health and wellness outcomes, the implementation of effective, safe and sustainable training interventions is significant (293). As noted, all-cause mortality may be significantly reduced through the identification of and engagement in guideline-concordant RT interventions by older adults (209). However, despite an abundance of research studies describing the benefits of RT among older adults, there is a large variation in the type of RT intervention employed.

For instance, extensive variability is notable among limited RT studies in the elderly (53, 144, 145, 148, 149, 152, 154, 157, 355). Briefly, among only these studies, combined progressive high-load and maximal power RT is examined, while others prescribed daily variation in the training stimulus. Second, training frequency and duration varied between 2-3 $d.wk^{-1}$ and 10-52 weeks, respectively. Furthermore, total-body and isolated lower-body RT is noted, and although machine-based exercises were mainly used, free weights and bodyweight trunk exercises are also reported. Additionally, lifting loads, whether prescribed using the percentage of 1RM or a repetition maximum (RM) target, ranged from 40-80% 1RM and 3-10RM within and between studies. Regarding training volume, the prescription, progression and modification of set and repetition schemes within training programs also differs significantly. For instance, Häkkinen, et al. (154) varied training volume using 3-6 sets of 5-20 repetitions across a 21-week intervention, whereas a fixed scheme of 4 sets of 8-10 over 12 weeks was used by Caserotti, et al. (53). Finally, 5-7 exercises were performed during RT sessions, yet rest intervals, lifting velocity, and time between training sessions were often unreported.

For improvements in strength and hypertrophy among older adults, ACSM recommend the use of free-weight and machine, multiple- and single-joint exercises for one to three sets per exercise with 60-80% of 1RM for 8-12 repetitions with 1-3 min of inter-set rest for 2-3 $d{\cdot}wk^{-1}$ (306). Progressive overload and variation are also advocated, yet no specific guidelines are provided. These recommendations alongside the significant body of research investigating RT in older adults highlights a large variation in the type of RT prescribed. Within the extensive range of effective stimuli, it is vital to confirm what organizational structure of acute program variables is the

most effective (i.e. the appropriate dose of RT) for eliciting optimal adaptions, thereby counteracting the negative effects of aging while avoiding overtraining or increasing the risk of injury (128). Therefore, examining the efficacy of different RT models in this setting is essential. The process of organizing a training program considering all of these factors may be referred to as *periodization*.

2.12 Periodization

Although lacking a universally accepted formal definition, periodization is a planning process typically applied in athletic populations, with aim to achieve peak physical and physiological performance at a pre-determined time point(s), e.g. major competition. Equally important, via better management of training stress, periodization reduces the potential for illness, injury and consequent performance decrements (i.e. overtraining) (141).

Despite often being over-simplified as training variety, Haff (141) notes that periodization is a comprehensive theoretical and practical paradigm in which workloads from multiple training factors are managed. For instance, athletes may undertake varying levels of RT, agility and sprint training, metabolic conditioning and technical skill training. Therefore, the training plan must be periodized appropriately in order to maximize adaptations, while including strategic recovery periods to avoid excessive fatigue. In detail, periodization is applicable at all levels of the training plan, including long duration (macrocycle), medium duration (mesocycle) and short-term (microcycle) training phases, as well as individual training days/sessions (179).

2.13 Underlying Theories in Periodization

An understanding of the key underlying theories in periodization is significant. Specifically, the general adaptive syndrome (GAS), stimulus-fatigue-recovery-adaptation theory, and the fitness-fatigue theory are considered fundamental to periodization.

2.13.1 The General Adaptive Syndrome

Briefly, GAS was developed from the classic work of Hans Selye who studied various types of biological stressors to organisms. Although not originally proposed to deal directly with human performance and later being criticized for describing reaction to stress as ‘general’ thereby defying the principle of training specificity,

GAS serves to help understand the need for variation in physical training (Figure 2.5). In detail, GAS consists of 4 key phases following the introduction of a new stressor (i.e. training stimulus), including: an alarm, resistance, supercompensation and exhaustion phase. This model highlights that stress can produce beneficial adaptation following an initial drop in the original capacity following an alarm stage, and can also lead to breakdown from excessive accumulation of total stressors (i.e. overtraining). Therefore, training variation creating periodic breaks from constant or overwhelming stressors is paramount for continued adaptation (138).

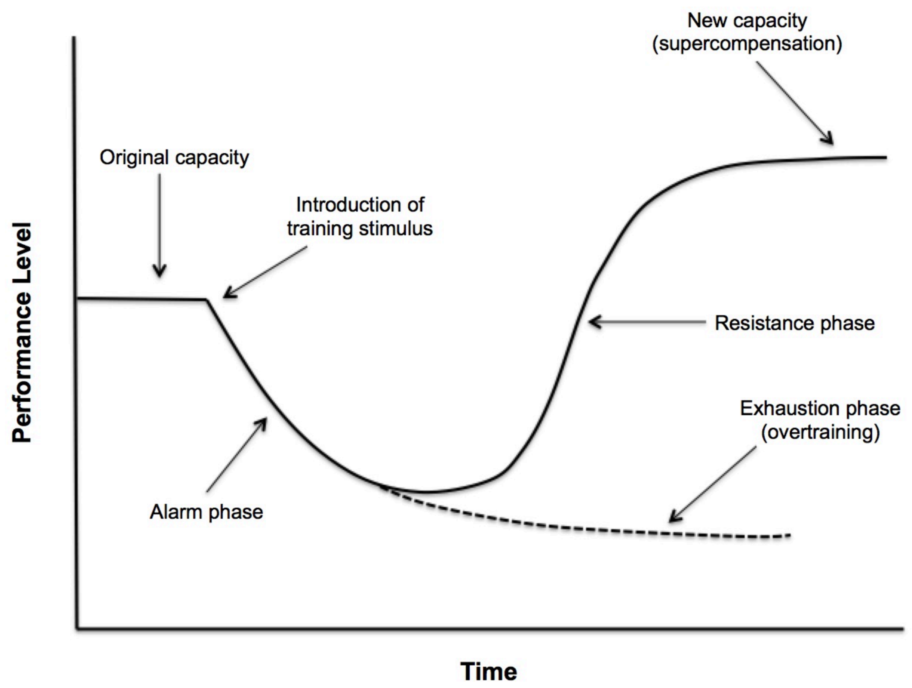

Figure 2.5. A visual presentation of GAS in periodization (adapted from (142)).

2.13.2 Stimulus-Fatigue-Recovery-Adaptation Theory

Whenever a training stimulus is applied there is a general response that has been termed the stimulus-fatigue-recovery-adaptation theory (142). Similar to GAS, the initial accumulation of fatigue in response to novel training stimuli causes a decline in performance, but also in the overall preparedness, with this reduction considered proportional to the magnitude of the training load applied. Over time fatigue dissipates allowing the recovery process to commence, eventually generating increased performance and preparedness above the original levels (i.e. supercompensation). Yet following this, failure to introduce a new training stimulus

will lead to reductions in performance and preparedness once more, referred to as a state of involution or detraining (Figure 2.6)(142). Ultimately, the appropriate sequence of training stimuli is based on the manipulation of training factors, striving to ultimately take advantage of the recovery-adaptation process (37).

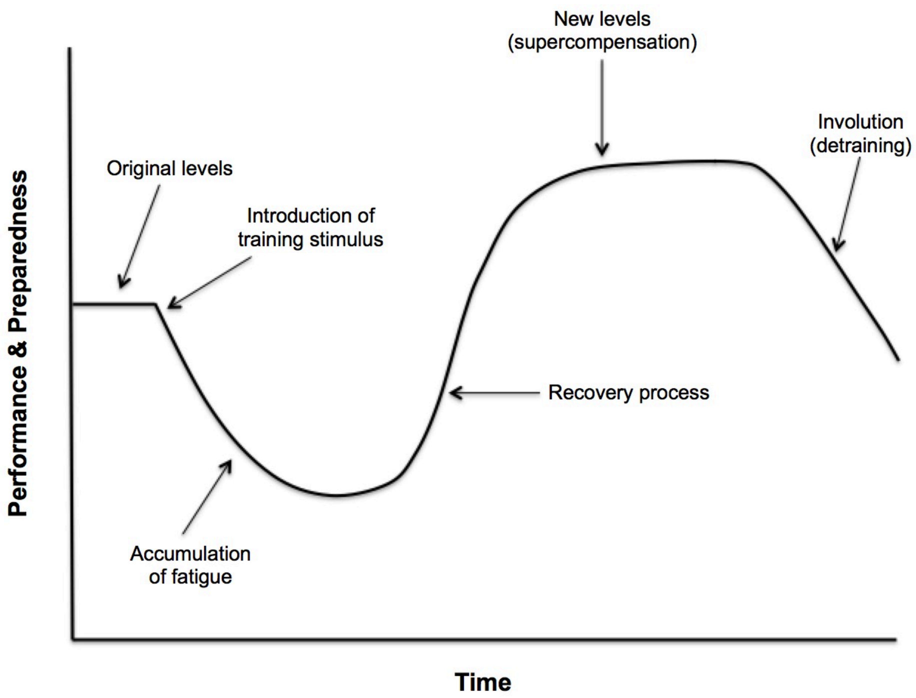

Figure 2.6. The stimulus-fatigue-adaptation-theory (adapted from (142)).

2.13.3 Fitness-Fatigue Theory

Finally, the fitness-fatigue theory defines overall performance preparedness as the summation of two after-effects of training stress: fatigue and fitness. In contrast to supercompensation where a cause-and-effect relationship exists between these two factors, the fitness-fatigue model proposes an opposite effect. This is an important distinction, in that optimal preparedness results from a training plan that minimizes fatigue while maximizing specific fitness characteristics (138). Figure 2.7 highlights the interplay of fitness and fatigue and the consequent impact on overall preparedness, following prolonged exposure to a specific training stimulus. However, it has been suggested a more complex model is common due to multiple interdependent fitness and fatigue aftereffects present following training, exerting a cumulative effect (142).

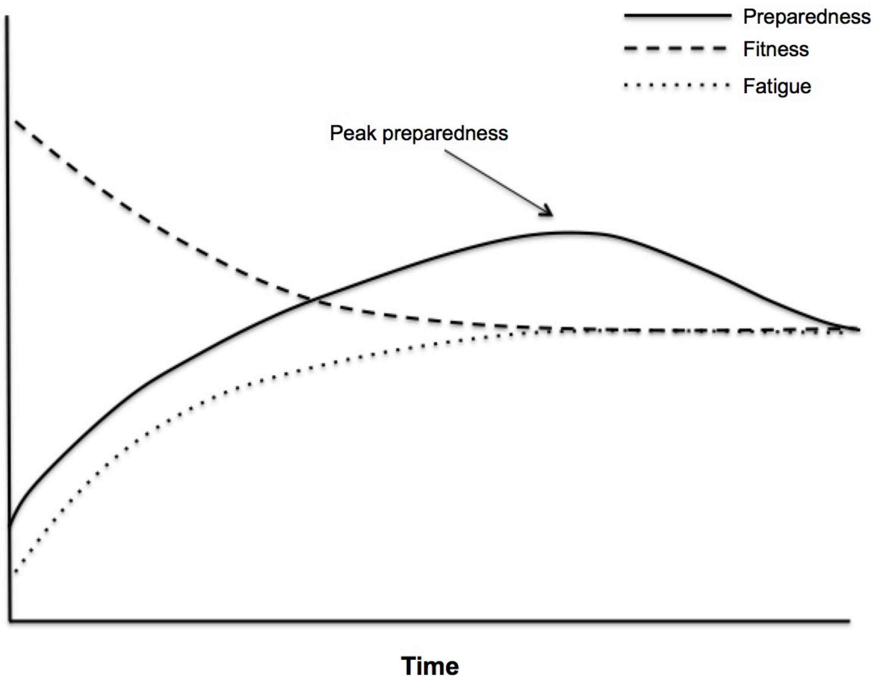

Figure 2.7. A basic depiction of the fitness-fatigue theory (adapted from (142)).

2.14 Models of Periodization

Due to the multitude of program variables that can be modified, influential periodization theorists devised and endorsed numerous periodization models based on their interpretation of the scientific evidence and anecdotal experience (194). Attempts to refine and modify models continue, with debate over whether such models should be implemented in solitude, or if complimenting methodologies from various models could be a more robust approach, dependent on the specific training scenario. Further, despite distinct differences between periodized training models, a set of core principles by which all models abide by is clear (194). For instance, established timeframes for the development and retention of specific physiological and performance adaptations and the existence of a sequential hierarchy, e.g. muscle hypertrophy development preceding maximal strength work, appear central in all proposed models. Consequently, biological adaptation to a given training intervention is believed to follow a predictable course, thereby allowing future training to be appropriately forecast (194). The most well recognized periodization models can be categorized as traditional (linear), or undulating (non-linear).

2.14.1 Traditional Periodization

Traditional periodization demonstrates gradually increasing intensity with a reduction in training volume between and within training cycles (macrocycles, mesocycles, and microcycles) as training progresses (311). Although commonly misinterpreted as being linear, the traditional model of periodization is technically non-linear via displaying wave-like increases in training loads at the various levels of the program (141).

Although the traditional model proposes a sequencing of different training goals (i.e. general to specific, low to high intensity training, etc.), it is also founded on the simultaneous development of many targeted abilities. For example, during a general athletic preparatory phase, the development of maximal strength, strength endurance and speed strength may be sought. Yet, many of these targeted abilities are incompatible, thereby hindering adaptation and producing suboptimal results. Although this may not be an issue among untrained individuals or recreational athletes, where a mixed training program is potentially more attractive and may increase adherence, this is considered a drawback among high-performance athletes (179).

In the early 1980s, block periodization (BP) became popular and widely used among high-performance practitioners (179). Specifically, the principles of traditional periodization are implemented using 4 week training blocks (mesocycles) which include highly concentrated workloads targeting a minimal number of training outcomes, e.g. hypertrophy or maximal strength (284). As a planning approach, BP seemed a potentially superior alternative to traditional multi-targeted mixed training. Ultimately, the sequencing of mesocycle blocks is suggested to exploit the favorable interaction of cumulative and residual training effects, thereby enhancing recovery and adaptation processes, resulting in superior performance (352).

2.14.2 Undulating

Undulating, or non-linear, periodization, first advocated by Poliquin (294), is characterized by more frequent manipulation of training focus (mainly intensity and volume). For instance, in weekly undulating periodization (WUP) each week presents a specific training goal, therefore similar to BP but using much shorter timeframes (i.e. 1 week versus a typical 4 week block in BP). This model was later adapted by Kraemer, et al. (205), resulting in what has more recently been classified as daily

undulating periodization (DUP).

In detail, the DUP model varies training volume and intensity on a daily basis, hence the variation of training components is more frequent and lasts for shorter periods of time than in WUP. While DUP may place considerable stress on the neuromuscular system due to the rapid and continuous change in training stimuli, it is this stress proposed to be effective in eliciting superior strength gains or in aiding to overcome training plateaus (311). Fleck and Kraemer (109) suggest the use of DUP for team sports, in which athletes are required to attain a high performance level throughout an entire course of a competition. Thereby, rather than working towards 'peak' physiological and neuromuscular performance at selected time points throughout the season, fundamental in traditional periodization, DUP theoretically allows the simultaneous development and maintenance of several training adaptations, e.g. muscle hypertrophy, maximal strength and power.

2.15 Quantifying Training Load in Periodization

When designing and implementing a RT plan, the ability to monitor and manage training stressors is considered to be an influential factor in optimizing the stimulus and thus overall effectiveness (37). For example, RT cannot be readily quantified using objective internal physiological measurements such as HR or VO_2 as typically used in aerobic exercise (359). Therefore, suboptimal performances attributable to training above or below optimal levels in RT may occur.

While an objective external assessment of RT workload (force x displacement) is possible using technologies such as linear position transducers, these methods are time-consuming, costly and therefore often impractical, especially when working with large groups and in non-athletic settings. Hence, estimating RT workload using volume load (VL) (number of sets x number of repetitions x weight lifted (kg)) is an established method for quantifying training loads (139, 237). Further, the overall training intensity (TI), calculated by dividing the total volume load by the total number of repetitions, represents the average kilograms lifted across a training session and can be used to measure the global intensity of RT (139).

Together, VL and TI can be used to plan and monitor external workload and global intensity within a periodized RT program. However, when considering other factors that contribute to the perceived intensity of RT, including exercise choice, rest periods and velocity of movement, there has been a focus towards establishing a more

simplistic and comprehensive measure of global RT intensity.

The sRPE is a modification of the classic RPE scale, used to evaluate an entire exercise session, and is proposed as a method for monitoring the global intensity of RT (240). Specifically, sRPE allows the individual to provide a global RPE for the entire training session, rather than traditionally reporting a series of acute RPE measures for each exercise within a session. Further, sRPE can be multiplied by the training session duration (in minutes) to calculate session load, can be used to measure the workload accomplished (113). However, using duration in the reflection of RT workload is questionable, therefore the number of repetitions or sets performed has been postulated as a more accurate marker (240). Nevertheless, sRPE and session load are recommended as markers of internal RT intensity and workload, respectively, and could provide a more practical and time-efficient alternative to VL and TI for planning and monitoring purposes. However, the use of sRPE in RT among non-athletic populations remains to be explored, including older adults and children (96, 239). Additionally, as the majority of studies examining sRPE were conducted in acute settings, mainly within a single exercise session, it is unknown whether these findings hold true over chronic training period. Also, the investigation of sRPE between different models of RT, for instance periodized and NP (i.e. a constant training stimulus excluding any variation), is critical.

Training monotony, defined as the variability of training and is a further measure commonly used in addition to VL for monitoring RT workloads (240). In order to calculate training monotony, the mean daily load is divided by the standard deviation (SD) of the mean daily load over a specified period, traditionally 1-week. Finally, the product of the total training load and monotony for the designated training period can be used to estimate training strain, representing the overall physical stress imposed on an individual (113). Excessive and/or monotonous training can induce negative psychological symptoms, such as mood disturbances and mental fatigue (121, 122), which is particularly undesirable based on evidence highlighting that mood state is directly related to performance (29) and non-compliance (250, 351). It has been proposed that implementing brief, simple, feasible and efficacious RT interventions while placing emphasis on adherence and long-term maintenance is most important in a public health setting, with subtle differences in strength gains resulting from complex RT protocols less critical (293). However, considering that training monotony and strain are theoretically greater in NP RT programs due to the

lack of training variety, it is proposed that simple periodized RT models providing some variation in the training stimulus may be preferable for ensuring training loads indicies (i.e. VL, monotony and strain) are not chronically elevated. Therefore, periodized RT is considered to reduce the risk of overuse and injury, and ultimately the development of overtraining. Subsequently, periodization strategies may importantly increase the perceived enjoyment and tolerance, and long-term adherence of RT in older adults.

2.16 Challenges in Periodization Research

Despite widespread acceptance of periodization, there is surprisingly little scientific evidence to support its application (108). The limitations surrounding periodization research are understandable, for instance, ensuring sufficient adherence to training in large cohorts over long-term interventions can be extremely difficult. Also, accessing athletic populations can be challenging due to 'disrupting' planned schedules (57). Therefore, a large portion of understanding of periodization is the result of observational and anecdotal evidence, inference from related studies (i.e. overtraining research), and few periodization studies among subjects of differing training status over limited timeframes (57).

The difficulty with these short-term studies is that individuals, athletic or non-athletic, generally perform RT over a period of months and years, whether aiming to optimize athletic performance or attain the substantial health benefits of regular RT. It is this longitudinal training model that underlies the necessity for periodization, i.e. logical variation in the training stimulus to promote continued to adaptations over time. Therefore, a research study that only lasts a few months does not provide conclusive evidence on how to optimally train over the long-term (57).

In order to compare the impact of different RT models, it is also essential to equalize the overall training volume at the completion of training. However, many studies evaluating periodized and NP RT had the periodized groups perform greater total training volume (161, 278, 349, 403). Therefore, whether differences are due to the periodization model, or simply greater accumulation of total training volume, also at possibly higher intensities, is unknown. However, Baker, et al. (14) proposed that if the overall training volume and intensity is equal, similar rates of adaptation are likely despite the periodization model. Also, some authors stress that better management of training loads is fundamental to a periodized training program, thereby safely

facilitating higher total training volumes across. Consequently, equalizing training volumes possibly counteracts a major advantage of periodized RT, thus further highlighting the challenges of periodization research (57).

Kiely (194) notes that a large portion of what are considered 'periodization studies', in fact simply demonstrate that training variation is a critical aspect of effective training, rather than any specific periodization models as an optimal means of providing variation. Additionally, due to periodized models being characterized by a set of core principles (i.e. established timeframes and a sequential hierarchy, etc.), although there is evidence to support the need for regular training variation, other core tenets of periodization are neither supported nor refuted (194). Overall, there are concerns that the commonly accepted 'science of periodization' creates the illusion that periodized training models have been empirically validated, which is not necessarily the case (194).

2.17 Efficacy of Periodized Resistance Training

Regarding the limited body of evidence, a meta-analysis of periodized and NP strength and power orientated RT programs concluded that periodization was a more effective strategy across both genders, all age groups and various training backgrounds (310). Yet, when controlling for other variables, only a small effect size (ES) (0.25) was evident for periodized RT. Nevertheless, several experimental studies have demonstrated statistically superior improvements in various performance indices following periodized RT, in contrast to a NP program, including; 1RM squat (278, 351), 1RM bench press (202, 256, 258), 1RM leg press (202, 256, 258), 1RM shoulder press (204), vertical jump (VJ) (202), and power output during cycling (278).

In contrast, short-term (6-weeks) NP, traditional and DUP RT induced similar muscle hypertrophy in recreationally active males (~25 years), yet 1RM squat significantly increased in the NP and DUP groups only. Moreover, 10 weeks of periodized and NP RT were reported as similarly effective for improvements in 1RM back squat and push-up performance among young trained males (332). Also, traditional periodized and NP RT induced significant increases in 1RM bench press and parallel back squat performance in untrained young females (166). Yet, the authors did note progressive strength increases in the periodized group, whereas the NP group demonstrated a plateau in strength adaptations near the end of the 15-week

RT period.

Despite a scarcity of evidence, Kiely (194) concluded that there is negotiation of a dynamic balance between the variation and novelty required to offset diminishing training returns arising from excess training habituation. Further, a concentrated focus is critical for progressing already well established training adaptations (194). Therefore, although limited, there is data to support that periodized RT promotes greater neuromuscular performance gains in comparison to a NP plan. However, most of these studies are short-term (<20 weeks), whereas the advantageous effect of periodized RT is potentially magnified across longer durations. Consequently, studies evaluating the efficacy of long-term periodized RT are essential.

2.18 An Optimal Periodized Resistance Training Model

As noted, periodization is predominantly governed by theory and opinion, with the suggestion that practitioners accept and apply periodization methodologies based on the name or the perceived reputation of an author, or the perceived value of the research study protocol (57). Despite limited research supporting the general efficacy of periodized RT strategies when compared to NP RT, greater research efforts have focused on determining an optimal periodization model. Yet, findings are somewhat contradictory and therefore which specific periodization structures are most effective dependent on the training scenario, remains unknown.

A 2015 meta-analysis (160) revealed that both traditional and undulating periodized RT (WUP and DUP) increased maximal strength significantly, with no clear evidence to favor either periodization model. However, across 17 total studies, the average age of participants was 24 years (ranging from 19-39 years old), and both untrained (<1 year RT experience; 7 studies) and trained individuals (≥ 1 year RT experience; 10 studies) were included. Finally, the average duration of RT interventions was 12.6 ± 4.1 weeks, with the authors endorsing longer-term studies.

Another recent review by Hartmann, et al. (163) notes that studies have demonstrated equal or statistically greater maximal strength improvements using DUP in comparison to traditional periodization (termed ‘strength-power periodization’), among low-moderate performance level athletes. However, traditional periodization was also found as a potentially superior structure for maximizing speed-strength in the short-term among elite athletes.

Additional studies not included in these reviews demonstrated that BP may

possibly enhance upper-body strength and power expression to a greater extent than traditional periodization, following 15 weeks of RT in experienced trained young males (20). However, no between-group differences were detected for lower-body performance or body composition. The same authors also reported that 10 weeks of WUD RT is significantly more effective than BP RT for increasing 1RM squat performance (27.7% versus 15.2% increase) and total thigh muscle CSA (5.8% versus 1.6% increase) in young recreationally trained women (21). Also, among elite adolescent judo athletes (~14.8 y), traditional and DUP models were concluded to be equally advantageous for neuromuscular adaptations (mVL thickness, maximal lower, upper and total body strength) following a very brief period of RT (4 weeks) (372). Finally, it was concluded that 12 weeks of traditional or DUP RT are both effective at increasing maximal lower and upper body strength among sub-elite youth ruby players (~17 y) (159).

Therefore, it seems that determination of the most effective model may be dependent on the specific training scenario and population. Yet, renowned periodization theorists have proposed, based on personal perspective and interpretation of the available evidence, an "optimal" training model (194). Ultimately, despite various periodization structures providing alternative formats for modulating RT variation and focus in a given timeframe, there is no major evidence to suggest a superior training model. Nevertheless, there is consensus that some form of periodization should be present in any RT program in order to enhance adaptations.

Importantly, many authors stress the increased possibility of observing differences between periodized RT models if longer training durations were implemented, thereby enhancing program differentiation. Also, despite the common application and investigation of periodization among young untrained, recreationally trained and trained subjects, the potential of periodized RT potential in clinical settings is limited. Therefore, the evaluation of periodized RT strategies in a more health and wellness focused context, particularly among the elderly, is warranted.

2.19 Application of Periodization in Health and Wellness

Given the popularity and feasibility of periodized RT among younger populations, the potential benefit of periodization strategies among inactive adults for physical function and health outcomes warrants examination (354). Overall, the possible better management of RT in turn may enhance the enjoyment and tolerance

of training, ultimately aiding long-term adherence and consequently enhancing the extensive long-term benefits of RT.

A recent systematic review (354) summarized the existing research wherein aerobic exercise, RT, or both, was prescribed to inactive adults using a recognized periodization model. The authors noted that substantial heterogeneity existed between studies, even under the same periodization model, and the majority of studies assessed overweight and obese adults, with traditional periodization being the most prevalent method. Overall, the findings indicated that various periodization strategies could be used to organize exercise training for sedentary adults in order to improve health and fitness compared, with no reports of adverse events. It was concluded that although it is premature to confirm that periodized training is superior to a NP model, periodization is a feasible means of prescribing exercise for inactive adults. The authors warranted further examination of periodization in untrained adults due to the substantial need of effective, yet sustainable exercise programming in an effort to reduce disease burden and improve QOL.

A further study not included in the above review highlighted that 14 weeks of DUP induced greater reductions in metabolic risk factors (insulin and a homeostasis model assessment of insulin resistance index) than traditional periodization, based on ES, among obese adolescents (112). Yet, due to the prescription of aerobic exercise alongside RT, the isolated effects of periodized RT are unknown. Therefore, perhaps the determination of an optimal RT model in a health and wellness context may also be dependent on the specific population and training scenario. Also noteworthy, many of these authors also stress the increased possibility of observing differences between periodized RT models if longer training durations were implemented, thereby enhancing program differentiation.

2.20 Periodization Strategies in Older Adults

As discussed, investigation into the potential of periodization strategies among older adults is lacking, with the few studies conducted assessing the impact of periodized RT on 1RM strength (73, 190, 298), peak power (190), functional capacity, body composition, and systemic inflammatory biomarkers (298) across 12 (190), 16 (298) and 18 (73) weeks. Overall, similar improvements in outcome measures were evident post-RT across the different RT models, despite the distinct differences in training structures. Yet, as noted, longer-term training interventions

(>18 weeks) should be employed to increase the likelihood of observing any potential superiority of periodized RT in untrained older adults.

