# Manipulation of resistance training variables for strength increases in young adults

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# Abstract

*Objectives:* Recent publications have reported that muscular strength is evidenced to improve longevity and reduce risks of all-cause mortality. The aims of the studies presented was to consider the most efficient methods of increasing muscular strength by manipulating the resistance training (RT) variables; load, type, frequency, rest interval, exercise order and intensity of effort.

*Design:* All but one of the included studies utilised a randomised controlled trial design with three experimental groups. The remaining study considered a within-participant design where participants performed unilateral exercise and so were compared between limbs.

*Method:* Muscular performance measurements were assessed using; a calculation of pre-intervention and post-intervention repetitions multiplied by the same absolute load, 1-repetition maximum and isometric torque measured for the lumbar extensors, knee extensors, and leg and back combined. Study duration varied between 6 and 12 weeks.

*Results:* Analyses revealed that use of high- and low-load and differing exercise order produce equivalent muscle performance results ($p$>0.05). Specific exercises for the lumbar extensors produced greater increases in isometric lumbar extension torque compared to Romanian deadlift training ($p$<0.05), whereas use of a whole-body-vibratory stimulus produced no greater increases in leg and back strength compared to isometric deadlift training alone ($p$>0.05). Resistance training $1 \cdot d \cdot wk^{-1}$ produced similar strength increases to RT $2 \cdot d \cdot wk^{-1}$ for the lumbar extensors in chronic low-back pain participants ($p$>0.05). The use of advanced training techniques in the form of pre-exhaustion training or breakdown set training produced no greater gains in strength than conventional sets of RT to momentary failure ($p$>0.05). Finally, where volume is equated; knee extensions performed not to failure produce similar increases in isometric knee extensor torque when compared to training to momentary failure ($p$>0.05)

*Conclusions:* The studies presented within this thesis show a coherent theme investigating optimal methods of increasing muscular strength by manipulating specific variables. The studies as a collective demonstrate the relative simplicity that can be used to attain considerable strength improvements by the use of uncomplicated resistance training.

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Firstly I would like to thank Dr. Dave Smith, who has always inspired, challenged and pressed me to succeed. It's no surprise you're an author on many of these and our other research articles together. I would like to thank Dr. James Steele who, for similar reasons and continued day to day support, has been of significant contribution to the completion of many of my articles. Hopefully we have a long future of collaborative work and coffee orientated walking research meetings.

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[As a side note, I should like to thank anyone who ever brought me coffee whilst I've been working on research articles and this thesis.]

# Table of Contents

# Abbreviations

| | | |
|---|---|---|
| CI | - | confidence interval |
| CLBP | - | chronic low-back pain |
| CONC | - | concentric |
| ECC | - | eccentric |
| ES | - | effect size |
| ICC | - | intraclass correlation coefficient |
| ILEX | - | isolated lumbar extension |
| MF | - | momentary failure |
| MF+ | - | beyond momentary failure |
| MU | - | motor unit |
| nRM | - | not repetition maximum |
| Pre-Ex | - | pre-exhaustion |
| RDL | - | Romanian deadlift |
| RI | - | rest interval |
| RM | - | repetition maximum |
| RT | - | resistance Training |
| SC | - | satellite cells |
| sdRM | - | self-determined repetition maximum |
| sEMG | - | surface electromyography |
| WBV | - | whole-body vibration |

# Exercise Group Abbreviations

CHAPTER 3:

| | | |
|---|---|---|
| BD | - | breakdown training |
| HLBD | - | heavy-load breakdown training |

CHAPTER 4:

| | | |
|---|---|---|
| DL | - | Romanian deadlift training |
| LUMX | - | isolated lumbar extension training |

CHAPTER 5:

| | | |
|---|---|---|
| ST | - | strength training only |
| ST+VT | - | strength training + vibration training |

CHAPTER 6:

| | | |
|---|---|---|
| 1 x / week | - | 1 $d \cdot wk^{-1}$ frequency of training |
| 2 x / week | - | 2 $d \cdot wk^{-1}$ frequency of training |

CHAPTER 7:

| | | |
|---|---|---|
| PE | - | Pre-exhaustion training |
| PER | - | Pre-exhaustion training with rest |

CHAPTER 8:

| | | |
|---|---|---|
| MMF | - | Momentary muscular failure training |
| NMF | - | Non-momentary muscular failure training |

All published articles:

| | | |
|---|---|---|
| CON | - | control group |

# List of Tables



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CHAPTER 9:



See also figures within published articles; chapters 3 to 8

# List of Publications

The titles are listed here in chronological order, including digital object identifier (DOI) or online ISSN number, as well as current and 5-year impact factor for the respective journals.

Bruce-Low, S., Smith, D., Burnet, S., **Fisher**, J., Bissell, G., Webster, L. (2012). One lumbar extension training session per week is sufficient for strength gains and reductions in pain in patients with chronic low back pain ergonomics. *Ergonomics*, 55(4), 500-507.
Doi: 10.1080/00140139.2011.644329, Impact factor: 1.56 (5yr: 1.80)

**Fisher**, J., Bruce-Low, S., Smith, D. (2013). A Randomized trial to consider the Effect of Romanian deadlift exercise on the development of Lumbar Extension Strength. *Physical Therapy in Sport*, 14, 139-145.
Doi: 10.1016/j.ptsp.2012.04.001, Impact factor: 1.65 (5yr: 1.96)

**Fisher**, J. P., Carlson, L., Steele, J., Smith, D. (2014). The effects of pre-exhaustion, exercise order, and rest intervals on a full-body resistance training intervention. *Applied Physiology Nutrition and Metabolism*, 39(11), 1265-1270.
Doi: 10.1139/apnm-2014-0162, Impact factor: 2.34 (5yr: 2.68)

**Fisher**, J., Van-Dongen, M., Sutherland, R. (2015). Combined isometric and vibration training does not enhance strength beyond that of isometric training alone. *Journal of Sports Medicine and Physical Fitness*, 55, 899-904.
Online ISSN 1827-1928, Impact factor: 0.97 (5yr: 1.28)

**Fisher**, J. P., Carlson, L., Steele, J. (2016). The effects of breakdown set resistance training on muscular performance and body composition in young males and females. *Journal of Strength and Conditioning Research*, 30(5), 1425-1432.
Doi: 10.1519/JSC.0000000000001222, Impact factor: 2.08 (5yr: 2.58)

**Fisher**, J., Blossom, D., Steele, J. (2016). A comparison of volume equated knee extensions to failure, or not to failure, upon rating of perceived exertion and strength adaptations. *Applied Physiology Nutrition and Metabolism*, 42(2), 168-174.
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# Contribution to papers with multiple authors

CHAPTER 4

*Publication*

Fisher, J. P., Carlson, L., Steele, J. (2016). The effects of breakdown set resistance training on muscular performance and body composition in young males and females. *Journal of Strength and Conditioning Research*, 30(5), 1425-1432.

*Contributions*

JP Fisher, L Carlson, and J Steele designed the study. JP Fisher obtained ethical approval. JP Fisher and L Carlson collected data. JP Fisher and J Steele performed statistical analyses. JP Fisher, L Carlson, and J Steele drafted the manuscript. All authors contributed to revising intellectual content of the manuscript and approved the final version.

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CHAPTER 5

*Publication*

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*Contributions*

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* Stewart Bruce-Low left academia in 2015.

CHAPTER 6

*Publication*

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* Michael Van-Dongen and Rion Sutherland were student research assistants that helped with this study. They left Southampton Solent University in 2013.

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# CHAPTER 1: Introduction

## 1.1. Resistance training, health and longevity

The importance of understanding resistance training cannot be underestimated. The health benefits associated extend far beyond that of muscular strength and/or sporting performance and so for that reason the term *resistance* training (RT), as opposed to *strength* training, is chosen quite specifically. That a person can use muscular tension provided by an array of resistance methods to enhance their own personal well-being and longevity is of fundamental importance in the modern world. There is nothing more pertinent to human survival than our body's ability to contract muscle. Without this we would not breathe, digest or perform essential bodily functions and we would not lift or walk or move without assistance. As primitive man this function would have been crucial to our survival. Recent evidence has supported that muscle mass index is a stronger predictor of life expectancy than body mass index (Srikanthan & Karlamangla, 2014) lending support to the importance of muscle mass and muscular strength.

The progression of physical and psychological conditions in society (e.g. diabetes, obesity, hypertension, etc. and depression, schizophrenia and anxiety, respectively) serve to show the degeneration in health and wellbeing of the lay person. Whilst public and private health systems and health care in general resist this tide of illness, they also suffer from the financial implications on an already strained global economy. Resistance training has been shown to improve physiological health (e.g. decrease gastrointestinal transit time (Koffler et al., 1992), increase resting metabolic rate (Campbell, Crim, Young & Evans, 1994), improve glucose metabolism (Hurley, 1994), improve resting blood pressure (Harris & Holly, 1997), improve bone mineral density (Menkes et al., 1993), reduce pain and discomfort from arthritis (Rall, Meydani, Kehayias, Dawson-Hughes & Roubenoff, 1996), decrease low back pain (Nelson et al., 1995), enhance flexibility (Risch et al., 1993), and improve maximum oxygen uptake and endurance fitness (Westcott, 1995). In addition resistance exercise can reduce psychological ill health (e.g. reduce symptoms of anxiety (Cassilhas et al., 2007) and improve cognition in older adults (Busse et al., 2008), improve sleep quality in depressed older adults (Singh et al., 2005), reduce symptoms of depression (Singh, Clements, & Fiatorone, 1997) and improve self-esteem (Tsutsumi et al., 1998). As such, evidence-based RT is nothing short of a prescriptive treatment which has the capacity to both enhance the quality, and increase the longevity of human life (Phillips & Winett, 2010).

The studies discussed herein do not measure specific health related variables, but rather focus on optimal and efficient methods of obtaining muscular strength. However, we might consider that a primary objective of RT is "*to have a biological age equal to, or lower than, our chronological age*" (Fisher, Steele, Brzycki, & DeSimone, 2014, p. 31). Recent publications have reported that muscular strength specifically is important in the prevention of multiple chronic conditions such as metabolic syndrome (Stump, Henriksen, Wei, & Sowers, 2006) and cardiovascular disease (Artero et al., 2012) as well as others (Wolfe, 2006). Indeed, specifically, muscular strength has been repeatedly evidenced to improve longevity and reduce risks of all-cause mortality (Winett & Carpinelli, 2000; Newman et al., 2006; Ruiz et al., 2008; Artero et al., 2011; Ratanen et al., 2012). Most recently a large review stated;

> *"A strong and inverse association of muscular strength with all-cause mortality has also been confirmed in several clinical populations such as cardiovascular disease, peripheral artery disease, cancer, renal failure, chronic obstructive pulmonary disease, rheumatoid arthritis and patients with critical illness"*
>
> (Volaklis, Halle, & Meisinger, 2015, p. 303).

The studies supporting strength increases and reduced mortality are extensive and consider a variety of strength testing measures. These include isoinertial (e.g. 1-repetition maximum; 1RM) testing of leg press and bench press (Ruiz et al., 2008; Artero et al., 2011), isometric testing of knee extensors (Menant et al., 2016) and isometric testing of handgrip (Rantanen et al., 2012; Newman et al., 2006). However, since handgrip strength shows little response to resistance training (Tieland, Verdijk, de Groot, & van Loon, 2015, Rhodes et al., 2000) and as such we might use caution to interpret the relationship between grip strength and mortality in the aforementioned studies; the studies presented herein use isoinertial and isometric strength testing methods (see also section 1.4).

## 1.2. Pre-existing recommendations

Due to the large volume of published information on resistance training, several sets of recommendations to improve muscular strength across all age groups have been produced based on pre-existing literature (e.g. the US Department of Health and Human Services, 2008; UK Department of Health, 2011; The World Health Organisation, 2010). Since primary care physicians confess to a "'*lack of knowledge' as a barrier to promoting or counselling patients about strength training*" (Abramson, Stein, Schaufele, Frates, & Rogan, 2000), it is important for others to provide the necessary guidelines. An inexperienced trainee might look to the likes of the American College of Sports Medicine (ACSM) at their Position Stand; *Resistance Training for Healthy Adults*, which is made available, open access. However, the ACSM, who include recommendations for load, frequency, volume, type, intensity of effort, exercise order, etc. (Kraemer et al., 2002; Ratamess et al., 2009), have received criticism for a lack of scientific rigour (Carpinelli, Otto, & Winett, 2004; Carpinelli, 2009). In fact Carpinelli (2009) suggested that if one were to follow the 2009 guidelines by the ACSM with intentions to attain the desired components of muscular fitness (e.g. strength, hypertrophy, power and endurance) then trainees would need to spend a minimum of 20 hours per week (5 hours per day x 4 days per week) performing resistance exercise. This is a far greater volume and frequency than government organisations recommend, and is potentially over-complicating the suggested requirements for resistance exercise. This is of concern since previous research has identified that perceived difficulty as well as lack of time are barriers to resistance exercise (Winett, Williams & Davy, 2009; Owen & Bauman, 1992; Ainsworth, 2000; Grubbs & Carter, 2002).

With the above in mind, the present author published a review of evidence-based RT recommendations (Fisher, Steele, Bruce-Low, & Smith, 2011, p. 147) which considered the plethora of RT research, and ultimately summarised the following endorsements:

> …appreciably the same muscular strength and endurance adaptations can be attained by performing a single set of ~8-12 repetitions to momentary muscular failure, at a repetition duration that maintains muscular tension throughout the entire range of motion, for most major muscle groups once or twice each week. All resistance types (e.g. free-weights, resistance machines,

bodyweight, etc.) show potential for increases in strength, with no significant difference between them...

Whilst these recommendations suggest that a far more simplistic and time-efficient approach to exercise is possible, contradicting the higher volume and more complex ACSM guidelines, the article also discusses areas where research is lacking and as such; counsel cannot be provided. The present thesis discusses a series of studies which has attempted to fill the gaps within the literature, furthering our knowledge and understanding of RT and the recommended protocols for optimally and efficiently improving muscular strength.

## 1.3. Variables

Since the present thesis represents a discussion of commonly manipulated resistance training variables such as load, type, frequency, rest interval and intensity of effort (Ratamess et al., 2009; Fisher et al., 2011) it is important to spend time clarifying exactly what is meant by the terminology, and more importantly; where gaps within the present body of literature exist, as well as the potential mechanisms by which they might catalyse differing adaptations. This further serves to provide rationale for the published articles presented within this thesis.

### 1.3.1. Load

The 'load' within RT represents a given resistance and is often considered as a percentage of maximal dynamic strength (e.g. 1RM). However, load has commonly and incorrectly been referred to as *intensity* through some of the RT literature (e.g. Sakamoto & Sinclair, 2012). Recent publications have challenged this misuse of the term (Fisher & Smith, 2012; Steele, 2014) clarifying that intensity cannot represent load because as a single entity load does not determine physiological effort, but rather that intensity is a measure of a variable (e.g. intensity *of* load, or intensity *of* effort). Previous ACSM recommendations have suggested that using a heavy load might induce greater strength gains than more moderate or lighter loads (Ratamess et al., 2009). However, for evidence to support this claim the authors cited a meta-analysis (Peterson, Rhea, & Alvar, 2004) which provided some questionable results, notably the effect sizes (ESs[1]) for strength when training with different %1RM; 70% = 0.07, 75% = 0.73, 80% = 0.57, and 85% = 1.12. This data suggests considerable

[1] Cohen (1992) suggests ES of 0.20-0.49 are considered as small, 0.50-0.79 as moderate and ≥0.80 as large.

variation in the strength improvements that can be attained from making very marginal changes to load (5%). Furthermore, whilst the largest ES is noted for the heaviest load, there is not a trend supporting that heavier loads equate to higher ESs. It does not make sense that chronic strength gains of this magnitude might be affected by such small manipulation of loading strategies.

The size principle (Denny-Brown and Pennybacker, 1938; and more recently Carpinelli, 2008) states that motor neurons are recruited from smallest to largest[2] since small motor neurons need less excitation to be activated than larger motor neurons. As such small motor neurons are often referred to as low threshold MUs, which have lower force capabilities, whereas larger motor neurons are high threshold MUs in reference to the degree of excitation needed for activation. Carpinelli (2008, p. 68) summarised: *"...when the central nervous system recruits motor units ... it begins with the smallest, more easily excited, least powerful motor units and progresses to the larger, more difficult to excite, most powerful motor units to maintain or increase force."* Carpinelli (2008) completed a review of RT load in context of our understanding of the size principle and reported that the majority of research supports no greater gains by using heavier or lighter training loads. A narrative review of RT included the consideration of load and supported that, when training to MF, load appears to make no difference to strength gains (Fisher et al., 2011). More recently a meta-analysis (Schoenfeld, Wilson, Lowery, & Krieger, 2016) again supported this conclusion reporting no significant differences between high ($\geq$65% 1RM) compared to low ($\leq$60% 1RM) load RT ($p$ = 0.09).

#### 1.3.1.1. Mechanisms relating to variation in load

From a mechanistic perspective the concept that heavier loads might catalyse greater strength adaptations is grounded in theory. For example, strength is a product of the number of motor units (MUs) innervated and thus muscle fibres recruited, and the rates at which motor neurons discharge action potentials (rate coding) (Duchateau, Semmler, & Enoka, 2006). Whilst strength increases are often a result of an increased ability to voluntarily activate previously unrecruited MUs, it is commonly thought that to maximise strength adaptation a person must maximally recruit all available MUs for adaptation (Gabriel et al.,

[2] The size is a reference to cell body of the motor neuron.

2006; Fisher et al., 2011; Schoenfeld, 2011). The use of a heavier load for resistance training will almost certainly produce a greater synchronous activation of motor units, evidenced by higher peak surface electromyography (sEMG) amplitude (Schoenfeld, Contreras, Willardson, Fontana, & Tiryaki-Sonmez, 2014; Jenkins et al., 2015; Looney et al., 2015). However, a peak sEMG and synchronous recruitment does not necessarily equate to greater complete MU activation. Fisher, Steele, and Smith (2016) discuss that, based on the size principle, a set of repetitions of a given exercise taken to momentary failure should recruit all available MUs albeit sequentially, rather than synchronously. Furthermore, that to empirically test this hypothesis would require more advanced EMG data handling (e.g. spike triggered averaging or initial wavelet analysis followed by principal component classification of major frequency properties and optimisation to tune wavelets to these frequencies).