To the authors knowledge, to-date, only one study has study has evaluated the long-term effects of periodized RT in untrained apparently healthy older adults (177). In detail, the efficacy of NP and DUP RT were compared over 25 weeks, with similarly significant improvements in body composition, strength, and reductions in HR and perceived exertion during ADL evident across both groups. However, a significant reduction in relative muscle activation at multiple time-points during a 4 min weight-loaded walking test was only noted in DUP (ES=0.9-1.0), in contrast to no change or a moderate increase in muscle activity following NP RT (ES=0.1-0.4). Additionally, although non-significant there was a greater reduction in the perceived exertion during ADL performance following RT in DUP, based on ES (DUP=0.6; NP=0.1). Therefore, despite a scarcity of evidence, it is reasonable to recommend future research to continue the exploration of periodized RT strategies in the aged. Particularly studies should comprehensively investigate the efficacy of long-tern periodized RT on neuromuscular, physiological and health-related outcomes, including muscle CSA, maximal force, RFD, muscle activity, ADL performance, body composition, blood biomarkers, and QOL. Together, a greater understanding of periodized RT and training load in this setting would ultimately aid in optimizing RT guidelines for maintaining the QOL and health of the aging population.

2.21 Summary

A fundamental process in aging is the inevitable deterioration in skeletal muscle mass and function, termed sarcopenia. While typically only associated with reductions in skeletal muscle mass, sarcopenia may also be central to a rise in obesity among older adults, referred to as sarcopenic obesity. Skeletal muscle atrophy appears central in both of these conditions, with several processes occurring at the muscle fiber level, specifically; whole muscle and individual fiber atrophy (including preferential atrophy of type II fibers), fiber type composition alterations, denervation, impaired MPS and diminished neuromuscular function. Hormonal changes, inflammatory status, nutrition and physical inactivity are also considered in the etiology of sarcopenia. The consequential impact of sarcopenia is significant, with a deterioration of muscle mass and coinciding drop in physical function reducing the ability to perform ADL, increasing the risk falls and fractures, thereby raising the

economic burden on healthcare systems and considerably impacting QOL in this population.

Resistance training is classified as the most effective strategy for preventing the onset and counteracting sarcopenia, and is also considered the primary intervention for improving and maintaining functional independence in older adults. A substantial body of evidence highlights the robust adaptability of the aging neuromuscular system in response to RT, including marked increase in muscle CSA, maximal strength, power, RFD, functional capacity and muscle activation following RT. However, a large variability in the type of RT employed is evident, with no current consensus on an optimal RT model for the aged.

Periodization refers to the logical planning of training with aim to maximize adaptations, while carefully managing training workloads. Research has highlighted the efficacy and feasibility of periodized RT for improving physiological and physical performance neuromuscular adaptations in young trained and untrained subjects. However, the potential use of periodized RT among older adults has received little attention. Also, due to relatively short-term nature of studies, an evaluation of long-term periodized RT on a comprehensive range of key neuromuscular, physiological and health-related outcomes is warranted. Consequently, periodization strategies provide scope to further enhance the vast benefits of RT in both preventing and counteracting the harmful impact of sarcopenia.

CHAPTER THREE

Periodization Strategies in Older Adults: Impact on Physical Function and Health Outcomes

N.B. The following chapter has been accepted for publication:

Conlon JA, Newton RU, Tufano JJ, Banyard, HG, Hopper AJ, Ridge AJ, & Haff GG. Periodization Strategies in Older Adults: Impact on Physical Function and Health. *Medicine and Science in Sports and Exercise,* 48(12): 2426-36, 2016.

However, the formatting has been adjusted from the original published manuscript to allow continuity through the entire thesis document.

3.1 Abstract

Purpose: This study compared the effect of periodized versus NP RT on physical function and health outcomes in older adults. **Methods:** Forty-one apparently healthy untrained older adults (female=21, male=20; 70.9 ± 5.1 y; 166.3 ± 8.2 cm; 72.9 ± 13.4 kg) were recruited and randomly stratified to a NP, BP or DUP training group. Outcome measures were assessed at baseline and following a 22-week x 3 d·wk^{-1} RT intervention, including; anthropometrics, body composition, blood pressure and biomarkers, maximal strength, functional capacity, balance confidence and QOL **Results:** Thirty-three subjects satisfied all study requirements and were included in analyses (female=17, male=16; 71.3 ± 5.4 y; 166.3 ± 8.5 cm; 72.5 ± 13.7 kg). The main finding was that all three RT models produced significant improvements in several physical function and physiological health outcomes, including; systolic blood pressure, blood biomarkers, body composition, maximal strength, functional capacity and balance confidence, with no between-group differences. **Conclusion:** Periodized RT, specifically BP and DUP, and NP RT are equally effective for promoting significant improvements in physical function and health outcomes among apparently healthy untrained older adults. Therefore, periodization strategies do not appear to be necessary during the initial stages of RT in this population. Practitioners should work towards increasing RT participation in the aged via feasible and efficacious interventions targeting long-term adherence in minimally supervised settings.

Key Words: Resistance training, program, model, sarcopenia

3.2 Introduction

Sarcopenia is one of the major physiological processes associated with aging, characterized by a progressive decline in skeletal muscle mass. It is estimated that total muscle mass is lost at a rate of 1-2% per year above the age of 50 years (10, 318). Consequently, aging has a significant impact on neuromuscular function via marked decreases in maximal strength, with strength losses of 2.5-5.0% per year previously reported (10, 115). This strength loss is considered to be the main contributing factor to the reduced functional capacity and an increased risk of falls and physical disability observed in older adults (363).

At present, no single pharmacological or behavioral intervention has been proven as successful as RT for slowing the progression of sarcopenia, primarily via inducing skeletal muscle hypertrophy and subsequent body composition improvements (40, 363). Ample evidence supports substantial strength gains in older adults across both genders following RT (40, 361). Furthermore, RT is considered the primary intervention for increasing and maintaining functional independence among older adults, with marked improvements in activities of daily living (ADL) performance observed following RT (127, 177). Therefore, RT drives adaptations that have a significant impact on QOL of older humans and is important for reducing the economic burden on healthcare. However, recent cross-sectional data indicate that only 4.4% of US adults aged ≥ 65 years participate in muscle-strengthening activities (227).

The ACSM recommend the use of free-weight and machine, multiple- and single-joint exercises for one to three sets per exercise with 60-80% of 1RM for 8-12 repetitions with 1-3 min of rest in between sets for 2-3 $d \cdot wk^{-1}$ (306). Progressive overload and training variety is also advocated, yet no specific guidelines are provided. These recommendations alongside the significant body of research investigating RT in older adults highlights a large variation in the type of RT employed. Therefore, it is vital to determine what organizational structure of program variables is most optimal for counteracting the negative effects of aging. The process of organizing a training program considering all of these factors may be referred to as *periodization*.

Although lacking a universally accepted formal definition, periodization is a planning process typically applied in sport performance, aiming to achieve peak physical performance at a pre-determined time point(s), e.g. major competition, while

minimizing the risk of overtraining. Traditional or linear periodization, demonstrates a progressive reduction in training volume while increasing training “intensity” (synonymous with “load” in a weightlifting context (348)), between and within training cycles. The principles of traditional periodization are commonly implemented using 4 week training blocks (mesocycles), i.e. BP, which include highly concentrated workloads targeting a minimal number of training outcomes (i.e. maximal strength, hypertrophy). Alternatively, undulating periodization is characterized by a much more frequent manipulation of volume and intensity, resulting in what has been termed DUP. Specifically, volume and intensity are manipulated on a daily basis, hence increasing training variation thought to improve physiological and performance adaptations.

Despite a limited body of evidence, studies have demonstrated statistically superior improvements in maximal strength (202, 256, 258, 278, 351) following periodized versus NP RT in young adults. Moreover, a meta-analysis of periodized and NP strength and power orientated RT programs concluded that periodization was a more effective training strategy across both genders, all age groups and various training backgrounds (310). Yet, when controlling for other variables, only a small ES)(0.25) was evident for periodized RT. Finally, a recent systematic review (354) concluded that although it is premature to endorse periodized training as superior to a NP program, periodization is a feasible means of prescribing exercise for sedentary adults. The authors highlighted the potential of periodization as significant due to the importance of establishing effective and sustainable training interventions for reducing disease burden and improving QOL.

Investigation into the application of periodization strategies specifically among older adults is lacking, with few studies assessing the impact of periodized RT on maximal strength (73, 190, 298), functional capacity, body composition, and inflammatory biomarkers (298) across 12 (190), 16 (298) and 18 (73) weeks. Yet, despite the distinct variation in the training structures implemented, similar changes in outcome measures among the various models were reported. However, it is proposed that longer-term training periods (>18 weeks) may augment program differentiation and increase the likelihood of observing any potential superiority of periodized RT. To-date, only one study has study has evaluated the long-term effects of periodized RT in older adults (177). Specifically, 25 weeks of NP and DUP RT induced similarly significant improvements in body composition, strength, and reductions in HR and

perceived exertion during ADL. However, a greater ES was noted for the reduction in perceived exertion during ADL performance following DUP (0.6) versus NP RT (0.1). Therefore, research should continue to assess the impact of periodized RT on key neuromuscular, physiological and health-related outcomes in the aging population, thus providing a greater understanding of periodization strategies in counteracting the detrimental effects of sarcopenia.

Therefore, the purpose of this study was to compare the effect of periodized (specifically BP and DUP) versus NP RT on physical function and health outcomes in older adults over a 22-week intervention. It was hypothesized that periodized RT would produce greater improvements in outcome measures than NP RT.

3.3 Methods

3.3.1 Subjects

Forty-one healthy older adults were recruited for the present study (female=21, male=20; 70.9 ± 5.1 y; 166.3 ± 8.2 cm; 72.9 ± 13.4 kg). Sample size estimation was based upon DEXA outcome measures during previous RT interventions of similar duration among older adults (177, 231), which displayed the most conservative ES among measures used in our study. An ES of 0.28 with a power of 80% at an alpha level of 0.05 produced a total sample size of thirty-six, based on a repeated-measures, within-between ANOVA model (G*Power 3.1 software).

All subjects provided medical clearance from their personal physician and completed a health history questionnaire. Exclusion criteria included lactose intolerance, a BMI of ≥ 30 $kg\cdot m^2$, any prescribed medication that could confound data, i.e. testosterone, corticosteroids, any pre-existing musculoskeletal, cardiovascular or neurological condition, or any other condition considered to cause risk to the subjects through RT or reduce their ability to adapt. Additionally, subjects were untrained, i.e. had not participated in structured exercise training designed to improve physical fitness over the previous 12 months. Finally, subjects were instructed to continue with every day normal activities and discouraged from engaging in any unaccustomed activity. The University Human Research Ethics Committee approved the study and subjects were fully informed of the nature and possible risks of all procedures before providing written informed consent.

3.3.2 Experimental Design

The present study employed a 3 (groups) x 3 (time-points) between-/within-subjects design, with a total duration of 31 weeks, comprising 2 familiarization sessions, a 4-week control period, a 22-week RT period, and the completion of all testing procedures. Subjects completed test protocols in weeks 2, 7 and week 31, using identical protocols. Weeks 3-6 were a control period to ensure reliability of baseline measures, during which time no RT was performed, and subjects simply maintained their normal recreational physical activities. Thereafter, subjects commenced a 22-week by 3 $d{\cdot}wk^{-1}$ RT intervention, excluding weeks 22, 25 and 28 where subjects trained 1 $d{\cdot}wk^{-1}$. These weeks were transition weeks and were modified ad hoc due to observing signs of overtraining in some subjects, therefore the aim was to promote recovery and reduce the potential for injury or illness. Furthermore, no RT was performed during week 19 for the completion of testing procedures at the mid-training time-point (data not included in the present study), and continued as normal in week 20. Therefore, the total number of prescribed training sessions over the training intervention was 60. Furthermore, subjects were randomly stratified into the three experimental RT groups (NP, BP and DUP) based on gender, age, BMI, and strength (peak isometric torque of the right knee extensors). A visual depiction of the experimental design is provided in Figure 3.1.

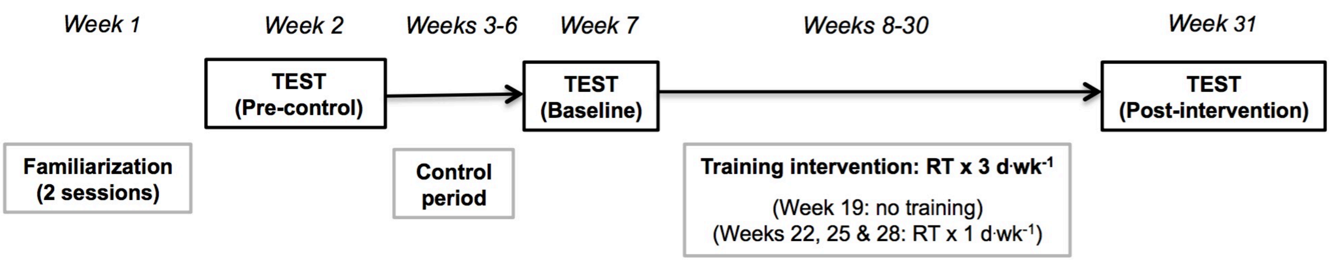

Figure 3.1. A visual depiction of the experimental design including familiarization, all testing procedures and the 22-week RT intervention.

3.3.3 Testing Procedures

Subjects were fully familiarized and instructed in the proper execution of all testing protocols across two familiarization sessions to reduce the influence of any

acute learning effects. Testing procedures were conducted using the same equipment at one location, by the same researcher across the study who was blinded to the subject's training group assignment, and with participants being tested at a similar time of day to reduce the effect of any diurnal variations. At each testing time-point, subjects were required to visit the testing location on three days separated by approximately 48 h in order to complete all testing procedures.

3.3.3.1 Anthropometric Measures

Body mass (BM) was measured by a calibrated electronic scale (HW200, A&D Mercury Pty, Ltd, Thebarton, SA) to the nearest 100 g and height was determined with a wall-mounted stadiometer (Model 220, SECA, Hamburg, Germany) to the nearest millimeter. Waist-to-hip ratio (WHR) was calculated by measuring waist and hip circumferences using an anthropometric flexible steel tape measure (Lufkin W606PM). Waist circumference was measured at the approximate midpoint between the lower margin of the last palpable rib and the top of the iliac crest, and hip circumference was measured at the widest portion of the buttocks. All anthropometric measurements were completed with subjects wearing light clothing and no shoes.

Dual-energy X-ray absorptiometry (DEXA): Total BF%, LBM, FM, BMC BMC and BMD were derived using DEXA (Discovery A, Hologic, Inc., Waltham, MA). Subject's legs were secured using non-elastic straps to prevent movement during the measurement. Quality assurance tests were run daily in accordance with standard operating procedures.

3.3.3.2 Physiological Measures

Blood Samples: Resting venous blood samples were collected from a superficial arm vein on the radial aspect of the arm using a needle and vacutainer following a 12 h overnight fast. Subjects were instructed to accurately log their dietary intake the day before the first blood sample was collected, which then served as a written record in order to replicate during the day before future blood samples for standardization. One 5 mL S.S.T vacutainer was collected and centrifuged for 10 min at 12,000g and stored at −80°C. At the end of the study, blood samples were analyzed for blood lipids (total cholesterol, HDL and LDL cholesterol, and triglycerides) and high-sensitivity CRP.

Blood Pressure: Resting blood pressure was measured by a digital blood

pressure monitor (Intelli Sense, Omron Healthcare, Australia) following a 5 min period of sitting quietly succeeding blood sample collection.

3.3.3.3 Physical Function

Maximal Neuromuscular Strength: An isokinetic dynamometer (Biodex *System 3 Pro,* Ronkonkoma, NY) was used to measure peak isometric torque (Nm) of the right knee extensors. Subjects were seated with the thigh and trunk secured to the device for all test protocols. The hip and knee angles were 110^o and 120^o, respectively (180^o refers to full extension). Subjects performed one 3 s submaximal contraction at 50% of perceived maximal intensity. Following 1 min of rest, subjects performed a maximal voluntary isometric contraction (MVIC) for 3 s, with 1 min rest between three separate repetitions. If any countermovement was evident or if peak torque differed by >5% among attempts, a further repetition was performed. The force signal was recorded on a computer and analyzed using LabChart software (PowerLab System, ADInstruments, NSW, Australia), with the highest measure included in statistical analyses.

Maximal muscle strength was measured for chest press and leg press exercises using the one repetition maximum (1RM) method. Subjects performed two submaximal sets of eight repetitions at 50% of the predicted 1RM, with 1 min rest between sets. Multiple 1RM contractions were then performed with the load increased progressively, aiming to establish 1RM within 3-5 efforts and with 3 min rest between attempts. The 1RM was recorded as the maximum weight that participants were able to move through a full range of motion without change in body position other than that dictated by the specific exercise motion.

Repeated chair rise: Subjects were seated in a hard-backed chair 43 cm from the floor, with arms folded across their chest. The instruction to rise as fast as possible to a full standing position and then return to a full sitting position five times was provided. The time to complete the test was recorded to the nearest tenth of a second using a hand-held stopwatch.

Stair climbing: Subjects climbed one flight of stairs (11 stairs per flight, 16 cm rise per stair) as rapidly as they could safely manage without the use of the handrails and making contact with all of the steps. The time to complete this task was recorded to the nearest hundredth of a second using custom-built portable timing mats connected to a hand-held, electronic timer device (Industrial Equipment & Control,

Melbourne, Australia).

Both the repeated chair rise and stair climbing protocols were performed in triplicate, with 1 min recovery allowed between attempts, and the mean time of all trials included in statistical analyses. The coefficient of variation for the repeated chair rise and stair climbing protocols was previously reported as 5.6% and 4.9%, respectively, among a similar population (127).

3.3.3.4 Quality of Life and Balance Assessment

Subject's functional health and well-being, i.e. health-related QOL, was obtained via the SF-36v2 Health Survey (SF-36v2) (QualityMetric, USA) (395). Additionally, the Activities-Specific Balance Confidence (ABC) Scale was completed to assess balance confidence during everyday activities in and outside of the home (296).

3.3.3.5 Physical Activity and Dietary Intake Standardization

Subjects were encouraged to maintain their habitual physical activity pattern and dietary intake throughout the study. Physical activity was assessed via the Community Health Activities Model Program for Seniors (CHAMPS) Physical Activity Questionnaire for Older Adults (University of California, USA) (131). Dietary intake was assessed using a 3 day weighed food diary, recorded by subjects during the week prior to testing weeks, and assessed for any significant changes in energy intake and macronutrient profile using FoodWorks 7 software (Xyris, QLD) and the AUSNUT 2007 database of Australian foods. Specifically, dietary intake was recorded on the same days throughout the study, however this was across three non-training days during weeks 1 and 6, and two "normal" days and one training day during week 30.

3.3.4 Resistance Training

All exercises were executed on RT machines (Cybex, MA, USA) with zero use of free weights. The resistance and repetitions performed in the work-sets for each exercise were recorded in a training log and served as a written record for subjects at the start of training sessions. Subjects were fully familiarized with all machines prior to commencing the training intervention. Furthermore, training sessions were performed at a regular time of day, with a minimum of 48 h between sessions, and

were supervised by exercise science bachelor degree qualified instructors to ensure proper exercise technique and reduce the risk of injury.

All training sessions commenced with a 5 min standardized warm-up consisting of light stationary cycling, rowing or brisk walking on an ergometer or treadmill (Technogym, London, UK). Resistance exercise selection remained the same across the study and was identical between all training groups, targeting concentric and eccentric muscle actions of major muscle groups and with lower-body and upper-body exercises alternated. Specifically, exercises included; seated leg press, lat pull-down, seated leg-curl, chest press, leg extension and seated row. A warm-up set of each exercise was completed at approximately 50% of the resistance of the first work-set. In order to provide recovery, a rest interval of 1 min was provided between the warm-up set and the first work-set, and a 1.5-2 min recovery period was employed between consecutive work-sets. Subjects were instructed to perform the concentric portion of exercises with maximal velocity to promote optimal neuromuscular adaptation and functional performance (39), and control the eccentric portion using a 2 s cadence as monitored by trainers.

Exercise resistance was prescribed using RM sets to ensure that the resistance stimulus was progressive to accommodate strength adaptations, requiring adjustment of the exercise resistance to ensure momentary muscular concentric failure (i.e. inability to complete a repetition in a full range of motion due to fatigue) at the prescribed RM target. At no point did subjects continue performing repetitions above the required RM target, yet the resistance was increased as necessary in 1.25, 2.5 or 5kg increments, depending on the absolute resistance. However, if a subject failed to complete the required number of repetitions, the number performed was recorded and the resistance was reduced accordingly for any remaining sets. Instructors initially led this careful adjustment of exercise resistance based on visual cues of exertion and by asking subjects how difficult they perceived work-sets. Once subjects were competent in ensuring muscular failure at the required RM target, instructors simply prescribed the resistance of the first work-set for each exercise based on the training log records and then observed to ensure this was modified accordingly.

The RM targets prescribed for each group across the intervention is outlined in Table 3.1. The training focus for each RM target was; 15RM = strength-endurance, 10RM = hypertrophy, and 5RM = maximal strength (13). The training intervention is displayed in blocks of training (mesocycles) to clearly outline the BP program.

Traditionally each training block includes several complete weeks (microcycles), however training blocks in the current study comprised 11 total training sessions due to scheduling constraints, specifically three complete microcycles plus two sessions within the following week. Overall, BP and DUP groups completed the same number of training sessions at each RM target. Moreover, as differences in the overall training volume between RT programs have been proposed to influence performance (108), total repetitions were equalized between training groups in order to reduce potential confounding factors, thereby allowing the sole examination of the effect of program structure on outcome measures. Therefore, the only difference between DUP and BP was the time and sequence of the load application. Furthermore, to check for any differences in workload between training groups across training blocks and the total training period, VL (number of sets x number of repetitions x weight lifted (kg)) was calculated.

Table 3.1.The prescribed RM targets for training groups across the training intervention, with training session numbers presented in brackets (reproduced from Conlon et al. (61) with permission from Wolters Kluwer Health, Inc.).

	Block 1 (1-11)	**Block 2 (12-22)**	**Block 3 (23-33)**	**Block 4 (34-42)**	**Block 5 (43-51)**	**Block 6 (52-60)**
NP	3 x 10RM					
BP	3 x 15RM	3 x 10RM	3 x 5RM	3 x 15RM	3 x 10RM	3 x 5RM
DUP	Session 1: 3 x 15RM Session 2: 3 x 10RM Session 3: 3 x 5RM					

3.3.5 Protein Supplementation

On completion of each training session each subject ingested a standard liquid whey protein supplement mixed with 200 ml of water according to current recommendations (23). Each 30 g serving contained 498 kJ, 24.1 g protein, 1.7 g total fat, 1.1 g saturated fat, 1.4 g total carbohydrate of which 1.4 g was sugars, and 42.6 mg sodium.

3.3.6 Statistical Analyses

Data were analyzed using SPSS statistical software (SPSS Inc., Version 22,

NY, USA). Normality of distribution was assessed using the Shapiro-Wilk statistic and where data was not normally distributed ($p<0.05$), log transformation procedures were applied with data re-checked for normality before applying parametric tests.

To validate the random stratification of subjects, a one-way analysis of variance (ANOVA) was used to check for between-group differences in baseline demographics and peak isometric torque. This analysis was also conducted on VL and repetitions performed across each training block and the total training period.

To check for any changes in outcome measures across the control period (pre-control to baseline), a group x time (3 x 2) repeated measures ANOVA was used to assess main effects for time and group x time interactions. A separate 3 x 2 repeated measures ANOVA was performed on outcome measures across the training period (baseline to post-intervention). Furthermore, an analysis of covariance (ANCOVA) was used to analyze between-group differences in the absolute change of outcome measures (i.e. post-intervention – baseline) including baseline data as the covariate. To examine any gender effects, a separate ANCOVA was performed on absolute change data including gender as the independent variable and baseline data as the covariate. When required, Tukey's test was used for post-hoc analyses.

Data are presented as mean ± standard deviation (SD), with 95% confidence intervals (CI) and Cohen's *d* within-group ES calculated for the main outcome measures using the pooled SD, with an ES of 0.2, 0.5 and 0.8 representing small, moderate, and large differences, respectively. Finally, post-hoc power analyses were calculated for outcome measures using the final sample size, at an alpha level of 0.05 and based on a repeated-measures, within-between ANOVA model (G*Power 3.1 software). Statistical significance was set at $p<0.05$ for all analyses.

3.4 Results

Unfortunately, one subject experienced an unforeseen accident and did not commence RT, and one subject dropped out in week 1 feeling unable to complete the training requirements. Additionally, there were six further dropouts over the course of the intervention due to injury or illness (NP=2; BP=1; DUP=3), with three injury cases relating directly to the study (NP = 1; BP = 1; DUP = 1). Specifically, two subjects experienced a minor muscle tear during 1RM procedures and one subject suffered an overuse injury. No other adverse events occurred during RT or testing procedures. Therefore, a total of thirty-three subjects completed the study (female=17,

male=16; 71.3 ± 5.4 y; 166.3 ± 8.5 cm; 72.5 ± 13.7 kg), with only these data included in analyses based on a per-protocol approach.

Subjects' demographics at baseline and post-RT are presented in Table 3.2, with no between- or within-group differences noted (p>0.05). Total fat mass was the only measure to demonstrate a gender effect (p=0.025), therefore data are presented for the entire training group for all other outcome measures to optimize statistical power.

Table 3.2. Training groups physical descriptive data at baseline and post-RT.

	NP		**BP**		**DUP**	
	Baseline	**Post-RT**	**Baseline**	**Post-RT**	**Baseline**	**Post-RT**
Gender	F = 6; M = 4	-	F = 6; M = 7	-	F = 5; M = 5	-
Age (y)	70.4 ± 6.1	-	71.8 ± 5.4	-	71.2 ± 4.2	-
Height (cm)	166.4 ± 10.6	166.3 ± 10.5	164.9 ± 5.8	164.9 ± 5.7	167.2 ± 9.9	167.4 ± 10.2
BM (kg)	72.2 ± 17.9	72.0 ± 17.7	71.7 ± 10.4	72.5 ± 10.7	74.6 ± 14.2	75.8 ± 14.4
BMI (kg.m^2)	25.8 ± 4.2	25.8 ± 4.3	26.3 ± 3.1	26.6 ± 3.2	26.7 ± 4.3	27.0 ± 4.0

3.4.1 Resistance Training

An adherence rate of ≥85% to RT was achieved by all subjects with no between-group differences (p=0.513) (NP = 95.6%; BP = 96.9%; DUP = 96.8%). Between-group differences in mean VL and repetitions performed across training blocks are presented in Figure 3.2. However, the group mean total VL was not statistically different between-groups (p=0.620) (NP = 514,104 ± 149,938 kg; BP = 495,559 ± 128,169 kg; DUP = 554,068 ± 151,897 kg), which was also true for group mean total repetitions performed (p=0.193) (NP = 13,287 ± 579; BP = 13,675 ± 354; DUP = 13,609 ± 619), respectively.