A secondary mechanism by which higher loading strategies might incur greater strength adaptations is that of mechanical tension. Considerable evidence supports that mechanical overload produces increases in strength and muscle size whilst chronic unloading of a muscle (and thus removing any mechanical tension) results in significant decreases in both muscle strength and cross sectional area (de Boer, Maganaris, Seynnes, Rennie, & Narici, 2007). Furthermore, it is thought that greater mechanical tension as a result of heavier loads is beneficial for favourable hypertrophic adaptations (Schoenfeld, 2010) as a result of mechanochemically transduced molecular and cellular responses in myofibres and satellite cells (Toigo & Boutellier, 2006). This, in turn, is thought to increase strength by the response of satellite cells (SC) to muscle injury to facilitate repair and remodelling (Hawke & Garry, 2001). Upon activation, SC proliferate and adjoin existing cells, or other SC, to create new myofibres providing the necessary nuclei to facilitate growth of contractile proteins and maintain the relationship between sarcoplasmic volume and myonuclei (Toigo & Boutellier, 2006). Since each myofibril contains actin and myosin protein filaments which produce force via the cross-bridges as they overlap during contraction (as a result of tropomyosin binding sites on the actin molecule), an increase in myofibres results in a greater number of binding sites and cross-bridges per muscle fibre; increasing force production, as well as increasing muscle fibre and whole muscle CSA.

Of additional consideration might be that of skill specificity in motor recruitment when performing maximal isoinertial or isometric contractions (Behm & Sale, 1993). Motor control research suggests that a motor schema is highly specific to the task being practised (Drowatzky & Zuccato, 1996; Mount, 1996), and furthermore that motor schemata are load-/force-specific (Schmidt, 2003). As such, repeatedly lifting heavier loads in a specific movement through RT, might serve to practise and refine that schema as a skill, which would include the maximal synchronous recruitment of MUs and muscle fibres. Indeed, maximal strength testing methods (e.g. 1RM, or isometric force; see section 1.4) generally require familiarisation to overcome this learning effect, and obtain more reliable data (Brown & Weir, 2001). This has most recently been supported by Mattocks et al., (2017) who reported that practise of a 1RM produced equivalent strength gains to that of a more traditional (4 sets of 8-12RM) resistance training programme.

The present thesis attempted to control for intensity of effort by all exercises being performed to momentary failure (except chapter 8, which was to assess the need to exercise to momentary failure). In "*The effects of breakdown set resistance training on muscular performance and body composition in young males and females*" (Chapter 3) load was an independent variable to create parity in the volume of training being performed. However, the pre- and post-intervention testing method used was that of muscular performance (repetitions at an absolute load; see section 1.4.2) and as such synchronous recruitment and skill acquisition were minimised to more accurately assess whether other mechanisms might have catalysed chronic strength adaptations.

### 1.3.2. Type

In review, resistance has been described as *"force acting against muscular contraction"* and resistance types described as: (i) constant[3] (e.g. free weights), (ii) variable (e.g. resistance machines - where the load is systematically varied according to a cam or series of cables, pulleys or linkage leverage chains), and (iii) accommodating (e.g. hydraulics - where resistance is proportional to force applied, and pneumatic - which compresses air as the form of resistance), (Fisher et al., 2011, p. 151). Exercises might further be considered in context of single-joint and multi-joint. It is beyond the scope of this thesis to consider the biomechanical advantages and disadvantages of these resistance types, as well as consider in detail the

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[3] The author notes *"whilst the mass of a dumbbell or barbell remains constant, the resistance or torque applied to the muscular system itself varies as lever length changes throughout a range of movement"* (Fisher, et al. 2011)

existing body of research which considers only differences in neural activation; instead we draw readers to Fisher et al. (2011) for a detailed review.

However, the present body of well-controlled research, which appropriately considers a cross-over testing design to nullify the potential neural effects of skill acquisition associated with training and testing using a single method, has reported no significant differences in strength gains between groups training using different resistance types (Sanders, 1980; Silvester & Rex, 1981; Boyer, 1990; Manning, Graves, Carpenter, Leggett, & Pollock, 1990; Willoughby & Gillespie, 1990). Furthermore, research has reported no significant difference in strength gains between groups training with free-weights and manual (partner applied) resistance (Dorgo, King, & Rice, 2009). More recently, evidence suggests the absence of need for any external resistance at all, where persons training using maximal co-contraction of agonist and antagonist muscle groups have shown considerable strength and hypertrophic adaptations (Maeo, Yoshitake, Takai, Fukunaga, & Kanehisa, 2014).

In the present thesis the 'type' of resistance has been considered (and thus manipulated) within *"A Randomized trial to consider the Effect of Romanian deadlift exercise on the development of Lumbar Extension Strength"* (Chapter 4). Within this published article, a comparison of free-weight Romanian deadlift (RDL) and isolated lumbar extension (ILEX) resistance exercises were compared in relation to strength improvements of the lumbar extensors. Variations of the deadlift have been suggested to improve lumbar extension strength (Mayer, Mooney, & Dagenais, 2008; Piper, 2001; Sheppard, 2003) supported by studies considering surface electromyography (sEMG; Chulvri-Medrano et al., 2010; Escamilla, Francisco, Kayes, Speer, & Moorman, 2002). Since isolated RT of the lumbar extensors has been evidenced to both strengthen the lumbar muscles and reduce low-back pain (Smith, Bruce-Low, & Bissell, 2008) it is important to consider if a relatively simple and cost-effective exercise such as the deadlift can stimulate these adaptations. However, to date there exists no peer-reviewed research which has considered this comparison.

#### 1.3.2.1. Mechanisms relating to type of exercise

Fundamentally the studies which assessed different types of exercise were evaluating the efficacy of MU recruitment in context of producing chronic strength adaptations. In review, Fisher et al., (2011) suggest that type of resistance does not affect strength increases, because a muscle fibre does not identify with what it contracts against; it simply contracts or does not. However, it is commonly accepted within resistance training literature that recruitment of a MU is a necessary stimulus in order for subsequent adaptation (Schoenfeld et al., 2014). Whilst, the above studies detail sEMG amplitude when performing a deadlift exercise (Chulvri-Medrano et al., 2010; Escamilla et al., 2002), sEMG provides at best an inference of MU activation, and is hindered with inherent complications (De Luca & Merletti, 1988; De Luca, 1997). For example, we should be cautious in interpretation of sEMG data specifically of the lumbar muscles due to cross-talk; Stokes, Henry, and Single (2003) discuss the lumbar multifidus as a challenging area to accurately record sEMG data. As such chapter 4 represent the first study to assess whether the RDL exercise provides sufficient MU activation stimulus to the lumbar extensors to provide chronic strength increases.

Whilst there is obvious disparity between a multi-joint, free-weight movement which has a large range of motion through the hip extensors (e.g. the RDL) and a single-joint, machine based movement limited in range of motion to the lumbar extensors (e.g. ILEX), this represents an ecologically valid comparison of a commonly used and accessible free-weight exercise compared to a proven testing and training device. However, we should consider the possible specificity of adaptations when practicing either the RDL or the ILEX exercise in the respective groups. However, to attempt to control for this specificity, this study employed a cross-over design where both groups were pre- and post-intervention tested on both exercises.

### 1.3.3. Frequency

The frequency of training is representative of the number of times within a given time-scale that RT is performed. The ACSM (Ratamess et al., 2009) have previously recommended 2-3 $d \cdot wk^{-1}$ for novice, 3-4 $d \cdot wk^{-1}$ for intermediate and 4-5 $d \cdot wk^{-1}$ for advanced training persons. However, in review Fisher et al. (2011) reported that equivocally the same strength gains can be attained by training at a low frequency (1-2 $d \cdot wk^{-1}$) compared to higher frequencies. Within this review the body of literature had considered major muscle groups but revealed an absence of literature considering specific training of the lumbar extensors, notably in low-back pain symptomatic persons. This represents an important area of research since the literature supports that specific ILEX training can reduce low-back pain (Smith et al., 2008) and indeed that frequencies of >1 d·wk$^{-1}$ can incur orthopaedic discomfort (Graves et al., 1990a). The included study "*One lumbar extension training session per week is sufficient for strength gains and reductions in pain in patients with chronic low back pain ergonomics*" (Chapter 6) compares resistance exercise frequencies of 1 and 2 d·wk$^{-1}$ on strength and pain outcomes relating to the lumbar extensors.

### 1.3.4. Rest interval

Within resistance training rest interval (RI) is the time between exercises, or sets of an exercise, when the body is able to recover from the demands imposed. Research has suggested that acute performance (e.g. a greater load and/or a greater number of repetitions in successive sets or exercises) is improved where a greater RI is permitted (Richmond & Goddard, 2004; Willardson & Burkett, 2005). However, there exists contrasting literature as to whether a greater RI produces chronic strength adaptations. For example, Ahtiainen, Pakarinen, Alen, Kraemer, and Häkkinen, (2005) found no differences in strength increases between 2 vs. 5 minute rest periods in trained males. Whilst, Robinson et al., (1995) reported greater 1RM increases for squat, and Schoenfeld, Pope, et al., (2014) reported greater 1RM increases for bench press and squat exercises with longer (3 minutes) compared to shorter (30 seconds and 1 minute, respectively) RIs.

It is, therefore, interesting that previous publications (Darden, 2004; Baechle & Earle, 2008) have promoted the use of pre-exhaustion (Pre-Ex) training as an attempt to improve strength adaptations beyond that of more traditional training methods. Pre-Ex training is considered an advanced RT technique and is described as the completion of a multi-joint exercise immediately following a single-joint exercise. An example being to perform a pec-fly (single-joint) immediately prior to a chest press (multi-joint) exercise. However, to date research has only considered the acute effects of Pre-Ex training on sEMG amplitude (Gentil, Oliveira, de Araujo Rocha Junior, do Carmo, & Bottaro, 2007; Brennecke et al., 2009). As such the present paper "*The effects of pre-exhaustion, exercise order, and rest intervals on a full-body resistance training intervention*" (Chapter 7) is the first intervention study to consider the chronic adaptive effects of Pre-Ex training. Since Pre-Ex training requires very short RI between the exercises (<5s) to appropriately test this training technique the methodological approach compared Pre-Ex training to a group performing the same exercises in the same order with a longer (60s) RI, thus serving to add to the dearth of literature considering RI.

#### 1.3.4.1. Mechanisms relating to rest interval

Manipulating the rest interval between exercises or exercise sets might best be thought of in context of how this practically affects the load a person can lift. As stated; a longer RI can permit a greater load and/or more repetitions in successive sets which use the same muscle groups (Richmond & Goddard, 2004; Willardson & Burkett, 2005). Previously discussed in section 1.3.1.1, there is a sound hypothesis as to why heavier loads might produce greater strength adaptations as a result of synchronous MU recruitment and practise of the specific motor schema. However, reducing a RI and/or exercising with a lighter load might change the mechanism of exercise cessation. For example, with a heavier load it is believed that central fatigue (a decrease in the number and discharge rates of motor units) results in the inability to stimulate the motor neurons that activate muscle fibres (Behm, Reardon, Fitzgerald & Drinkwater, 2002). Whereas, with a lighter load and/or longer time under muscular tension, it is thought that momentary failure occurs as a result of peripheral fatigue (resulting from a combination of insufficient adenosine triphosphate (ATP), low pH, and inability to transmit the impulse across the neuromuscular junction; Boyas & Guéval, 2011; Gandevia, 2001). As a result, there are potentially greater increases in inorganic phosphate ($P_i$), along with increases in $H^+$ (as a result of the prolonged ATP production), and thus concurrent decreases in intramuscular pH (Schott, McCully & Rutherford, 1995; Takada et al., 2012; MacDougall et al., 1999). These increases in metabolic stress are correlated to muscle hypertrophy ($P_i$, $r$=0.876; and intramuscular pH, $r$=0.601; MacDougall et al., 1999). See also the previous section (1.3.1.1) discussing mechanisms by which muscle hypertrophy produces chronic strength adaptations. The skill acquisition of practising lifting heavier loads, and the higher metabolic stress potentially incurring greater myofibrillar hypertrophy likely underpins the previous ACSM and NSCA recommendations that heavy loads are necessary for strength increases whilst more moderate loads produce greater increases in muscle CSA (Ratamess et al., 2009; Baechle & Earle, 2008).

Within the study presented herein which considers rest interval (chapter 7), neither metabolite accumulation nor hypertrophy were measured, and the adaptations as result of synchronous MU recruitment and skill acquisition were minimised by pre- and post-intervention testing using change in muscular performance (repetitions at an absolute load; see section 1.4.2). As such the presented study is more ecologically valid and outcome focused with a view towards providing resistance training recommendations for strength rather than assessing mechanistic pathways.

### 1.3.5. Exercise order

Exercise order within RT is often considered in relation to prioritising exercises to the early part of a workout so as to maximise acute performance (e.g. lift a heavier load/perform a larger number of repetitions; Miranda et al., 2010; Simão, Figueiredo, Leite, Jansen, & Willardson, 2012). From this evidence the ACSM (Ratamess et al., 2009) have suggested that this greater load/volume might catalyse superior gains in strength for specific movements. However, evidence of improved acute performance (e.g. load lifted or repetitions performed) is not evidence of chronic adaptation (e.g. strength). The included study "*The effects of pre-exhaustion, exercise order, and rest intervals on a full-body resistance training intervention*" (Chapter 7) represents the first published empirical research study to have tested the muscular performance adaptations for multiple exercises where exercise order was manipulated across multiple training groups. As such, we have compared a group of participants performing the tested exercises at the start of the workout (priority training) against groups of participants who performed a single-joint exercise prior to the tested exercises. This would provide a degree of fatigue to the muscles used in the tested exercises and as such decrease acute performance. Since no previous research has considered the chronic adaptations of exercise order this study serves to fill another gap within the literature.

#### 1.3.5.1. Mechanisms relating to Exercise Order

Differentiation in exercise order might catalyse differing strength adaptations based on the aforementioned discussions of training using a heavier load by prioritising an exercise to the start of the workout along with development of the specific motor schema of performing that exercise with a heavier load (see section 1.3.1.1). However, the published article within this thesis which considers exercise order (chapter 7) tested muscular performance (repetitions at an absolute load; see section 1.4.2) and as such should have minimised the impact of training using synchronous MU recruitment as well as skill acquisition.

### 1.3.6. Intensity of effort

Intensity of effort of resistance exercise is a reference to how hard a participant works in performance of lifting a load and the number of repetitions they perform in relation to the number of repetitions possible (Fisher & Smith, 2012; Steele, 2014). For example when performing an exercise a person might cease the exercise based on one of the following examples (Steele, Fisher, Giessing & Gentil, 2017):

- Not Repetition Maximum (nRM): When a trainee completes a pre-determined number of repetitions despite their ability to complete any further repetitions should they desire
- Self-determined Repetition Maximum (sdRM): When the trainee determines that they could not complete the next repetition if it was attempted, but does not attempt the next repetition
- Momentary failure (MF)[4]: When the trainee reaches the point where, despite attempting to do so, they cannot complete the concentric phase of their current repetition without change to posture or repetition duration
- Beyond Momentary Failure (MF+): When the trainee has completed a pre-determined advanced training technique after already achieving MF, or with intent to exceed conventional MF

In review Fisher et al. (2011) suggested that when intensity of effort is maximised (e.g. that participants train to MF) other variables such as volume, load, exercise type, etc. appear to be of secondary importance. The articles presented within this thesis all directly or indirectly consider intensity of effort, and more-so fill a substantial gap in the literature in consideration of the concept of advanced training techniques (e.g. training beyond

[4] It is noteworthy that "momentary failure" is used since it is not practically possible in resistance exercise to determine whether exercise cessation has occurred as a result of peripheral or central mechanisms, muscular or neuromuscular mechanisms. As such this has been updated from previous literature which used the term momentary muscular failure (MMF; Fisher et al., 2011).

momentary muscular failure; MF+). Intensity of effort, as a variable, has been considered within the following studies;

(i). "*The effects of breakdown set resistance training on muscular performance and body composition in young males and females*" (Chapter 3), where breakdown set RT (considered an advanced training technique) is intended to maximise the recruitment of both type II and type I motor units (MUs) and allows the combination of high muscular tension, MU fatigue, metabolic stress and ischemia due to extended time under tension to catalyse greater muscle damage (Schoenfeld, 2011).

(ii). "*Combined isometric and vibration training does not enhance strength beyond that of isometric training alone"* (Chapter 5) considered the addition of direct- and whole-body-vibration to maximal isometric contraction training. The addition of a vibratory stimulus is suggested to increase sensory in-flow of fast shortening and lengthening of muscle fibres, as such the muscle elicits a reflex contraction and this deformation of tissues activates muscle spindles and leads to enhancement of the stretch-reflex loop. There is a resulting increase in MU recruitment by excitatory activation of the α-motor neuron (Cardinale & Bosco, 2003). Increasing intensity of exercise can be manipulated using WBV by increasing frequency (Hz) and/or amplitude (mm) of displacement through vibration (Delecluse, Roelants, & Verschueren, 2003). This is further supported by research showing increasing effect sizes (ESs) for strength with increased frequency and amplitude (Marín & Rhea, 2010). Since the study "*Combined isometric and vibration training does not enhance strength beyond that of isometric training alone"* (Chapter 5) compared maximal isometric training with and without vibration it can be considered that intensity of effort might have been higher for participants performing maximal contractions with direct- and whole body-vibration, as a result of greater MU activation, compared to those without.

(iii). "*The effects of pre-exhaustion, exercise order, and rest intervals on a full-body resistance training intervention"* (Chapter 7), compared Pre-Ex training to the same exercises performed in the same order with a longer RI, and the same exercises performed in a priority exercise order. Pre-Ex training has previously been promoted in the literature as an advanced RT technique (Darden, 2004; Baechle & Earle, 2008) since it is claimed to exercise specific muscles beyond MF. For example the pectoralis major muscle is exercised to MF by performing a pec-fly (single-joint) exercise, and then exercised beyond MF (e.g. MF+) by immediately performing a chest press (multi-joint) exercise where the synergist muscles (in this example the triceps and anterior deltoids) assist in performing the exercise, whilst the pectorals continue to be activated.

(iv). And "*A comparison of volume equated knee extensions to failure, or not to failure, upon rating of perceived exertion and strength adaptations*" (Chapter 8). As stated, intensity of effort has been suggested to be the most significant variable towards achieving strength increases (Fisher et al., 2011). However, advanced RT techniques (e.g. Pre-Ex; chapter 7 or breakdown set; chapter 3) are aimed at increasing motor unit recruitment, producing a greater degree of fatigue, enhancing mechanical tension and/or inducing greater metabolic stress beyond that of training to momentary failure (Schoenfeld, 2011). These techniques are advocated within both commercial (Darden, 2004; Fleck & Kraemer, 2014; Philbin, 2004; Westcott, 2003) and academic literature (Baker & Newton, 2005; Schoenfeld, 2011) however, there is no evidence to support the use of these methods in increasing strength beyond that of traditional RT. In, the final study; "*A comparison of volume equated knee extensions to failure, or not to failure, upon rating of perceived exertion and strength adaptations*" (Chapter 8) the methodological design considers a within participant approach to RT by using unilateral training to MF or not to momentary failure for independent legs, something which had previously not been considered accurately within the current body of literature. It is known that there is a large heterogeneity in response to RT (Hubal et al., 2005) and thus the use of within subject designs offers a more rigorous test of the role of intensity of effort. In addition, previous articles comparing training to failure or not to failure have been identified as having methodological inadequacies (e.g. training at maximal velocities which equates to high tension and thus likely maximal MU recruitment; Izquierdo et al., 2006, using impractical methods – 40 single repetitions performed once every 30 seconds; Folland et al., 2002, etc.). Finally, the methodological design used within "*A comparison of volume equated knee extensions to failure, or not to failure, upon rating of perceived exertion and strength adaptations*" (Chapter 8) afforded the consideration of the popular '5 x 5' training (5 sets of 5 repetitions) advocated by the late Bill Starr (1978). To date the efficacy of this RT method had never been considered in peer-reviewed scientific literature.

#### 1.3.6.1. Mechanisms relating to intensity of effort

Perhaps the primary variable under consideration within this thesis is the intensity of effort at cessation of exercise. The aforementioned studies presented in chapters 3, 5, and 7, have all considered whether different training methods or equipment used can enhance intensity of effort beyond MF (e.g. to MF+). Chapter 3 and 7 have used advanced resistance training techniques, which are underpinned by the hypothesis that by extending the exercise set a greater/more complete recruitment of MUs can be obtained and furthermore; that there might also be a greater metabolic stress in the active muscles. These mechanisms have previously been discussed in context of how they might catalyse chronic strength adaptations in sections 1.3.1.1 and 1.3.4.1, respectively. Since chapters 3 and 7 used muscular performance measures (e.g. repetitions to failure with an absolute load) this controlled for any skill element obtained by the practice of synchronous MU recruitment. However, if greater recruitment of MUs and thus muscle fibres occurred as a result of a training method resulting in chronic adaptations, or greater hypertrophy occurred resulting in greater cross-bridges and binding sites, leading to greater force production then favourable adaptations would still be evident.

Within Chapter 5, where resistance training was considered with and without a vibratory stimulus, the fundamental question asked is whether greater MU recruitment is possible beyond that of a maximal isometric contraction alone. The vibratory stimulus is thought to stimulate fast shortening and lengthening of muscle fibres, and result in a reflex contraction resulting in MU recruitment by excitatory activation of the α-motor neuron. This seems reasonable since the body of research supports that voluntary contractions cannot maximally recruit all MUs (De Luca, Lefever, McCue, & Xenakis, 1982; Kukulka & Clamann, 1981; Van Cutsem, Feiereisen, Duchateau, & Hainaut, 1997). However, assessing MU synchronisation is only possible by assessing the maximal force of a voluntary contraction compared to the maximal force resulting from artificial external electrical stimulation (Belanger & McComas, 1981) using transcranial magnetic stimulation or interpolated twitch technique. Whilst Gabriel et al. (2006) discuss this in review, stating that an additional 2-5% is generally possible following external stimulation other publications have been more critical of the research methods and reported more equivocal results, discussing the relative changes in recruitment in accordance with differing speed and type of muscle contraction (Duchateau et al., 2006). If external vibratory stimulus can produce a greater MU activation during maximal isometric contractions performed during a training routine then this might catalyse chronic adaptations producing greater maximal isometric strength post-intervention.

The final publication considering intensity of effort uses a volume matched approach of training to momentary failure or not to failure (chapter 8). Within this research article it is hypothesised that training to MF would be optimal since it would ensure maximal (albeit voluntary) MU recruitment, which would be greater than the condition where exercise which is not performed to MF. As such training to MF, and the subsequent higher MU recruitment would catalyse greater strength adaptations.

## 1.4. Muscular performance and strength measurement

Since muscular strength has been identified as a variable relating to all-cause mortality it is important to consider the methods of measuring muscular force in context of the present thesis. Within the presented studies, strength testing methods include isometric; where the muscle contracts but there is no change in joint angle (chapters 4, 5, 6 and 8), and isoinertial; where a load remains the same throughout movement but the participant controls the velocity of the movement (chapters 3, 4, and 7; Brown & Weir, 2001).

### 1.4.1 Isometric force measurement

Early research identified a force-velocity relationship which recognises that maximal force is developed when the speed of muscle shortening is zero (e.g. an isometric contraction), and that force decreases as the velocity of movement increases (Wilkie, 1950; Lord, Aitkens, McCrory, & Bernauer, 1992). This concept is replicated throughout the literature and, in fact, has been identified that whilst the force a muscle can produce is dependent upon velocity, the inverse is also true; that muscle velocity is dependent upon the force applied to that muscle (Lieber & Fowler, 1993). The authors continue, discussing the degree to which maximal force decreases as a product of increased velocity, stating that: *"in a muscle that is shortening at only 1% of its maximum contraction velocity (extremely slow) tension drops by 5% relative to maximum isometric tension…as contraction velocity increases to only 10% of maximum, muscle force drops by 35%"* (Lieber & Fowler, 1993, p. 848).

One of the considerable benefits of isometric testing exist in its high test-retest reliability (Viitasalo, Saukkonen, & Komi, 1980; Robinson, Greene, Graves, & MacMillan, 1992; Coldwells et al., 1994), as well as the validity of measuring the force at a maximal voluntary contraction (Wilkie, 1950). We should also consider that research dating back to 1895 (Blix) demonstrated that the amount of force produced by a muscle during an isometric contraction varies in relation to the muscles length (and as such the angle being tested). This is a product of biomechanical (e.g. the moment within a joint) and biological factors (e.g. pennation angle of muscle fibres, and the number of cross-bridge attachments; Knapik, Wright, Mawdsley, & Braun, 1982). As such isometric testing provides exact, maximal values at each testing point through a range of motion, and accurately represent the strength curve or force-length (often referred to as *'length-tension'*) relationship (Lieber & Fowler, 1993; Bruce-Low et al., 2012; Fisher et al., 2013).

In context within the present thesis, isometric testing was used for single-joint exercises (the lumbar extensors; chapters 4 and 6, and the knee extensors; chapter 7) and for multi-joint exercises (leg and back; chapter 5). These testing methods were chosen because of the need to specifically isolate muscles for measurement and identify differing force production at specific points through a range of motion (e.g. the lumbar extensors and knee extensors) and to replicate the training exercise (e.g. the leg and back dynamometer).

### 1.4.2. Isoinertial strength and muscular performance measurement

Isotonic force testing makes reference to the use of a contraction to lift an object of fixed mass against gravity (Brown & Weir, 2001). However, as the authors go on to state, the term '*isotonic'*, which literally means 'constant tension', is not technically accurate since the force or tension varies throughout a range of motion. With this in mind, whilst it has not gained popularity in scientific publication, the correct term (and thus the term used within this thesis) is '*isoinertial'*.

This approach to strength testing generally utilises free weights or resistance machines[5] by gradually increasing the load, through the process of trial and error, up to a

[5] The use of resistance machines further complicates the use of isoinertial and isotonic terminology since resistance machines often use a variable resistance cam which varies the amount of resistance, and thus the required torque, normally with the intention to match the strength curve of the relevant muscle/muscle group.

point where a person can only lift the load for a single repetition (e.g. a 1RM). Variations of this exist in the form of 3-, 5-, or even 10-RM, or even the maximal number of possible repetitions with a fixed resistance, although these are no longer tests of maximal strength, but rather a measure of muscular performance (Brown & Weir, 2001). However, authors have used equations to predict 1RM based on RM testing (e.g. Berger, 1961; Brzycki, 1993; Kravitz, Akalan, Nowicki, & Kinzey, 2003; Mayhew, Ball, Arnold, & Bowen, 1993; Morales & Sobonya, 1996) and these have been validated with relative success in multiple studies ($r$ = 0.60-0.99; Knutzen, Brilla, & Caine, 1999; LeSuer, McCormick, Mayhew, Wassertstein, & Arnold, 1997; Whisenant et al., 2003; do Nascimento et al., 2007). We should also consider that mechanically a free weight (and many resistance machines) will have a sticking point (a position in the range of motion where the resistive torque is greater than the muscular torque) as a result of the force-length relationship (Brown & Weir, 2001; Carpinelli, 2011; Kompf & Arandjelović, 2016). As such the muscles might actually be performing submaximally through all but one point in the range of motion where they are producing maximal force. However, isoinertial strength testing requires more commonly used gym equipment rather than the technical use of isometric dynamometers, and as such might represent greater ecological validity.

Carpinelli (2011) is critical of the use of 1RM strength testing suggesting the need for a degree of familiarisation for participants and also suggesting that, in fact, maximal strength testing has little application or necessity in the practice of strength training. Whilst authors have cited use of specific training loads (e.g. %RM) for obtaining optimal adaptations to strength, endurance and hypertrophy (ACSM; Ratamess et al., 2009) more recent reviews have suggested that equivocally the same strength and hypertrophy gains can be obtained irrespective of high and low loads so long as repetitions are performed until momentary failure (MF; Fisher et al., 2011; Fisher, Steele, & Smith, 2013). With this in mind, the historical tradition of needing to know a 1RM to then determine a training load for specific (e.g. strength or endurance) might no longer be necessary. Fisher et al. (2011, p. 150) discuss muscular endurance considering the disparity between absolute; the number of repetitions performed at a given resistance, and relative; the number of repetitions performed at a given %1RM citing the example:

> …a pre training 1RM of 100kg might produce 10 repetitions at an absolute value of 70kg, which is also the relative value of 70%1RM. However, after a training regime where the 1RM has improved to 120kg, a participant will almost certainly be capable of greater than 10 repetitions at the absolute value of 70kg, but likely still only produce a maximum of 10 repetitions at the relative value of 70% 1RM (now 84kg).

With the above in mind, and since submaximal loads are far more ecologically valid as well as safer than maximal loads, an alternate testing method is that of repetitions to failure with an absolute load. This methodological approach has previously been utilised in the literature (DeSouza et al., 2010) and has been supported by Carpinelli (2011) as there being a strong relationship between increases in maximal strength and increases in repetitions to failure with a given absolute load. Recent publications reporting maximal strength changes (1RM) following training interventions serve to support this concept. For example, Schoenfeld et al. (2016) and Schoenfeld, Contreras, Vigotsky and Peterson (2016b) reported significant changes in maximal strength (1RM) for bench press as well as significant increases in the number of repetitions performed with an absolute load (50% of pre-testing 1RM). Whilst other studies have shown that maximal strength increases catalyse no change to relative muscular endurance (Hickson, Hidaka, & Foster, 1994; Mazzetti et al., 2000) as discussed by Fisher et al., (2011). Further supporting evidence comes from Klemp (2016) who reported significant changes in maximal strength (1RM) for bench press and back squat but no change in the repetitions performed at a relative load (60% of pre- and post-testing 1RM), and Mayhew, Ball and Bowen (1992), who reported 1RM increases for 171 male (67.7kg to 78.1kg; 13.7%) and female (29.4kg to 37.0kg; 25.9%) college students for the bench press exercise with no change in repetitions performed at relative loads (55-95% 1RM; males, pre = 10.8 ±5.6, post = 11.0 ±6.6 repetitions, females, pre = 12.4 ±6.8, post = 12.6 ±7.7 repetitions).

In context of the present thesis, chapter 4 used 1RM testing for the RDL, however later publications (chapters 3 and 7) used repetitions to failure with an absolute load for chest press, leg press and pull-down exercises to assess increases in muscular performance due to ease, accessibility, and the high ecological validity.

## 1.5. Summary

There is considerable evidence to support a positive relationship between isometric and isoinertial muscular strength and reduced mortality (Ruiz et al., 2008; Artero et al., 2011; Menant et al., 2016). However, current guidelines might be seen as complicated or time consuming with a need to lift heavy weights, or follow specific protocols pertaining to rest interval, exercise order or use of advanced training technique with a view to enhancing intensity of effort (Kraemer et al., 2002; Ratamess et al., 2009). Furthermore, exercise type and the use of potentially expensive equipment (e.g. ILEX, vibration platforms, etc.) further confound any clear recommendations. Since perceived difficulty, as well as lack of time, are barriers to resistance exercise (Winett et al., 2009; Owen & Bauman, 1992; Ainsworth, 2000; Grubbs & Carter, 2002) the aims of the present thesis are to consider the manipulation of the detailed variables of load (chapter 3), type (chapters 4 and 5), frequency (chapter 6), rest interval and exercise order (chapter 7), and intensity of effort (chapters 3, 5, 7, and 8) upon muscular strength adaptations.

# CHAPTER 2: General Methods

Since each study within this thesis is presented as published works, a more detailed description of the respective methodological approaches used can be found within each article. However, the present chapter represents a summary of methods which are generic across multiple publications. Much of the content discussed within this chapter has been summarised in to table 2.2.

## 2.1 Ethics, research design, power analysis and participants

Ethical approval was granted for all studies by the Health, Exercise and Sport Sciences ethics committee at Southampton Solent University. All studies utilised a randomised controlled trial design with three experimental groups except for *"A comparison of volume equated knee extensions to failure, or not to failure, upon rating of perceived exertion and strength adaptations"* (Chapter 8) which considered a within-participants design where participants performed unilateral exercise and so were compared between limbs. An *a-priori* power analysis was conducted before data collection for all studies to meet the required β power of 0.8 at an α value of $p \leq 0.05$. Effect sizes (ES) from previous research were used to determine participant numbers (*n*) using ESs calculated using Cohen's *d* (1992) and equations from Whitley and Ball (2002; Chapters 3, 4, 5, 6, and 7) or G* power (Faul, Erdfelder, Lang, & Buchner, 2007; Faul, Erdfelder, Buchner, & Lang, 2009; Chapter 8).

All participants were healthy[6] asymptomatic (Chapters 3, 4, 5, 7, and 8) or low-back pain symptomatic (Chapter 6) young adults (Chapter 3: (mean ±SD); BD = 38 ±7 years; HLBD = 37 ±13 years; CON = 34±12 years, Chapter 4: LUMX = 23 ±5 years; DL = 27 ±7 years; CON = 25 ±8 years, Chapter 5: ST+VT = 20 ±1 years; ST = 21 ±1 years; CON = 21 ±1 years, Chapter 6: M = 46 ± 14 years, Chapter 7: PE = 49 ±6 years, PER = 47 ±12 years, CON = 47 ±13 years, Chapter 8: M = 21 ± 1 years). Participants were considered trained (chapters 3 & 7; $\geq$ 6

[6] E.g. not obese, currently suffering from any medical condition, etc

months, chapter 4; >2 years), untrained (chapters 5 & 6[7]), and recreationally active (chapter 8).

## 2.2 Independent variables

The specifically assessed independent variables of load, type, frequency, rest interval, exercise order and intensity of effort have been discussed in chapter 1 and are detailed in table 2.1 in relation to each study. However, as a product of testing specific hypotheses and sound research methods, multiple other variables were considered and controlled throughout the studies. For example the volume of work undertaken by participants was maintained at a single set of each exercise performed to momentary failure unless otherwise tested as part of the research hypotheses (e.g. chapters 3 & 8). Participants completed ecologically valid, whole-body workouts in "*The effects of breakdown set resistance training on muscular performance and body composition in young males and females*" (Chapter 3) and "*The effects of pre-exhaustion, exercise order, and rest intervals on a full-body resistance training intervention"* (Chapter 7) which are compared in table 2.1, whereas in each of the other studies only a single resistance training exercise was performed. All training groups across the 6 studies exercised 2 $d \cdot wk^{-1}$, except in the study *"A Randomized trial to consider the Effect of Romanian deadlift exercise on the development of Lumbar Extension Strength"* (Chapter 4) where participants only trained 1 $d \cdot wk^{-1}$ and "*One lumbar extension training session per week is sufficient for strength gains and reductions in pain in patients with chronic low back pain ergonomics*" (Chapter 6) where frequency of training was compared between groups. Repetition duration was also controlled between training groups maintained at 2 s concentric: 4 s eccentric (chapters 3, 4, 6 & 7), isometric contractions of 30 s (weeks 1-2), 35 s (weeks 3-4) and 40 s (weeks 5-6; chapter 5) and 2 s concentric: 1 s isometric: 2 s eccentric (chapter 8).

[7] These were not specifically defined as 'untrained' within the article but were not currently undertaking any specific low-back strengthening exercises and as such should be considered untrained for this muscle group.