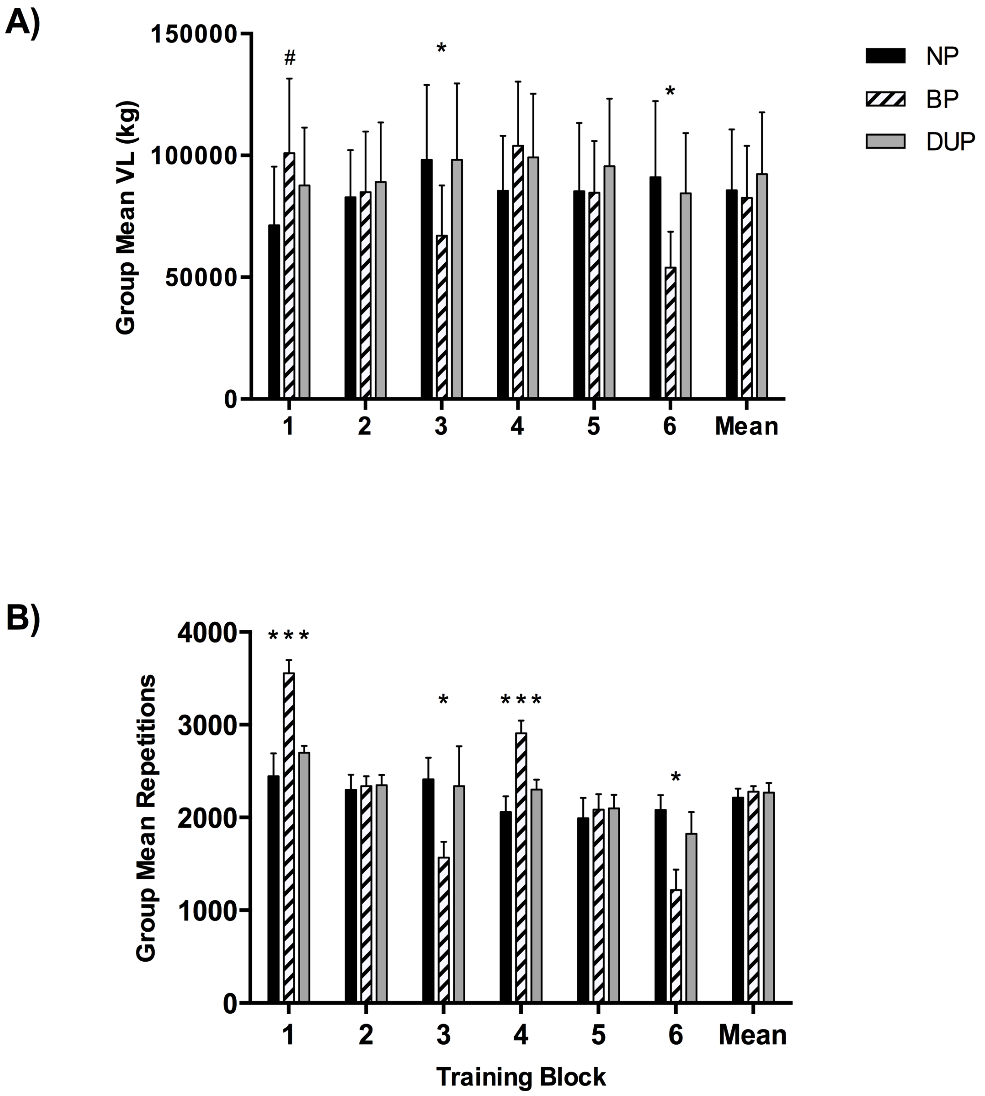

Figure 3.2. Group mean A) total VL and B) repetitions performed, across training blocks. * Signifies statistically different from both other groups, and # indicates statistically different from NP (p<0.05).

3.4.2 Outcome Measures

3.4.2.1 Control Period

There was a significant main effect for time for total cholesterol (p=0.047), triglycerides (p=0.020) and repeated chair rise performance (p<0.001) across the control period, with no significant interactions or between-group differences noted (p>0.05). Total cholesterol significantly increased from 5.71 ± 0.64 to 5.98 ± 0.64 mmol/L (ES=0.42), 5.83 ± 0.88 to 6.05 ± 1.00 mmol/L (ES=0.23) and 5.04 ± 0.97 to 5.20 ± 1.42 mmol/L (ES=0.13), for NP, BP and DUP groups, respectively. Similarly, triglycerides significantly increased from 1.07 ± 0.24 to 1.30 ± 0.45 mmol/L

(ES=0.64) for NP, 0.92 ± 0.28 to 0.97 ± 0.26 mmol/L for BP (ES=0.19), and 1.10 ± 0.51 to 1.15 ± 0.44 mmol/L (ES=0.10) for DUP. Finally, there was a significant reduction in the mean time for completing the repeated chair rise test, specifically 10.32 ± 1.37 to 9.70 ± 1.02 s (ES=0.51), 10.78 ± 1.89 to 10.12 ± 1.52 s (ES=0.38) and 9.87 ± 1.36 to 9.47 ± 0.99 s (ES=0.34), for NP, BP and DUP groups, respectively.

3.4.2.2 Body Composition, Anthropometric & Physiological Measures

Group mean ± SD, 95% CI and ES data for body composition, anthropometric (excluding height, BM and BMI) and physiological measures are presented in Tables 3.3 and 3.4, respectively. A significant main effect for time was evident for systolic blood pressure (p=0.034), total BF% (p<0.001), LBM (p<0.001), FM (p<0.001) and HDL cholesterol (p=0.039). However, no significant interactions or between-group differences were evident (p>0.05). As noted, a significant gender effect was found for total FM (p=0.025) with a significantly greater reduction evident in males (-3.48 ± 1.94 kg, ES=0.30) versus females (-1.86 ± 2.13 kg, ES=0.12), baseline to post-training.

3.4.2.3 Physical Function

Group mean ± SD, 95% CI and ES data for all physical function measures are presented in Table 4. A significant main effect for time (p<0.001) was noted for peak isometric torque, chest press and leg press 1RM, stair climbing and repeated chair rise performance. Furthermore, a significant interaction was found for chest press (p=0.034) and leg press (p=0.009) 1RM, but not peak isometric torque, stair climbing or repeated chair rise assessments (p>0.05). However, no between-group differences were detected for any physical function measures (p>0.05) based on ANCOVA.

3.4.2.4 Quality of Life and Balance Assessment

No main time effect or significant interactions for health-related QOL were noted, specifically physical and mental summary scores from the SF-36v2 (p>0.05) (Table 3). Also, a significant main time effect (p=0.018) on balance confidence was evident, however no significant interaction or between-group differences were noted (p>0.05).

3.4.2.5 Physical Activity and Dietary Intake Standardization

There was no significant interaction or main time effect for the frequency of total and moderate-intensity physical activity performed ($p>0.05$). In addition, dietary intake did not change significantly in the pooled data of the whole cohort for energy intake across the overall study period (7981.1 ± 1552.1 to 7847.8 ± 1992.8 kJ, 1.7%, ES=0.07). Furthermore, the % of energy derived from carbohydrate was statistically unchanged (p>0.05) (38.9 ± 7.2 to 40.3 ± 8.7 %, ES=0.17). However, the % of energy derived from protein significantly increased ($p=0.007$) (19.5 ± 4.3 to 21.2 ± 4.9 %, ES=0.37) and the % of energy derived from fat significantly decreased ($p=0.029$) (33.8 ± 6.4 to 31.1 ± 6.3 %, ES=0.43) for the entire cohort over the course of the study.

Table 3.3. Changes in anthropometric and health-related QOL outcome measures across the training period.

	NP			BP			DUP			All Groups			
Measure	**Mean ± SD**	**95% CI**	**ES**	**Mean ± SD**	**95% CI**	**ES**	**Mean ± SD**	**95% CI**	**ES**	**Mean ± SD**	**95% CI**	**ES**	**Power**
WHR													
Baseline	0.86 ± 0.08	0.80-0.92	-	0.86 ± 0.10	0.80-0.92	-	0.86 ± 0.09	0.80-0.93	-	0.86 ± 0.09	0.83-0.89	-	-
Post-training	0.84 ± 0.09	0.78-0.90	0.24	0.85 ± 0.10	0.79-0.91	-0.10	0.87 ± 0.08	0.81-0.93	0.12	0.85 ± 0.09	0.82-0.89	0.11	0.17
SBP (mm Hg)													
Baseline	148.2 ± 16.0	136.7-159.2	-	137.4 ± 22.5	123.8-151.0	-	129.0 ± 12.6	120.0-138.0	-	138.1 ± 19.1	131.4-144.9	-	-
Post-training	135.1 ± 20.3	120.6-149.6	0.77	134.2 ± 21.1	121.4-146.9	0.15	129.1 ± 13.1	119.8-138.4	0.01	132.9 ± 18.3	126.4-139.4	0.28	0.78
DBP (mm Hg)													
Baseline	76.3 ± 14.5	65.9-86.7	-	73.6 ± 11.7	66.5-80.7	-	71.6 ± 4.7	68.2-75.0	-	73.8 ± 11.0	69.9-77.7	-	-
Post-training	72.1 ± 12.1	63.5-80.7	0.31	70.3 ± 11.6	63.6-77.3	0.28	71.9 ± 7.0	66.9-76.9	0.05	71.3 ± 10.3	67.7-75.0	0.23	0.61
RHR (bpm)													
Baseline	61.6 ± 10.0	54.5-68.7	-	65.5 ± 13.5	57.4-73.7	-	64.9 ± 8.0	59.2-70.6	-	64.2 ± 10.8	60.3-68.0	-	-
Post-training	64.0 ± 6.6	59.3-68.7	0.29	66.8 ± 9.7	60.9-72.6	0.11	62.7 ± 7.3	57.4-67.9	0.29	64.7 ± 8.09	61.8-67.6	0.05	0.07
Total BF%													
Baseline	34.8 ± 7.1	29.7-39.9	-	35.7 ± 6.8	31.6-39.8	-	31.5 ± 6.0	27.2-35.8	-	34.2 ± 6.71	31.8-36.5	-	-
Post-training	30.5 ± 7.4	25.2-35.7	0.59	32.7 ± 7.0	28.4-36.9	0.43	27.4 ± 7.6	21.9-32.8	0.60	30.4 ± 7.41	27.8-33.0	0.54	1.00
Total FM (kg)													
Baseline	25.4 ± 7.2	20.3-30.6	-	26.2 ± 6.4	22.3-30.1	-	24.0 ± 6.6	19.3-28.8	-	25.3 ± 6.58	23.0-27.7	-	-
Post-training	22.4 ± 7.3	17.1-27.6	0.41	24.3 ± 6.6	20.3-28.2	0.29	21.0 ± 6.6	16.2-25.7	0.45	22.7 ± 6.74	20.3-25.1	0.39	0.98
Total LBM (kg)													
Baseline	45.8 ± 13.2	36.4-55.3	-	44.9 ± 8.2	40.0-50.0	-	50.1 ± 10.0	43.0-57.2	-	46.8 ± 10.3	43.1-50.4	-	-
Post-training	49.1 ± 13.9	39.1-59.0	0.24	47.4 ± 8.4	42.3-52.5	0.30	53.9 ± 12.4	45.1-62.8	0.34	49.9 ± 11.5	45.8-54.0	0.28	0.78
Total BMC (g)													
Baseline	2235.1 ± 612.6	1796.9-2673.2	-	2311.4 ± 480.5	2021.0-2601.7	-	2180.7 ± 419.2	1880.8-2480.6	-	2248.7 ± 494.6	2073.3-2424.0	-	-
Post-training	2218.5 ± 620.1	1774.8-2662.0	0.03	2323.0 ± 498.5	2021.8-2624.2	0.02	2138.6 ± 434.3	1828.0-2449.3	0.10	2235.4 ± 510.4	2054.5-2416.4	0.03	0.05
Total BMD (g/cm^2)													
Baseline	1.08 ± 0.14	0.98-1.18	-	1.11 ± 0.14	1.03-1.20	-	1.05 ± 0.10	0.97-1.12	-	1.08 ± 0.13	1.04-1.13	-	-
Post-training	1.07 ± 0.14	0.97-1.17	0.00	1.12 ± 0.15	1.03-1.21	0.00	1.04 ± 0.11	0.96-1.12	0.10	1.08 ± 0.13	1.04-1.13	0.00	0.05
Physical QOL													
Baseline	52.6 ± 7.83	47.0-58.2	-	52.0 ± 5.62	48.6-55.4	-	55.0 ± 4.16	51.8-58.2	-	53.0 ± 6.01	50.9-55.2	-	-
Post-training	53.6 ± 4.45	50.4-56.8	0.17	52.0 ± 6.21	48.2-55.7	0.00	55.4 ± 5.73	51.0-59.8	0.07	53.5 ± 5.58	51.5-55.5	0.09	0.13
Mental QOL													
Baseline	50.6 ± 11.4	42.4-58.8	-	54.6 ± 4.62	51.8-57.3	-	58.6 ± 1.53	57.4-59.8	-	54.5 ± 7.52	51.7-57.2	-	-
Post-training	53.3 ± 5.60	49.3-57.3	0.30	58.3 ± 4.81	55.4-61.2	0.79	58.1 ± 2.99	55.8-60.4	0.29	56.7 ± 5.08	54.8-58.5	0.34	0.92

N.B. SBP = systolic blood pressure; DBP = diastolic blood pressure; Power = post-hoc power analyses.

Table 3.4. Changes in physiological, physical function and balance confidence outcome measures across the training period.

	NP			BP			DUP			All Groups			
Measure	**Mean ± SD**	**95% CI**	**ES**	**Mean ± SD**	**95% CI**	**ES**	**Mean ± SD**	**95% CI**	**ES**	**Mean ± SD**	**95% CI**	**ES**	**Power**
CRP (mg/L)													
Baseline	1.97 ± 1.29	0.97-2.96	-	1.39 ± 1.91	0.21-2.76	-	1.88 ± 2.55	-0.53-3.16	-	1.73 ± 1.93	0.99-2.48	-	-
Post-training	1.84 ± 1.71	0.53-3.16	0.13	2.05 ± 3.76	-0.64-4.74	0.22	1.89 ± 2.34	-0.89-3.69	0.08	1.93 ± 2.69	0.89-2.97	0.09	0.13
Total Chol (mmol/L)													
Baseline	5.98 ± 0.64	5.49-6.47	-	6.05 ± 1.00	5.41-6.69	-	5.20 ± 1.42	4.18-6.22	-	5.75 ± 1.11	5.35-6.16	-	-
Post-training	5.90 ± 0.29	5.68-6.12	0.21	5.93 ± 0.98	5.31-6.55	0.20	5.45 ± 1.18	4.60-6.30	0.19	5.77 ± 0.92	5.43-6.10	0.02	0.05
HDL Chol (mmol/L)													
Baseline	1.57 ± 0.37	1.28-1.85	-	1.74 ± 0.30	1.55-1.93	-	1.34 ± 0.30	1.13-1.55	-	1.56 ± 0.35	1.43-1.69	-	-
Post-training	1.66 ± 0.34	1.39-1.92	0.28	1.80 ± 0.34	1.58-2.02	0.33	1.42 ± 0.32	1.19-1.65	0.26	1.64 ± 0.36	1.50-1.77	0.23	0.61
LDL Chol (mmol/L)													
Baseline	3.82 ± 0.65	3.32-4.32	-	3.86 ± 0.92	3.28-4.44	-	3.34 ± 1.32	2.40-4.28	-	3.68 ± 1.00	3.31-4.05	-	-
Post-training	3.71 ± 0.30	3.48-3.94	0.19	3.68 ± 0.91	3.11-4.26	0.22	3.57 ± 1.05	2.82-4.32	0.19	3.65 ± 0.81	3.36-4.00	0.03	0.06
Triglyceride (mmol/L)													
Baseline	1.30 ± 0.45	0.94-1.49	-	0.97 ± 0.26	0.80-1.23	-	1.15 ± 0.44	0.83-1.47	-	1.12 ± 0.39	0.98-1.27	-	-
Post-training	1.18 ± 0.40	0.77-1.73	0.22	0.95 ± 0.30	0.79-1.31	0.00	0.99 ± 0.33	0.75-1.23	0.41	1.03 ± 0.35	0.90-1.16	0.24	0.65
Peak Iso Torque (Nm)													
Baseline	153.0 ± 47.6	118.9-187.0	-	147.5 ± 47.6	119.0-176.3	-	161.7 ± 55.9	121.7-201.6	-	148.7 ± 47.9	131.8-165.7	-	-
Post-training	168.2 ± 55.8	128.3-208.1	0.29	175.4 ± 46.9	147.1-203.8	0.59	180.1 ± 50.3	144.2-216.1	0.35	166.6 ± 46.4	150.2-183.1	0.40	0.98
Chest Press 1RM (kg)													
Baseline	32.4 ± 14.9	19.9-44.9	-	27.3 ± 11.0	19.9-34.6	-	35.8 ± 14.6	25.4-46.3	-	31.6 ± 13.5	26.5-36.8	-	-
Post-training	40.5 ± 18.1	25.4-55.6	0.49	37.5 ± 13.9	28.1-46.8	0.81	44.5 ± 19.2	30.8-58.3	0.51	40.7 ± 16.7	34.4-47.1	0.60	1.00
Leg Press 1RM (kg)													
Baseline	92.9 ± 29.1	72.1-113.7	-	94.0 ± 28.4	75.9-112.0	-	121.0 ± 40.2	90.1-151.9	-	101.5 ± 33.8	89.1-113.9	-	-
Post-training	132.2 ± 39.5	103.9-160.4	1.13	146.8 ± 42.4	119.9-173.7	1.46	170.8 ± 61.5	123.5-218.1	0.96	149.0 ± 48.7	131.2-166.9	1.13	1.00
Stair Climbing (s)													
Baseline	3.73 ± 0.60	3.27-4.19	-	3.95 ± 1.01	3.31-4.59	-	3.93 ± 0.77	3.38-4.48	-	3.89 ± 0.80	3.59-4.18	-	-
Post-training	3.31 ± 0.51	2.93-3.70	0.75	3.59 ± 0.91	3.02-4.17	0.37	3.53 ± 0.78	2.97-4.09	0.52	3.49 ± 0.75	3.22-3.77	0.52	1.00
Repeated Chair Rise (s)													
Baseline	9.70 ± 1.02	8.84-10.6	-	10.1 ± 1.63	9.09-11.2	-	9.47 ± 0.99	8.76-10.2	-	9.79 ± 1.28	9.31-10.3	-	-
Post-training	7.23 ± 0.91	6.47-8.00	2.56	8.31 ± 1.31	7.48-9.14	1.21	7.60 ± 0.96	6.92-8.29	1.92	7.79 ± 1.16	7.35-8.22	1.64	1.00
Balance Confidence													
Baseline	9.42 ± 0.66	8.95-9.89	-	9.25 ± 0.60	8.89-9.61	-	9.58 ± 0.71	9.08-10.1	-	9.40 ± 0.64	9.18-9.63	-	-
Post-training	9.63 ± 0.42	9.32-9.93	0.38	9.59 ± 0.41	9.34-9.84	0.66	9.62 ± 0.49	9.26-9.97	0.07	9.61 ± 0.43	9.46-9.76	0.39	0.98

N.B. Chol = cholesterol; Iso = isometric; Power = post-hoc power analyses.

3.5 Discussion

This study investigated the effect of 22 weeks of BP, DUP and NP RT on a comprehensive range of physical function and health outcomes in apparently healthy untrained older adults. Contrary to our original hypothesis that periodized RT would enhance training adaptations, all three training models were equally effective for promoting significant improvements in various physical function and physiological health outcomes through RT in this population.

In order to compare the impact of different RT models, it is essential to equalize the overall training volume at completion of training. If not, whether differences are due to the periodization structure, or simply greater accumulation of total training volume, is unknown. In contrast, it has been proposed that if the overall training volume and intensity is equal, similar rates of adaptation will occur despite the periodization model (14), supported by the present findings. In detail, NP, BP and DUP RT, regardless of differences in program structures (Figure 3.2), demonstrated an equally significant beneficial impact on several important physical function and health-related outcomes. Therefore, despite failing to detect an optimal training model, our data further support the considerable public health implications of RT for older adults. Overall, the present RT interventions were successful at improving systolic blood pressure (mean change for all groups, -3.2%), total BF% (-11.9%), FM (-11.1%), LBM (6.7%), HDL cholesterol (5.9%), peak isometric torque (15.1%), chest press (30.3%) and leg press (47.1%) 1RM, repeated chair rise (9.9%) and stair climbing (20.7%) performance, and balance confidence (2.3%) (Tables 3 and 4). This range of positive adaptation is considerable and collectively lowers the risk of chronic disease, while preserving independence and increasing QOL. Considering maximal strength improvements alone, based on annual strength reductions between 2.5-5% with advancing age (10, 115), the present 15.1% increase in peak isometric torque indicates counteracting ~3-6 years of age-related strength loss following only 22 weeks of RT. This rises to ~7-15 years when based on the average 38.7% improvement across chest press and leg press 1RM measures.

As noted, previous investigation of periodized RT in older adults is lacking, with few studies examining limited outcome measures in untrained subjects. Yet in agreement with the present findings, similar strength and body composition improvements have been previously reported between NP and DUP structures following 25 weeks of RT (177), and NP and BP RT across an 18-week training

period (73). What's more, 12 weeks of traditional and undulating periodized RT produced comparable increases in lower-body strength and power in elderly men (190). Finally, 16 weeks of traditional and undulating periodized RT were found to be equally effective for leg press 1RM and functional capacity improvements among untrained elderly females (298). Therefore based on the current available evidence, it appears that RT periodization is not critical for optimizing physical function and physiological adaptations in untrained older adults.

The GAS is central to periodization theory, which states that if a system experiences a stressful bout of exercise, it will respond with a temporary decrease in performance followed by supercompensation. However, if the applied stress remains at the same magnitude (i.e. intensity, volume and frequency), the system will accommodate to this stress and adaptations will plateau. Consequently, training programs are often organized to routinely provide a novel stimulus, thereby promoting continued adaptations. Considering this, it is important to acknowledge the inclusion of untrained subjects in the present and previous studies examining periodization in older adults. Based upon the emerging evidence that regular performance of RT can attenuate the hypertrophic response (334), increasing muscle mass may become more difficult over time, subsequently hindering performance improvements. Thus, more advanced RT protocols such as structured periodization of increasingly heavier loads or greater time under tension may be necessary to elicit meaningful adaptations to RT in trained individuals. Also, based upon the idea that initial strength adaptations are predominantly due to enhanced neural activation and coordination, more advanced RT may be required for continued adaptation once these basic motor skills are acquired (206). However, recent evidence highlighting significant improvements in muscular hypertrophy following only 9 weeks (18 sessions) of RT in older adults (225) challenges this notion. Nevertheless, the present 22-week training period was possibly too brief to observe any advantage of periodized RT, and consequently NP, BP and DUP RT provided a similar novel training stimulus across the untrained cohort. Therefore, whether periodized RT strategies enhance training adaptations in older adults with at least one year of consistent RT experience warrants examination.

However, despite no statistical between-group differences noted in outcome measures following RT, there are some distinctions worth noting based on ES data. First, the largest ES for improvements in isometric and dynamic (1RM) strength were

apparent in BP (Table 3.4). Yet, as strength improvements following RT are the result of motor learning as well as physiologic changes in muscle, and as BP performed an intensified block of 5RM immediately prior to post-intervention testing, subjects were ultimately practicing the specific motor schema associated with lifting heavier loads and greater force production. Therefore, larger strength improvements resulting from BP are not surprising and highlight the neuromuscular specificity of training. Also, while such 'peaking' may be critical in sport performance, i.e. prior to major competition, this is less relevant in a health and wellness setting. Nevertheless, considering that strength has been shown to be more important than quantity in estimating mortality risk (275), future studies should include more routine strength assessments across RT interventions in order to confirm this.

Similarly, the ES for improvements in balance confidence was also greatest in BP (0.66), followed by NP (0.38) and DUP (0.07), suggesting a possible association with maximal strength. Yet this pattern was not observed for the significant increase in functional capacity measures, with the greatest magnitude of effect noted in NP>DUP>BP. Such disparity between the impact of RT models on strength, balance and functional abilities proposes that factors other than maximal strength likely influence functional capacity among older adults. For instance, power is postulated as a greater indicator of functional status than strength, and a positive association between RT-induced power adaptations and ADL performance has been highlighted among the elderly (27, 28). However, due to the exclusion of power measures in the present study, further research is required to confirm the impact of periodized and NP RT models on neuromuscular abilities along the entire force-velocity curve in the aging population.

Further, the reduction in triglycerides differed among groups, with an ES of 0.57, 0.22 and 0.00 for DUP, NP and BP groups, respectively, thus suggesting that daily manipulation of the training stimulus may be most preferable for improvements in blood lipids. Finally, there was a moderate, borderline large ES for the reduction in systolic blood pressure (0.77) following NP RT, with a non-meaningful effect noted in BP and DUP (Table 3.3). Consequently, NP, BP and DUP models may all hold promise in improving different aspects of health and physical function, and further investigation may lead to the recommendation of an appropriate RT model based upon the specific outcome(s) desired. As noted, whether such between-group differences would increase in magnitude among experienced lifters remains unknown.

It has been proposed that implementing brief, simple, feasible and efficacious RT interventions with emphasis on long-term adherence should be prioritized in a public health setting, with subtle differences in strength gains resulting from complex RT protocols less critical (293). The application of basic periodization strategies may therefore be advantageous via better management of training monotony, which likely enhances the enjoyment of and tolerance to RT, ultimately aiding long-term adherence. On the other hand, loads equivalent to 90% and 30% of 1RM lifted to momentary muscular concentric failure were reported to produce similar acute increments in protein synthesis (49). Therefore, based upon the size principle, the degree of motor unit activation achieved during RT may consequently be considered more important than the external load. What's more, a recent meta-analysis concluded that RT using low loads ≤60% 1RM promotes substantial increases in strength and hypertrophy among untrained individuals (335). Therefore, RT involving lifting low loads to muscular failure may offer a simplistic and feasible training model for the aging population, particularly when aiming to optimize adherence under minimal supervision (293).

However, as persistently training to muscular failure is suggested to increase the potential for overtraining and psychological burnout (120), and likely caused the signs of overtraining observed in the present study, the safety and sustainability of this approachable is questionable. Also, although loads ≤60% 1RM were found to induce considerable training adaptations, there was a trend for the superiority of higher loads (≥65% 1RM) on both strength and hypertrophy, with relatively short training durations (6-13 weeks) in the small number of studies included acknowledged as limitations (335). Also, whether loads ≤60% 1RM promote continued adaptation once a training base is established is unknown. Nevertheless, the minimal effective dose of heavier loads necessary for optimizing training adaptations in older adults requires examination. For instance, 'heavier' loads ~65% 1RM may be sufficient, rather than 5RM loads (~87% 1RM) as prescribed in the current study.

Yet, above all, due to such drastically low participation rates reported among the elderly (227), educating this population on the vast benefits of RT and engaging them in any type of regular training is significant. Accessibility and affordability of RT is also critical, where these factors should be the primary focus prior to examining the finer aspects of program design. Also, despite ACSM providing clear and concise recommendations for RT in older adults (306), it seems the public health message of

‘move more, sit less’ is most commonly endorsed. Obviously performing any regularly physical activity (walking, swimming, cycling) is beneficial compared to a sedentary lifestyle, but perhaps an increased effort to specifically promote RT is required, particularly when a large portion of the aged population are likely completely unaccustomed to lifting weights.