Table 2.1. Disparity in training interventions between chapters 3 and 7.

| **The effects of breakdown set resistance training (chapter 3)** | | **The effects of Pre-Exhaustion resistance training (chapter 7)** | |
|---|---|---|---|
| **Workout A** | | **Workout*** | |
| Chest Press | *MedX* | Chest Press | *MedX* |
| Leg Press | *MedX* | Leg Press | *MedX* |
| Pull-Down | *MedX* | Pull-Down | *Hammer Strength wide* |
| Overhead Press | *Nautilus Evo* | Pectoral fly | *Nautilus Nitro Plus* |
| Adductor | *Nautilus Evo* | Leg Extension | *MedX* |
| Abductor | *Nautilus Evo* | Pullover | *Nautilus 2ST* |
| Abdominal Flexion | *MedX Core* | Abdominal Flexion | *MedX Core* |
| Lumbar Extension | *Roman Chair* | Lumbar Extension | *MedX Core* |
| **Workout B** | | | |
| Pectoral fly | *Nautilus Evo* | | |
| Pullover | *Nautilus Evo* | | |
| Leg extension | *MedX* | | |
| Dip | *Nautilus Evo* | | |
| Biceps Curl | *Nautilus Evo* | | |
| Seated Calf Raise | *Hammer Strength* | | |
| Leg Curl | *MedX* | | |
| Torso Rotation | *MedX Core* | | |

*(repeated $2 \cdot d \cdot wk^{-1}$)

## 2.3 Dependent variables

In "*The effects of breakdown set resistance training on muscular performance and body composition in young males and females*" (Chapter 3) and "*The effects of pre-exhaustion, exercise order, and rest intervals on a full-body resistance training intervention"* (Chapter 7) the dependent variable was change in muscular performance, determined by a calculation of pre-intervention and post-intervention repetitions multiplied by the same absolute load. For example participants were tested at a controlled repetition duration (2 s CONC: 4 s ECC) on each of three exercises (chest press, leg press and pull-down). The number of repetitions performed pre- and post-intervention was multiplied by the load lifted to give a total load-volume. Pre-intervention load-volume was subtracted from post-intervention load-volume to provide an absolute value for change in muscular performance. This should be considered a change in dynamic strength performance.

In contrast, in the studies *"A Randomized trial to consider the Effect of Romanian deadlift exercise on the development of Lumbar Extension Strength"* (Chapter 4), "*Combined isometric and vibration training does not enhance strength beyond that of isometric training alone"* (Chapter 5), "*One lumbar extension training session per week is sufficient for strength gains and reductions in pain in patients with chronic low back pain ergonomics*" (Chapter 6) and "*A comparison of volume equated knee extensions to failure, or not to failure, upon rating of perceived exertion and strength adaptations"* (Chapter 8) isometric torque was measured for the lumbar extensors (chapters 4 & 6), knee extensors (chapter 8) and for the leg and back combined (chapter 7).

Sole, Hamrén, Milosavljevic, Nicholson, and Sullivan (2007) reports reliability values of 0.50-0.69 as *"moderate"*, 0.70-0.90 as *"high"* and greater than 0.90 as *"very high"*. The MedX lumbar extension machine (chapters 4 & 6) has a test-retest reliability reported as $r$ = 0.94-0.98 for asymptomatic persons (as per chapter 4; Pollock et al., 1991) and $r$ = 0.63-0.96 for low-back pain symptomatic persons (as per chapter 6; Robinson et al., 1992). Within our own laboratory the MedX lumbar extension machine has produced strong intraclass correlation coefficient values (ICC) values of 0.931 (95% confidence intervals; CIs = 0.845 to 0.972). Recent literature has reported high to very high reliability for multiple isometric testing machines (Cybex and Biodex) for the knee extensors ($r$ = 0.88-0.92; de Araujo Ribeiro Alvares et al., 2015). However, the MedX knee extension machine used within chapter 8 shows higher still unilateral and bilateral reliability values ($r$ = 0.88 and $r$ = 0.98, respectively; Welsch et al., 1998) and within our own laboratory ICC = 0.926 (95% CIs = 0.779 to 0.984). Finally, the leg and back dynamometer (TK5002, Takei, Japan) used in chapter 6, has shown strong relations to both leg strength ($r$ = 0.90) and back strength ($r$ = 0.79) as well as reliability values of $r$ = 0.80 and $r$ = 0.91, respectively (Coldwells, Atkinson, & Reilly, 1994).

Table 2.2. Research Studies and Design Details

| Chapter number and Article Title | Research Design | Frequency & Duration | Independent Variable | Groups and Participants | Dependent Variable |
|---|---|---|---|---|---|
| *3 The effects of breakdown set resistance training on muscular performance and body composition in young males and females* | RCT with 3 experimental groups | 2 d·wk$^{-1}$ 12-weeks | Load Intensity of Effort | BD; *n* = 11 HLBD; *n* = 14 CON; *n* = 11 | Pre- to post-intervention change in Muscular performance (load-volume) |
| *4. A Randomized trial to consider the Effect of Romanian deadlift exercise on the development of Lumbar Extension Strength* | RCT with 3 experimental groups | 1 d·wk$^{-1}$ 10-weeks | Type | LUMX; *n* = 12 DL; *n* = 12 CON; *n* = 12 | Romanian deadlift 1RM, isometric torque reported as individual angles of extension and strength index (SI) |
| *5. Combined isometric and vibration training does not enhance strength beyond that of isometric training alone* | RCT with 3 experimental groups | 2 d·wk$^{-1}$ 6-weeks | Type Intensity of Effort | ST+VT; *n* = 8 ST; *n* = 8 CON; *n* = 8 | Pre- to post-intervention change in Isometric deadlift strength |
| *6. One lumbar extension training session per week is sufficient for strength gains and reductions in pain in patients with chronic low back pain ergonomics* | RCT with 3 experimental groups | 1 / 2 d·wk$^{-1}$ 12-weeks | Frequency | 1 d·wk$^{-1}$; *n* = 31 2 d·wk$^{-1}$; *n* = 20 CON; *n* = 21 | Isometric torque reported as individual angles of extension |
| *7. The effects of pre-exhaustion, exercise order, and rest intervals on a full-body resistance training intervention* | RCT with 3 experimental groups | 2 d·wk$^{-1}$ 12-weeks | Rest Interval Exercise Order Intensity of Effort | PE; *n* = 14 PER; *n* = 17 CON; *n* = 8 | Pre- to post-intervention change in Muscular performance (load-volume) |
| *8. A comparison of volume equated knee extensions to failure, or not to failure, upon rating of perceived exertion and strength adaptations* | Within subject unilateral training of MMF and NMF | 2 d·wk$^{-1}$ 6-weeks | Intensity of Effort | Within groups; MMF; *n* = 9 NMF; *n* = 9 | Change (pre- to post-intervention) Isometric torque of the knee extensors reported as strength index (SI) |

## 2.4 Statistical analyses

All data was assessed for assumptions of normality of distribution using a Kolmogorov-Smironov test, confirming parametric analyses were appropriate. Within all studies baseline data was analysed to confirm no statistically significant differences between groups. This was done using a repeated measures ANOVA for chapter 4 and 6, a one-way ANOVA for chapters 3, 5 and 7 and a paired samples *t*-test for chapter 8.

Within the studies *"A Randomized trial to consider the Effect of Romanian deadlift exercise on the development of Lumbar Extension Strength"* (Chapter 4) and "*One lumbar extension training session per week is sufficient for strength gains and reductions in pain in patients with chronic low back pain ergonomics*" (Chapter 6) data was analysed using a 3 x 2 (group x test) repeated measures ANOVA. This permitted examination of between (differences between the groups), within (differences between pre- and post-intervention tests) and interaction effects (combinations of both between and within effects). Within the respective studies, analyses revealed significant within groups and interaction effects for isometric strength (chapters 4 & 6), and strength index (SI)[8], and Romanian deadlift 1RM (chapter 4). Where significant interaction effects occurred paired samples *t*-tests with Bonferroni adjustment (Perneger, 1998; Armstrong, 2014) were conducted for each group to identify significant pre- to post-test results.

Within the remaining studies "*The effects of breakdown set resistance training on muscular performance and body composition in young males and females*" (Chapter 3), "*Combined isometric and vibration training does not enhance strength beyond that of isometric training alone"* (Chapter 5) and "*The effects of pre-exhaustion, exercise order, and rest intervals on a full-body resistance training intervention"* (Chapter 7) data was analysed based on absolute change pre- to post-intervention. This has been considered a simplified analyses to accurately assess the hypotheses in question (e.g. a between-groups comparison of which intervention produces the most favourable change; Vickers, 2005). In the case of chapters 3, 5, and 7 a one-way ANOVA was used to examine baseline data between groups,

[8] Within chapters 4 and 8 strength index (SI) was analysed. This represents the area under a force curve created in each isometric test and accommodates potential increases or decreases throughout the entire strength curve for all seven test positions. This negates biasing data by seeking average increases or decreases or only considering specific joint angles.

and then a further one-way ANOVA was used to analyse between group differences in absolute strength change (post-test values – pre-test values). Where one-way ANOVA revealed statistically significant differences ($p < 0.05$) a post hoc Tukey HSD test was performed to identify between which groups the differences occurred. Where assumption of the homogeneity of variance (that the variance within each of the groups was equal) was violated Welch's F test statistic was used rather than sphericity assumed.

Finally, for "*A comparison of volume equated knee extensions to failure, or not to failure, upon rating of perceived exertion and strength adaptations"* (Chapter 8) data was also analysed based on absolute change pre- to post-intervention for strength index (SI). However, since this study utilised a within participants design (one group training each limb unilaterally) paired samples *t*-tests were used to compare baseline strength and absolute change in strength. Further, within chapters 3, 7 and 8, 95% CIs were calculated (where a change was considered significant if the 95%CIs did not cross zero), in addition to ES using Cohen's *d* (1992) for each outcome to compare the magnitude of effects between groups where an ES of 0.20-0.49 was considered as small, 0.50-0.79 as moderate and ≥0.80 as large.

Following assessment for normality of distribution using Shapiro-Wilk test, additional analyses were performed for this thesis to compare data between respective published articles. Starting strength in the studies which considered the use of ILEX training has been compared between studies to assess pre-intervention strength between trained males (chapter 4, $n$=36) and CLBP symptomatic participants (chapter 6, $n$=71) using an independent samples *t*-test. Furthermore, for the participants which trained 1 x / week (chapter 4, $n$=12; chapter 6, $n$=31) ANOVA with repeated measures was performed to assess strength change between and within groups.

Data from the studies which assessed advanced training techniques (chapters 3 and 7) were also reconsidered as collapsed data and in combination. In an attempt to support the practical application of these studies the data presented as muscular performance has been recalculated from load-volume (absolute muscular endurance) based on predictive equations of repetitions completed and load used, to calculate 1RM (Brzycki, 1993):

$$\text{Predicted 1RM} = \frac{\text{weight}}{(1.0278 - (0.0278 \times \text{repetitions}))}$$

Previous research has suggested this formula provides a very high correlation to actual 1RM ($r = 0.99$; do Nascimento et al., 2007).

Using the predicted 1RM values ANOVA with repeated measures was performed for between and within groups for both chapters 3 and 7. Furthermore, to assess the between group efficacy by including all resistance training exercises, data was collapsed to produce a single pre- and post-strength variable (the sum of predicted 1RM values for chest press, leg press and pull down exercises). Data was assessed using Shapiro-Wilk and determined not to be normally distributed. A Wilcoxon-signed-rank test was then performed to consider strength increase between and within groups.

All statistical analysis was performed using IBM SPSS statistics for windows (version 20; IBM Corp., Portsmouth, Hampshire, UK) and $p < 0.05$ set as the limit for statistical significance.

# CHAPTER 3: The effects of breakdown set resistance training on muscular performance and body composition in young males and females

# The Effects of Breakdown Set Resistance Training on Muscular Performance and Body Composition in Young Men and Women

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## Abstract

Fisher, JP, Carlson, L, and Steele, J. The effects of breakdown set resistance training on muscular performance and body composition in young men and women. *J Strength Cond Res* 30(5): 1425–1432, 2016—Breakdown (BD) training has been advocated by multiple commercial and academic publications and authors, seemingly as a result of the acute hormonal and muscle activation responses it produces. However, there is a relative dearth of research that has empirically considered this advanced method of resistance training (RT) over a chronic intervention while appropriately controlling other RT variables. The present study considered 36 male and female participants divided into 3 groups: BD ($n = 11$), heavy-load breakdown ($n = 14$), and traditional ($n = 11$), performing full-body RT programs 2 times per week for 12 weeks. No significant between-group differences were identified for change in absolute muscular endurance for chest press, leg press, or pull-down exercises or for body composition changes. Effect sizes for absolute muscular endurance changes were large for all groups and exercises (0.86–2.74). The present study supports previous research that the use of advanced training techniques stimulates no greater muscular adaptations when compared with performing more simplified RT protocols to momentary muscular failure.

**Key Words** drop sets, advanced techniques, muscle, lean mass, body fat

## Introduction

Resistance training (RT) leading to momentary muscular failure (MMF) has been evidenced as producing significantly greater muscular strength and hypertrophic adaptations when compared with RT not performed to MMF (14,15,18). It is thought that the sequential recruitment of motor units (MUs) and muscle fibers, which occurs during RT performed to MMF through Henneman's size principle (3,23) among other potential mechanisms of adaptations (28), might stimulate the greatest increases in muscular strength and hypertrophy (14,15). A recent meta-analysis further supports that when controlled for effort by training to MMF, significant strength and hypertrophy occur with both light and heavy loads (30).

Though training to MMF seems to be important for optimizing adaptations, the use of advanced RT techniques that allow a trainee to potentially train *beyond* MMF should be considered. Recent work has examined advanced RT techniques, such as rest-pause (18) and pre-exhaustion (13), finding they offer no further benefit over training simply to MMF. Another commonly discussed technique is that of breakdown (BD) sets (also known as drop sets and descending sets; Refs. 25,29). Breakdown sets require the performance of a set to MMF with a given load before immediately reducing the load and continuing repetitions to subsequent MMF. As such, this technique can allow MMF to be achieved in addition to potentially inducing greater fatigue-related stimuli. It is thought that this might maximize recruitment of both type II and type I MUs through use of both heavier and lighter loads thus allowing the combination of high muscular tension and inducing greater MU fatigue, metabolic stress, and ischemia because of extended time under tension (29).

We might also consider fatigue in context of the reduction to muscular force made as a product of the exercise. For example, a person will reach MMF with a load of 80% 1 repetition maximum (1RM) when their maximal force production <80% 1RM. This occurs as a product of inability to continue recruiting muscle fibers as well as a reduction in the rate of discharge (rate coding; Ref. 10). As a result, we might hypothesize that many lower-threshold MUs and thus muscle fibers have not reached a state of complete fatigue despite their recruitment. However, if the load is reduced (e.g., to 50% 1RM), then recruitment and rate of discharge are likely sufficient to produce enough force to continue exercise. In this example, our participant will reach MMF with a load of 50% 1RM when maximal force production <50% 1RM. This represents a pertinent example of BD

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training, and as such, we should consider whether this greater reduction to acute force results in chronic muscular adaptations in size and strength.

To date, there are few empirical research studies that have considered the use of BD training. Keogh et al. (24) and Goto et al. (20) considered the acute effects of BD training on muscle activation and hormonal response, respectively. However, neither study provides evidence toward chronic adaptations. Goto et al. (20) reported greater increases in growth hormone (GH) after the BD training protocol (sets of knee extension at 90% 1RM followed by a set at 50% 1RM) compared with a traditional RT protocol (sets of knee extension at 90% 1RM). Although this increased GH might suggest greater potential gains in hypertrophy (e.g., Ref. 28), authors have critiqued the hormone hypothesis suggesting that increases in GH are not proxy markers for strength or hypertrophy (4,32). In addition, Keogh et al. (24) used a variation of BD training whereby participants only performed a single repetition at a near-maximal load (95% 1RM) before reducing the load for each of 5 consecutive repetitions. A similar method was considered by Berger and Hardage (2) who compared a set of 10 maximal repetitions, starting at 1RM and decreasing in load for each subsequent repetition. The authors reported greater increases in strength compared with performing a single set of repetitions to 10RM. However, this protocol limits application by the use of a series of single near-maximal repetitions rather than multiple consecutive repetitions for a set to MMF before decreasing the load.

A further study by Goto et al. (19) compared traditional training to BD training reporting favorable strength increases for the BD training protocol. All participants performed 6 weeks of an identical resistance exercise protocol and were then divided into either BD or traditional training groups. The traditional training group performed 5 sets of knee extension and leg press exercise 2 times per week at 90% 1RM with 3 minutes rest between exercise sets. The BD training group performed the same protocol with an additional set performed 30 seconds after the fifth sets using 50% 1RM, where all sets in both groups were continued to a point of MMF. The authors reported significantly greater results for leg press 1RM and maximal isokinetic torque (300 degree per second) and muscular endurance (repetitions to MMF at 30% of maximal voluntary contraction [MVC]) for the knee extension for the BD protocol compared with the traditional protocol. In addition, the authors reported that the BD group showed greater increases in muscle cross-sectional area (CSA) of the thigh compared with the traditional group; however, this did not reach significance ($p < 0.08$). Although this seems to support the efficacy of BD training, there was a disparate training volume between the BD and traditional training groups, and BD training has customarily been described by the *immediate* performance of subsequent repetitions at the lighter load, not after a 30-second rest interval.

The most recent study considering BD training compared multiple and single-set training protocols in men and women training 2 times per week for 10 weeks (17). The single-set training group performed 9 exercises (chest press, heel raise, rear deltoid fly, elbow flexion, seated row, knee extension, knee flexion, abdominal flexion, and push-ups) and upon reaching MMF immediately reduced the load by 10–15% and continued for as many repetitions (~2 to 3) as possible. When they reached MMF a second time, they repeated the BD set, reducing the load by a further 10–15% and performed further repetitions to MMF (~2 to 3). The multiple-set group performed the same exercises to their self-determined 10RM (i.e., they stopped when they perceived themselves to be 1 repetition away from MMF; Ref. 18) for a single set in a circuit format, performing 3 circuits (e.g., 3 sets of each exercise). Data revealed significantly greater improvements in strength for heel raise, elbow flexion, and knee flexion for the BD training group compared with the multiple-set group. However, when data were analyzed by gender, women showed a greater strength increase for chest press, seated row, heel raise, and push-up for the BD training protocol compared with the multiple-set training protocol, whereas there were no significant between-group differences for changes in strength for men. Although this represents an ecologically valid approach to RT, the study does not control for volume of training and intensity of effort between groups.

It is surprising that a method as commonly advocated as BD training, in both commercial (e.g., Refs. 7,16,26,31) and academic literature (e.g., Refs. 1,29), is lacking evidence to support its efficacy. With this in mind, the aim of the present study was to determine the effects of 12-week RT with and without BD protocols on muscular performance and body composition.

## Methods

### Experimental Approach to the Problem

A randomized controlled trial design was adopted, with 3 experimental groups included. The effects of 3 RT interventions were examined in trained participants upon muscular performance and body composition.

### Subjects

The study design was approved by the relevant ethics committee at the first author's institution. Participants were required to have had at least 6 months of RT experience (single-set training to MMF for multiple exercises including most major muscle groups, ~2 times per week) and no medical condition for which RT is contraindicated to participate. Potential participants were considered from the present membership pool in a U.S. fitness facility (Discover Strength, Chanhassen, MN, USA). Forty-one (men, $n = 13$; women, $n = 28$) persons, age range 18–51 years, attended an initial briefing and eligibility assessment regarding the research after advertisement and were subsequently recruited. Figure 1 shows a CONSORT diagram highlighting the participant numbers for enrolment, allocation, follow-up, and analysis stages for the study. Written informed consent was obtained from all participants before any participation. Participants were randomized using a computer randomization program to 1 of 3 groups: BD ($n = 11$), heavy-load breakdown (HLBD, $n = 14$), and a control (CON, $n = 11$) group. Participants were asked to refrain from any exercise away from the supervised sessions.

### Procedures

*Testing.* Pre- and postmuscular performance testing was performed in the following order with 120 seconds rest between exercises using chest press, leg press, and pull-down (MedX, Ocala, FL, USA) resistance machines. As participants were existing members of the facility where testing and training took place, all participants used their preexisting training load for testing. It was estimated that this load would allow performance of 8–12 repetitions at the 2-second concentric 4-second eccentric (2:4) repetition duration used for testing and training. Pre- and posttesting used the same absolute load allowing total volume (e.g., load × repetitions) to be calculated as has been done in previous research (8,13). This method allows comparison of absolute muscular endurance and is considered a representative method of muscular performance. This testing method provides strong ecological validity to realistic training conditions as most persons infrequently test or use their maximal strength. In addition, it likely has greater application for BD training, which might provide greater stimulus for lower-threshold MUs as opposed to maximal strength testing which will recruit higher threshold MUs. The test was ceased when the participant failed during the concentric phase of a repetition or could not maintain the required repetition duration. Posttesting was performed at least 48 hours after the final training session as per previous research (13). The instructor performing the pre- and posttesting was blinded to group assignment.

Body composition was estimated using air displacement plethysmography (Bod Pod GS; Cosmed, Chicago, IL, USA). Details of the test procedures for estimation of body composition have been previously described in detail elsewhere (9). Briefly, while wearing minimal clothing (swimsuit or tight-fitting underwear) and a swim cap, participants were weighed using a calibrated digital scale. The participant is then seated in the Bod Pod for body volume measurement. From the body

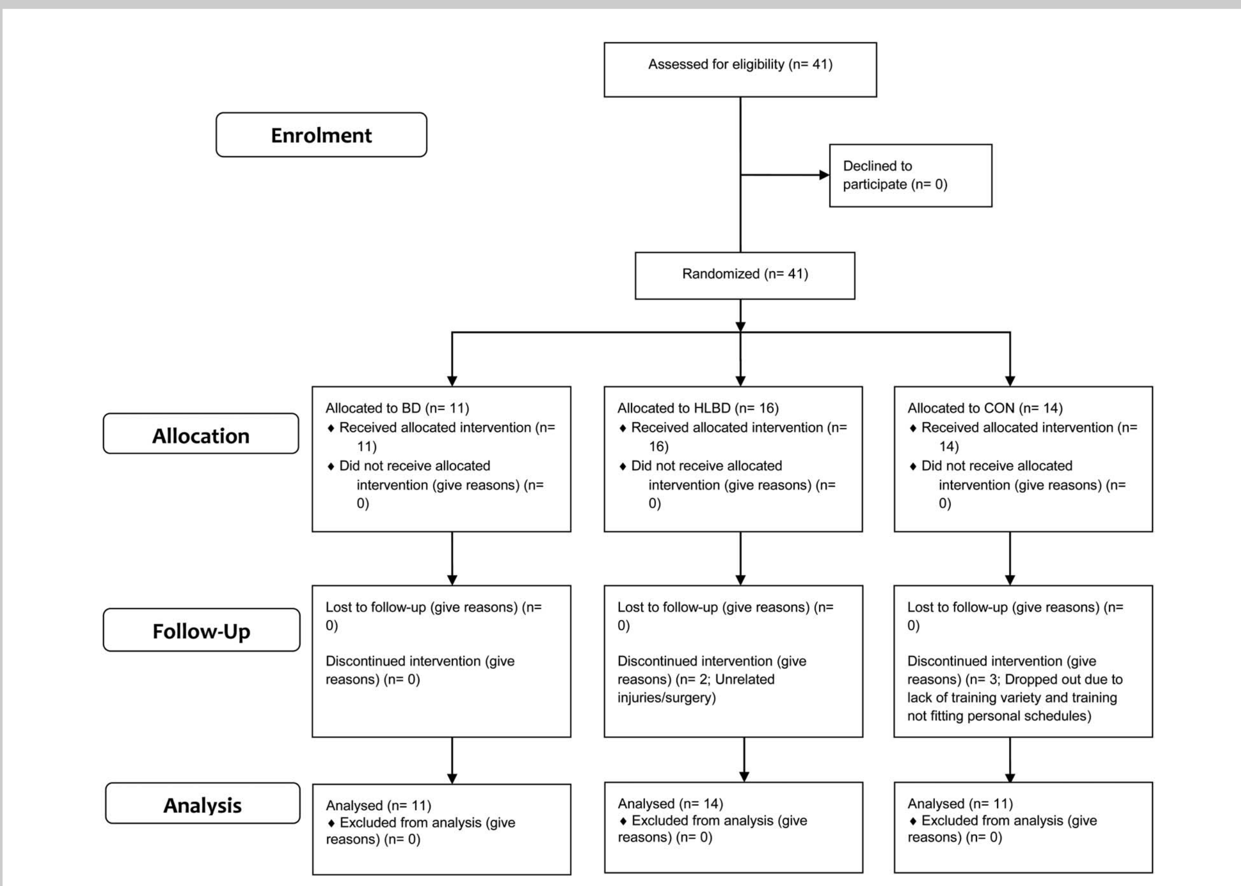


**Figure 1.** Consort diagram.

**TABLE 1.** Participant baseline characteristics.*†

| | BD | HLBD | CON | *p* |
|---|---|---|---|---|
| Age (y) | 38 ± 7 | 37 ± 13 | 34 ± 12 | 0.654 |
| Stature (cm) | 167.12 ± 9.70 | 167.42 ± 8.15 | 173.81 ± 9.85 | 0.160 |
| Body mass (kg) | 68.81 ± 10.15 | 69.16 ± 13.36 | 75.77 ± 15.96 | 0.387 |
| BMI | 24.63 ± 2.91 | 24.50 ± 3.14 | 24.86 ± 3.32 | 0.961 |
| Sex ratio (men:women) | 3:8 | 2:12 | 6:5 | NA |

*BD = breakdown; HLBD = heavy-load breakdown; CON = control; BMI = body mass index; NA = not applicable.
†Results are means ± *SD*; *p* values for between-group effects using analysis of variance.

mass and body volume measurements and predicted thoracic lung volumes, body density is estimated by the Bod Pod software and lean and fat mass estimations calculated using the Siri equation.

*Training Intervention (Breakdown, Heavy-Load Breakdown, and Control Group).* Training was performed 2 times per week (with at least 48 hours between sessions) for 12 weeks. Each exercise was performed for one set per training session at a 2:4 repetition duration until MMF (i.e., when they reached a point of concentric failure during a repetition) to control for intensity of effort between groups (31). All participants performed 2 exercise sessions per week. The first of these, workout "A," consisted of chest press, leg press, pull-down (MedX) overhead press, adductor, abductor (Nautilus Evo, Vancouver, WA, USA), abdominal flexion (MedX Core Ab Isolator), and lumbar extension (Roman chair using bodyweight or manual resistance; Hammer Strength, Rosemount, IL, USA). The second session, workout "B," consisted of pec-fly, pullover (Nautilus Evo), leg extension (MedX), dip, biceps curl (Nautilus Evo), seated calf raise (Hammer Strength), leg curl, and core torso rotation (MedX) resistance machines.

All groups performed a single set of each exercise for both workouts A and B with the exception of the BD method,

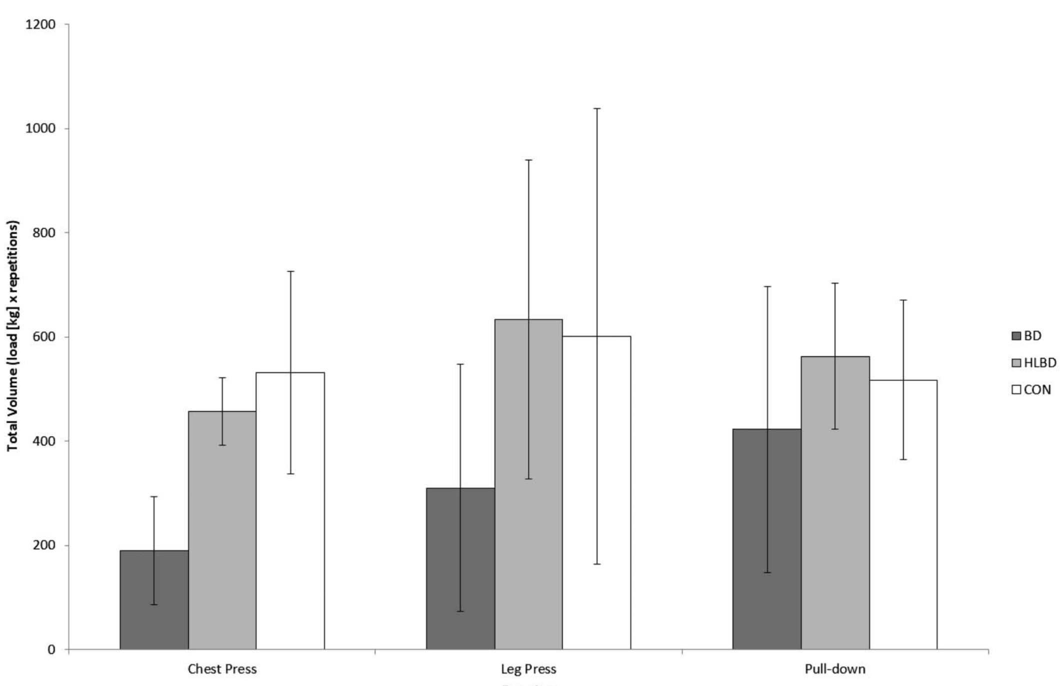


**Figure 2.** Mean muscular endurance changes and 95% confidence intervals for each group and exercise. BD = breakdown; HLBD = heavy-load breakdown; CON = control.

**Table 2.** Mean changes and ESs for body composition outcomes.*†

| | BD | | | HLBD | | | CON | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Change | 95% CI | ES | Change | 95% CI | ES | Change | 95% CI | ES | *P* |
| Body mass (kg) | 0.55 ± 1.15 | −0.22 to 1.32 | 0.48 | −0.05 ± 2.07 | −1.25 to 1.14 | −0.02 | 0.48 ± 2.16 | −0.98 to 1.93 | −0.22 | 0.677 |
| Body fat (%) | 0.00 ± 1.57 | −1.05 to 1.05 | 0 | −0.01 ± 3.33 | −1.93 to 1.92 | 0 | 0.94 ± 2.01 | −0.41 to 2.29 | 0.46 | 0.592 |
| Lean mass (kg) | 0.41 ± 1.14 | −0.35 to 1.32 | 0.36 | −0.19 ± 1.37 | −0.98 to 1.14 | −0.14 | −0.32 ± 1.58 | −1.38 to 1.93 | −0.20 | 0.606 |

*BD = breakdown; HLBD = heavy-load breakdown; CON = control; CI = confidence interval; ES = effect size.
†Results are mean + *SD*; ES = Cohen's *d*; *p* values for between-group effects using analysis of variance.

which was used for the chest press, leg press, and pull-down exercises in workout A only (e.g., the exercises that were tested). All other exercises were performed to MMF with a load permitting 8–12 repetitions. Once participants were able to perform more than 12 repetitions before achieving MMF, load was increased by ~5%. This is in accordance with previous recommendations and research (e.g., Refs. 12,27, respectively). For the chest press, leg press, and pull-down exercises, the BD group performed a single set of 8–12 repetitions to MMF and immediately reduced the load by ~30% and then continued performing repetitions to MMF. Using the same 3 exercises, the HLBD group used a heavier load permitting only ~4 repetitions; upon reaching MMF, they decreased the load by ~20% and continued performing repetitions to MMF and then repeated the BD reducing the load by a further 20% and performing repetitions to MMF. The CON group performed all exercises for a single set of 8–12 repetitions to MMF with no BD. The group protocols were chosen to allow parity between training load (the BD and CON groups both used the same relative load to begin; permitting 8–12 repetitions) and repetition volume (the HLBD and CON groups both performed a total of ~8 to 12 repetitions).

#### Statistical Analyses

Power analysis of research using low-volume RT in trained participants (13) was conducted to determine participant numbers ($n$) using an effect size (ES), calculated using Cohen's $d$ (5) of 1.25 for improvements in strength. Participant numbers were calculated using equations from Whitley and Ball (34) revealing each group required 9 participants to meet required $\beta$ power of 0.8 at an $\alpha$ value of $p \leq 0.05$.

After dropouts data were available from 36 participants (BD, $n = 11$; HLBD, $n = 14$; CON, $n = 11$), data met assumptions of normality of distribution when examined using a Kolomogorov-Smirnov test. Baseline data were compared between groups using a 1-way analysis of variance (ANOVA) to determine whether randomization had succeeded. Between-group comparisons for absolute changes in muscular performance and body composition outcomes were performed using 1-way ANOVA. Where assumptions of homogeneity of variance were violated, the Welch's $F$ test statistic was used. Any significant between-group effects were examined further with post hoc Tukey testing to determine the location of significant differences. Statistical analysis was performed using IBM SPSS Statistics for Windows (version 20; IBM Corp., Portsmouth, Hampshire, United Kingdom) and $p \leq 0.05$ set as the limit for statistical significance. Furthermore, 95% confidence intervals (CIs) were calculated in addition to ES using Cohen's $d$ (5) for each outcome to compare the magnitude of effects between groups where an ES of 0.20–0.49 was considered as small, 0.50–0.79 as moderate, and ≥0.80 as large. Because of the discrepancy in gender ratio between the CON group and both BD and HLBD groups, the above analyses were also conducted with men excluded and it is noted in the Results where these findings differed from the combined gender results. The researcher who performed the data analyses was blinded to group assignment.

## Results

### Participants

Participant baseline demographics are shown in Table 1. Demographic variables did not differ between groups at baseline.

### Absolute Muscular Endurance

The ANOVA did not reveal any significant between-group effects for baseline muscular endurance data for any exercise. Figure 2 shows the mean changes in absolute muscular endurance with 95% CIs for each group and exercise with 95% CIs indicating that significant changes in muscular performance within each group occurred for every exercise. The ANOVA did not reveal any significant between-group effects for change in absolute muscular endurance for chest press (CP) ($F_{2,18.089} = 3.531$, $p = 0.051$), leg press (LP) ($F_{2,33} = 0.349$, $p = 0.708$), and pull-down (PD) ($F_{2,33} = 0.286$, $p = 0.753$). Results did not differ when women were examined separately, and no significant differences were identified though it is noted that observed β for female-only comparisons ranged 0.11–0.45, and so, this may have resulted in a type II error. The ESs for muscular performance changes were all considered large and for BD, HLBD, and CON groups, respectively, were 1.22, 2.74, and 1.46 for chest press; 1.29, 1.19, and 0.86 for leg press; and 1.32, 2.48, and 2.27 for pull-down.

### Body Composition

The ANOVA did not reveal any significant between-group effects for baseline body composition data. Table 2 shows mean changes, 95% CIs, and ESs for body composition changes. The ANOVA did not reveal any significant between-group effects for change in body mass ($F_{2,33} = 0.394$, $p = 0.677$), body fat percentage ($F_{2,33} = 0.532$, $p = 0.592$), or lean mass ($F_{2,33} = 0.509$, $p = 0.606$). Results did not differ when women were examined separately, and no significant differences were identified though it is noted that observed β for female-only comparisons ranged 0.178–0.267, and so, this may have resulted in a type II error.

## Discussion

The present study examined the effects of BD training using both heavy- and traditional-load protocols, compared with a control group training to MMF, in trained participants. Results indicated that neither BD (+61.5%) nor HLBD (+54.7%) groups attained significantly greater gains in absolute muscular endurance than CON group (+51.3%). The use of 3 training protocols accommodated parity between groups in both repetition volume (HLBD and CON groups both performed ~12 repetitions per exercise) and training load (BD and CON groups both used an initial load allowing 8–12 repetitions). The advanced technique of immediately reducing the load when reaching MMF and performing subsequent repetitions both with a heavy- (HLBD) and a moderate-load (BD) resulted in no greater gains in muscular performance improvement beyond that of performing a single-set protocol of 8–12 repetitions to MMF. The magnitude of improvement in muscular performance for all groups and all exercises was considered large and significant from examination of ESs and 95% CIs.