As the control period was used to ensure reliability of baseline measures, it is important to acknowledge the statistical change in measures during this 4-week period of no RT. Despite familiarization sessions, the significant improvement in repeated chair rise performance was likely due to practice of the protocol. Yet, the magnitude of effect across the control period (NP=0.51, BP=0.38, DUP=0.34) was minute in contrast to that observed post-RT (NP=2.56, BP=1.21, DUP=1.91). Therefore, the improvement in function following RT was considered to be a direct result of the intervention. Additionally, the ES for the increase in total cholesterol was moderate for NP (0.42), and small for BP (0.23) and DUP (0.13) following the control period, with this pattern also evident for the increase in triglycerides (ES; NP=0.64, BP=0.19 and DUP=0.10). Although subject’s dietary intake was statistically unchanged during this period based on the 3 day weighed food dietary analyses, many subjects commented that during the control period they were enjoying their “final few weeks of freedom” before embarking on 22 weeks of RT. Therefore, it is questioned whether additional foods and drinks were consumed but unreported in the dietary analysis, which may have influenced such blood biomarker results. However, as body composition indices remained unchanged during this time, this remains speculative and highlights the limitation of self-reported dietary intake.

Finally, as noted, thirty-three subjects fulfilled all study requirements and were included in the final analyses, however this did not satisfy the a priori sample size estimate of thirty-six subjects. Therefore, the present sample size is a potential limitation and it could be argued that between-group statistical differences were possibly undetected due to type II error. It is recommend that future long-term training studies recruit an adequate cohort to ensure sufficient statistical power, considering the present dropout rate of 19.5%.

In summary, NP, BP and DUP RT models are equally effective for promoting significant improvements in various physical function and physiological health outcomes in apparently healthy untrained older adults. Consequently, periodization strategies do not appear to be necessary during the initial stages of RT in aging

individuals. The present data support the considerable public health implications of RT, ultimately lowering the risk of chronic disease, while preserving independence and increasing QOL. The impact of periodization strategies on neuromuscular abilities along the entire force-velocity curve, in previously trained older adults, and on long-term enjoyment, tolerance, and adherence remains unknown. Practitioners should work towards increasing RT participation among older adults via feasible and efficacious interventions targeting long-term adherence in minimally supervised settings.

CHAPTER FOUR

Periodization Strategies for Older Adults: Impact on Neuromuscular Adaptations

N.B. The following chapter is under review for publication:

Conlon JA, Newton RU, Tufano JJ, Banyard, HG, Hopper AJ, Ridge AJ, & Haff GG. Periodization Strategies for Older Adults: Impact on Neuromuscular Adaptations. *European Journal of Applied Physiology*, 2016 (in review).

However, the formatting has been adjusted from the original manuscript to allow continuity through the entire thesis document.

4.1 Abstract

This study compared the effect of periodized versus NP RT on neuromuscular adaptions in older adults. Forty-one apparently healthy untrained older adults (female=21, male=20; 70.9 ± 5.1 y; 166.3 ± 8.2 cm; 72.9 ± 13.4 kg) were recruited and randomly stratified to a NP, BP, or DUP training group. Outcome measures were assessed at baseline and following a 22-week RT intervention (3 $d \cdot wk^{-1}$), including; muscle CSA, VJ performance, isometric and isokinetic peak torque, isometric RFD and muscle activation. Thirty-three subjects satisfied all study requirements and were included in analyses (female=17, male=16; 71.3 ± 5.4 y; 166.3 ± 8.5 cm; 72.5 ± 13.7 kg). Block periodization, DUP and NP RT induced statistically significant improvements in muscle CSA, VJ peak velocity, peak power and jump height, and peak isometric and isokinetic torque of the knee extensors at $60^{o} \cdot s^{-1}$ and $180^{o} \cdot s^{-1}$, with no between-group differences. Muscle activity and absolute RFD measures were statistically unchanged across the entire cohort following RT. Periodized RT, specifically BP and DUP, and NP RT are equally effective for promoting increases in muscular hypertrophy, strength and power among untrained older adults. Consequently, periodization strategies are not essential for optimizing neuromuscular adaptations during the initial stages of RT in the aging population.

Key Words: Elderly, sarcopenia, health, adaptation, training model

4.2 Introduction

The association between aging and the progressive loss of muscle mass is referred to as 'sarcopenia', commencing around the age of 50 years and accelerating beyond the sixth decade (318). This decline in muscle mass is thought to be predominantly mediated by a reduction in the size of muscle fibers, commonly measured by the anatomical CSA, and/or number of individual muscle fibers (88, 222). Despite an equal decline in the number of type I and II muscle fibers, cellular age-related atrophy is fiber-type specific, most notable in type II fibers (222).

Due to the significant relationship between maximal force production and muscle CSA, the ability of the neuromuscular system to express muscle strength and power similarly diminishes with aging (343). Specifically, muscular power development is suggested to decline more rapidly than maximal strength and is more closely related to functional capacity (27, 183, 343). Further, many ADL require a rapid development of force in a limited amount of time (<200 ms; e.g. preventing a fall), which is significantly less time than that required to achieve maximal force production (~300-600 ms) (2). Consequently, the ability to develop a rapid rise in muscle force and subsequently large impulse under such time restrictions, i.e. RFD (Δforce/ Δtime), is suggested to be more important than both maximal muscle force and power in older adults (355), and has been shown to be reduced among healthy elderly individuals when compared with younger counterparts (183).

In addition, neural mechanisms also contribute to this cascade of age-related neuromuscular decline, including a reduction in the maximal voluntary activation of the agonist muscles (148). Overall, such unfavorable alterations in neuromuscular capacity are responsible for the compromised functional capacity observed in older adults, thereby increasing the risk of falls, reducing independence and QOL, and ultimately increasing the economic burden of health care in this population.

Fortunately, a continually growing body of research highlights the adaptability of the aging neuromuscular system, with RT shown to induce marked increases in muscle CSA (145, 148), maximal force (53, 145, 148, 149, 154), power (53, 149), RFD (53, 149) and muscle activation (145, 148, 149, 152, 154). Therefore, the implementation of effective, safe and sustainable RT models among this population is clinically relevant and feasible; however due to the vast variability of training programs evident in the literature, a general consensus for an 'optimal' RT model remains unknown.

Among the studies listed above, a large variability in the RT intervention characteristics is evident. Specifically, some studies combine progressive high resistance and maximal power RT, while others implement daily variation in the training stimulus, for instance hypertrophy, strength and power days within a microcycle. Second, training duration and frequency varied from 10 to 24 weeks and 2-3 $d \cdot wk^{-1}$, respectively. Furthermore, total-body and isolated lower-body RT have both been used, and although machine-based exercises were mainly implemented, free weights and bodyweight trunk exercises have also been reported. Additionally, lifting loads, whether prescribed using the percentage of 1RM or RM target, ranged from 40-80% 1RM and 3-10RM within and between studies. Regarding training volume, the prescription, progression and modification of set and repetition schemes within training programs has also differed significantly. Finally, 5-7 exercises were performed during RT sessions, yet rest intervals, lifting velocity, and time between training sessions were often unreported.

The process of organizing RT variables (load, volume, modality, frequency and duration) within a training program is typically referred to as *periodization.* Due to the large number of variables that may be organized in various formats, periodization can be complex in nature, particularly in a high performance setting where specific training outcomes are warranted at pre-determined time-points (e.g. major competition). Two of the most common periodization strategies include BP and DUP. Specifically, BP classically uses a four week block of highly concentrated training targeting specific training outcomes, e.g. muscular hypertrophy or maximal strength (284). Alternatively, DUP varies training volume and intensity on a daily basis, hence there is a more frequent manipulation of the training stimulus.

In older adults, the impact of periodized RT on 1RM strength (73, 177, 190, 298), maximal force (177) and power (190), has been examined across 12 (190), 16 (298), 18 (73) and 25 weeks (177). Overall, similar improvements in outcome measures were evident post-RT across the various RT groups, despite the distinct differences in training structures. However, a comprehensive assessment of long-term effects of periodized RT on neuromuscular adaptations in older adults has not been completed, specifically muscle CSA, maximal force, power, RFD, and muscle activation.

Therefore, the aim of this study was to evaluate the impact of long-term (22 weeks) BP, DUP and NP RT on neuromuscular adaptations in older adults. We

hypothesized that BP and DUP would produce greater improvements in training outcomes when compared to a NP structure.

4.3 Methods

4.3.1 Subjects

Forty one healthy older adults were recruited for the present study (female=21, male=20; 70.9 ± 5.1 y; 166.3 ± 8.2 cm; 72.9 ± 13.4 kg). Sample size estimation was based upon muscle CSA and activity measures during previous RT interventions of similar duration among older adults (149, 177), which displayed the most conservative ES among measures used in our study. An ES of 0.27 with a power of 80% at an alpha level of 0.05 produced a total sample size of thirty-nine, based on a repeated-measures, within-between ANOVA model (G*Power 3.1 software).

All subjects provided medical clearance from their personal physician and completed a health history questionnaire. Exclusion criteria included lactose intolerance (protein supplementation provided), a BMI ≥ 30 $kg \cdot m^2$, any prescribed medication that could confound data, e.g. testosterone or corticosteroids, any pre-existing musculoskeletal, cardiovascular or neurological condition, or any other condition considered to cause risk to the subjects through RT or testing procedures, or reduce their ability to adapt. Additionally, subjects were untrained, specifically they had not participated in structured exercise training designed to improve physical fitness over the previous 12 months. Finally, subjects were instructed to continue with their normal daily activities and discouraged from engaging in any unaccustomed physical activity outside of their designated RT program. The Edith Cowan University Human Research Ethics Committee approved the study and subjects were fully informed of the nature and possible risks of all procedures before providing written informed consent.

4.3.2 Experimental Design

The present study employed a 3 (groups) x 3 (time-points) between-/within-subjects design, with a total duration of 31 weeks, comprising two familiarization sessions, a 4-week control period, a 22-week RT period, and completion of all testing procedures. Subjects completed testing sessions in weeks 2, 7 and 31, using identical protocols. Weeks 3-6 were used as a control period to ensure reliability and stability of baseline measures, during which no RT was performed, and subjects simply

maintained their normal recreational physical activities. Thereafter, subjects commenced a 22-week RT intervention at a frequency of 3 $d \cdot wk^{-1}$, excluding weeks 22, 25 and 28 when subjects trained 1 $d \cdot wk^{-1}$. These weeks were classed as transition weeks and were modified *ad hoc* due to observing signs of persistent fatigue and a reduced motivation to train among some subjects. Therefore, the aim was to promote recovery and reduce the potential for injury or illness. Furthermore, no RT was performed during week 19 for the completion of testing procedures at the mid-training time-point (data not included in the present study) and continued as normal in week 20. Therefore, the total number of prescribed training sessions over the intervention was 60. Furthermore, subjects were randomly stratified into the three experimental RT groups (NP, BP and DUP) based on gender, age, BMI, and strength (peak isometric torque of the right knee extensors). A visual depiction of the experimental design is provided in Figure 4.1.

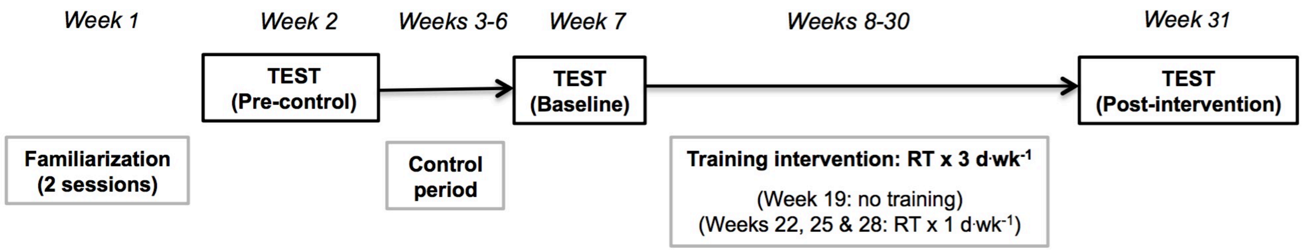

Figure 4.1. A visual depiction of the experimental design including familiarization, all testing procedures and the 22-week RT intervention (reproduced from Conlon et al. (62) with permission from Wolters Kluwer Health, Inc.).

4.3.3 Testing Procedures

Subjects were fully familiarized and instructed in the proper execution of all testing protocols across two familiarization sessions to reduce the influence of any acute learning effects. Testing procedures were conducted using the same equipment at one location, by the same researcher across the study who was blinded to the subject's training group assignment, and with subjects being tested at a similar time of day to reduce the effect of any diurnal variations. At each testing time-point, subjects were required to visit the testing location on three occasions, separated by approximately 48 h in order to complete all testing procedures.

4.3.3.1 Anthropometric Measures

Body mass was measured by a calibrated electronic scale (HW200, A&D Mercury Pty, Ltd, Thebarton, SA) to the nearest 100 g and height was determined with a wall-mounted stadiometer (Model 220, SECA, Hamburg, Germany) to the nearest millimeter.

4.3.3.2 Muscle Hypertrophy

Muscle CSA of the quadriceps femoris muscle group, specifically the mVL and rectus femoris (mRF), was measured using B-mode axial-plane ultrasound (Aloka SSD-α10, software version 6.1.09, Aloka Co., Ltd., Tokyo, Japan). Images were captured using a 10 MHz linear-array probe (60 mm width) implementing the extended field of view technique (277). Specifically, a line from the lateral epicondyle of the femur to the greater trochanter was highlighted and two perpendicular lines at 50 and 66% from the greater trochanter were marked. A continuous single view was taken by moving the probe transversely across the thigh on the marked site, applying minimal pressure to avoid compression of the underlying tissue and with subjects instructed to relax their thigh throughout the procedure. Three images of each site were analyzed for CSA values using ImageJ digitizing software (1.46r, National Institutes of Health, USA), with mean data included in statistical analyses. The average intraclass correlation coefficient (ICC) (with 95% confidence intervals: CI) for muscle CSA measures was 0.993 (0.985-0.996).

4.3.3.3 Neuromuscular Performance

Measures of neuromuscular performance included isometric and isokinetic peak torque, VJ, isometric RFD, and muscle activation via surface EMG. Prior to performing these tests, subjects completed a warm-up consisting of 5 minutes of light stationary cycling. Vertical jump performance was assessed following anthropometric and muscle CSA measures at the start of the test week, with peak torque assessments and related surface EMG measures carried out approximately 96 h following. Strong verbal encouragement was provided throughout all protocols.

<u>*Isometric & Isokinetic Peak Torque:*</u> An isokinetic dynamometer (Biodex *System 3 Pro,* Ronkonkoma, NY) was used to measure isometric peak torque (Nm) and isokinetic peak torque ($N{\cdot}sec^{-1}$) of the right knee extensors. To prevent an order effect, protocols were randomized using a freely available online computer program

(http://www.psychicscience.org/random.aspx). The torque signal was collected at a sampling frequency of 1000 Hz and recorded on a computer for later analysis using LabChart 8 software (PowerLab System, ADInstruments, NSW, Australia). Subjects were seated with the thigh and trunk secured to the device for all test protocols. Both isometric and isokinetic measures were normalized (*n*) using body mass (*m*) to assess strength (*S*) independent of any changes in body size during the intervention using the following equation:

$$S_n = S / m^b$$

Where *b* is the allometric parameter, specifically 0.67 for isometric and 1 for isokinetic peak torque (188).

Isometric peak torque was measured with the hip and knee angles at 110° and 120°, respectively (180° refers to full extension). Subjects performed one submaximal 3 s contraction at 50% of perceived maximal intensity. Following 1 min of rest, participants performed a maximal voluntary isometric contraction (MVIC) for 3 s, with 1 min rest between three separate repetitions. If any countermovement was evident or if peak torque differed by >5% between attempts, a further repetition was performed. The average peak torque measured across the three MVIC trials was included in statistical analyses. The ICC (with 95% CI) for isometric peak torque was 0.949 (0.897-0.975).

Isokinetic peak torque was measured at $60^{o} \cdot s^{-1}$, $180^{o} \cdot s^{-1}$ and $300^{o} \cdot s^{-1}$, with the hip and knee at 110° and 90°, respectively. Subjects completed one submaximal set of three repetitions at 50% of self-perceived maximal intensity, before two sets of three maximal repetitions were performed at each angular velocity, with 1 min recovery between sets. The average peak torque at each angular velocity was used for statistical analyses. The average ICC (with 95% CI) for isokinetic peak torque measures was 0.924 (0.847-0.963).

Vertical Jump: Peak velocity, peak force, peak power and jump height were measured during a countermovement jump (CMJ) using a force plate (400s Performance Plate, Fitness Technology, Adelaide, Australia). Subjects were instructed to lower to a self-selected depth and maximally jump upward as quickly as possible with their hands held on their hips. Vertical ground reaction forces were recorded via the force plate, collected at a sampling frequency of 600Hz using the Ballistic Measurement System software (Fitness Technologies, Adelaide, Australia).

Three total trials were performed with mean data used for statistical analyses. The average ICC (with 95% CI) for VJ measures was 0.961 (0.919-0.982).

Rate of Force Development (RFD): The isometric RFD ($N \cdot sec^{-1}$) was defined as the slope of the isometric torque-time curve in the time intervals 0-30 ms (RFD_{30}), 0–50 ms (RFD_{50}), 0–100 ms (RFD_{100}) and 0–200 ms (RFD_{200}) (2). The onset of muscle contraction was defined as the time point at which the torque curve exceeded the baseline by >7.5 N·m to account for electromechanical delay (2), and if torque dropped >5 N·m below the baseline at the beginning of a contraction, RFD analysis was not undertaken based on excessive countermovement. Offline analysis was performed using LabChart software with mean data included in statistical analyses. The average ICC (with 95% CI) for RFD measures was 0.891 (0.776-0.947).

Surface EMG: Muscle activity of the mVL and mRF of the right leg was measured during isometric neuromuscular assessments via surface EMG using a Bagnoli-8 desktop EMG system (Delsys, MA, USA). Prior to electrode placement, the skin was carefully prepared via shaving, gentle abrading and cleaning with alcohol. A surface bipolar electrode (DE-2.1 single differential surface EMG sensor) with a 1 cm inter-electrode distance was positioned on the skin over the belly of each muscle, parallel to the direction of muscle fibers, according to SENIAM recommendations (114). A sampling frequency of 2000 Hz with a gain of 2,000, and a band-width frequency filter of 10-450 Hz was used. The signal was full-wave rectified with the average root mean square (RMS) amplitude (mV) calculated for both muscles using a 250ms window around the point of peak torque during the MVIC. LabChart software was used to record and analyze data with mean data included in statistical analyses. The average ICC (with 95% CI) for EMG measures was 0.868 (0.657-0.949).

4.3.3.4 Physical Activity and Dietary Intake Standardization

Subjects were encouraged to maintain their habitual physical activity and dietary intake throughout the study. Physical activity was assessed via the CHAMPS Physical Activity Questionnaire for Older Adults (University of California, USA) (131). Dietary intake was assessed using a 3 day weighed food diary, recorded by subjects during the week prior to testing weeks, and assessed for any significant changes in energy intake and macronutrient profile using FoodWorks 7 software (Xyris, QLD) and the AUSNUT 2007 database of Australian foods. Specifically,

subjects were provided with validated scales and measuring devices, with dietary intake recorded on the same days throughout the study. However, this was across three non-training days during weeks 1 and 6, and two "normal" days and one training day during week 30.

4.3.4 Resistance Training

All exercises were executed on RT machines (Cybex, MA, USA) with zero use of free weights. The resistance and repetitions performed in the work-sets for each exercise were recorded in a training log and served as a written record for subjects at the start of the training sessions. Subjects were fully familiarized with all machines prior to commencing the training intervention. Furthermore, training sessions were performed at a regular time of day, with a minimum of 48 h between sessions, and were supervised by exercise science bachelor degree qualified instructors to ensure proper exercise technique and reduce the risk of injury.

All training sessions commenced with a 5 min standardized warm-up consisting of light stationary cycling, rowing or brisk walking on an ergometer or treadmill (Technogym, London, UK). Resistance exercise selection remained the same across the study and was identical between all training groups, targeting concentric and eccentric muscle actions of major muscle groups and with lower-body and upper-body exercises alternated. Specifically, exercises included: seated leg press, lat pull-down, seated leg-curl, chest press, leg extension and seated row. A total-body RT regime was prescribed due to examining the impact on upper-body outcome measures not presented here. A warm-up set of each exercise was completed at approximately 50% of the resistance of the first work-set. In order to provide recovery, a rest interval of 1 min was required between the warm-up set and the first work-set, and a 1.5-2 min recovery period was employed between consecutive work-sets. Subjects were instructed to perform the concentric portion of exercises with maximal velocity to promote optimal neuromuscular adaptation and functional performance (39), and control the eccentric portion using a 2 s cadence as monitored by the instructors.

Exercise resistance was prescribed using RM sets to ensure that the resistance stimulus was progressive to accommodate strength adaptations, requiring adjustment of the exercise resistance to ensure momentary neuromuscular concentric failure (i.e. inability to complete a repetition in a full range of motion due to fatigue) at the

prescribed RM target. At no point did subjects continue performing repetitions above the required RM target, yet the resistance was increased as necessary in 1.25, 2.5 or 5kg increments, depending on the absolute resistance. However, if a subject failed to complete the required number of repetitions, the number performed was recorded and the resistance was reduced accordingly for any remaining sets. Instructors initially led this careful adjustment of exercise resistance based on visual cues of exertion and by asking participants how difficult they perceived work-sets. Once subjects were competent in ensuring muscular failure at the required RM target, instructors simply prescribed the resistance of the first work-set for each exercise based on the training log records and then observed to ensure this was modified as necessary.

The RM targets prescribed for each group across the intervention is outlined in Table 4.1. The training focus for each RM target was; 15RM = strength-endurance, 10RM = hypertrophy, and 5RM = maximal strength. The training intervention is displayed in blocks of training (mesocycles) to clearly outline the BP program. Traditionally each training block includes several complete weeks (microcycles); however, training blocks in the current study comprised 11 total training sessions due to scheduling constraints, specifically three complete microcycles plus two sessions within the following week. Overall, BP and DUP groups completed the same number of training sessions at each RM target. Moreover, as differences in the overall training volume between RT programs have been proposed to influence performance (108), total repetitions were equalized between all training groups in order to reduce potential confounding factors, thereby allowing the sole examination of the effect of program structure on outcome measures. Therefore, the only difference between DUP and BP groups was the time and sequence of the load application. Furthermore, to check for any differences in workload between training groups across training blocks and the total training period, volume load (number of sets x number of repetitions x weight lifted (kg)) was calculated, which is an established method for quantifying training loads (140).

Table 4.1.The prescribed RM targets for training groups across the training intervention, with training session numbers presented in brackets (reproduced from Conlon et al. (61) with permission from Wolters Kluwer Health, Inc.).

	Block 1 (1-11)	Block 2 (12-22)	Block 3 (23-33)	Block 4 (34-42)	Block 5 (43-51)	Block 6 (52-60)
NP	3 x 10RM					
BP	3 x 15RM	3 x 10RM	3 x 5RM	3 x 15RM	3 x 10RM	3 x 5RM
DUP	Session 1: 3 x 15RM Session 2: 3 x 10RM Session 3: 3 x 5RM					

4.3.5 Protein Supplementation

On completion of each training session, all subjects ingested a standard liquid whey protein supplement mixed with 200 ml of water according to current recommendations (23). Each 30 g serving contained 498 kJ energy, 24.1 g protein, 1.7 g total fat, 1.1 g saturated fat, 1.4 g total carbohydrate of which 1.4 g was sugars, and 42.6 mg sodium. This was completed before leaving the facility to ensure full compliance.

4.3.6 Statistical Analyses

Data were analyzed using SPSS statistical software (SPSS Inc., Version 22, NY, USA). Normality of distribution was assessed using the Shapiro-Wilk statistic and where data was not normally distributed ($p<0.05$), log transformation procedures were applied with data re-checked for normality before applying parametric tests.

To validate the random stratification of subjects, a one-way analysis of ANOVA was used to check for between-group differences in baseline demographics and peak isometric torque. This analysis was also conducted on volume load and repetitions performed across each training block and the total training period.

To check for any changes in outcome measures across the control period (pre-control to baseline), a group x time (3 x 2) repeated measures ANOVA was used to assess main effects for time and group x time interactions. A separate 3 x 2 repeated measures ANOVA was performed on outcome measures across the training period (baseline to post-intervention). Furthermore, an ANCOVA was used to analyze

between-group differences in the absolute change of outcome measures (i.e. post-intervention – baseline) including baseline data as the covariate. To examine any gender effects, a separate ANCOVA was performed on absolute change data including gender as the independent variable and baseline data as the covariate. When required, Tukey's test was used for post-hoc analyses.

Data are presented as mean ± SD, with 95% CI and Cohen's *d* within-group ES calculated for the main outcome measures using the pooled SD, with an ES of 0.2, 0.5 and 0.8 representing small, moderate, and large differences, respectively. Statistical significance was set at $p<0.05$ for all analyses.

4.4 Results

Unfortunately, one subject experienced an unforeseen accident not related to the study and did not commence RT, and one subject dropped out in week 1 feeling unable to complete the training requirements. Additionally, there were six further dropouts over the course of the intervention due to injury or illness (NP=2; BP=1; DUP=3), with three injury cases relating directly to the study (NP = 1; BP = 1; DUP = 1). Specifically, two subjects experienced a minor muscle tear during 1RM procedures and one participant suffered an overuse injury. Therefore, a total of thirty-three subjects completed the study (female=17, male=16; 71.3 ± 5.4 y; 166.3 ± 8.5 cm; 72.5 ± 13.7 kg), with only these data included in the analyses based on a per-protocol approach.

Subejcts' demographics at baseline and post-training are presented in Table 4.2, with no between- or within-group differences noted ($p>0.05$). The only measure to demonstrate a gender effect was EMG amplitude (RMS) of the mVL ($p=0.043$), therefore data are presented for the entire training group for all other outcome measures to maximize statistical power.

Table 4.2. Training groups physical descriptive data at baseline and post-RT

	NP		BP		DUP	
	Baseline	**Post-RT**	**Baseline**	**Post-RT**	**Baseline**	**Post-RT**
Gender	F = 6; M = 4	-	F = 6; M = 7	-	F = 5; M = 5	-
Age (y)	70.4 ± 6.1	-	71.8 ± 5.4	-	71.2 ± 4.2	-
Height (cm)	166.4 ± 10.6	166.3 ± 10.5	164.9 ± 5.8	164.9 ± 5.7	167.2 ± 9.9	167.4 ± 10.2
BM (kg)	72.2 ± 17.9	72.0 ± 17.7	71.7 ± 10.4	72.5 ± 10.7	74.6 ± 14.2	75.8 ± 14.4
BMI (kg.m^2)	25.8 ± 4.2	25.8 ± 4.3	26.3 ± 3.1	26.6 ± 3.2	26.7 ± 4.3	27.0 ± 4.0

4.4.1 Resistance Training

An adherence rate of ≥85% to RT was achieved by all subjects with no between-group differences (*p*=0.513) (NP = 95.6%; BP = 96.9%; DUP = 96.8%). The group mean total volume load was not statistically different between-groups (*p*=0.62) (NP = 514,104 ± 149,938 kg; BP = 495,559 ± 128,169 kg; DUP = 554,068 ± 151,897 kg) (NP versus BP ES=0.13; NP versus DUP ES=0.26; BP versus DUP=0.42), which was also true for group mean total repetitions performed (*p*=0.19) (NP = 13,287 ± 579; BP = 13,675 ± 354; DUP = 13,609 ± 619) (NP versus BP ES=0.81; NP versus DUP ES=0.54; BP versus DUP=0.13), respectively.