Recent publications (13,14,18) have suggested that training to MMF seems sufficient stimulus to catalyze optimal muscular adaptations without the need for advanced training methods, such as pre-exhaustion or rest-pause training. Schoenfeld (29) suggested that BD training might produce greater adaptations as a result of the high muscular tension associated with heavier loads, greater MU fatigue, and metabolic stress and ischemia as a result of the increased time under tension. Indeed, multiple commercial texts (7,16,26,33) and academic publications (1,29) have previously recommended the use of BD training. However, although this hypothesis seems logical, the present study has failed to support any chronic adaptations from BD training beyond that of more simple methods. In fact, the present study is concurrent with our understanding of the size principle that there is a sequential recruitment of MUs, from the smallest to the largest, as a product of fatigue (3,23). As such, the present study supports that this sequential recruitment sufficiently stimulates adaptation without the need for subsequent stimulation in the form of BD training or other advanced techniques. However, it would be imprudent not to discuss that the analyses for the CP revealed $p = 0.051$, with ESs differing considerably between BD, HLBD, and CON groups (1.22, 2.74, and 1.46, respectively). Although we cannot state that a $p = 0.05$ value approaches significance because we cannot be certain whether a greater sample size would have resulted in a higher or lower $p$ value, we can ascertain from ESs that in the present study greater (although not significant) improvements in muscular performance were obtained for the CP when using a heavier load. Conversely, this trend was not consistent for LP or PD exercise. It should, however, also be noted that for the PD exercise, the CON group attained an ES similarly high as did the HLBD group, and thus, this may just be reflection of the heterogeneity of responses within those groups for those exercises.

Body composition changes within the present study were minimal in all participants across all training groups and were likely within the margin of error, as has been reported in previous research (13), for the method of measurement used (6,11). However, research has reported large increases in CSA of the quadriceps in young and older women (ESs = 1.08 and 2.23, respectively) without significant change in body mass, body composition, and fat-free mass (22). In addition, large increases in quadriceps CSA, after 9 weeks of lower-body RT in young and older men (ESs = 1.61 and 4.64, respectively), were apparent with only small but significant increases in body mass (0.9 and 0.8 kg, respectively) with no change to body composition. Within the present study, the pooled male data showed a statistically significant increase in body mass of 1.5 kg (95% CIs = 0.37–2.7 kg). Because there was no change in body composition, from a practical perspective, these figures might represent a relatively meaningful increase in muscle mass over a 12-week period. This suggests that hypertrophic adaptations might have occurred within the present study but were unidentifiable by our anthropometric measurements. Considering this, future research should look to specifically investigate the effects of advanced techniques, such as BD training upon more valid measures of hypertrophy such as magnetic resonance imaging, computed tomography, or ultrasound. In addition, because the present study measured absolute muscular endurance, future research should consider maximal strength testing as well as peak torque testing using isokinetic and isometric dynamometry.

The present study has considered trained participants and as such adds to the limited research considering this population group. However, the training intervention only applied BD training to the 3 tested exercises. Because other exercises performed also recruited the major muscles that were used in the tested exercises (e.g., pec-fly, pullover, leg extension, and leg curl), we might consider that performing BD training for other exercises might have affected results. In addition, although the present study attempted between-group parity in training load (BD and CON) and repetitions (HLBD and CON), it could be argued that upon reaching failure performing another set, albeit with a decreased load, amounts to performing a higher training volume. Further that volume load (repetitions × sets × load) was not equated between groups may have affected outcomes. As such, future research should consider further manipulation and control of these variables in accordance with BD training.

We should also consider the large number of women within the present study and indeed the disparate number of men and women between groups (Table 1). Although statistical analysis was performed for independent genders, we should be cautious to consider these results wholly representative of either population specifically. Our research design may have been improved by use of a gender counterbalanced approach to randomization. The female-only comparisons resulted from considerably reduced power and thus may reflect a type II error. However, the combined gender groups were deemed sufficiently powered based on a priori estimates, and indeed, muscular performance outcomes in this study were examined using absolute changes as opposed to relative changes, the former of which has been shown to not differ between genders despite differences in relative changes (21). There was though slightly more favorable ESs in the BD group despite not achieving significance that may reflect sampling and randomization inadequacy possibly affected these outcomes. Future research might consider a similar methodological approach with different population groups controlled for gender and differing manipulation of variables discussed herein. In addition, further research might investigate the perceived effort and muscular discomfort associated with training to, and beyond, MMF along with potential psychological effects, such as motivation, enjoyment, etc., considering that recent research has also suggested that motivation to continue performing RT using advanced techniques, such as BD sets, may be lower than RT involving lower intensity of effort (17).

## Practical Applications

Results from the present study suggest that considerable increases in muscular performance can be attained by the use of brief, infrequent, and uncomplicated resistance exercise, specifically in persons with previous RT experience. Furthermore, this study adds to the relative dearth of empirical research that advanced training techniques seem to produce no greater gains in muscular performance than traditional sets of RT performed to muscular failure. From a practical perspective, the present study reinforces our understanding of the size principle that exercise to MMF recruits all available MUs irrespective of load and advanced techniques. For strength coaches and athletes with limited time resources and engaging in sport-specific skill training, the present study supports that a time-efficient manner of uncomplicated training seems an efficacious approach to improving absolute muscular endurance.

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# CHAPTER 4: A Randomized Trial to Consider the Effect of Romanian Deadlift Exercise on the development of Lumbar Extension Strength

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Original research

# A randomized trial to consider the effect of Romanian deadlift exercise on the development of lumbar extension strength

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ABSTRACT

*Objective:* To consider the efficacy of 10 weeks of Romanian deadlift (DL) training in increasing lumbar extension strength compared to isolated lumbar extension (LUMX) training.
*Design:* Comparison of pre- and post-test data for Romanian deadlift 1RM, and lumbar extension torque between and within groups.
*Participants:* Male trained subjects ($n = 36$; ($\bar{x} \pm$ SD) 24.9 ± 6.5 years; 178.5 ± 5.2 cm; 81.6 ± 10.0 kg).
*Main outcome measures:* Pre- and post-testing included a Romanian deadlift 1RM and isometric strength tests every 12° through full range of motion on the MedX lumbar extension machine (MedX, Ocala, FL).
*Results:* Repeated measures analysis of variance (ANOVA) with Bonferroni adjustments revealed that 1RM Romanian deadlift significantly increased from pre- to post-test in the DL group ($p < 0.008$; 143.3 ± 23.4 kg to 166.3 ± 21.9 kg) and the LUMX group ($p < 0.008$; 135.8 ± 23.1 kg to 146.0 ± 25.5 kg). In contrast, tested functional torque (TFT) significantly increased at 6 out of 7 joint angles ($p < 0.008$) for the LUMX group only. The control group showed no significant differences pre- to post-test.
*Conclusions:* These data suggest that the Romanian deadlift does not enhance lumbar extension torque. However, performing specific isolated lumbar extension training appears to improve both lumbar extension torque and Romanian deadlift 1RM.



## 1. Introduction

The prevalence of low back pain and injury in both trained and untrained persons, as well as amateur and competitive athletes (e.g. weight lifters, ballet dancers, gymnasts, javelin throwers, tennis players, cross-country skiers, rowers, orienteers and golfers) is well documented (Alexander, 1985; Alricsson & Werner, 2006; Bahr, Anderson, Loken, Fossan, Hansen & Holme, 2004; Bono, 2004; Calhoon & Fry, 1999; DeHaven & Lintner, 1986; Gluck, Bendo, & Spivak, 2008; Hutchinson, 1999; Mazur, Yetman, & Risser, 1993; Nadler, Malanga, Bartoli, Feinberg, Prybicien, Deprince, 2002; Renkawitz, Boluki, & Grifka, 2006; Stuelcken, Ginn, & Sinclair, 2008). Bono (2004) discussed the importance of both lower back dynamic power in movements such as the golf or baseball swing, a gymnast's landing, a power-lifter's squat and a boxer's punch, as well as static strength in examples such as an infielder's stance, a cyclers tuck or a ballerina's arabesque.

Bono (2004) stated that "*low back pain is a symptom not a diagnosis*", which is fitting with studies that have shown a relationship between low back pain and weak lumbar musculature (Luoto, Heliövaara, Hurri, & Alaranta, 1995; Mayer, Graves, Robertson, Pierra, Verna & Ploutz-Snyder, 1999; Risch et al., 1993; Suni, Oja, Miilunpalo, Pasanen, Vuori & Bos, 1998). Other research has shown that the muscles of the lumbar region can be strengthened using specific isolated machine-based training, improving function and reducing low back pain symptoms and disability (Carpenter et al., 1991; Choi, Pai Raiturker, Kyung-Joon, Dai Jin, Yu-Sik & Sang-Ho, 2005; Graves et al., 1990, 1994; Pollock, Leggett, Graves, Jones, Fulton & Cirulli, 1989; Risch et al., 1993). This plethora of evidence suggests benefits, for almost all individuals, in performing some form of lower back exercise whether in an effort to maximize athletic performance or simply to reduce the potential for low back pain.

Mayer, Mooney, and Dagenais (2008) highlight four ways to exercise and improve lumbar strength; (i) machines, (ii) benches and roman chairs, (iii) free weights (e.g. deadlift), and (iv) floor and stability balls. Indeed many major gyms now include some form of

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lower back exercise machine, or roman chair. Great success has been attained with the MedX lumbar extension machine (see method for validity and reliability data) in both measuring isometric force production and strengthening the lumbar muscles (Bruce-Low, Smith, Bissell, Burnet, Fisher & Webster, 2012; Carpenter et al., 1991; Graves et al., 1990; Pollock et al., 1989; Smith, Bruce-Low, & Bissell, 2008). However, more common 'lower-back' exercises, such as the roman chair, have been shown not to improve lumbar extension strength when tested on an isometric dynamometer, even where training resistance has increased throughout an intervention (Mayer, Udermann, Graves, & Ploutz-Snyder, 2003). Other research has considered alternative lumbar extension machines that do not fixate the pelvis and therefore do not isolate the lumbar extensors, once again reporting no significant increase in isometric torque production in the lumbar muscles from training on such machines (Graves et al., 1994). These authors reported that this was likely due to the rotational movement of the pelvis permitted by such exercises, allowing gluteal and hamstring activation to assist in the movement. Indeed, researchers have reported significantly greater activation of the lumbar multifidus during back extension where the pelvis was stabilized (San Juan, Yaggie, Levy, Mooney, Udermann & Mayer, 2005), adding that muscle activation of the gluteus maximus and biceps femoris were decreased where the pelvis was restrained (Da Silva, Lariviere, Arsenault, Nadeau, & Plamondon, 2009). In contrast, another study found greater activation of the erector spinae muscles in an unrestrained condition (Benson, Smith, & Bybee, 2002), although participants in this study subjectively reported greater effort in the lumbar muscles where the pelvis was restrained.

In addition to these machine-based exercises, a popular barbell exercise, the stiff-legged deadlift (also commonly referred to as the 'Romanian deadlift') is often advocated for strengthening the back extensors (Mayer et al., 2008; Piper, 2001; Sheppard, 2003). Based on this, many strength and conditioning coaches and personal trainers also recommend this exercise to strengthen the lumbar muscles, supported by the National Strength and Conditioning Association (NSCA Baechle & Earle, 2008). Indeed, researchers using electromyography (EMG) have found activation of the lumbar muscles from performing variations of the deadlift. For example, Chulvi-Medrano, Garcia-Masso, Colado, Pablos, Alves de Moraes & Fuster, (2010) report lumbar activation (measured on the lumbar multifidus and the lumbar erector spinae) when considering the deadlift (non-specific reference to conventional, sumo, or Romanian although the pictures within their article clearly represent the Romanian deadlift); and Escamilla, Francisco, Kayes, Speer, and Moorman (2002) report lumbar activation (measured on the L3 'paraspinals') when considering both the sumo and conventional deadlifts.

Since variations of the deadlift have been shown to activate lumbar muscles through EMG (Chulvi-Medrano et al., 2010; Escamilla et al., 2002) researchers have advocated the use of the Romanian deadlift exercise for strengthening of the back extensors (Frounfelter, 2000; Mayer et al., 2008; Piper, 2001; Sheppard, 2003). However, EMG data only infer an acute training response. In addition we might be careful in interpretation of EMG data of specific lumbar muscles; De Luca (1997) details limitations of using EMG signals to include crosstalk (readings from synergist muscles) and indeed; Stokes, Henry, and Single (2003) specifically discuss the lumbar multifidus as a challenging area to accurately record EMG data.

To date we could find no peer reviewed research that has shown that performing the Romanian deadlift, or any of its variations, will enhance the torque production of the lumbar muscles. It is surely of considerable interest to many athletic- and personal-trainers as well as athletes and recreational gym goers to know the efficacy of this exercise as regards to whether it can strengthen the lumbar muscles and thus potentially reduce the risk of injury or likelihood of low back pain. Therefore, the aim of the present study was to determine the effects of a 10-week, progressive Romanian deadlift training program upon lumbar extension torque. By comparing the force increases (lumbar extension torque and Romanian deadlift 1RM) between a MedX training group and a Romanian deadlift training group we can consider whether the Romanian deadlift enhances force production to a similar degree as specific isolated lumbar extension training.

## 2. Methods

### 2.1. Experimental approach to the problem

The effect of a 10-week progressive training program, using the Romanian deadlift, on lumbar torque production was evaluated using a MedX (Ocala, Florida) lumbar extension machine. This machine can be used to measure lumbar extension range of motion (ROM) in a seated position as well as test isometric strength at 12° intervals. It can also be used for dynamic, variable resistance lumbar extension training. Pre and Post strength testing was performed for all subject groups using the Romanian deadlift 1RM, and the Lumbar Extension Machine. A prospective, between groups, repeated measures exercise training study was conducted with healthy individuals who were randomly allocated to 1 of 3 groups; lumbar extension training once a week (LUMX; $n = 12$), Romanian deadlift training once a week (DL; $n = 12$) or a control group (CON; $n = 12$).

### 2.2. Subjects

Following approval by the relevant ethics committees, 36 asymptomatic male subjects ($\bar{x} \pm$ SD) (age $= 24.9 \pm 6.5$ years), were recruited by advertisement within a University environment (specifically requesting participants who did not suffer from any lower back pain). All subjects provided written informed consent prior to participation, were required to have had greater than 2 years resistance training experience, including a deadlift variation (non-specific) and were currently involved in a resistance training program that did not include specific lumbar exercises or the Romanian deadlift. All subjects were asked to refrain from other deadlifts (any variation), squats or other exercises that might place a direct stress or training effect on the lower back or gluteal and hamstring chain of muscles throughout the duration of their participation, other than those required by the study itself.

Two subjects, who verbally reported through interview, currently suffering from a form of lower back pain or discomfort, were excluded from the study. Six participants who, at some point during the study, failed to attend a training session ($n = 4$, DL; $n = 2$, LUMX) were withdrawn from the study. One participant, who did not complete the post-test was also excluded ($n = 1$, CON). When asked about their withdrawal from the study all but one of these participants cited inconvenience of the training session/post-test as their reason for withdrawal. One participant who underwent 3 training sessions for the DL group withdrew reporting severe delayed onset muscle soreness (DOMS) from training to muscular failure (see also Fig. 1). All other participants completed the 1×/week protocol with the required compliance.

### 2.3. Testing procedures: (i) deadlift

Prior to testing, all subjects were provided with a comprehensive training session to familiarize them with the Romanian deadlift and verify their ability to perform it safely. Once appropriate

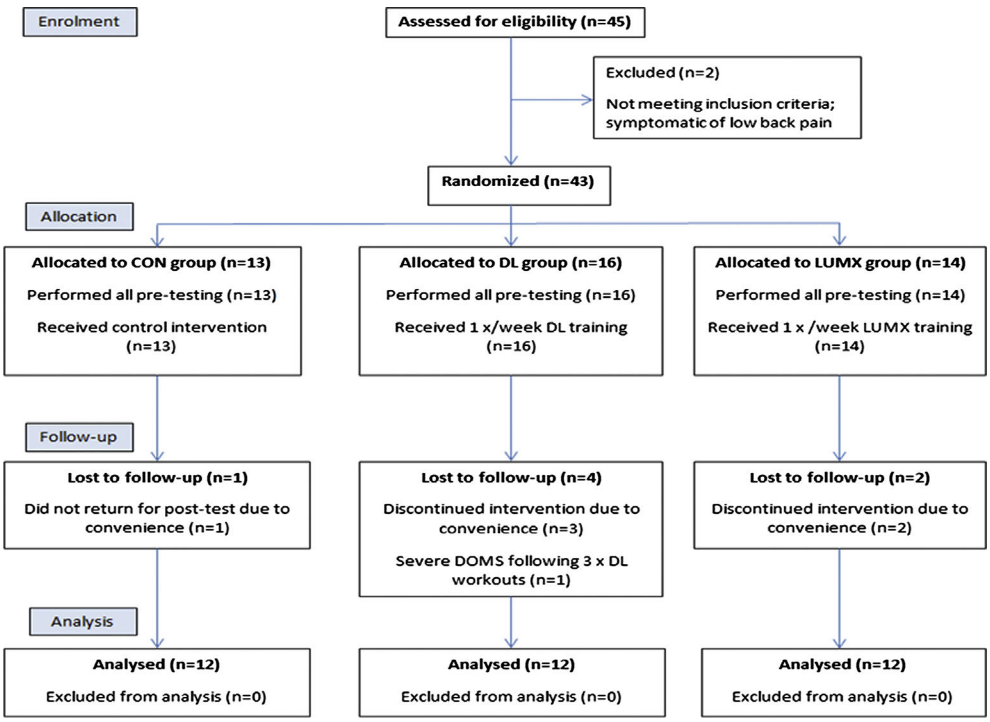


**Fig. 1.** Consort diagram showing enrollment, allocation, continuence and analysis.

technique was demonstrated subjects returned for a second session where they performed a standardized 5 min warm-up on a cycle ergometer up to 70% heart rate maximum, followed by 8 repetitions at 50%, and then 3 repetitions at 70% of their predicted 1-repetition-max (1RM). Each subject was then given 3–5 attempts to perform a maximal lift with approximately 3 min rest in between to allow for adequate recovery (Brown & Weir, 2001). For the Romanian deadlift 1RM lifting straps were used to ensure the weight was maximal, and not limited by the grip strength of the subjects (Fig. 2).

### *2.4. Testing procedures: (ii) lumbar extension machine*

Subjects were seated in the MedX Lumbar extension machine in an upright position with their thighs at an angle of 15° to the seat. A restraining belt was secured over the anterior part of the upper thigh and femur restraint pads were firmly positioned over the thigh just superior to the knees. These restraints prevent unwanted vertical movement of the pelvis or thighs. The machine also incorporates a counter-weighting procedure to counterbalance the mass of the upper body and also the effects of gravity acting on the upper body. When ready to test, the movement arm on the machine was locked at the relevant joint angle (measured using the machine's goniometer) and the subject was requested to build up to maximal tension over 2–3 s and to maintain the contraction for a further 1 s. The torque produced was measured by a load cell attached to the movement arm. The validity and reliability of both the restraint and counter-weighting procedures are well-established (Graves et al., 1990, 1994; Inanami, 1991) and the torque measurements show very high test–retest reliability at all angles ($r = 0.63–0.96$ (Robinson, Greene, Graves, & Mac Millan, 1992) for patients with lumbar pain and $r = 0.94–0.98$ (Pollock, Graves, Leggett, Young, Garzarella & Carpenter, 1991) for asymptomatic patients) (Fig. 3).

One week following the 1RM maximal Romanian deadlift, subjects then completed two isometric lumbar extension strength tests (not less than 72 h apart). As previous research (Graves et al., 1990) has shown it is important that subjects are familiar with the testing procedure to produce reliable results, the initial testing session was designated as a familiarization session. The second test was used to obtain pre-test measures of lumbar extension strength.

**Fig. 2.** Romanian deadlift, showing range of motion.

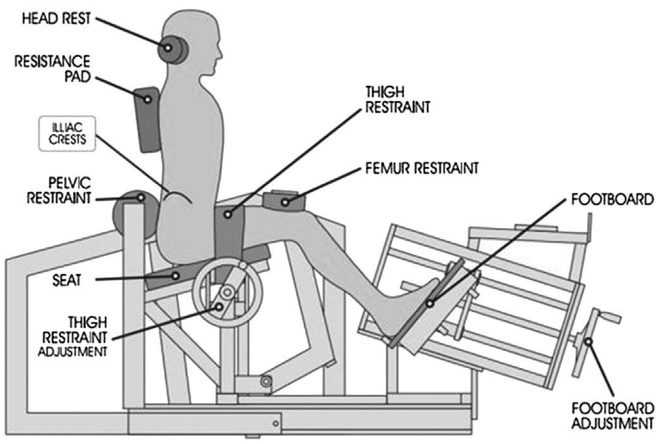


**Fig. 3.** MedX lumbar extension machine, showing restraint system.

In accordance with standard procedure on this machine, isometric lumbar extension torque was measured at intervals of 12°, starting from full lumbar flexion (72°) to full lumbar extension (0°). Prior to testing, the restraining and counter-weighting procedures were carried out as described previously, and lumbar ROM in the machine was measured using the machine's goniometer.

Following these procedures, strength tests were conducted at each joint angle using the procedure described, with approximately 10 s rest between the strength tests at each joint angle. Subjects were asked if they felt they exerted maximal effort at each angle and any tested angles in which the subject felt he did not give a maximal effort were repeated.

### *2.5. Group assignment*

Subjects were assigned to one of the training groups or the control group using simple randomization (blindly selecting 1 of 3 cards denoting group allocation), following testing and prior to any training. One of the test administrators and one of the statisticians were blinded to group assignment, however due to the research design the administrator supervising training intervention could not be blinded to group assignment. A power analysis of previous research with asymptomatic subjects (Graves et al., 1990) was conducted to determine sample size ($n$). A treatment effect size (ES) of 1.26 for the MedX lumbar extension machine was calculated using Cohen's $d$ (Cohen, 1992). Subject numbers were calculated using equations from Whitley and Ball (2002). These calculations revealed that each group required a minimum of 10 subjects to meet the required power of 0.8 at an alpha value of $p \leq 0.05$.

### *2.6. Exercise training*

Subjects in the LUMX group performed one lumbar extension training session per week for 10 weeks. Subjects in the DL group performed one DL training session per week for 10 weeks. All testing and training was performed within the University sport science laboratories. For each of the training groups this involved one set of ~8–12 repetitions at a weight equivalent to ~80% of the maximum tested functional torque (TFT)/1RM through the subject's full ROM on either the lumbar extension machine or the DL to volitional fatigue within a time frame of between 60 and 90 s. Subjects performing the DL were permitted to use lifting straps to ensure the exercising set was not limited by grip strength, and were supervised and provided with coaching guidance based on that of previous research (Frounfelter, 2000; Gardner & Cole, 1999). Verbal commentary during any testing/training was restricted to coaching guidance of technique rather than encouragement of performance. Whilst the protocol used for the DL group might not be perceived as optimal, the volume and frequency were balanced with that of the LUMX group which was essential for an unbiased comparison. Also, it is important to note that contrary to the perceptions of many individuals involved in resistance training, research has shown that single-set workouts, 1×/week are sufficient to stimulate optimal strength gains (e.g. Fisher, Steele, Bruce-Low, & Smith, 2011; Smith & Bruce-Low, 2004).

Repetitions for both groups were performed slowly, with the LUMX group advised to take 2 s to lift the weight and 4 s to lower it as is the standard protocol with the machine. The DL group were advised the same; to lift in a slow and deliberate manner without explosive movements. This is fitting with other literature (Gardner & Cole, 1999) and allowed accurate comparison between the training modalities. When subjects could perform more than 12 repetitions the weight was increased by approximately 5%. This training protocol is standard in studies using the machine and in resistance training in general (Ratamess et al., 2009) and has been found to produce optimal strength increases. Training at a non-explosive repetition rate is suggested to maximize muscular tension, eliminate external forces such as momentum, and to reduce the risk of injury (Bruce-Low & Smith, 2007).

### *2.7. Statistical analysis*

Descriptive statistics (means and SDs) were derived for demographic data and strength variables. 1RM Romanian deadlift (measured in kg) and force at each lumbar extension joint angle (measured in Nm) as well as lumbar extension SI value were evaluated within each group using an analysis of variance (ANOVA) with repeated measures for training effects. The lumbar extension SI value is a product of force produced at each joint angle reported as the area under a force curve. This allows for inclusion of potential increases and decreases throughout the entire strength curve at all 7 test positions (0°, 12°, 24°, 36°, 48°, 60°, and 72°) without biasing the data by seeing an average increase or decrease or only considering specific joint angles. Where a significant difference was observed, a paired samples $t$-test was completed with a Bonferroni adjustment (to reduce the risk of type-2 error); meaning significance was accepted at the alpha level $p \leq 0.008$.

## 3. Results

All data were checked and confirmed to be normally distributed using a Kolmogorov–Smirnov test. There were no significant differences in age, stature, or body mass between the groups ($p > 0.05$ in all cases; Table 1). In addition, between-group pre-test analyses revealed no significant differences for the Romanian deadlift 1RM, the MedX SI value, and the lumbar extension joint angles ($p > 0.05$ in all cases). Analysis of the lumbar extension joint angle data, expressed as the mean ± standard deviation ($\bar{x} \pm$ SD), using a repeated measures ANOVA revealed a significant time-× group interaction effect ($p < 0.05$), as did the lumbar extension SI data ($p < 0.05$). The Romanian deadlift 1RM values, expressed as the mean ± standard deviation, also showed a significant interaction effect ($p < 0.05$).

**Table 1**
Subject characteristics (mean ± SD).

| Group | $n$ | Age ($y$) | Height (cm) | Weight (kg) |
|---|---|---|---|---|
| LUMX | 12 | 23.1 ± 4.5 | 177.7 ± 4.1 | 77.2 ± 9.7 |
| DL | 12 | 26.5 ± 7.0 | 178.4 ± 6.8 | 82.1 ± 8.3 |
| CON | 12 | 24.5 ± 7.5 | 179.3 ± 4.5 | 84.4 ± 11 |

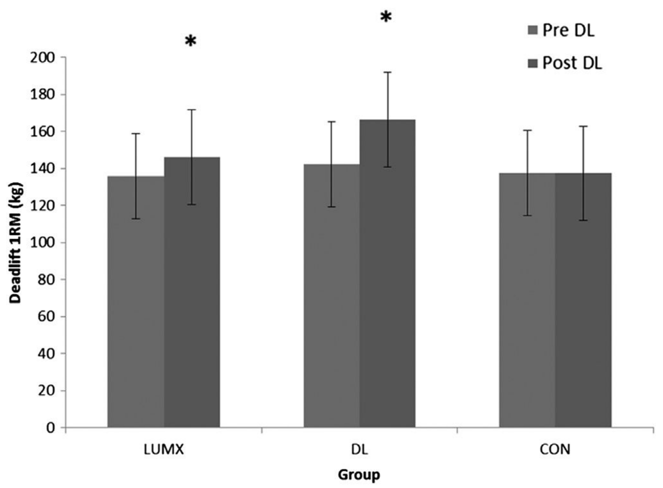


**Fig. 4.** Deadlift 1-repetition-max (kg), *Post-test > pre-test ($p < 0.008$). Error bars represent SD values.

Paired samples *t*-tests with a Bonferroni adjustment showed the following pre- to post-test results. For the Romanian deadlift 1RM (Fig. 4); there were no significant differences for the CON group; ($t_{(11)} = 0.178$, $p = 0.862$), there was a significant difference for the DL training group; ($t_{(11)} = -8.23$, $p < 0.008$ [pre- 143.3 kg ± 23.4 to post- 166.3 kg ± 21.9]), and there was also a significant difference for the LUMX training group; ($t_{(11)} = -3.57$, $p < 0.008$ [pre- 135.8 kg ± 23.1 to post- 146.0 kg ± 25.5]).

For the MedX SI values (Fig. 5); there was no significant difference for the CON group ($t_{(11)} = 1.03$, $p = 0.328$), there was no significant difference for DL group ($t_{(11)} = -1.37$, $p = 0.199$), however, there was a significant difference for the LUMX training group ($t_{(11)} = -8.15$, $p < 0.008$ [pre- 16262.8 ± 4273.0 to post- 19472.4 ± 4932.3]).

For the lumbar extension joint angles (Fig. 6); there was no significant difference for the CON group ($p > 0.008$), there was no significant difference for the DL training group ($p > 0.008$), however, there was a significant difference for 6 out of the 7 tested joint angles for the LUMX training group ($p < 0.008$).

## 4. Discussion

The present study considered the use of the Romanian deadlift exercise as a method of training the lumbar extensor muscles in

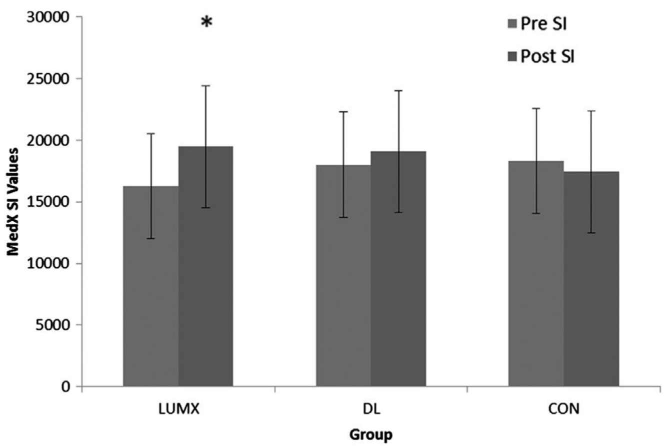


**Fig. 5.** MedX SI values. *Post-test > pre-test ($p < 0.008$). Error bars represent SD values.

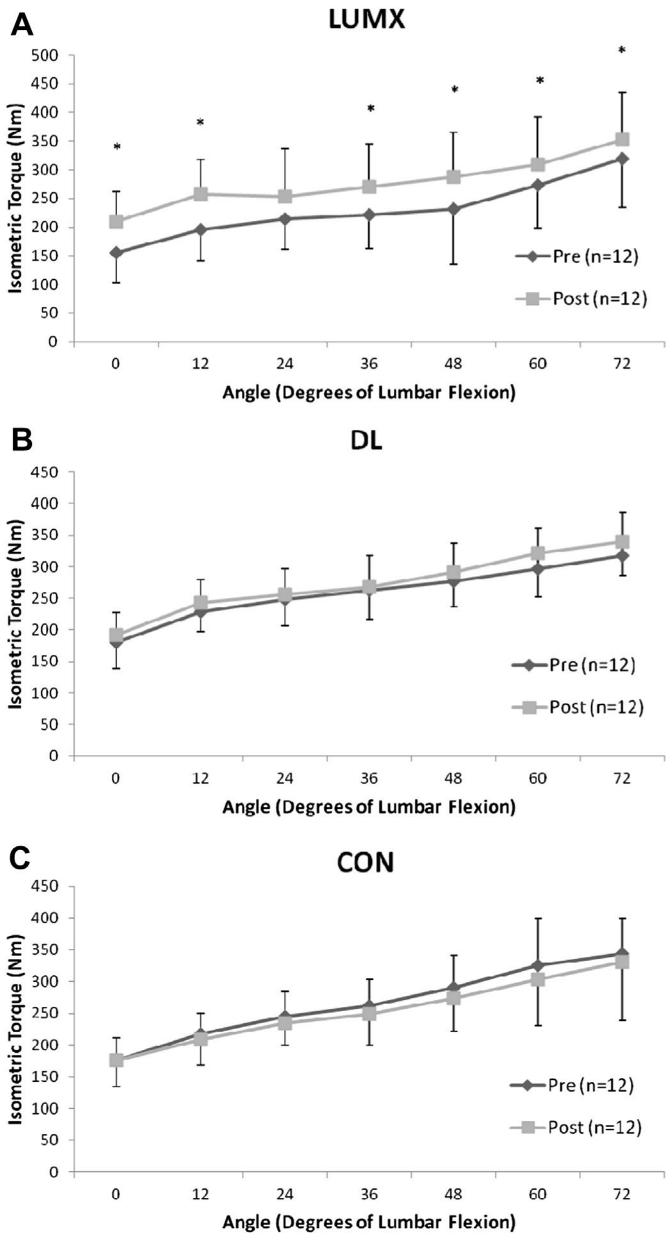


**Fig. 6.** Pre- and post-training isometric lumbar extension torque values (mean ± SD) for the LUMX group (A, $n = 12$), DL group (B, $n = 12$), and CON group (C, $n = 12$) plotted as a function of angle of lumbar flexion (* = $p < 0.008$).

asymptomatic males with previous training experience. The data showed that progressive training of the Romanian deadlift, 1×/week for 10 weeks, significantly improved the 1RM performance of the Romanian deadlift, but did not significantly enhance lumbar extension torque at any of the joint angles tested on the MedX lumbar extension machine. These findings are supported by previous research, which has suggested that pelvic stabilization is necessary to optimally activate and strengthen the lumbar extensors (Da Silva et al., 2009; Graves et al., 1994; Mayer et al., 2003; San Juan et al., 2005). Indeed, other authors have suggested that where there is no pelvic stabilization it is the hamstring and gluteal muscles that are primarily acting to "de-rotate" the pelvis, rather than the lumbar muscles acting to provide lumbar extension (Graves et al., 1994).

In contrast, performing isolated lumbar extension exercise once per week for 10 weeks was sufficient to significantly increase lumbar extension torque at 6 of the 7 tested angles, as well as significantly increasing the Romanian deadlift 1RM. This increase in 1RM supports previous research showing activation of the lumbar muscles during Romanian, sumo, and traditional deadlift variations (Chulvi-Medrano et al., 2010; Escamilla et al., 2002) and suggests that isolated training of the lumbar extensors can enhance compound movement performance.

We should acknowledge that a specificity of training related to the testing machine may exist. The DL group was disadvantaged by an absence of practice on the lumbar extension machine on which they were pre- and post-tested for functional torque. However, the same is true of the LUMX group and the Romanian deadlift testing; they did not practice the Romanian deadlift testing method, and yet still showed significant improvements pre- to post-intervention.

It could be argued that the Romanian deadlift-trained group required a higher frequency and/or volume of training to stimulate torque increases in the lumbar muscles. However, the Romanian deadlift group made significant improvements in their Romanian deadlift 1RM pre- to post-test (16%) by performing only one set, once per week. This is fitting with other research that has reported strength increases from low-volume, low-frequency training (e.g. Fisher et al., 2011; Smith & Bruce-Low, 2004) and suggests that it was not the reduced volume but the movement itself that was insufficient to stimulate strength changes. Indeed, a once-weekly training frequency appears effective in strengthening the lumbar muscles using specific isolated training within the present study as well as proving as effective as 2× and 3×/week protocol in previous studies (Carpenter et al., 1991; Graves et al., 1990). In addition, the 1×/week protocol used herein by the LUMX group provided sufficient stimulus to produce significant improvements in their pre- to post-test 1RM Romanian deadlift.