4.4.2 Outcome Measures

4.4.2.1 Control Period

There was a significant main effect of time on isokinetic peak torque at $180^{o}{\cdot}s^{-1}$ (*p*=0.02) and VJ peak power (*p*=0.001) across the control period, with no significant interactions or between-group differences noted (*p*>0.05). Specifically, isokinetic peak torque (normalized to body mass) at $180^{o}{\cdot}s^{-1}$ decreased by 6.3% (ES=0.30) in NP, 12.6% (ES= 0.33) in BP, and 2.9% (ES=0.08) in DUP. Furthermore, peak power increased by 2.0% (ES=0.02), 6.0% (ES=0.16) and 1.4% (ES=0.01), in NP, BP and DUP groups, respectively. No other main effects, interactions or between-group differences were apparent for any other variable across the control period.

4.4.2.2 Muscle Hypertrophy

Group mean ± SD, 95% CI and ES data for muscle CSA of the mVL and mRF is presented in Table 4.3. A significant main time effect (*p*<0.001) was evident across

the training intervention for mVL 50% and 66%, and mRF 50% and 66% sites, however no significant interactions or between-group differences were noted ($p>0.05$).

4.4.2.3 Neuromuscular Performance

Isometric & Isokinetic Peak Torque: Group mean ± SD, 95% CI and ES data for isometric and isokinetic peak torque normalized to body mass is presented in Table 4.3. There was a significant main time effect ($p<0.001$) for peak isometric torque and isokinetic torque at $60^{o}{\cdot}s^{-1}$ and $180^{o}{\cdot}s^{-1}$, but not $300^{o}{\cdot}s^{-1}$ ($p=0.053$) across the RT period. However, no significant interactions or between-group differences were detected ($p>0.05$).

Vertical Jump: Group mean ± SD, 95% CI and ES data for peak velocity, peak force, peak power and jump height derived from vertical jump assessment is presented in Table 4.4. There was a significant main time effect ($p<0.001$) for peak velocity, peak power and jump height from baseline to post-RT, yet no significant interactions or between-group differences were noted ($p>0.05$). Peak force remained statistically unaltered following RT ($p>0.05$).

Rate of Force Development (RFD): Group mean ± SD, 95% CI and ES data for RFD measures is presented in Table 4.5. No significant main time effects, interactions or between-group differences were noted for RFD across any time interval assessed, from baseline to post-training ($p>0.05$).

Surface EMG: Group mean ± SD, 95% CI and ES data for average RMS amplitude EMG during peak isometric torque is presented in Table 4.4. No main time effect or significant interactions were noted for mRF RMS ($p>0.05$). Despite no significant main time effect for mVL RMS ($p>0.05$), a significant interaction ($p=0.03$) was noted, yet there were no between-group differences based on ANCOVA ($p>0.05$). As described, a significant gender effect was found for mVL RMS ($p=0.043$) with a statistically greater change evident in males (10.9%, ES=0.08) versus females (7.4%, ES=0.09), baseline to post-training.

4.4.2.4 Physical Activity and Dietary Intake Standardization

There was no significant interaction or main time effect for the frequency of total and moderate-intensity physical activity performed ($p>0.05$). In addition, habitual dietary intake (excluding protein supplementation) did not change

significantly in the pooled data of the whole cohort for energy intake across the overall study period (7981.1 ± 1552.1 to 7847.8 ± 1992.8 kJ, ES=0.07). Furthermore, the percentage of energy derived from carbohydrate was statistically unchanged ($p>0.05$) (38.9 ± 7.2 to 40.3 ± 8.7 %, ES=0.17). However, the percentage of energy derived from protein significantly increased ($p=0.007$) (19.5 ± 4.3 to 21.2 ± 4.9 %, ES=0.37) and the percentage of energy derived from fat significantly decreased ($p=0.029$) (33.8 ± 6.4 to 31.1 ± 6.3 %, ES=0.43) for the entire cohort over the course of the study.

Table 4.3. Changes in muscle size and peak torque across the training period.

	NP			BP			DUP			All Groups		
Measure	**Mean ± SD**	**95% CI**	**ES**	**Mean ± SD**	**95% CI**	**ES**	**Mean ± SD**	**95% CI**	**ES**	**Mean ± SD**	**95% CI**	**ES**
mVL 50% (cm^2)												
Baseline	15.0 ± 4.70	11.6-18.4	-	16.0 ± 4.81	13.1-18.9	-	18.1 ± 5.84	13.9-22.2	-	16.3 ± 5.10	14.5-18.1	-
Post-training	18.9 ± 5.60	14.9-22.9	0.75	20.0 ± 6.04	16.4-23.7	0.73	21.5 ± 5.29	17.7-25.3	0.61	20.1 ± 5.61	18.1-22.1	0.71
mVL 66% (cm^2)												
Baseline	12.4 ± 4.58	9.12-15.7	-	12.9 ± 4.00	10.5-15.4	-	13.4 ± 4.62	10.1-16.7	-	12.9 ± 4.25	11.1-14.1	-
Post-training	13.5 ± 4.39	10.4-16.7	0.25	14.7 ± 4.42	12.0-17.3	0.43	15.7 ± 4.08	12.8-18.6	0.53	14.6 ± 4.26	13.1-16.2	0.40
mRF 50% (cm^2)												
Baseline	5.58 ± 2.75	3.61-7.54	-	5.35 ± 2.22	4.01-6.69	-	6.13 ± 2.76	4.15-8.10	-	5.66 ± 2.49	4.77-6.54	-
Post-training	6.27 ± 2.45	4.51-8.02	0.29	6.38 ± 2.69	4.75-8.00	0.42	7.41 ± 2.10	5.91-8.91	0.52	6.66 ± 2.43	5.80-7.52	0.41
mRF 66% (cm^2)												
Baseline	2.46 ± 1.32	1.51-3.40	-	2.30 ± 1.26	1.54-3.05	-	2.74 ± 1.30	1.81-3.67	-	2.48 ± 1.26	2.03-2.93	-
Post-training	2.80 ± 1.61	1.65-3.96	0.23	2.84 ± 1.33	2.04-3.64	0.42	3.28 ± 1.08	2.51-4.06	0.45	2.96 ± 1.33	2.49-3.44	0.37
***Isometric PT (Nm)**												
Baseline	8.41 ± 2.14	6.97-10.1	-	8.14 ± 2.13	6.95-9.56	-	8.66 ± 2.58	6.91-10.7	-	8.38 ± 2.21	7.59-9.16	-
Post-training	9.20 ± 2.58	7.46-11.2	0.37	9.52 ± 2.06	8.39-10.9	0.70	9.32 ± 1.90	8.08-10.8	0.39	9.36 ± 2.12	8.61-10.1	0.45
***Isokinetic PT at $60^{o}\cdot s^{-1}$**												
Baseline	1.51 ± 0.30	1.30-1.73	-	1.43 ± 0.51	1.12-1.73	-	1.67 ± 0.52	1.30-2.04	-	1.53 ± 0.46	1.37-1.69	-
Post-training	1.74 ± 0.34	1.49-1.98	0.72	1.63 ± 0.56	1.29-1.97	0.37	1.94 ± 0.64	1.48-2.40	0.46	1.76 ± 0.53	1.57-1.94	0.46
***Isokinetic PT at $180^{o}\cdot s^{-1}$**												
Baseline	1.04 ± 0.21	0.89-1.19	-	0.90 ± 0.41	0.66-1.15	-	1.18 ± 0.38	0.90-1.45	-	1.03 ± 0.36	0.90-1.16	-
Post-training	1.16 ± 0.25	0.98-1.34	0.52	1.10 ± 0.35	0.89-1.31	0.52	1.26 ± 0.38	0.99-1.53	0.21	1.17 ± 0.33	1.05-1.29	0.41
***Isokinetic PT at $300^{o}\cdot s^{-1}$**												
Baseline	0.76 ± 0.14	0.66-0.86	-	0.73 ± 0.31	0.55-0.92	-	0.91 ± 0.32	0.68-1.14	-	0.80 ± 0.28	0.70-0.89	-
Post-training	0.84 ± 0.17	0.72-0.97	0.51	0.86 ± 0.43	0.60-1.12	0.35	0.94 ± 0.35	0.69-1.18	0.09	0.88 ± 0.34	0.76-1.00	0.26

N.B. mVL = vastus lateralis; mRF = rectus femoris; * = normalized to body mass; PT = peak torque.

Table 4.4. Changes in vertical jump performance and surface EMG outcome measures across the training period.

	NP			BP			DUP			All Groups		
Measure	**Mean ± SD**	**%95 CI**	**ES**	**Mean ± SD**	**%95 CI**	**ES**	**Mean ± SD**	**%95 CI**	**ES**	**Mean ± SD**	**%95 CI**	**ES**
VJ PF (N)												
Baseline	3406.6 ± 1234.1	2458.0-4355.3	-	3235.7 ± 1085.5	2546.0-3925.3	-	3271.7 ± 731.6	2709.4-3834.1	-	3297.8 ± 1010.1	2920.6-3674.9	-
Post-training	3583.8 ± 1334.7	2557.9-4609.8	0.14	3395.9 ± 795.6	2890.3-3901.4	0.17	3552.2 ± 874.9	2879.7-4224.7	0.35	3499.2 ± 974.8	3135.2-3863.2	0.20
VJ PV (m.s^{-1})												
Baseline	1.63 ± 0.20	1.48-1.79	-	1.66 ± 0.35	1.44-1.89	-	1.79 ± 0.32	1.54-2.04	-	1.69 ± 0.30	1.58-1.81	-
Post-training	1.75 ± 0.19	1.61-1.89	0.63	1.71 ± 0.32	1.50-1.91	0.15	1.84 ± 0.27	1.63-2.05	0.17	1.76 ± 0.27	1.66-1.86	0.25
VJ PP (W)												
Baseline	1794.0 ± 651.4	1293.3-2294.7	-	1798.2 ± 604.9	1413.9-2182.5	-	2163.6 ± 752.3	1585.3-2741.9	-	1906.6 ± 664.3	1658.5-2154.6	-
Post-training	1947.5 ± 710.7	1401.2-2493.8	0.23	1872.8 ± 561.3	1516.1-2229.4	0.13	2263.4 ± 772.4	16669.7-2857.2	0.13	2012.4 ± 672.6	1761.2-2263.5	0.16
VJ JH (cm)												
Baseline	11.9 ± 3.24	9.40-14.4	-	13.3 ± 6.32	9.29-17.3	-	14.9 ± 6.12	10.2-19.6	-	13.4 ± 5.45	11.3-15.4	-
Post-training	14.1 ± 3.15	11.7-16.5	0.69	14.3 ± 6.08	10.5-18.2	0.16	15.3 ± 5.33	11.2-19.4	0.07	14.5 ± 4.98	12.7-16.4	0.21
mVL RMS (mV)												
Baseline	84.2 ± 57.6	39.9-128.5	-	114.4 ± 58.8	64.9-163.2	-	84.2 ± 42.3	55.2-116.8	-	94.0 ± 52.3	71.7-115.7	-
Post-training	78.5 ± 44.6	44.2-112.8	0.11	104.3 ± 56.8	56.8-151.8	0.17	114.2 ± 49.1	72.7-155.7	0.65	99.9 ± 50.4	77.3-119.1	0.12
mRF RMS (mV)												
Baseline	54.6 ± 31.2	30.6-78.6	-	56.9 ± 25.3	35.8-78.1	-	50.5 ± 18.5	34.9-66.0	-	54.0 ± 24.9	43.8-64.3	-
Post-training	58.1 ± 34.3	31.8-84.4	0.11	56.9 ± 27.3	34.1-79.7	0.00	64.9 ± 31.7	38.4-91.4	0.55	59.9 ± 30.2	47.4-72.4	0.21

N.B. VJ = vertical jump; PF = peak force; PV = peak velocity; PP = peak power; JH = jump height; mVL = vastus lateralis; mRF = rectus femoris; RMS = root mean square.

Table 4.5. Changes in RFD across the training period.

	NP			BP			DUP			All Groups		
Measure	**Mean ± SD**	**%95 CI**	**ES**	**Mean ± SD**	**%95 CI**	**ES**	**Mean ± SD**	**%95 CI**	**ES**	**Mean ± SD**	**%95 CI**	**ES**
RFD_{30} ($N \cdot sec^{-1}$)												
Baseline	934.7 ± 388.3	656.6-1212.9	-	952.3 ± 404.0	708.1-1196.4	-	1152.9 ± 566.6	747.5-1558.2	-	1007.7 ± 451.1	847.8-1167.7	-
Post-training	1097.0 ± 550.2	703.4-1490.6	0.34	1086.0 ± 457.2	809.7-1362.2	0.31	1103.0 ± 409.1	810.4-1395.6	-0.10	1094.5 ± 458.9	931.7-1257.2	0.19
RFD_{50} ($N \cdot sec^{-1}$)												
Baseline	831.9 ± 331.1	595.1-1068.7	-	838.0 ± 370.2	614.3-1061.7	-	940.1 ± 396.6	656.4-1223.8	-	867.1 ± 359.0	739.8-994.4	-
Post-training	1006.0 ± 594.8	580.5-1431.4	0.57	976.3 ± 438.4	711.4-1241.2	0.34	953.7 ± 373.1	686.8-1220.6	0.04	978.5 ± 459.5	815.5-1141.4	0.27
RFD_{100} ($N \cdot sec^{-1}$)												
Baseline	718.6 ± 302.4	502.3-935.0	-	701.0 ± 307.9	514.9-887.0	-	849.6 ± 436.9	537.1-1162.1	-	751.4 ± 345.4	628.9-873.8	-
Post-training	797.3 ± 366.8	534.9-1059.7	0.23	736.8 ± 300.2	555.3-918.2	0.12	793.1 ± 391.7	512.9-1073.3	-0.14	772.2 ± 340.0	651.6-892.7	0.06
RFD_{200} ($N \cdot sec^{-1}$)												
Baseline	441.6 ± 186.8	308.0-575.3	-	467.3 ± 195.5	349.2-585.5	-	561.2 ± 281.6	359.8-762.7	-	488.0 ± 221.3	409.5-566.5	-
Post-training	500.8 ± 177.2	374.1-627.6	0.33	470.2 ± 164.1	371.1-569.3	0.02	537.1 ± 214.1	383.9-690.2	-0.10	499.8 ± 180.6	435.7-563.8	0.06

N.B. RFD_{30} = 0-30 ms; RFD_{50} = RFD 0-50 ms; RFD_{100} = RFD 0-100 ms; RFD_{200} = RFD 0-200 ms.

4.5 Discussion

This study evaluated periodized RT, specifically BP and DUP, and NP RT effects on neuromuscular outcomes across a 22-week training intervention. The main finding was that all three RT models induced similar and significant improvements in muscular size, strength and power indices, specifically mVL and mRF CSA, VJ peak velocity, peak power and jump height, and peak isometric torque and isokinetic torque of the knee extensors at $60^{o}\cdot s^{-1}$ and $180^{o}\cdot s^{-1}$. Therefore, in contrast to our original hypothesis, BP and DUP RT models did not induce superior neuromuscular adaptations compared to NP RT among the elderly. A further important finding was the unchanged muscle activity and RFD measures across the entire cohort following RT.

The present data leads us to confirm that aging muscle retains the capacity to undergo positive hypertrophic adaptations to RT, central in counteracting sarcopenia and the subsequent detriment in physical function. Previously the magnitude of CSA in response to RT has been described as minor in comparison to neural and strength changes among previously untrained older adults (145, 149). However, studies demonstrating hypertrophic adaptation over short-term RT challenge this notion, with recent reports of a 7.1% increase in mVL CSA following only 9 weeks of RT (18 sessions) (225). Although we did not assess the time-course of muscle hypertrophy, on average participants experienced a 24% increase in quadriceps femoris CSA (mvL and mRF) over the 22-week RT period (Table 5). With total muscle mass and muscle size estimated to normally decline at a rate of 1-2% per year over the age of 50 years (318), the present data highlight the substantial benefit of engaging older adults in performing RT ~3 h per week, with an average weekly muscle hypertrophy of ~1.1% observed throughout the initial stages of RT.

As anticipated, the present RT interventions produced positive improvements in several physical performance measures, including VJ peak velocity (average change across entire cohort, 4.5%), peak power (6.3%) and jump height (12.2%). Despite no statistical between-group differences, NP displayed a considerably greater effect on peak velocity and jump height compared to BP and DUP (Table 4), signifying a potential advantage of NP RT in this population. Furthermore, significant increases in peak isometric torque (13.8%) and isokinetic torque at $60^{o}\cdot s^{-1}$ (17.7%) and $180^{o}\cdot s^{-1}$ (19.8%) were observed across all groups, with no statistical between-group differences evident. Yet, BP demonstrated a markedly greater effect on peak isometric torque (ES=0.70), in contrast to NP (ES=0.37) and DUP (ES=0.39) (Table 3). However, considering the concentrated 5RM block completed by BP leading up to

the post-RT assessments, subjects ultimately practiced the specific motor schema associated with lifting heavier loads and greater force production. Conversely, DUP lifted 5RM loads 1 $d\cdot wk^{-1}$ and NP were only ever exposed to 10RM loads. Therefore, greater maximal strength adaptation in BP is predictable and such specificity of training may explain previous findings (284).

Considering isokinetic torque, NP displayed the greatest increase at $60^{o}\cdot s^{-1}$, while NP and BP exhibited a slightly greater increase at $180^{o}\cdot s^{-1}$ compared to DUP (Table 3). Interestingly, despite the greatest increase in isometric torque, BP displayed only a small effect for isokinetic torque $60^{o}\cdot s^{-1}$ (ES=0.37) along with DUP (ES=0.46), in contrast to NP (ES=0.72). This variability between assessment techniques highlights the importance of comprehensively evaluating strength expression following RT. Also, although not statistically significant, NP displayed the greatest effect on isokinetic torque at $300^{o}\cdot s^{-1}$ (NP=0.51; BP=0.35; DUP=0.09). Considering this alongside the greater effect on VJ peak velocity and jump height, NP RT may be a potentially superior training model for maximal impulse (force x time) and power development in older adults, compared to BP and DUP. While rejecting our original hypothesis, perhaps daily manipulation between 15, 10 and 5RM loads in DUP compromised physical performance adaptations via excessive variation in the training stimulus, while the final 5RM block in BP favored improvements in peak isometric torque, yet inhibited maximal impulse and power development.

This outlines the challenges of evaluating different RT models with timing constraints, as more regular assessments in BP would have been preferable to examine any fluctuations in training outcomes between-and within-training blocks. Yet, whether a traditional BP structure comprised of intensive training blocks ~4 weeks in duration targeting minimal training outcomes is the most appropriate training structure in older adults is questionable. Ultimately, RT should promote ongoing concurrent improvements in the most meaningful morphological and physical performance qualities, with an ongoing focus on enhancing muscular hypertrophy, strength and power being a recommended framework. Although a DUP training structure may be proposed for this purpose from a theoretical standpoint, when considering the present findings, a weekly undulating periodization (WUP) model with weekly shifts between training outcomes holds promise, thereby avoiding longer intensified training blocks as present in BP, and potentially excessive variation in DUP. Therefore, further exploration of WUP RT in this context is recommended.

The RFD is an additional important performance parameter, particularly in ADL

performance and fall prevention among older adults (355). Based upon previous findings (2, 355), a concurrent increase in isometric torque and RFD in the initial and early phase of the isometric torque-time curve was anticipated in the present study. In contrast, RFD measures remained statistically unchanged post-RT across all training groups. Nevertheless, NP induced a greater increase in all RFD measures, particularly RFD_{50} and RFD_{200} (Table 5), consistent with the greater effect on other high impulse characteristics (VJ peak velocity and jump height, and isokinetic torque at $300^{o}{\cdot}s^{-1}$). We propose several possible theories to support why RFD measures remained statistically unchanged following the present RT interventions. First, one study demonstrated that RFD in the early phase of rising muscle force (0-10, 0-20,…0-200 ms) was unchanged following high-intensity RT among untrained young males (8). Specifically, muscle biopsies revealed a decreased proportion of fast type IIX muscle fibers following RT, with a fiber type transition toward the slow type II phenotype, i.e. type IIX to IIA, which was believed to be at least partially responsible for the unchanged early RFD measures. Thus, the balance between increased muscle strength and decreased proportion of type IIX muscle fibers appears important for potential changes in early RFD and perhaps such shifts in fiber type were evident in the present cohort, yet this remains speculative. In opposition, improvements in the initial and early-phase RFD (0-30, 0-50, 0-100, 0-200 ms) have been reported in aging individuals following 12-weeks of RT (355). Therefore, further research is required and should explore the possible fiber-type shifting phenomenon in the elderly.

Second, due to assessing RFD under isometric conditions, a lack of specificity between training (dynamic contractions) and assessment protocols may have inhibited the transfer of training. In support, another study showed that RFD remained unaltered following 10 weeks of DUP RT involving training to muscular failure using RM zones, i.e. 8-10RM (148). Moreover, there was no improvement in RFD following 20 weeks of 'hypertrophic' RT (i.e. medium-load, high-volume) in healthy older men (389). Likewise, both studies assessed RFD exclusively during isometric muscle contraction, whereas RT was comprised entirely of dynamic actions.

Finally, the absence of specific ballistic training methods involving highly impulsive actions used to enhance RFD and other rapid force and impulse qualities must be acknowledged. Therefore, based on ample data showing significant muscular power improvements in older adults following RT incorporating ballistic training protocols (39, 53, 145, 152), the inclusion of ballistic training into a comprehensive periodized RT program is advocated to ensure that muscular strength, hypertrophy and power are equally optimized.

Therefore, whether routinely targeting specific power development within a periodized RT program is superior to a NP training structure in older adults requires investigation.

A further unexpected finding was the absence of a statistical increase in muscle activity pre to post-RT, specifically mRF and mVL RMS amplitude EMG. Considering the body of evidence showing significant increases in muscle activity following RT among older adults (2, 145, 148, 149, 355), it seems unlikely that the present physical performance improvements (VJ peak velocity, peak power and jump height, and peak isometric and isokinetic torque of the knee extensors at $60^{o}\cdot s^{-1}$ and $180^{o}\cdot s^{-1}$) were solely due to morphological adaptation (i.e. muscle CSA). Nevertheless, muscle activation is a major limiting factor influencing the expression of RFD (34, 111), supported by the present data with both RFD and muscle activity parameters remaining statistically unchanged in response to RT. In agreement with our findings, there was no increase in muscle activity following 8 weeks of progressive RT in healthy young males (366), or a 12-week RT intervention among the elderly (157). Considering the principle of specificity of RT once more, both studies assessed knee extensor muscle activity during isometric contraction, whereas all training was performed using dynamic actions. Therefore as discussed in reference to RFD, the nature of the specific adaptation to RT appears, as within younger counterparts, to be highly specific to the mode of training, and suggests adaptation in the actual skill of performing the task (157).

However, DUP demonstrated a 37.3% and 20.7% increase in mVL (ES=0.65) and mRF (ES=0.55) RMS amplitude, respectively, with no change or only trivial effects in NP and BP groups for the same measures (Table 4). This suggests that a frequent manipulation of training stimuli via DUP may stimulate greater increases in muscle activity in older adults. However, considering the smaller improvements in high impulse strength qualities (VJ peak velocity and power, and peak isokinetic torque at $300^{o}\cdot s^{-1}$) and maximal force production in DUP, the current findings are somewhat inconsistent, with no single RT model demonstrating superiority across the entire spectrum of neuromuscular adaptations. Also, as muscle activity was measured during MVIC assessment, it is important to consider the moderate increase in EMG measures in DUP (average ES=0.60) versus NP (average ES=0.00), but similar improvements in isometric peak torque (NP=0.37; DUP=0.39). Therefore, greater muscle activation for the same magnitude of improvements in force expression was noted in DUP, when compared to NP, thereby indicating a potential maladaptation in neural outcomes following DUP. Consequently, the relationship between various outcome measures to different models of RT among older adults requires further investigation. Also, periodized and NP RT models may have provided a similarly novel training stimulus among the present

RT naïve subjects. Therefore, whether the differences in training outcomes would be amplified among previously trained individuals due to a potential increased sensitivity to training variety is unknown.

The 4-week control period excluding RT served to ensure reliability and stability of baseline measures. Accordingly, it is important to acknowledge the significant main time effect for isokinetic peak torque at $180^{o}\cdot s^{-1}$ (*p*=0.021) and VJ peak power (*p*=0.001) over this period. In detail, isokinetic peak torque at $180^{o}\cdot s^{-1}$, when normalized to body mass, decreased by 3.6% (ES=0.30) in NP, 12.6% (ES=0.33) in BP and 2.9% (ES=0.08) in DUP. As all other performance measures remained statistically unchanged across the control period, it is difficult to understand why this may have occurred at the specific angular velocity of $180^{o}\cdot s^{-1}$. Nevertheless, the magnitude of effect was small for NP and BP, and trivial for DUP, and this finding does not question the positive increase in this measure following RT being a direct result of the intervention. Second, peak power increased by 2.0%, 6.0% and 1.4% for NP, BP and DUP groups, respectively, with no between-group differences noted. Such increases in peak power are likely due to practice and increased familiarity with VJ assessment, particularly as the present cohort were largely unaccustomed to any jumping actions, despite familiarization sessions to reduce the influence of acute learning effects. Therefore, multiple familiarization sessions are recommended for practicing particularly unfamiliar protocols in older adults. Such increases in peak power across the control period were trivial based on ES (NP=0.02; BP=0.16; DUP=0.01). Yet, despite a significant main time effect post-RT ($p<0.05$), the magnitude of ES remained trivial to small in all training groups (NP=0.23; BP=0.13; DUP=0.13). Consequently, the improvement in VJ peak power following RT must be interpreted with caution.

Concurrent RT and protein supplementation is considered the gold standard for maximizing the anabolic environment in senescent muscle (40), ultimately promoting skeletal muscle hypertrophy and consequent neuromuscular adaptation (86, 249). Therefore, it must be acknowledged that the inclusion of protein supplementation in the present study may have influenced greater improvements in outcome measures, in comparison to isolated RT. Nevertheless, the current RDA for protein is likely insufficient among the elderly (23), and a large proportion of this population fail to meet this inadequate guideline (323). Also, no major adverse effects have been reported for long-term protein supplementation in healthy older adults, specifically in renal function or 24 h nitrogen balance (380). Therefore, consuming an adequate amount of high-quality protein at each meal, in combination with RT,

represents a promising strategy to prevent or delay the onset of sarcopenia in older adults (282).

Finally, thirty-three subjects fulfilled all study requirements and were included in the final analyses, however this did not satisfy the a priori sample size estimate of thirty-nine subjects. Therefore, the present sample size is a potential limitation and it could be argued that between-group statistical differences were possibly undetected due to type II error. It is recommended that future long-term training studies recruit an adequate cohort to ensure sufficient statistical power, considering the present dropout rate of 19.5%.

In summary, NP, BP and DUP RT produces similar improvements in various morphological and physical performance parameters among apparently healthy untrained older adults, specifically muscle CSA, VJ performance, and peak isometric and isokinetic torque. Therefore, periodization strategies do not appear to be critical during the initial stages of RT among older adults. Alternatively, practitioners should focus on engaging the elderly in regular RT to experience the significant impact of training adaptations on overall health, physical function and quality of life. Finally, the examination of periodization strategies among previously trained older adults is warranted, with alternate training models such as WUP recommended for consideration.

4.6 Perspective

This study supports the efficacy of both periodized and NP RT for significant morphological and physical performance improvements among the aging population. Therefore, practitioners may implement basic periodization strategies, based on a BP or DUP model as evident in this investigation, or a NP program, when aiming to induce muscular size, strength and power adaptations in the early stages of RT in RT-naïve elderly. These findings support the considerable public health implications of RT, ultimately lowering the risk of chronic disease, while preserving independence and increasing QOL. The impact of periodization strategies in previously trained older adults, and on long-term enjoyment, tolerance, and adherence remains unknown. Ultimately, exercise and health practitioners should concentrate efforts on increasing RT participation in older persons via feasible and efficacious interventions targeting long-term adherence in minimally supervised settings.

CHAPTER FIVE

Training Load Indices, Perceived Tolerance and Enjoyment Among Different Models of Resistance Training in Older Adults

N.B. The following chapter is under review for publication:

Conlon JA, Newton RU, Tufano JJ, & Haff GG. Training Load Indices, Perceived Tolerance and Enjoyment Among Different Models of Resistance Training in Older Adults. *Journal of Strength and Conditioning*, 2016 (in review).

However, the formatting has been adjusted from the original published manuscript to allow continuity through the entire thesis document.

5.1 Abstract

The purpose of this study was to investigate the relationship between training load indices VL, training monotony and strain, and perceived tolerance and enjoyment, across periodized and NP RT in older adults. Forty-one healthy, untrained apparently healthy older adults (female=21, male=20; 70.9 ± 5.1 y; 166.3 ± 8.2 cm; 72.9 ± 13.4 kg) were randomly stratified into a NP, BP or DUP RT group, and completed a 22-week RT intervention at a frequency of 3 d·wk^{-1}. All training was executed on RT machines and training volume was equalized between training groups based on total repetitions. Despite statistical differences in VL, training monotony and strain between NP, BP and DUP RT, perceived tolerance and enjoyment was similar across training models. Therefore, no meaningful relationships between training load indices (VL, monotony, and strain), and perceived tolerance and enjoyment were evident. Based on these results, periodization strategies do not appear to impact perceived tolerance or enjoyment of RT among the elderly, yet are recommended for better management of training load, potentially reducing the risk of illness and injury and promoting long-term adherence. The interplay between training load indices, perceived tolerance and enjoyment, and key physiological and performance training adaptations requires exploration in pursuit of an optimal RT model for older adults.

Key Words: Periodization, volume load, monotony, strain, adherence

5.2 Introduction

Sarcopenia describes one of the major physiological processes associated with aging, defined as the age-associated loss of skeletal muscle mass and function (107). The degree of sarcopenia evident serves as a significant predictor of all-cause mortality (68, 248), thus affecting not only the quality, but also the quantity of life among the aged (68, 76). A large proportion of healthcare costs attributed to aging result from treatment of medical conditions associated with sarcopenia, including, insulin resistance (35, 60), obesity (26, 91), and arthritis (319, 391). Additionally, the loss of muscle strength in sarcopenia predisposes older adults to a higher risk of falls and resultant injuries (123, 324). The total cost of sarcopenia in the American Health System was calculated at approximately $18.4 billion in 2004 (187).

Through inducing skeletal muscle hypertrophy and subsequent improvements in body composition, RT is classified as the most effective intervention for preventing the onset and counteracting sarcopenia (38, 361). Equally significant, RT is proposed to be the optimal form of exercise for improving functional capacity (174), and is supported by several studies demonstrating improved ADL performance following RT in older adults (175, 177, 238, 342, 345, 362). A continually growing body of research highlights the robust adaptability of the aging neuromuscular system in response to RT, including both morphological and performance related changes, including muscle CSA, maximal strength, power, RFD, functional capacity and muscle activation (53, 127, 145, 147, 149, 225, 355, 363).

However, despite an abundance of studies reporting the benefits of RT among older adults, there is a large variation in the type of RT intervention employed, specifically regarding key program variables, including training volume and load, training frequency, recovery and exercise modality. Current recommendations from ACSM advocate progressive overload and training variety (i.e. periodization) (307), however no specific guidelines are outlined. Therefore, the most optimal RT model for counteracting the negative effects of aging remains unknown.

When designing and implementing a RT plan, the ability to monitor and manage training stressors is considered to be an influential factor in optimizing the stimulus and thus the overall effectiveness of the intervention (37). However, this process is acknowledged to a lesser extent in non-athletic settings, yet the potential for the overtraining and subsequent adverse effect on neuromuscular adaptation is potentially heightened in any population if the training load is not appropriately managed, including among the elderly.

Estimating the overall RT load using VL (number of sets x number of repetitions x weight lifted (kg)) is an established method (139). However, considering other factors that

influence the perceived effort of RT, for instance, rest periods, velocity of movement, exercise choice, sRPE has been proposed as an accurate training load monitoring tool. Specifically, sRPE is multiplied by the number of repetitions or sets performed in RT to calculate session load (240). We recently demonstrated that there was meaningful relationship between VL and session load across long-term RT in older adults, with fatigue being a likely confounding factor due to consistently training to momentary muscular concentric failure during RT (61).

Nevertheless, two further measures derived from sRPE and recommended for monitoring training load include training monotony and strain. First, training monotony refers to the variability of training, and is calculated by dividing the mean daily training load by the SD of the mean daily load over a specified period, traditionally 1-week (113, 240). Second, the product of the total training load and monotony of a designated period is used to calculate strain, representing the overall physical stress experienced (113, 240). Strategies designed to minimize training monotony and strain are recommended due to reducing the risk of illness, injury and consequent performance decrements (i.e. overtraining) (113, 141). For instance, using periodization strategies to prescribe multiple ‘heavy’ and ‘light’ training days to accomplish a set training load, rather than performing continuous slightly less severe ‘hard’ days in a NP program (113, 141).

It has been recommended that brief, simple, feasible and efficacious RT interventions placing emphasis on adherence and long-term maintenance are important for public health, with subtle differences in strength gains resulting from complex RT protocols less critical (293). However, as training monotony and strain are theoretically greater in NP programs due to a fixed training stimulus, the application of basic periodization strategies may optimize the long-term management of training load. Consequently, periodized RT may also increase an individual’s tolerance and enjoyment of training, thereby enhancing adherence.

Therefore, the purpose of this study was to investigate the relationship between training load monitoring indices (VL, monotony and strain), and perceived tolerance and enjoyment, across periodized and NP RT in older adults. We hypothesized that via better management of VL, monotony and strain, periodized RT would promote greater ratings of tolerance and enjoyment than a NP program. Therefore, VL, monotony and strain were predicted to demonstrate meaningful relationships with perceived tolerance and enjoyment of RT for the entire cohort.

5.3 Methods

5.3.1 Experimental Approach to the Problem

The present investigation is part of a larger series of studies that explored the impact of various RT models on the physical function, health and wellness of older adults. Subjects were required to complete a 22-week RT intervention at a frequency of 3 $d\cdot wk^{-1}$, excluding transition weeks 14, 17 and 20 where subjects trained 1 $d\cdot wk^{-1}$. These transition weeks and were modified ad hoc to promote recovery and reduce the potential for injury and illness due to observing signs of fatigue and a reduced motivation to train among subjects. Further, RT was performed 2 $d\cdot wk^{-1}$ in week 6 due to the completion of maximal strength assessments (data not included in the present study), therefore the total number of prescribed training sessions was 59. Finally, subjects were randomly stratified into three experimental RT groups- NP, BP, or DUP, based on gender, age, BMI, and MVIC of the knee extensors.

5.3.2 Subjects

Forty-one healthy older adults (female=21, male=20; 70.9 ± 5.1 y; 166.3 ± 8.2 cm; 72.9 ± 13.4 kg) were recruited for the present study, with no significant between-group differences in physical descriptive data at the initiation of the study (p>0.05) (Table 5.1). All subjects completed a health history questionnaire and provided medical clearance form their personal physician completed prior to participation. Exclusion criteria included a BMI of ≥30 $kg\cdot m^2$, possessing any pre-existing musculoskeletal, cardiovascular or neurological condition, or any other condition considered to cause risk to the subjects through RT or reduce their ability to adapt. Further, subjects were untrained, i.e. had not participated in structured exercise training designed to improve physical fitness over the previous 12 months, and were instructed to continue with their normal daily activities yet discouraged from engaging in any unaccustomed physical activity. The Edith Cowan University Human Research Ethics Committee approved the study and subjects were fully informed of the nature and possible risks of all procedures before providing written informed consent.

Table 5.1. Subject’s physical descriptive data across training groups.

	NP	**BP**	**DUP**
Gender	F = 7; M = 5	F = 7; M = 7	F = 7; M = 6
Age (y)	70.4 ± 6.1	71.8 ± 5.4	71.2 ± 4.2
MVIC (N)	147.7 ± 45.4	132.1 ± 43.0	148.2 ± 47.1
BMI ($kg.m^2$)	26.4 ± 4.2	26.3 ± 3.0	26.4 ± 3.9

5.3.3 Procedures

5.3.3.1 Resistance Training

Subjects were fully familiarized with all RT procedures prior to the RT intervention. Training sessions were performed at a regular time of day, with a minimum of 48 h between sessions, and were supervised by exercise science bachelor degree qualified instructors to ensure proper exercise technique and reduce the risk of injury.

Training sessions commenced with a 5 min standardized warm-up of light stationary cycling, rowing or brisk walking on an ergometer or treadmill (Technogym, London, UK). All resistance exercises were performed using machines (Cybex, MA, USA) with zero use of free weights. A warm-up set of each exercise was completed at approximately 50% of the resistance of the first work-set. Rest intervals were 1 min between the warm-up set and the first work-set, and a 1.5-2 min between consecutive work-sets. Also, subjects were coached to execute the concentric portion of exercises with maximal velocity to optimize neuromuscular adaptation and functional performance (39), and control the eccentric portion using a 2 s cadence as monitored by trainers. Exercise selection was unaltered across the intervention and between training groups, targeting concentric and eccentric muscle actions of all major muscle groups. Specifically, lower-body and upper-body exercises were alternated, including; seated leg press, lat pull-down, seated leg-curl, chest press, leg extension and seated row.

Exercise resistance was prescribed using RM sets to ensure that the resistance stimulus was progressive to accommodate strength adaptations, requiring adjustment of the exercise resistance to ensure momentary muscular concentric failure at the prescribed RM target. At no point did subjects continue performing repetitions above the required RM target, yet the resistance was increased as necessary in 1.25, 2.5 or 5 kg increments, depending on the absolute resistance. If a subject failed to complete the required number of repetitions, the number performed was recorded and the resistance was reduced accordingly for any remaining sets. The resistance and repetitions performed in the work-sets for each exercise were recorded in a training log and served as a written record for subjects at the start of training sessions.

The RM targets prescribed for each group across the intervention is outlined in Table 5.2. The training focus for each RM target was; 15RM = strength-endurance, 10RM = hypertrophy, and 5RM = maximal strength (13). The training intervention is displayed in blocks of training to clearly outline the BP program. Traditionally, each training block (mesocycle) includes several complete weeks (microcycles); however, training blocks in the

present study comprised 11 total training sessions (three complete microcycles plus two sessions within the following week) due to scheduling constraints. Overall, BP and DUP groups completed the same number of training sessions at each RM target. Further, as differences in the overall training volume between RT programs have been proposed to influence performance (108), total repetitions were equalized between training groups in order to reduce potential confounding factors. Consequently, the time and sequence of the load application was the only difference between DUP and BP groups.

Table 5.2. The prescribed RM targets for training groups across the training intervention, with training session numbers presented in brackets (reproduced from Conlon et al. (61) with permission from Wolters Kluwer Health, Inc.).

	Block 1 (1-11)	**Block 2 (12-22)**	**Block 3 (23-33)**	**Block 4 (34-42)**	**Block 5 (43-51)**	**Block 6 (52-60)**
NP	3 x 10RM					
BP	3 x 15RM	3 x 10RM	3 x 5RM	3 x 15RM	3 x 10RM	3 x 5RM
DUP	Session 1: 3 x 15RM Session 2: 3 x 10RM Session 3: 3 x 5RM					

5.3.4 Training Load Indices

To monitor training load during the intervention, VL was calculated across training weeks (1-22) and blocks (1-6), consistent with established methods (140). Likewise, training monotony and strain were also computed, excluding transition weeks 14, 17 and 20 due to subjects only performing RT 1 $d \cdot wk^{-1}$. Table 5.3 outlines monotony and strain calculations, with session load calculated by multiplying the sRPE by the number of repetitions performed (240). The sRPE recording procedures used in the present study are outlined in detail elsewhere (61).

Table 5.3. Equations used for the calculation of training monotony and strain across training weeks and blocks.

	Monotony	Strain
Per Training Week	Mean daily load of training week ÷ SD of mean daily load	Total training load of training week × training monotony
Per Training Block	Mean daily load of training block ÷ SD of mean daily load	Total training load of training block × training monotony

5.3.5 Perceived Tolerance and Enjoyment

Concurrent with the recording of sRPE, a 7-point Likert scale was used to assess subject's perceived tolerance and enjoyment of RT on completion of each session. In detail, subjects rated how much they agreed or disagreed with the statements, "I have found the exercise session to be tolerable" and "I have found the exercise session enjoyable" on a scale of one (strongly disagree) to seven (strongly agree). As with sRPE, subjects were reminded to provide a global rating of tolerance and enjoyment of the entire training session, and both scales were visible at all times during RT.

5.3.6 Statistical Analyses

Data were analyzed using SPSS statistical software (SPSS Inc., Version 22, NY, USA). All data are presented as mean ± SD. Normality of distribution was assessed using the Shapiro-Wilk statistic and where data was not normally distributed (p<0.05), non-parametric analyses were performed. A one-way ANOVA was used to assess any between-group differences in the group mean VL accomplished on completion of the RT period, adherence to training and the total number of training sessions missed due to illness.

For the main analyses, a one-way ANOVA was used to detect any statistical between-group differences in the group mean VL, training monotony and strain, and perceived tolerance and enjoyment across training weeks and blocks (excluding transition weeks 14, 17 and 20 for monotony and strain). When required, Tukey's test was used for post-hoc analyses. Finally, Spearman's rank-order correlation analyses were used to assess the relationship between VL, training monotony and strain, and perceived tolerance and enjoyment of RT, for the entire cohort. Specifically, mean data from each training week was used and correlations were interpreted as weak (0.2-0.39), moderate (0.40-0.59), strong

(0.60-0.79) and very strong (≥0.80). Statistical significance was set at $p<0.05$.

5.4 Results

Unfortunately, one subject suffered an unforeseen accident unrelated to the study and did not commence RT, and a further subject dropped out in week 1 due to feeling unable to fulfil training requirements, therefore these data are not included in the analyses. Additionally, there were six further dropouts across the intervention due to illness or injury (NP=2; BP=1; DUP=3), with three injury cases directly related to RT. In detail, two subjects (NP and BP) experienced a minor muscle strain during maximal strength testing procedures, and one subject (DUP) suffered from a muscle strain during RT, preventing continuation. However, all data was included in analyses up until the time of dropout.

The group mean total VL on completion of the RT period was not statistically different between-groups (p=0.779) (NP = 508,1257 ± 136,374 kg; BP = 473,793 ± 147,635 kg; DUP = 458,591 ± 234,606 kg). Moreover, an adherence rate of ≥85% to RT was achieved by the entire cohort with no significant between-group differences (p=0.533) (NP = 94.8%; BP = 96.9%; DUP = 96.7%), which also evident for the number of training sessions missed due to illness (p=.189) (NP=21, BP=8, DUP=13). Group mean VL, monotony and strain are presented across training weeks and blocks in Figures 5.1 and 5.2, respectively (excluding transition weeks 14, 17 and 20 for monotony and strain). Similarly, perceived tolerance and enjoyment of RT is displayed across training weeks (Figure 5.3) and blocks (Figures 5.4). Significant between-group differences are highlighted where appropriate. Finally, the relationship between training load indices (VL, monotony and strain), and perceived tolerance and enjoyment for the entire cohort is outlined in Table 5.4.

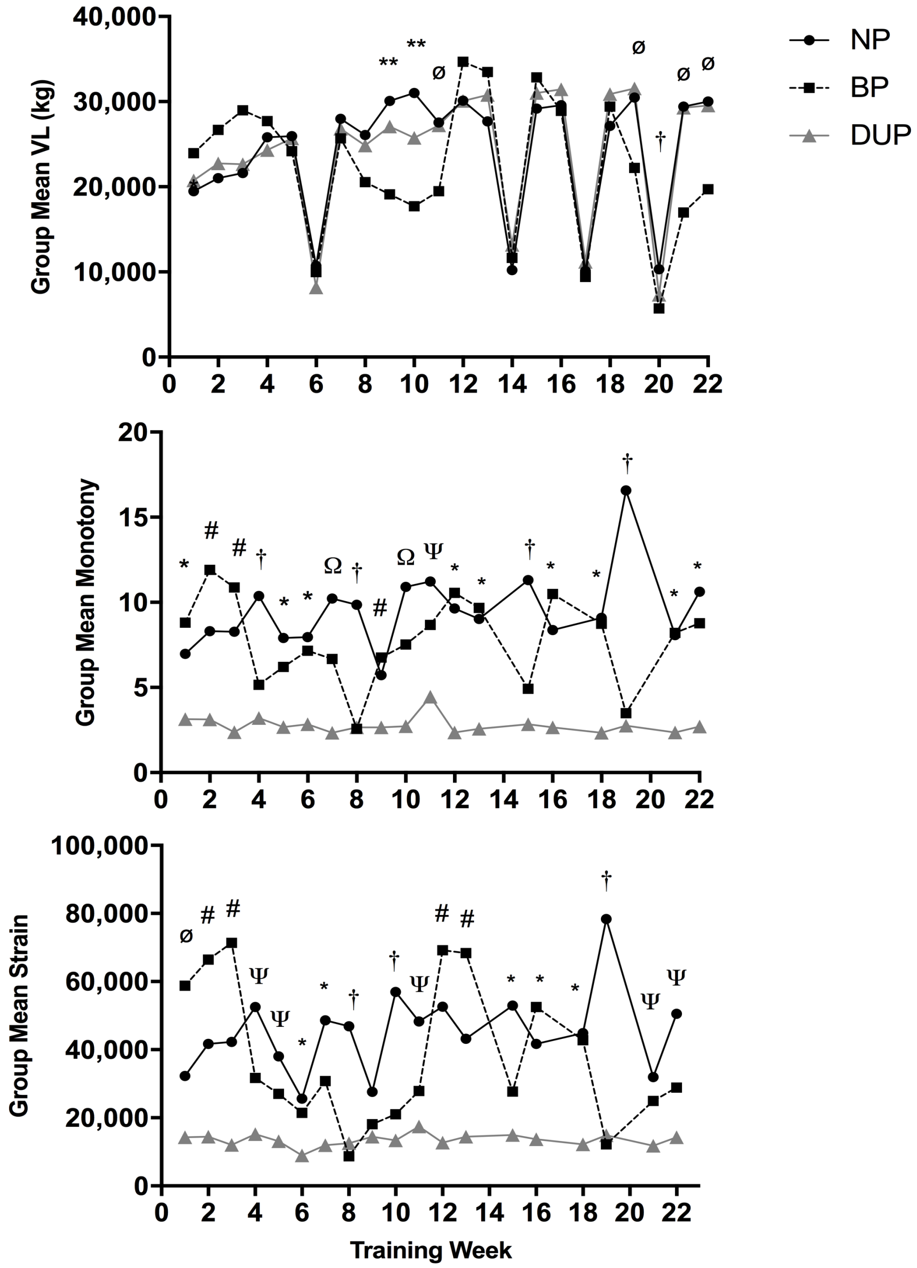

Figure 5.1. Group mean VL, training monotony and strain for NP, BP and DUP across training weeks. ** BP statistically different from NP (p<0.05); Ø BP statistically different from NP and DUP (p<0.05); † NP statistically different from BP and DUP (p<0.01); * DUP statistically different from NP and BP (p<0.05); # BP and DUP statistically different (p<0.05); Ω all groups statistically different (p<0.05); Ψ NP and DUP statistically different (p<0.05). N.B. Note the reduced VL and missing training monotony and strain data for transition weeks 14, 17 and 20.

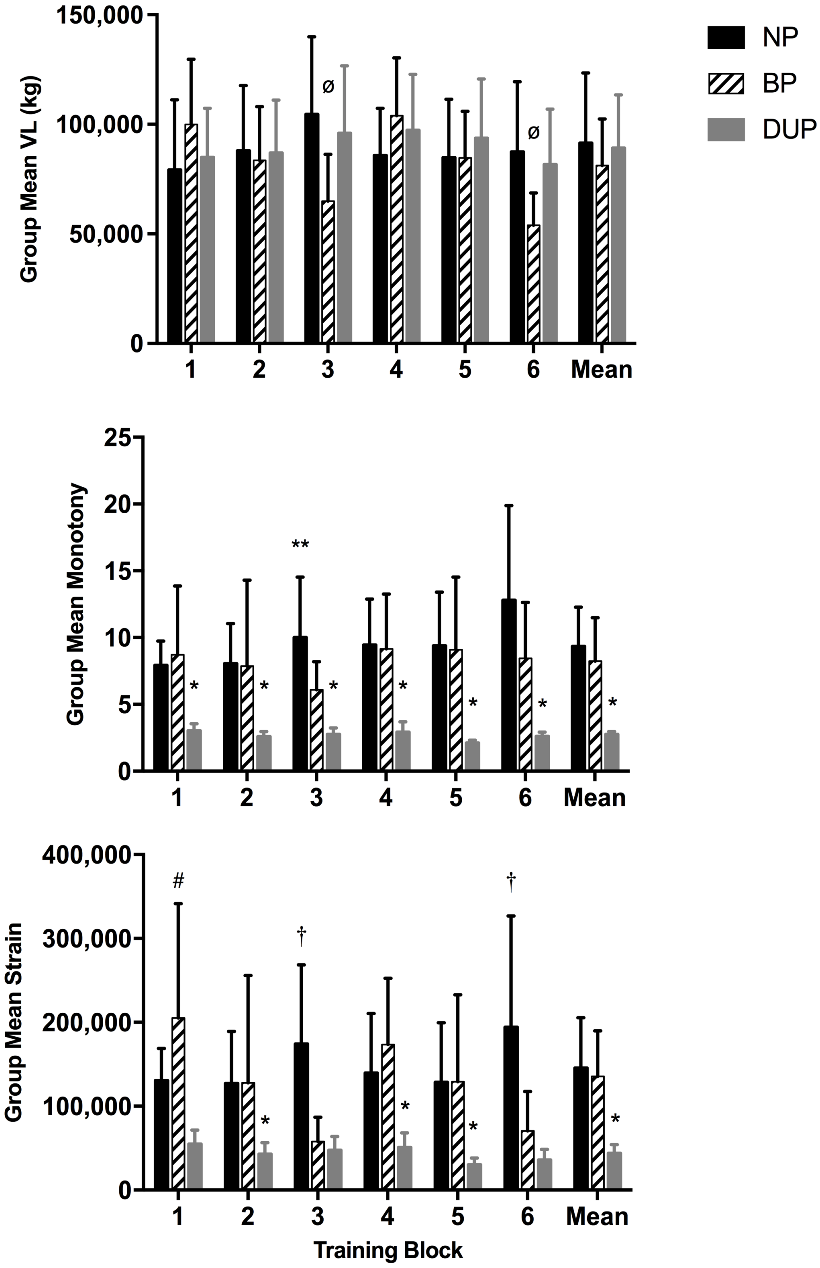

Figure 5.2. Group mean VL, training monotony and strain for NP, BP and DUP across training blocks. Ø Statistically different from NP and DUP (p<0.05); * statistically different from NP and BP (p<0.01); ** statistically different from BP (p<0.01); # statistically different from DUP (p<0.01); † statistically different from BP and DUP (p<0.01).

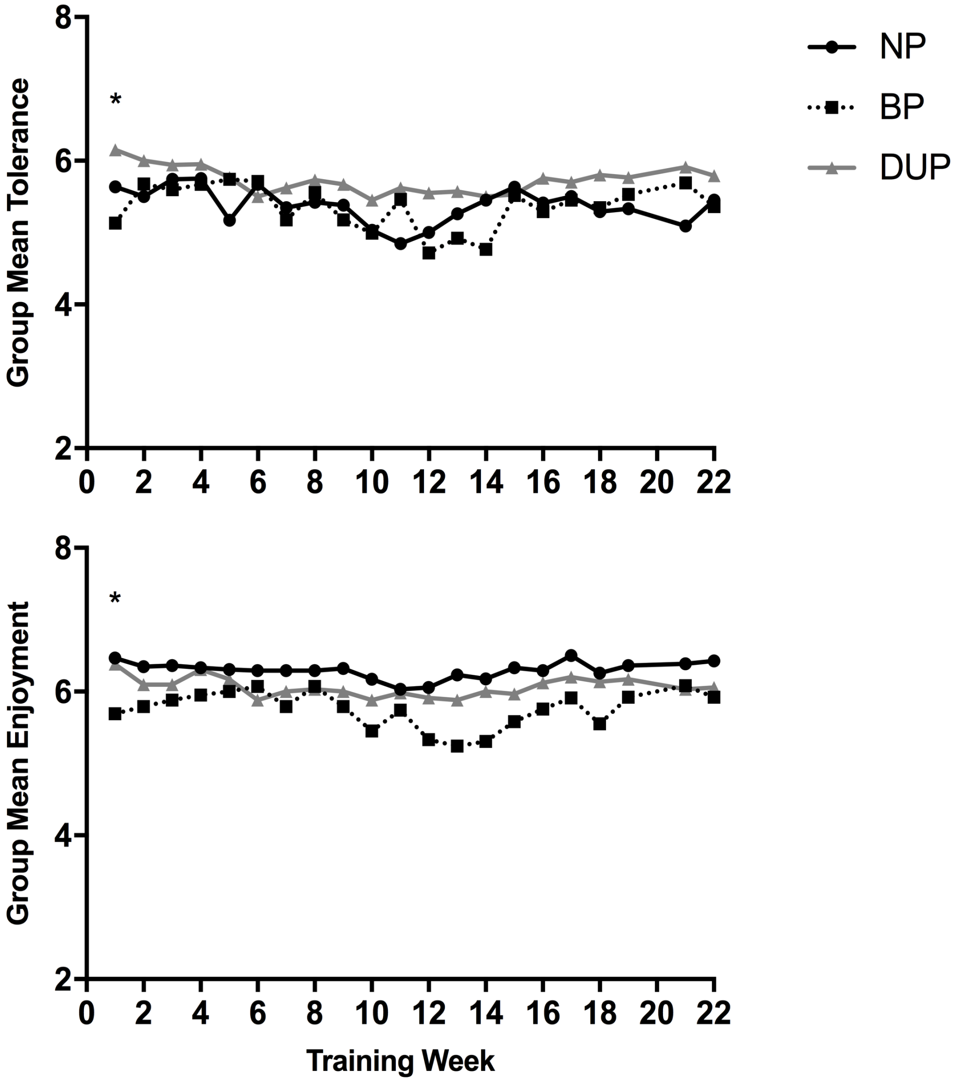

Figure 5.3. Group mean perceived tolerance and enjoyment for NP, BP and DUP across training weeks. * BP and DUP statistically different (p<0.05).

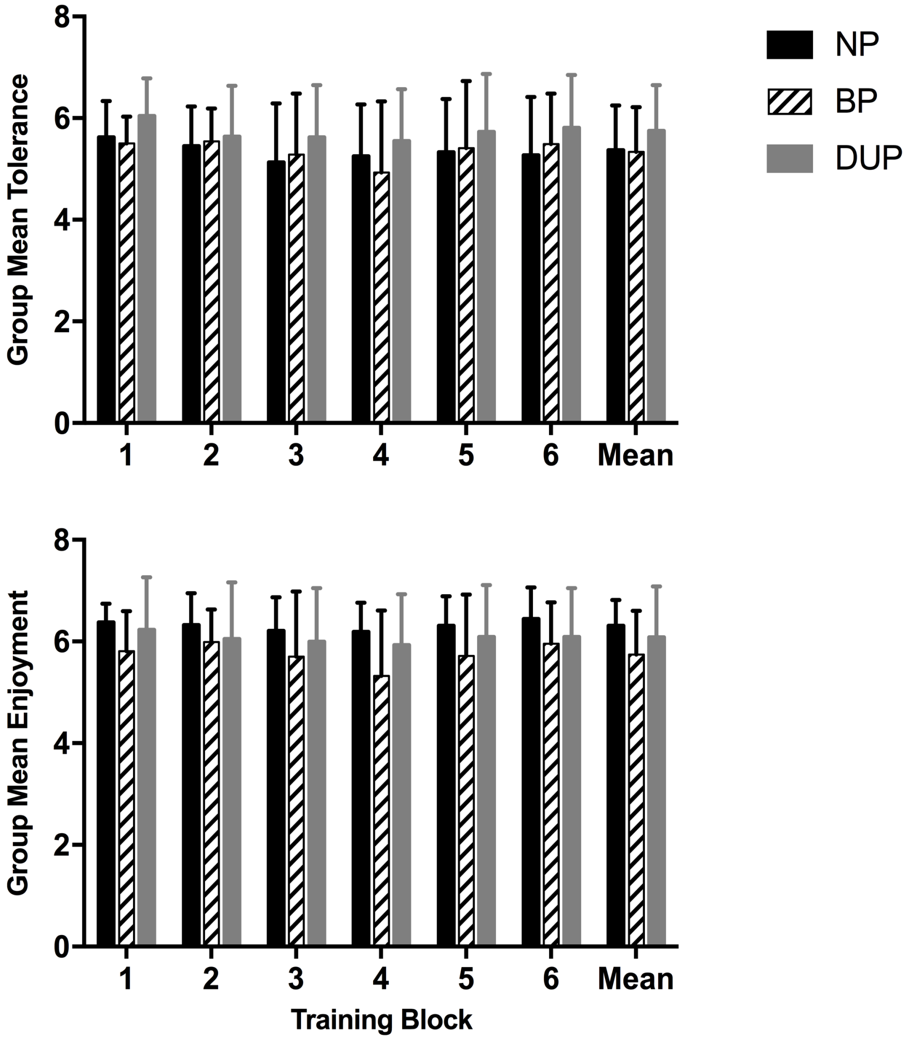

Figure 5.4. Group mean perceived tolerance and enjoyment for NP, BP and DUP across training blocks.

Table 5.4. The relationship between VL, training monotony and strain, and perceived tolerance and enjoyment for the entire cohort. * Statistically significant correlation (*p*<0.01).

	VL	Monotony	Strain	Tolerance	Enjoyment
VL		-.067	-.12*	-.01	.05
Monotony	-.07		.90*	-.15*	-.07
Strain	-.12*	.90*		-.06	-.02
Tolerance	-.01	-.15*	-.06		.47*
Enjoyment	.05	-.07	-.02	.47*	

5.5 Discussion

The purpose of this study was to investigate the relationship between training load indices (VL, monotony and strain), and perceived tolerance, and enjoyment, across periodized and NP RT in older adults. However, despite statistical between-group differences in VL, monotony and strain during RT (Figures 5.1 and 5.2), perceived tolerance and enjoyment were similar across NP, BP and DUP RT groups across the intervention (Figures 5.3 and 5.4). Therefore, contrary to our original hypothesis, periodization strategies do not promote greater perceived tolerance or enjoyment of RT among the elderly, and consequently there were no meaningful correlations between training load indices (VL, monotony and strain) and perceived tolerance and enjoyment (Table 5.4).

Due to the distinct RT structures, significant differences in VL, training monotony and strain were evident between NP, BP and DUP groups during the RT intervention (Figures 5.1 and 5.2). Briefly, despite no statistical differences in group mean total VL on completion of the RT period ($p>0.05$), there were significant between-group differences in training weeks 9, 10, 11, 19, 20, 21, 22 (Figure 5.1), and training blocks 3 and 6 (Figure 5.2), due the time and sequence of load application. Additionally, due to daily variation in the training stimulus, training monotony and consequent training strain were chronically minimized in DUP, in contrast to NP and BP.

Particularly in a health and wellness setting, individuals likely consider how well they tolerate and how much they enjoy RT equally as important as the significant health benefits it provides. Contrary to our hypothesis, excluding week 1, subject's ratings of perceived tolerance and enjoyment were not statistically different between NP, BP and DUP RT groups throughout the intervention (Figure 5.3 and 5.4). The significantly greater perceived tolerance and enjoyment in week 1 evident in DUP when compared to BP, was likely due to the initial introduction of subjects with the RT intervention environment and peers, and is not considered meaningful due to the lack of differences for the remaining weeks. Importantly, it is apparent that all training groups felt they tolerated RT well and equally significant, enjoyed their participation.

Anecdotally, subjects noticeably enjoyed building relationships with their peers, trainers and members of the research team across the RT period, ultimately expanding their social networks. All personnel working on the study continually fostered a friendly, supportive and motivating training environment, to help promote positive psychological well-being (78) and long-term adherence (337). Therefore, despite significant differences in VL, training monotony and strain, similar ratings of tolerance and enjoyment levels across RT

models, are perhaps not surprising. This positive engagement with RT supports the notion that physical activity is related to healthy psychological function (274), improving an individual's overall QOL. Yet, whether the same level of social support and interaction is experienced in 'real world' RT settings is uncertain. Exercise centers are encouraged to promote specific times for older participants to attend, and even provide space to socialize after training sessions (78). Such simple strategies should increase the likelihood that aging individuals, particularly widowed or unmarried, will find a "training buddy" who can increase the support and motivation to adhere to long-term RT (78).

The use of RM sets is a further possible influential factor underlying the disconnect between RT load indices (VL, training monotony and strain), and perceived tolerance and enjoyment of RT in the present study. As noted, sRPE does not significantly differ between NP, BP and DUP RT when training to muscular failure in older adults, with fatigue proposed as a confounding factor (61). Thus, fatigue also possibly impacted subjects' perceived tolerance and enjoyment to RT across NP, BP or DUP RT, thereby negating the influence of differences in VL, monotony and strain between training models. Therefore, whether subject's ratings of tolerance and enjoyment would have been similar across training groups in the absence of RM sets remains unknown and requires further investigation.

A strong association between increased training load indices and the incidence and risk of injury and illness has been demonstrated across numerous athletic disciplines (43, 65, 124, 125, 192, 251, 300). Pyne, et al. (302) also suggested that integrated indices of training loads, such as strain, are possibly more highly correlated with illness than individual factors such as training volume. Consequently, reductions in training monotony and strain are advocated to help prepare athletes to cope with demands of the sport, while better managing injury risk (65). It seems reasonable to also apply this approach in non-athletic populations, thereby avoiding prolonged periods of monotonous training and reducing the overall physical stress induced, consequently minimizing the risk of illness and injury.

As described, transition weeks were implemented in the latter stages of RT to promote recovery and reduce the risk of injury or illness due to observing a general rise in fatigue and a reduced motivation to train. This was considered a likely result of consistently training to muscular failure, and may have been avoided by using other means of prescribing exercise resistance, e.g. %1RM (67, 120). Yet, whereas DUP demonstrated a chronically reduced training strain (Figures 5.1 and 5.2), the greater overall physical stress coupled with the constant performance of RM sets possibly heightened the risk of injury and illness in NP and BP. Also, despite a statistically lower week 1 training strain in NP compared to BP, BP

displayed a significantly lower training strain than NP in weeks 8, 10, 19 and blocks 3 and 6 (Figures 5.1 and 5.2). Therefore, although less frequent than DUP, variation of the training stimulus across training blocks in BP did alleviate the overall physical stress in subjects, particularly due to the reduced VL in maximal strength blocks 3 and 6 (Figure 5.2).

As no formal measures of fatigue, injury or illness were included in the present study, a detailed analysis is not permitted. However, although not statistically different among groups, the number of sessions missed due to illness was greater in NP (NP=21, BP=8, DUP=13). Yet, it is important to acknowledge that the RT intervention was conducted predominantly between the cooler months of March-September in Australia, when the risk of common cold and influenza is considerably greater (75). Therefore, RT cannot be confirmed as the only contributing factor underlying these missed sessions. In addition to the RT-related injury cases resulting in drop-out (NP=1; BP=1, DUP=1), two further subjects in the NP group presented with overuse injuries. Specifically, one subject suffered from a bicep muscle strain and was unable to perform upper-body exercises for six continuous training sessions, and the other suffered complained of pectoral muscle pain that prevented performing the chest-press exercise for the final 11 training sessions. Whether the possible increased risk of injury in the NP group, based on monotony and strain, would have manifested to a greater extent had the RT intervention continued beyond 22 weeks subjects is questioned. Yet, as the implementation of safe and effective RT with focus on long-term adherence is crucial in aging individuals (293), basic periodization strategies are recommended for better management of RT load indices (133, 302).

Finally, there was a very strong significant relationship between training monotony and strain for the entire cohort (r=0.90; $p \leq 0.01$), which was expected considering that strain is a product of monotony, and is consistent with previous findings (7). Moreover, a novel finding was the moderate significant relationship between perceived tolerance and enjoyment of RT (r=0.47; $p \leq 0.01$). Although it seems logical that as an individual's perceived tolerance to RT increases, so does their level of enjoyment, this further supports the necessity to consider such psychological factors in the design and implementation of RT among the elderly. Additionally, the impact of the different RT models on key outcome measures, e.g. muscle hypertrophy and functional capacity, must also be considered in the overall effectiveness of an intervention. While the inclusion of such training outcomes was outside the scope of our study, this highlights an area for future examination, for instance, the interplay between RT load, ratings of tolerance and enjoyment, and important training adaptations.

In conclusion, despite distinct differences in training load indices (VL, training monotony and strain), perceived tolerance and enjoyment of RT are similar across NP, BP and DUP training models in older adults. Therefore, no relationships between VL, monotony and strain, and perceived tolerance and enjoyment of RT were evident. Based on these results, periodization strategies do not appear to impact perceived tolerance or enjoyment of RT among the elderly, yet are recommended for better management of training load indices, potentially reducing the risk of illness and injury and promoting long-term adherence. The interplay between RT load indices, perceived tolerance and enjoyment, and key physiological and performance training adaptations requires exploration in pursuit of an optimal RT model for older adults.

5.6 Practical Applications

Exercise practitioners are recommended to implement basic periodized RT models, such as BP or DUP, for better management of training load in the aging population, thereby reducing the potential risk of illness and injury across long-term NP programs. However, NP, BP and DUP RT are perceived as similarly tolerable and enjoyable during the initial stages of training among untrained older adults. Additionally, chronic training to muscular failure should be avoided by using alternative methods for exercise load prescription, such as %1RM. Finally, practitioners should strive to foster a friendly, supportive and motivating training environment to enhance positive psychological well-being and long-term adherence to RT.

CHAPTER SIX

Application of Session RPE Among Different Models of Resistance Training in Older Adults

N.B. The following chapter has been accepted for publication:

Conlon JA, Newton RU, Tufano JJ, & Haff GG. Application of Session RPE Among Different Models of Resistance Training in Older Adults. *Journal of Strength and Conditioning,* 29(12): 3439-46, 2016.

However, the formatting has been adjusted from the original manuscript to allow continuity through the entire thesis document.

6.1 Abstract

The aim of this study was to assess the relationship between external measures of RT workload and intensity, VL and TI, and related internal measures, session load and session RPE (sRPE), across a chronic RT intervention and between different models of RT in older adults. Forty-one healthy, untrained older adults (female=21, male=20; 70.9 ± 5.1 y; 166.3 ± 8.2 cm; 72.9 ± 13.4 kg) were randomly stratified into three RT groups; non-periodized (NP), block periodized (BP) or daily undulating periodized (DUP), and completed a 22-week RT intervention at a frequency of 3 $d \cdot wk^{1}$. All training was executed on RT machines and training volume was equalized between training groups based on total repetitions. Session RPE was measured 10-15 min following each training session. There were no meaningful relationships between VL and session load, or TI and sRPE. Also, no significant differences were detected between training groups for mean sRPE across the training intervention. Based on these results, session load and sRPE do not appear to be valid markers of RT workload and intensity when compared to established external measures in healthy untrained older adults. However, sRPE and session load may hold as promise as monitoring tools in RT that does not involve training to muscular failure. Furthermore, sRPE does not significantly differ between NP, BP and DUP RT models, highlighting that this measure is not sensitive to such periodization as evident in the present study.

Key Words: Workload, volume load, training intensity, session load, periodization.

6.2 Introduction

When designing and implementing a RT plan, the ability to monitor and manage training stressors is considered to be an influential factor in optimizing the stimulus and thus overall effectiveness of the intervention (37). Specifically, RT cannot be readily quantified using objective internal physiological measurements such as HR or oxygen consumption (VO_2) as typically used in aerobic exercise (359). Therefore, suboptimal performances attributable to training above or below optimal levels in RT may occur.

While an objective external assessment of RT workload (force x displacement) is possible using technologies such as linear position transducers, these methods are time-consuming, costly and therefore often impractical, especially when working with large groups and in non-athletic settings. Hence, estimating RT workload using VL (number of sets x number of repetitions x weight lifted (kg)) is an established method for quantifying training loads (139, 237). What's more, TI which is calculated by dividing the total VL by the total number of repetitions, represents the average kilograms lifted across a training session and can be used to measure the global intensity of RT (139).

Together, VL and TI can be used to plan and monitor external workload and intensity within a periodized RT program. However, although these methods are convenient and do not require specialised equipment, when considering other factors that contribute to the perceived intensity of RT, such as exercise choice, rest periods, velocity of movement and accumulated fatigue, there has been a great deal of focus towards establishing a more simplistic and comprehensive measure of global RT intensity.

The sRPE is a modification of the classic RPE scale, used to evaluate an entire exercise session, and is proposed as a method for monitoring the global intensity of RT (240). Specifically, sRPE allows the individual to provide a global RPE for the entire training session, rather than traditionally reporting a series of acute RPE measures for each exercise within a session. Traditionally, it was recommended for sRPE to be recorded 30 min post-exercise to prevent perceptual feelings at the immediate termination of exercise from skewing the measure (69, 84, 165, 240, 359). However, this timeframe may be impractical in some training settings and more recently measuring sRPE 10-15 minutes post-exercise has been proposed as a valid methodology (170, 207, 208, 341).

Furthermore, sRPE can be multiplied by the training session duration (in minutes) in order to calculate session load, which may be used to measure the workload accomplished (113). However, using duration in the reflection of RT workload is questionable, therefore the number of repetitions or sets performed has been postulated as a more accurate marker

(240). Nevertheless, sRPE and session load are recommended as markers of internal RT intensity and workload, respectively, and could provide a more practical and time-efficient alternative to VL and TI for planning and monitoring purposes.

Briefly, sRPE has been reported in the contemporary scientific literature to be a reliable method for quantifying the relative exercise intensity (%1RM) of RT in healthy adults when performed to a pre-determined number of repetitions (69, 170, 359), and may be dependent on the mode of exercise (maximal strength, hypertrophy, power) (84, 341). However, although %1RM was initially suggested as the primary mediator of sRPE, authors have suggested total VL as the principle mediating factor (299). What's more, recent studies have examined the influence of work rate (total VL lifted per unit time) on sRPE response and have demonstrated that sRPE is more closely linked to changes in work rate than to total workload (208). Furthermore, strong relationships between sRPE and established objective measures of aerobic exercise intensity, specifically HR and VO_2, have been reported (165). Specific to RT, strong correlations between sRPE and number of repetitions performed, time under tension and session duration between different RT schemes (3 sets x 8 repetitions at 70% 1RM and 3 sets x 14 repetitions at 40% 1RM) have been noted (170). However, the relationship between the more novel measures (sRPE and session load) and established measures (TI and VL) of RT intensity and workload, is scarce, with only one study reporting a strong positive relationship between total VL and sRPE across different training schemes (226).

There is also little research surrounding the use of sRPE in RT among non-athletic populations, including older adults and children (96, 239). Additionally, as the majority of studies concerning sRPE were conducted in acute settings, mainly within a single exercise session, it is unknown whether these findings hold true over chronic training period. Furthermore, investigation of sRPE between different models of RT, i.e. periodized and non-periodized, is critical. These considerations are significant due to the complex nature of RT program design, specifically the sequencing of acute training variables over time. Therefore, research into the application of sRPE among different populations, across a chronic training period, and between different models of RT is essential.

The primary aim of the present study was to assess the relationship between commonly used external measures of RT workload and intensity, VL and TI, and more novel internal measures, session load and sRPE, across a chronic RT intervention in older adults. A secondary aim was to assess sRPE in response to different models of RT, specifically periodized and non-periodized, in this population. It was hypothesized that a meaningful

relationship would be found between VL and session load, and TI and sRPE measures. Additionally, it was predicted that the reporting of sRPE would vary among different models of RT, specific to the sequencing of acute program variables, particularly training intensity and volume.

6.3 Methods

6.3.1 Experimental Approach to the Problem

The present investigation is part of a larger series of studies that explored the impact of various RT models on the physical function, health and wellness of older adults. In detail, subjects were required to complete a 22-week RT intervention at a frequency of 3 $d \cdot wk^{-1}$, excluding weeks 14, 17 and 20 where subjects trained 1 $d \cdot wk^{-1}$. These weeks were classified as transition weeks with the aim to promote recovery and reduce the potential for injury or illness. Therefore, the total number of prescribed training sessions over the 22 week training intervention was 60. Furthermore, subjects were randomly stratified into three experimental RT groups based on gender, age, MVIC of the knee extensors and body mass index (BMI). Specifically, the three RT groups were; NP, BP and DUP.

6.3.2 Subjects

Forty-one healthy older adults (female=21, male=20; 70.9 ± 5.1 y; 166.3 ± 8.2 cm; 72.9 ± 13.4 kg) were recruited for the present study. Physical descriptive data of the subjects across training groups is presented in Table 6.1, with no significant differences between groups at the initiation of the study (p>0.05). All subjects provided medical clearance from their personal physician and completed a health history questionnaire prior to participating in the study. Exclusion criteria included a BMI of ≥ 30 $kg \cdot m^2$, possessing any pre-existing musculoskeletal, cardiovascular or neurological condition, or any other condition considered to cause risk to the subjects through RT or reduce their ability to adapt. Additionally, subjects were untrained, i.e. had not participated in structured exercise training designed to improve performance over the previous 12 months. Finally, subjects were instructed to continue with normal daily activities and discouraged from engaging in any unaccustomed activity. The University Human Research Ethics Committee approved the study and subjects were fully informed of the nature and possible risks of all procedures before providing written informed consent.

Table 6.1. Subject's physical descriptive data across training groups.

	NP	BP	DUP
Gender	F = 7; M = 5	F = 7; M = 7	F = 7; M = 6
Age (y)	70.4 ± 6.1	71.8 ± 5.4	71.2 ± 4.2
MVIC (N)	147.7 ± 45.4	132.1 ± 43.0	148.2 ± 47.1
BMI (kg.m^2)	26.4 ± 4.2	26.3 ± 3.0	26.4 ± 3.9

6.3.3 Procedures

6.3.3.1 Resistance Training

All exercises were executed on RT machines (Cybex, MA, USA) with zero use of free weight movements. The resistance and repetitions performed in the work-sets for each exercise were recorded in a training log and served as a written record for subjects at the start of training sessions. Subjects were fully familiarised with all machines prior to commencing the training intervention. Furthermore, training sessions were performed at a regular time of day, with a minimum of 48 h between sessions and in the presence of qualified instructors to assure proper exercise technique and reduce the risk of injury.

All training sessions commenced with a 5 min standardised warm-up consisting of light stationary cycling, rowing or brisk walking on an ergometer or treadmill (Technogym, London, UK). A warm-up set of each exercise was completed at approximately 50% of the resistance of the first work-set. In order to provide recovery, a rest interval of 1 min was provided between the warm-up set and the first work-set, and a 1.5-2 min recovery period was employed between consecutive work-sets. Subjects were instructed to perform the concentric portion of exercises with maximal velocity to promote optimal neuromuscular adaptations (39, 106, 255). Additionally, subjects were instructed to control the eccentric portion using a 2 s cadence as monitored by trainers.

Exercise resistance was prescribed using RM sets to ensure that the resistance stimulus was changed to accommodate strength adaptations, requiring adjustment of the exercise resistance to ensure muscular failure at the prescribed RM target (200, 203). Specifically, when a subject was capable of performing an exercise for the required number of repetitions for three consecutive sets at a fixed resistance, 1.25, 2.5 or 5kg increments were applied, depending on the absolute resistance being used. If a subject failed to complete the required number of repetitions, the number of repetitions performed was recorded and the resistance was reduced accordingly for any remaining sets.

An outline of the RM target prescribed for each group across the intervention is outlined in Table 6.2. The training focus for each RM target was; 15RM = strength-endurance, 10RM = hypertrophy, and 5RM = maximal strength. The training intervention is displayed in blocks of training to clearly outline the BP programme. Traditionally each training block includes several complete weeks (microcycles), however training blocks in the current study comprised 11 total training sessions due to scheduling constraints, specifically three complete microcycles plus two sessions within the following week. Overall, BP and DUP groups completed the same number of training sessions at each RM target. Moreover, as differences in the overall training volume between RT programs have been proposed to influence performance (14, 108, 403), total repetitions were equalized between all training groups in this study in order to reduce potential confounding factors. Therefore, the only difference between DUP and BP groups was the time and sequence of the load application. Exercise selection was consistent across the study and among all training groups, targeting concentric and eccentric muscle actions of major muscle groups and with lower-body and upper-body exercises alternated. Specifically, exercises included; seated leg press, lat pull-down, seated leg-curl, chest press, leg extension and seated row. Finally, once subjects were competent in training procedures the duration of sessions were as follows; 15RM = 60 min, 10RM = 50 min, and 5RM = 40 min.

Table 6.2. The prescribed RM targets for training groups across the training intervention (training session numbers presented in brackets).

	Block 1 (1-11)	**Block 2 (12-22)**	**Block 3 (23-33)**	**Block 4 (34-42)**	**Block 5 (43-51)**	**Block 6 (52-60)**
NP	3 x 10RM					
BP	3 x 15RM	3 x 10RM	3 x 5RM	3 x 15RM	3 x 10RM	3 x 5RM
DUP	Session 1: 3 x 15RM Session 2: 3 x 10RM Session 3: 3 x 5RM					

6.3.3.2 Session RPE and Session Load

Approximately 10-15 min following completion of each session, subjects reported their sRPE according to the OMNI-Resistance Exercise Scale (OMNI-RES), validated to measure RPE in resistance exercise (313). Specifically, the OMNI-RES includes four

illustrations along a scale of 0-10, and subjects reported their sRPE in response to the statement, "I have found the exercise session to be"'. Subjects were reminded to provide a global rating of intensity for the entire training session, with 0 representing 'extremely easy' and 10 representing 'extremely hard', and the OMNI-RES was in full view of the subjects during all sessions. As noted, session load is computed by multiplying sRPE and training session duration (113), with total repetitions or sets performed suggested as a better indicator than duration in RT (240). In the present study, although training session duration varied according to the RM zone (15RM = 60 min, 10RM = 50 min, and 5RM = 40 min), this was based on general observation. Therefore, it was deemed more scientifically valid to calculate session load using total repetitions performed in order to accurately reflect the sequencing of training load application across the intervention. However, session load was calculated using both methods to assess any differences in results.

6.3.4 Statistical Analyses

Data were analyzed using SPSS statistical software (SPSS Inc., Version 22, NY, USA). All data are presented as mean ± SD. Normality of distribution was assessed using the Shapiro-Wilk statistic and where data was not normally distributed (p<0.05), non-parametric analyses were performed. Correlation analyses were used to assess the relationship between VL and session load, and TI and sRPE, for the entire cohort. Specifically, mean data from each training block was used and CI at the 95% level were computed for all correlation analyses. Finally, a repeated-measures ANOVA was used to detect any between-group differences in sRPE across training blocks. Statistical significance was set at p<0.05.

6.4 Results

Unfortunately, one subject suffered an unforeseen accident not related to the study and did not commence the training intervention, and one subject dropped out in week 1 due to feeling unable to complete training requirements, therefore these data are not included in the analyses. In addition, there were six further dropouts across the study due to illness or injury (NP=2; BP=1; DUP=3), with three injury cases were related directly to the RT intervention (NP=1; BP=1, DUP=1). Specifically, two subjects experienced a minor muscle tear during 1RM procedures and one subject suffered from an overuse injury preventing continuation in the study. However, all data was included in analyses up until the time of dropout. All subjects maintained an adherence rate ≥85% to RT over the course of study and were therefore all included in the final analyses.

There was no significant relationship between VL and session load derived from training session duration (r = .032; p = .635), 95% CI [-0.100, 0.164] or total repetitions performed (r = .039; p = .569), 95% CI [0.094, 0.170] (Figure 6.1). Furthermore, a non-meaningful (.01 to .19) but statistically significant relationship was detected between TI and sRPE (r = .169; p = .012), 95% CI [0.038, 0.295] (Figure 6.2). Finally, no statistical differences were detected between training groups for mean sRPE across the training intervention (p > 0.05) (Figure 6.3).

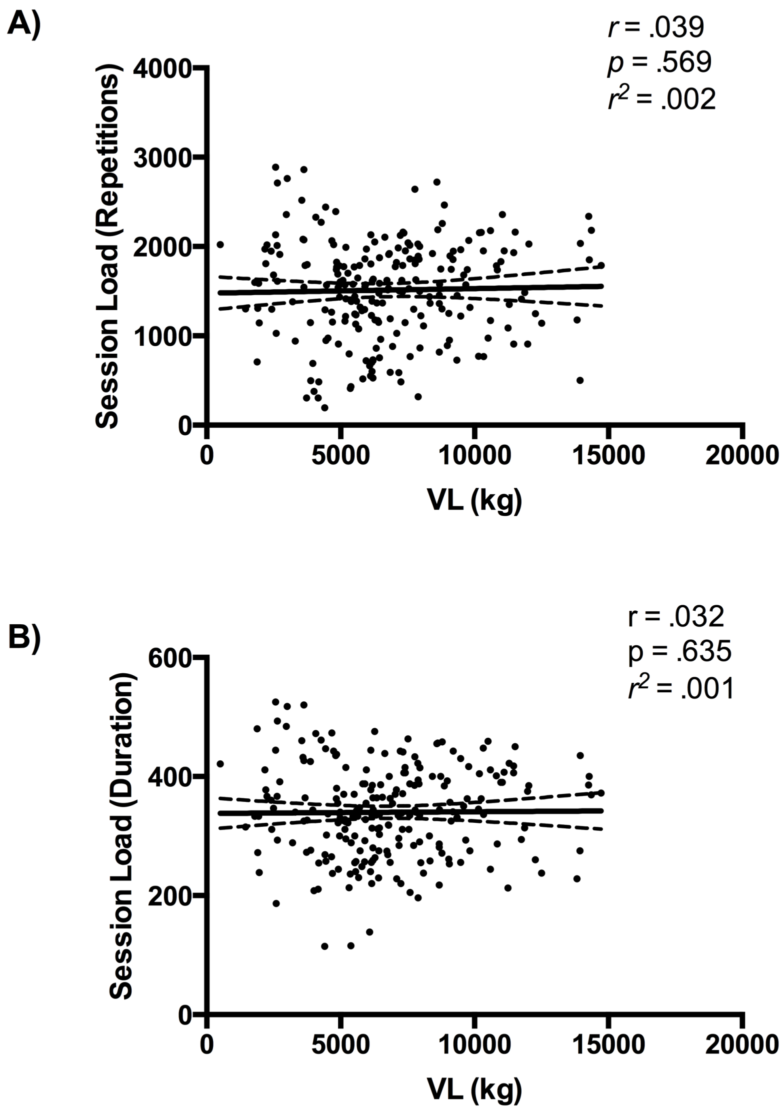

Figure 6.1. The relationship between; A) VL and session load (duration), and B) VL and session load (total repetitions).

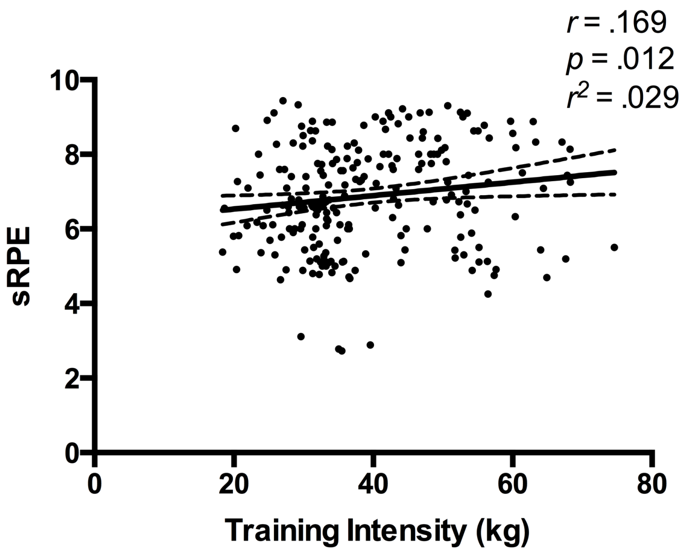

Figure 6.2. The relationship between TI and sRPE

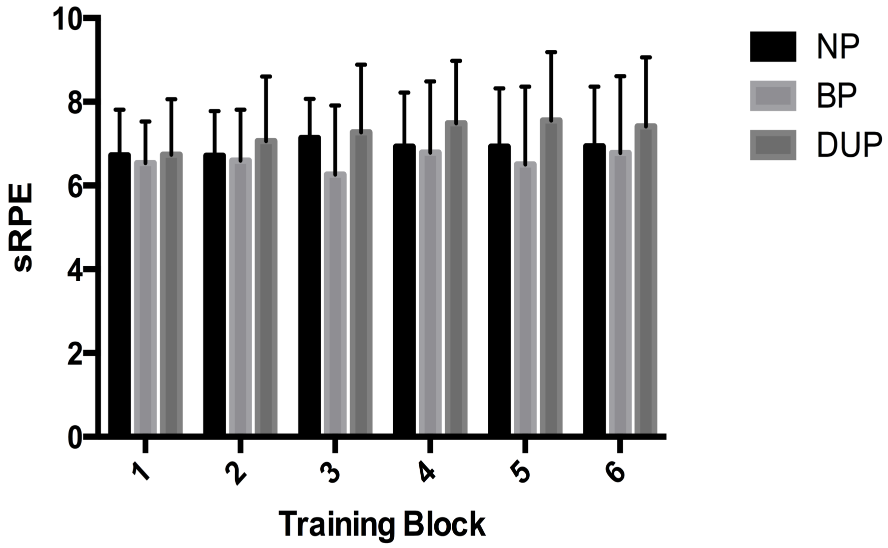

Figure 6.3. Mean group sRPE across the training intervention.

6.5 Discussion

The primary aim of this study was to assess the relationship between established external measures of RT workload and intensity, VL and TI, and more novel internal measures, session load and sRPE, across a chronic RT intervention in older adults. The

current findings displayed no relationship between VL and session load, evident in both calculations of session load, i.e. multiplying sRPE by training session duration or total repetitions performed. In addition, no relationship between TI and sRPE was evident.

When examining the periodization literature, despite VL typically not including any measure of displacement, it is considered to be a reasonable estimate of workload and is commonly applied in RT (237, 350). Although authors suggest that the VL is a flawed workload estimate when using exercises without an external load, such as a body mass jump squat (237), this was not a concern in the present study as all training was performed on machines. Therefore, due to failing to detect a relationship between VL and session load, the present data does not support the use of session load derived from sRPE as an estimate of RT workload (240). To the authors' knowledge this is a novel finding, with no other studies having previously assessed this relationship.

However, one study by Lodo, et al. (226) reported a strong positive relationship between total VL and sRPE across different acute training schemes, specifically strength, hypertrophy and endurance. A higher sRPE displayed a corresponding greater total VL, with the authors concluding that sRPE is more sensitive to changes in total VL than to intensity when expressed as %1RM. Yet, this study and the present differed in research aims, as Lodo, et al. (226) did not assess the relationship between VL and session load derived from sRPE, but rather correlated a measure of external workload (VL) and internal intensity (sRPE). Therefore, as total VL was significantly higher in both the strength and hypertrophy training schemes, it would be interesting to note whether this was also observed in session load, in line with the aims of the present study, highlighting the need for further research in this area.

Regarding markers of intensity, as TI is a product of VL and sRPE is central in the calculation of session load, it is not surprising that there was also no relationship evident between TI and sRPE. As noted, sRPE is proposed as a marker of perceptual global RT intensity, encompassing factors other than the exercise intensity. McGuigan and Foster (240) note that exercise choice and order, rest intervals and velocity of movement impact the perception of effort in resistance exercise, and are therefore reflected in the quantification of global RT intensity via sRPE. Moreover, depending on the phase of training as defined by the periodization, accumulated fatigue will also likely influence sRPE.

Considering this and that TI is simply a measure of the average exercise intensity (weight lifted) in a training session, this may partially explain the non-meaningful relationship between TI and sRPE. In contrast, previous studies reported strong associations between sRPE and relative RT exercise intensity (%1RM) when workload remains

consistent, therefore promoting sRPE as a valid measure for quantifying and monitoring the relative exercise intensity of acute RT bouts (69, 170, 359). Specifically, an increase in sRPE at higher exercise intensities has been attributed to the more intense corollary signals sent from the sensory cortex due to greater motor unit recruitment and firing frequency (129, 170). However these studies used %1RM as the marker of exercise intensity rather than TI, which may contribute to the difference in results. Nevertheless, this warrants further research to clarify such conflicting data. Furthermore, an important consideration when comparing present data to other findings is the application of RM sets performed to muscular failure in the current study.

The use of RM sets is an established alternative to resistance exercise intensity prescription using the %1RM method. In detail, rather than prescribe a pre-determined number of repetitions at a %1RM, true RM sets are prescribed as targets or ranges, i.e. 10RM or 8-12RM, where the individual must adjust the resistance to reach muscular failure (volitional exhaustion) at the specific repetition target or within the target range. Both techniques offer advantages dependent on the setting, yet due to the need for regular 1RM testing to accurately prescribe intensity based on this measure, RM sets are widely applied. Specifically, RM sets are common in the research community in order to ensure that the RT stimulus is changed to accommodate participant's strength adaptations (200, 203). Moreover, RM sets are considered central to some periodization models, specifically the DUP model (294, 311).

It has been previously reported that traditional RPE collected immediately following one set of the back squat exercise was shown to significantly differ between resistance exercise completed at various intensities, specifically 50%, 70% and 90% of 1RM, when performed to a pre-determined number of repetitions, but not when performed to volitional exhaustion (377). Similarly, Hiscock, et al. (170) found that sRPE was higher following 3 sets x 8 repetitions at 70% 1RM when compared to 3 sets x 14 repetitions at 40% 1RM in the same 5 exercises, despite matched rest intervals and workload. However, the same study found that there were no significant differences in sRPE regardless of the intensity (%1RM) and that sRPE was significantly greater when sets were performed to muscular failure, in agreement with Vasquez, et al. (377).

These findings support the idea that fatigue may be a confounding variable when attempting to utilise RPE for the assessment of resistance exercise. The responsible mechanisms have been previously well described (170), where training to muscular failure may produce a greater disruption in homeostasis, i.e. acid-base balance, than RT sets with a

pre-determined end-point. This heightened stress as observed via increased lactate accumulation has been show to occur in exhaustive resistance exercise (48), and was found to result in a reduction in mean muscle activation when measured by surface electromyography (182). Consequently, this may interfere with excitation and contraction coupling resulting in a decreased ability to produce power, leading to an increased RPE response (377).

Furthermore, researchers have examined sRPE across RT exercises performed to muscular failure between low-intensity (60% 1RM) and high-intensity (90% 1RM) protocols, highlighting that sRPE was significantly greater following the low-intensity session, involving a significantly higher amount of workload than the high-intensity session (299). Therefore, it appears that when using multiple RM sets, sRPE is more closely associated with total workload than exercise intensity, supporting the work of Lodo, et al. (226). Consequently, a high sRPE following RT using RM sets may not be indicative of high-intensity exercise (heavy resistance) necessary for optimal strength adaptations (291), but rather reflective of fatigue due to an increased workload. Therefore, practitioners must be aware of the limitations and issues of using sRPE and should not consider it a valid measure of relative exercise intensity for planning and monitoring RT when utilising RM sets to muscular failure. Finally, it is important to consider the difference between traditional RPE and sRPE when assessing the literature. Although there is evidence to support that the average RPE, as measured immediately after individual sets, and sRPE do not significantly differ (69), variation between the two measures have been noted (239).

A secondary aim of the present study was to assess sRPE among different models of RT, i.e. periodized and non-periodized, in the present population. The findings revealed no statistical differences for sRPE between NP, BP and DUP training groups across the training intervention. Although the total volume of training was equal between groups based on the prescribed total repetitions, the sequencing of RM targets was markedly different dependent on the periodization scheme (Table 6.2). Therefore, fluctuations in VL and TI data across training blocks for the BP group and daily training days for the DUP group are present. With reference to Figure 6.3, differences in sRPE across training blocks for the BP group are anticipated, as this time frame defined the fluctuations in VL and TI specific to this training model. However, it is clear that sRPE is not sensitive to such periodization of training variables in the present study. These findings may be a result of the use of RM sets resulting in an increased perceived intensity of training. This further supports the lack of relationship between VL and session load, and TI and sRPE, and is in disagreement with previous findings showing that sRPE is able to quantify relative exercise intensity (69, 84) and

correlates strongly with VL (226).

It is also noteworthy that despite performing all exercises to muscular failure, the mean sRPE among training groups ranged between 6.26 and 7.49 across training blocks, where higher sRPE data may be anticipated when performing exercise to volitional exhaustion. Yet, although not the same scale as used in the present study, Hiscock, et al. (170) reported lower sRPE values in the range of 5-6 following RT sessions exercise sets that were performed to muscular failure at 40 and 70% 1RM, using a 10 item Borg scale. However, the study population was young male team-sport athletes that may also contribute to the differences when compared to the current data. Nevertheless, research is warranted to further explore this across various study populations.

In conclusion, session load and sRPE do not appear to be valid markers of RT workload and intensity when compared to established external measures, TI and VL, in healthy untrained older adults. What’s more, sRPE does not significantly differ between NP, BP and DUP training models when implementing true RM sets to muscular failure. Although sRPE and session load may hold promise as a monitoring tool in RT in the absence of RM sets, further research over a chronic RT period and across both athletic and non-athletic populations is warranted.

6.6 Practical Applications

To effectively understand the training stressors encountered by an athlete or individual, the ability to accurately plan, track and monitor the workload (volume) and intensity of a RT program is significant. The strength and conditioning professional is able to monitor the workload and global intensity of RT across a training period using the established VL and TI calculations. Based on the current evidence, although proposed as potentially more simplistic and comprehensive alternate measures, session load and sRPE are not recommended when prescribing resistance exercise using RM sets to muscular failure, primarily due to fatigue confounding the perception of effort. Although these novel techniques may prove valid when not implementing training to muscular failure, further research is required to confirm this. Therefore, at present, VL and TI measures are recommended to accurately quantify RT and to ensure that the athlete or individual is training as planned.

CHAPTER SEVEN

Final Summary, Conclusion and Recommendations

7.1 Final Summary

The central aim of this thesis was to investigate the efficacy of periodized RT strategies on key neuromuscular, physiological and health-related outcomes in older adults. Secondary aims included the examination of training load indices, perceived enjoyment and tolerance, and the application of sRPE in this setting. Overall, this adds to the significant body of research highlighting the considerable public health implications of RT in the aged, benefiting a vast range of physiological, neuromuscular and health-related outcomes. In particular, the originality of this thesis is evident through demonstrating the feasibility, efficacy and safety of BP and DUP RT models in RT-naïve elderly persons. Additionally, the examination of training load, including both traditional (VL, monotony and strain) and novel (sRPE) indices, ensures a comprehensive assessment of the application of periodized RT in a public health context. Specifically, in preventing and counteracting the detrimental age-related loss of muscle mass and function (i.e. sarcopenia).

As described, current ACSM guidelines for RT in older adults advocate variation in a program over time, yet do not provide any direction on how to best prescribe training variety. However, this thesis could influence future guidelines, by providing insight into and supporting the successful application of two well-recognized periodization strategies, each providing alternate formats of training variety for the aged. Notably, the present BP and DUP models are by no means complicated means of training prescription, and although unable to confirm superiority based on this thesis, may be valuable tools for ensuring older adults remain involved in RT across the entire lifespan, i.e. beyond the initial 22 weeks of training.

Overall, it is hoped that this thesis stimulates practitioners to think beyond current guidelines when it comes to prescribing RT for the older adult, and helps spread the notion that periodization strategies are not just limited to athletic settings. Ultimately, the body of research presented strongly backs the concept that 'exercise is medicine', visibly demonstrating the striking beneficial impact of RT on the physiology, function, health and overall QOL among the aging population.

7.2 Conclusions

On commencing this thesis, it was hypothesized that periodized RT would promote significantly greater improvements in training adaptations, induce greater ratings of enjoyment and tolerance to RT, superior to a NP training model. Further, sRPE (and the related session load) were hypothesized to be a valid tools for RT monitoring purposes across the different models of RT.

In opposition to these original hypotheses, it is broadly concluded that NP, BP and DUP RT models are equally effective for promoting significant improvements in key physical function, physiological, and neuromuscular adaptations among apparently healthy untrained older adults. Consequently, periodization strategies are not critical during the initial stages of RT among the elderly (Chapters Three and Four). Additionally, periodized RT does not appear to impact an elder person's perceived tolerance or enjoyment of RT, yet may be important for the better management of training load, potentially reducing the risk of illness and injury beyond the initial stages of training (Chapter Five). Finally, novel training load indices, session load and sRPE are not valid markers of RT workload and intensity when compared to established measures (VL and TI). Therefore, practitioners should be cautious to rely solely on such novel measures for load monitoring purposes across RT in older adults (Chapter Six).

7.3 Future Research Recommendations

Several future research recommendations have been described within the separate experimental studies throughout this thesis. In summary, the examination of periodization strategies among previously trained older adults is warranted, with alternate training models such as WUP recommended for consideration. Additionally, the use of true RM sets to momentary concentric muscular failure is not advised over chronic training periods, with other means of exercise load prescription recommended, such as %1RM. Finally, the implementation of BP and DUP periodization strategies do not have to be strictly defined by exact sequencing of training stimuli as used in the present study. For instance, once a sufficient foundation of general strength is established, power-specific RT methods may be incorporated into either periodized model. Thereby, as in any population, training specificity is equally important in the elderly and the training stimulus should be modified accordingly, dependent on the warranted adaptation(s).

Nonetheless, above all else, due to the alarming low RT participation rates among the aged, a consistent recommendation throughout this thesis is for practitioners to primarily work towards engaging this population with RT, via feasible and efficacious interventions targeting long-term adherence in minimally supervised settings. Anecdotally, the community environment that was established among the participants, research team and exercise trainers during the period of data collection of this thesis was a major factor in the success of the intervention, and the enjoyment and adherence of the older adults involved. Thereby, above all else, it is highly recommended that practitioners aim to offer RT services exclusive to the

older population, thereby providing a safe, non-threatening and friendly group environment. More so, it is crucial that those personnel involved in the delivery of such services truly appreciate their influence on the overall impact of a RT intervention. Central to this process is establishing the trust of participants, communicating the vast benefits of RT wherever possible in a relatable context, and fostering a supportive, encouraging and enriching culture among elders.

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APPENDIX A

Participant Information Letter

Chief Investigator: Jenny Conlon **E-mail:** j.conlon@ecu.edu.au

Thank you for expressing interest in this research project. The following information is to fully inform you of the purpose and the nature of this study, which has been approved by the ECU Human Research Ethics Committee. Please read all of the information carefully and do not hesitate to contact the chief investigator for further information.

BACKGROUND: Resistance training is effective in preventing and treating the age-related loss of muscle mass (i.e. sarcopenia) and increasing strength among older adults. However, at current there is no consensus on an optimal resistance training model for older adults. Research has consistently highlighted the superiority of periodized (i.e. appropriately organized and structured) resistance training when compared to non-periodized resistance training among young athletes. However, investigation into the use of periodized resistance training among older adults is scarce. Therefore, the aim of this study is to investigate the effect of periodized versus non-periodized resistance training on health outcomes and physical function in older adults. This project will ultimately assess the impact of periodized resistance training on the overall health profile of aging individuals and may influence future resistance training recommendations.

STUDY OUTLINE: The total duration of the proposed study is 31 weeks, including 2 familiarization sessions, a 4-week control period (no training), a 22-week resistance training period and the completion of all testing procedures (Figure 1).

Wk 1	Wk 2	Wks 3-6	Wk 7	Weeks 8-18	Wk 19	Weeks 20-30	Wk 31
*	Test	Control period	Test	Training period	Test	Training period	Test

Figure 1. Study structure *(**familiarisation*).

Participants will be tested on four separate occasions, at weeks 2, 7, 19 and 31, using the tests described below. Weeks 3-6 will be used as a control period during which time no training will be carried out and participants will simply maintain their normal recreational physical activities. Thereafter, participants will commence a 22-week supervised resistance training program. Participants will be fully familiarized and instructed in the proper execution of all testing protocols across two sessions before initiation of the study. All testing and training sessions will take place at Edith Cowan University (ECU), Joondalup.

TESTING WEEKS: For each testing week, participants will be required to visit ECU on three separate days in order to complete all testing procedures. Each testing day will require participants to attend the testing location for approximately 2 hours. Participants will be required to wear light and loose fitting clothing at testing sessions including shorts. Specific tests are described below:

1) *Anthropometric Measures*- Body mass, standing height, and waist and hip circumference.

2) *Physiological Measures*- Muscle ultrasound will be used to measure muscle cross-sectional area of the quadriceps muscle group. Participants will be required to simply lay in the horizontal position for approximately 30 min. A DEXA scan (dual-energy x-ray absorptiometry) will also be performed to assess body composition. This scan takes approximately 15 min and requires participants to lay in the horizontal position. Resting blood pressure will be measured by a digital blood pressure monitor.

3) *Blood Samples*- Blood samples will be collected from the arm vein following a 12 h overnight fast by a qualified professional for blood profile analysis.

4) *Functional Capacity*- The repeated chair rise test will be used which requires participants to rise as fast as possible to a standing position and then return to a full sitting position five times. Stair climbing ability will also be measured where participants will climb on flight of stairs as fast as they can safely manage.

5) *Quality of life questionnaire*- Health-related quality of life and balance confidence will be measured using questionnaires.

6) *Dietary Intake and Physical Activity Standardization*- Participants will maintain their habitual physical activity pattern and dietary intake throughout the study. Physical activity will be assessed via a questionnaire and dietary intake will be assessed using a 3 day weighed food diary.

7) *Neuromuscular Performance Measures*- Isometric strength will be measured via maximal voluntary contraction of the quadricep and hamstring muscle groups and isokinetic strength of the same muscles will be measured using an isokinetic dynamometer. Muscular power will be assessed from countermovement jump performance, where participants are required to lower themselves and explosively jump upward as quickly as possible. Finally, dynamic muscle strength and endurance will be measured for chest press and leg press exercises. (N.B. Dynamic muscle strength will also be tested in week 13 during a scheduled training session).

Figure 1. Neuromuscular performance testing using an isokinetic dynamometer.

8) *Muscle Activity*- Four small surface electrodes will be carefully attached to the skin over the muscle to measure muscle activity of the quadriceps and hamstrings during the isometric and isokinetic strength tests.

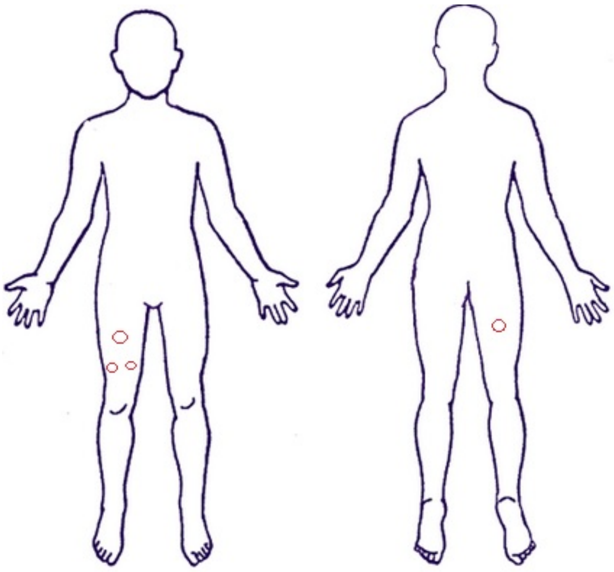

Figure 2. Location of surface electrodes for muscle activity measures.

RESISTANCE TRAINING: Participants will commence a 22-week resistance training program at week 8 a frequency of 3 days per week, with a minimum of 48 h between sessions. Resistance exercise selection will target all major muscle groups and will be executed on machines, with a total of 6 exercises completed per session. Training sessions will last approximately 75 min, including a standard warm-up and cool-down, and will be supervised by qualified trainers. Resistance will be increased progressively throughout the study. Approximately 15 min following the completion of training sessions, participants will report their session rating of perceived exertion (RPE), perception of tolerance to, and the enjoyment of the resistance training session.

PROTEIN SUPPLEMENTATION: On completion of each training session participants will ingest a standard liquid whey protein supplement to support training adaptations and help recovery.

ELIGIBILITY: In order to take part in this study, participants will be asked to obtain medical clearance from their personal physician and complete a health history questionnaire. Participants will be instructed to continue with every day normal activities, yet be dis-encouraged from engaging in any unaccustomed activity.
Exclusion criteria will include:

- Lactose intolerance;
- A body mass index ≥ 30 kg/m^2;
- Any pre-existing musculoskeletal, cardiovascular or neurological condition;
- Participation in a structured exercise training designed to improve performance in the previous 12 months;
- Being unable to commit to 22 weeks of resistance training without interruption and attend all testing sessions.

POSSIBLE RISKS AND DISCOMFORT: Blood samples may provide mild discomfort due to the nature of the procedure, however only qualified professionals will obtain samples. Secondly, DEXA scans are routine clinical tests but carry a small risk to the subject through exposure to radiation. The level of radiation exposure is exceedingly small (0.5-1 uSv) in comparison to the natural annual radiation dose in western communities (approximately 2000-25000 uSv). For instance, an individual would receive radiation exposure of approximately 28 uSv on an airline flight of between Australia and Europe or 30-45 uSv during a typical chest x-ray. The number of scans proposed in this study is well within the guidelines provided by the manufacturer of the DEXA machine. In addition, mild discomfort may be experienced during preparation of the muscle activity surface electrodes via skin irritation as a result of abrasive cleaning. Finally, participants may experience muscle soreness following strength tests and resistance training, however all efforts will be made to reduce this via sufficient warm-up and cool-down procedures. It is stressed that all health and safety procedures at ECU will be followed closely at all times throughout this study.

BENEFITS OF PARTICIPATION: Participation will provide the unique opportunity of receiving a supervised 22-week resistance training program and access to top-of-the range gym facilities at ECU. Additionally, participants will receive a detailed health assessment during each testing week, with the series of tests being performed costing upwards of $1000 if undertaken at a private clinic. The tests will provide participants with information on their body composition, levels of muscular strength, endurance and power, functional capacity and muscle physiology. Finally, participants will have the opportunity to ask questions regarding the research topic.

CONFIDENTIALITY OF INFORMATION: Anonymity is assured throughout the project and all personal information will be treated with full confidentiality. Participant's personal information will be de-identified following collection and will only be accessible by the chief researcher during the study period. In addition, only members of the research team will have access to the data collected. Data will be stored on a password-protected computer and encrypted hard drives and any paper documentation will be locked in a filing cabinet within the chief investigator's office. All data will be stored according to ECU policy and regulations following the completion of the study.

DISTRIBUTION OF RESULTS: This project is being carried out for the purpose of a PhD research thesis with the intention for the results obtained to be presented at conferences and published in peer-reviewed journals, as magazine/website articles or as part of a book section. Any distribution of reference to the data obtained will not contain participant's identifiable information. A copy of the published results can be obtained by participants from the chief investigator upon request.

PROJECT DATES: This project will take place between January and October 2014. Therefore, participants will have to be able to commit to 22 weeks of resistance training without interruption and attend all testing sessions during this time period. Exact dates will be confirmed following the provision of medical clearance and informed consent. The research team will aim to schedule training session times around participant's current commitments as best as possible, which will be discussed prior to participation.

QUESTIONS: If you have any questions or require further information regarding this study please contact Jenny Conlon on (08)-6304-2133, or e-mail j.conlon@ecu.edu.au. If you have

any concerns or complaints about the research project and wish to talk to an independent person, you may contact:

Human Research Ethics (08)-6304-2170, email research.ethics@ecu.edu.au.

It is stressed that participation in this project is voluntary and participants are free to withdraw at any time, for any reason without prejudice.

APPENDIX B

Participant Checklist & Informed Consent Letter

I have carefully read and clearly understand all the content of the information sheet and participant checklist and consent to being a participant in the research project titled "The Effect of Periodized Resistance Training on Physical Function and Health Outcomes in Older Adults."

Declaration

- I have had all questions relating to the study answered to my satisfaction.
- I agree to participate in this project and give my consent freely.
- All questionnaires pertaining to this study have been filled out truthfully to the best of my knowledge.
- I understand that I am free to withdraw at any time, for any reason without prejudice.
- I understand that the procedures will be carried out as detailed in the information sheet, a copy of which I have retained.
- I agree that the research data obtained from this study may be published, provided that I am not identifiable in any way.
- I agree that collected data may be used in future studies, other than the one titled above that have been approved by the ethics committee and that only members of the research team involved in the current project will have access to the data for future research.

Participant: ______________________ ________________ **Date:** _______________
Printed name Signature

The researcher certifies that the participant has a full understanding of the procedures and their involvement as outlined in this form. The participant has given verbal confirmation of their understanding, which meets the research's satisfaction prior to signing this form.

Investigator: ____________________ ________________ **Date:** _______________
Printed name Signature

Witness: ____________________ ________________ **Date:** _______________
Printed name Signature

If you have any questions or require further information about the research project, ple ase contact Miss Jenny Conlon on (08)-6304-2133 or e-mail j.conlon@ecu.edu.au. If you have any concerns of complaints regarding the research project and wish to talk to an independent person, you may contact:

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