## 5. Future research

In consideration of the data presented, it could be hypothesized that training using the Romanian deadlift itself serves to strengthen the posterior chain of hip extensors (gluteals, biceps femoris, semitendinosus and semimembranosus amongst others), without directly enhancing the strength of the lumbar extensors. Certainly the literature suggests that these muscles show considerable activation during the Romanian, and, sumo and traditional deadlift exercise (Chulvi-Medrano et al., 2010; Escamilla et al., 2002; respectively), however perhaps future research might consider testing the force production of the hamstrings and gluteal muscles as a result of Romanian deadlift training. This contrasts with the effects of the lumbar extension exercise, which clearly strengthened the lumbar extensors. Interestingly, subjects in the LUMX group reported some muscular soreness in their gluteal and hamstring muscles in the days following their lumbar extension exercises. Therefore, whilst the restraining mechanism in the machine prevents these muscles from contributing to the measured lumbar force production (Graves et al., 1994), they might still be activated in an isometric contraction against the restraints. Since there was no measurement of activation, force production, or strength testing for the gluteal and hamstring muscles in the present study this is purely speculative. However, future research could examine possible training effects in these muscles from isometric contraction when performing isolated lumbar extension exercise.

We should also acknowledge that the present study used male, asymptomatic participants with previous deadlift experience, performing the Romanian deadlift variation and as such the results cannot be generalized to other persons, or variations of the deadlift. Future research might consider other specific population groups based on age, gender, training experience, low back pain, etc. as well as other variations of the deadlift exercise.

## 6. Conclusion and practical applications

In conclusion the present data suggest that training using the Romanian deadlift appears to enhance 1RM performance of the Romanian deadlift but does not specifically strengthen the lumbar extensors. Therefore, coaches and athletes should ideally employ isolated lumbar extension exercise in addition to the Romanian deadlift if strength increases in the lumbar muscles are also desired. Given the well documented potential of this area for injury, and the debilitating effects of injury to the lumbar region, we argue that protection of this vulnerable area should certainly be a priority for athletes engaged in sports as well as the lay person wishing to remain injury free. As previous research has shown that isolated lumbar extension exercise can be effective in both prevention and treatment of lower back injuries (see, for example, Bruce-Low et al., 2012; Choi et al., 2005; Leggett et al., 1999; Mooney, Kron, Rummerfield & Holmes; 1995), we suggest that this exercise would be a valuable addition to many athletes' strength training regimens, even when performed in low-volume and low-frequency (e.g. 1×/week). In application, although the Romanian deadlift can be a valuable exercise, strength coaches should not assume that this will be sufficient exercise for the lumbar extensors as well as for the posterior chain.

*Conflict of interest*
None declared.

*Ethical approval*
The present study received ethical approval from the departmental and University ethics board, Southampton Solent University, UK.

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# CHAPTER 5: Combined isometric and vibration training does not enhance strength beyond that of isometric training alone

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# Combined isometric and vibration training does not enhance strength beyond that of isometric training alone

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***Aim.*** **Research considering combined vibration and strength training is extensive yet results are equivocal. However, to date there appears no research which has considered the combination of both direct vibration and whole-body vibration when used in an isometric deadlift position. The aim of this study was to compare groups performing isometric training with and without direct and whole-body vibration.**

***Methods.*** **Twenty four participants (19-24 years) were randomly divided into: isometric training with vibration (ST+VT: N.=8), isometric training without vibration (ST: N.=8), and control (CON: N.=8). Within the training groups participants trained twice per week, for 6 weeks, performing 6-sets of maximal isometric deadlift contractions, increasing in duration from 30 seconds to 40 seconds (weeks 1-6). Hip and knee angle was maintained at 60° and 110°, respectively for both testing and training. Training sessions for ST+VT were identical to ST with the addition of a direct vibratory stimulus through hand-held straps and whole-body vibration via standing on vibration a platform. The amplitude remained constant (2 mm) throughout the intervention whilst the frequency increased from 35Hz to 50Hz. Pre- and post-test isometric strength was measured using an isometric deadlift dynamometer.**

***Results.*** **Results revealed significant increases in isometric strength for both ST+VT ($P<0.001$, 23.8%) and ST ($P<0.001$, 32.5%) compared to CON, with no significant differences between ST+VT and ST training groups.**

***Conclusion.*** **The present study provides evidence to suggest that there are no greater gains to be incurred by the addition of a vibratory stimulus to traditional strength training.**

**Key Words:** vibration - resistance training - Muscle strength - Isometric contraction

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Vibration training (VT) continues to grow in both general use and amongst the research community. However, equivocal results have been reported regarding effectiveness for acute and chronic changes to peak power,[1, 2] vertical jump height,[3-5] recovery,[6] flexibility,[3, 7] muscle activation,[8-10] hormonal responses,[9] bone mineral density,[11, 12] and balance.[13] Whilst traditional resistance training holds multiple health benefits [14] as well as notable increases in muscular strength,[14] the research on the use of VT for muscular strength have reported ambiguous results. Much of the research has reported no significant differences for strength training (ST) in combination with VT (ST+VT) compared to ST in isolation in the upper [15] and lower body.[9, 16-21] Indeed, more recently Preatoni *et al.*[22] compared ST, VT and combined ST + VT, reporting significant strength gains for the ST group only. However, other research has reported favourable gains for the addition of direct vibration on a seated bench-pull exercise,[23] and whole-body vibration in isometric and dynamic knee extensor strength,[24] as well as lumbar extension strength and counter-movement jump.[25]

Of important consideration is the method of application of vibration *e.g.* directly to the muscle or through the use of a whole body vibration (WBV) platform.[26] Whilst not complex, the following mechanisms are often overlooked in the literature and as such have been included herein. The mechanics of WBV are a product of mass and acceleration due to gravity (*g*) using the formula *force = mass x acceleration*. A traditional resistance training exercise generally increases the load lifted (mass), thus requiring a greater force to be applied. However, the use of a vibration platform does not require the manipulation of mass, but rather affects the acceleration; ultimately affecting the gravitational load.[27] Cardinale and Bosco [27] discuss the proposed mechanisms associated with strength increases as a result of vibration training, and whilst it is beyond the scope of the present piece to discuss this in detail, it is potentially worth highlighting their summary. The authors suggest mechanisms catalysing strength improvement to include a sensory response to the fast shortening and lengthening of the muscle-tendon complex in attempt to dampen the vibratory waves. They continue, discussing that the muscle or tendon can *"elicit a reflex muscle contraction"*, and cite evidence to support increased muscle activation, possibly related to increased synchronization, as a result of vibratory stimulus. Ultimately, regardless of mechanism, this potential to increase strength might be considered beneficial for symptomatic, injured or infirm persons where the addition of external mass is inappropriate. As such continued research considering VT methods along with the equivocal results discussed previously make this an important area for future research.

Intensity of exercise whilst using WBV (*e.g*. increasing *g*) can be manipulated by increasing frequency (Hz) or amplitude (mm) of vibration.[24] Indeed research has supported that effect sizes (ES) for strength and power whilst using WBV show a general increase in accordance with increases in frequency (Hz) and/or amplitude (mm).[1, 28] Furthermore, other variables common in ST programmes such as duration, repetitions, sets, rest periods, intensity of effort etc. can also affect outcome measures.[1, 28]

Much of the research has considered the combination of isometric training with vibration, some of which reported significant improvements in measured performance,[24, 29] whilst others reported non-significant results when compared to non-vibration training groups.[30-32] In many of these studies the isometric nature of training the lower body has been heavily based around WBV in a squat position.[8, 30, 31] However, one of the features of many vibration platforms is the ability to attach straps to the vibration source. Pulling on these straps would allow a person to receive direct vibration, via the straps, as well as WBV whilst standing on the vibration platform. As such pulling with the arms, whilst pushing through the legs, could provide a significantly greater training stimulus than simply holding a bodyweight isometric position. That is, persons can essentially perform an isometric deadlift exercise.

To date there appears to be no research which has considered the combined use of direct and whole-body vibration through the use of a maximal isometric deadlift exercise. Since variations of the deadlift are commonplace and have been identified as significant exercises for increasing lower body strength,[33] they should be considered with regard to vibration training. With this in mind, the aim of the present study was to determine how isometric deadlift strength training with and without vibration affects isometric deadlift strength following a 6-week training intervention.

## Materials and methods

### *Experimental approach to the problem*

The effect of a 2 x/week, 6-week progressive training program, using an isometric deadlift with or without vibration, on isometric deadlift strength was considered. Pre and post strength testing was performed for all participants using the "leg and back" dynamometer (TKK5002, Takei, Japan). It is noteworthy that since the "leg and back" dynamometer does not isolate the legs or the back but rather considers the entire musculature involved in a deadlift movement (*e.g*. leg extensors, hip extensors and trunk extensors) that in the present piece we make reference to this test as an isometric deadlift strength test. A prospective between groups repeated measures design was conducted with asymptomatic healthy participants randomly allocated to 1 of 3 groups: isometric deadlift with vibration (ST+VT: N.=8), isometric deadlift without vibration (ST: N.=8) or a control group (CON: N.=8). A power analysis using previous research [32] was carried out to determine participant numbers (N.) using treatment ES calculated using Cohen's d [34] of 1.51 and 1.58 for vibration and non-vibration training groups, respectively. Participant numbers were calculated using equations from Whitley and Ball.[35] These calculations (N.=(2/ES$^2$) x 7.9) showed that each group required 7 participants to meet the required power of 0.8 at an alpha level of $P<0.05$.

### *Participants*

Following approval by the relevant research laboratory and university ethics committee, 33 asymptomatic, untrained (had not conducted any subjectively assessed moderate to high intensity activity over the past six months, including sports) male participants volunteered to take part in this study and provided written informed consent. Twenty four participants completed the intervention: 8 participants were withdrawn due to missing training/testing sessions, and 1 participant withdrew with health issues unrelated to the study. Participant characteristics are provided in Table I.

### *Testing procedures*

Prior to testing, all participants performed a standardised progressive warm-up of 5-minutes on a Cybex total arc cross trainer (Cybex, Derbyshire, UK) up to 65% age-predicted max heart rate (APMHR). Following the warm-up all participants performed 2 practice attempts followed by 3 maximal isometric deadlift contractions using the isometric leg and back dynamometer (TKK5002, Takei, Japan). Significant relations to both leg strength (r=0.90) and back strength (r=0.79) as well as reliability values of r=0.80 and r=0.91, respectively have been reported for this piece of equipment.[36] One-minute of rest was provided between each practice attempt and each maximal test. Feet were placed hip width apart, and the hip and knee angle of each participant was measured and controlled at 60° and 110° (as previously used by Machado *et al.*[37] and de Ruiter *et al.*[8]), respectively. All angles were measured and confirmed throughout the study using a goniometer (Prestige Medical, Manchester, UK). No verbal motivation or feedback was provided to avoid affecting results. The highest value of the three maximal attempts was recorded. The post-test followed an identical process and was completed with at least 48 hours (m=3.2±1.5 days) recovery following the final training session.

### *Group assignment*

Participants were assigned to one of three groups using simple randomization (blindly selecting 1 of 3 cards denoting group allocation) following testing and prior to any training. One of the test administrators and the statistician was blinded to group assignment, however due to the research design the administrator supervising training could not be blinded to group assignment.

### *Training procedures*

Identical training protocols were used for both ST+VT and ST training sessions. Participants stood directly on the Power Plate® pro5 AIRdaptive™ (Powerplate, London, UK) barefoot to avoid dampening from the shoe soles and insoles which might decrease the vibration stimulus.[38] Participants placed their feet hip width apart, with their hips and knees bent to 60° and 110°, respectively, identical to the testing protocol. Training sessions were performed 2 x/week for 6-weeks as used in previous research.[29] Each training session consisted of 6 maximal contractions [21] with 1 minutes rest between. Participants were asked to maximally pull on a strap which was attached to the vibration platform, whilst maximally pushing through their legs (as if performing a deadlift exercise) throughout each repetition. The maximal contractions lasted for 30 seconds for weeks 1 and 2, and progressed to 35 seconds (weeks 3 and 4) and 40 seconds (weeks 5 and 6). The only difference between training groups was the addition of vertical vibration to the platform for the ST+VT group which began at a frequency of 35Hz and amplitude of 2 mm (as previously used).[25] The amplitude remained constant throughout the intervention whilst the frequency increased from 35Hz (weeks 1 and 2), to 40Hz (weeks 3 and 4) and 50Hz (weeks 5 and 6). Duration and frequency were increased throughout the 6-week intervention to ensure a progressive stimulus for training groups. The control group did not perform any prescribed training and all participants were asked to refrain from any other exercise throughout the duration of the intervention.

### *Statistical analysis*

All data were confirmed to be normally distributed using a Kolmogorov-Smirnov test, and a one-

TABLE I.—*Participant characteristics (mean±SD).*

| Group | N. | Age (y) | Height (cm) | Weight (kg) |
|---|---|---|---|---|
| VIB | 8 | 20.3±1.1 | 175.6±4.1 | 75.0±2.8 |
| NVIB | 8 | 21.0±1.3 | 180.1±3.2 | 74.6±4.3 |
| CON | 8 | 21.1±0.7 | 178.5±6.8 | 76.1±3.1 |

way analysis of variance (ANOVA) revealed no significant between group differences in age, stature, or body mass (P>0.05, Table I.). Between groups pre-test values for the isometric deadlift test were also analysed using a one-way ANOVA revealing no significant differences (P>0.05). A one-way ANOVA was performed to examine absolute change between pre- and postintervention results between groups. Where statistically significant between groups effects were found, a *post-hoc* Tukey test was performed to determine where the significance occurred. ES were calculated based on Cohen's d.[34] Statistical significance was set to P>0.05 and all statistical tests performed using the statistical package for social sciences (SPSS v.20).

## Results

Following the 6-week intervention a one-way ANOVA comparing absolute change between pre and postintervention isometric deadlift strength values (*e.g.* postintervention – preintervention = absolute change) between CON, ST+VT and ST groups revealed a significant between groups effect (P<0.001). Pairwise comparisons were performed using a Tukey *post-hoc* test revealing a significant difference in change in isometric strength between both intervention (ST+VT and ST) groups compared with the CON group (P<0.001). No significant differences between intervention groups were found. Mean absolute changes pre to postintervention for each group were 1.0±5.6kg (CON), 20.3±7.8kg (23.8%; ST+VT), and 26.4±4.7kg (32.5%; ST). Treatment ESs were calculated using Cohen's d [34] as 1.56 (ST+VT) and 1.84 (ST) (Figure 1).

## Discussion

The purpose of this study was to examine the effect of isometric deadlift training with and without vibration on maximal isometric deadlift strength. The data revealed a significant absolute change in maximal strength, pre to postintervention, in the ST+VT and ST groups compared to the CON group. The data revealed no significant differences between training groups (VT+ST and ST). These results suggest that there are no greater gains to be obtained by the use of progressive intensity, direct and whole-body vibration training compared to isometric training alone. Indeed, the treatment ES's for both groups were large (1.56; ST+VT and 1.84; ST) according to Cohen's d [34] supporting the absence of between group differences. In addition these ES's were similar to those reported by Iodice, *et al.* [32] (*e.g.* 1.51 and 1.58 for vibration and non-vibration groups, respectively). Previous research has compared combined ST+VT (using WBV) to ST alone and reported supportive results to the present study; that the addition of VT does not enhance performance measures beyond that of ST alone.[8, 18-20, 22, 31] The present study utilised a vertical vibrating platform which is associated with greater ES [1, 28] as well as using progressive frequencies (35-50Hz), and amplitude (2 mm) similar to the other research detailed herein.

Reasoning behind these results might be attributable to muscle activation and intensity of effort. For example, Marín *et al.*[39] reported similar muscle activation and rate of perceived exertion values for

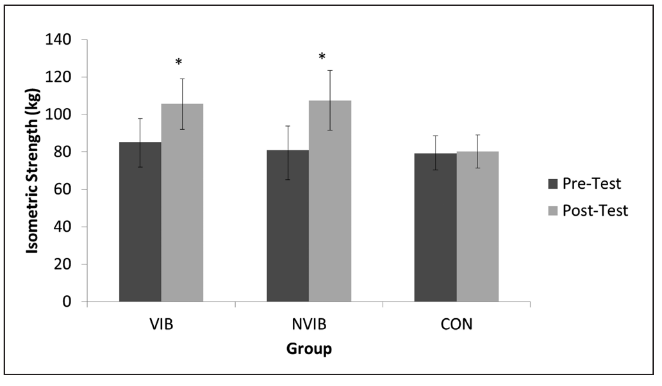


Figure 1.—Isometric deadlift strength values (kg)
*Absolute change pre to postintervention significant to control group (P<0.001). Error bars represent SD values.

increasing loads (20-70 kg) and increasing intensity vibrations (reported as acceleration: from 12-89 $m \cdot s^{-2}$) when comparing bodyweight isometric squat tasks with vibration against loaded isometric squats using a smith machine without vibration. This suggests that the vibratory stimulus provided no additional stress to the muscle and more importantly; perceived exertion to the participant.

Delecluse *et al.*[24] reported significant increases in knee extensor strength for VT and ST with no significant differences between groups. The methods used within that study included training 3 x/week for 12 weeks at a progressive intensity of 2.28 *g* (2.5 mm and 35Hz), 2.71 *g* (2.5 mm and 40Hz), 3.91 *g* (5 mm and 35Hz) and 5.09 *g* (5 mm and 40Hz) using multiple exercises. The resistance training group performed traditional resistance exercises to repetition maximum (RM), suggesting that intensity of effort was maximal. As such the similar improvements in strength suggest that muscle activation was likely similar between groups. Osawa and Oguma[25] reported significantly greater increases for a WBV group compared to a ST group in measures of isometric and isokinetic knee extensor strength, isometric lumbar extension strength and counter-movement jump. Their 7-week intervention used similar frequency and amplitude to the present study (35Hz, 2 mm, respectively), although it is noteworthy that total training time was greater than the present investigation. However, the intensity of effort was likely far greater in the WBV group as a result of the additional *g* as a result of vibration. The authors[25] report the mean acceleration (*g*) in Table I of their article as a result of load (0 kg to 70 kg) and vibratory stimulus (35Hz and 2 mm). In the ST group the acceleration remained constant at 1.00 *g*, however in the WBV group the acceleration increased from 2.10 *g* to 2.95 *g* as load increased. Since the muscles were acting against greater acceleration due to gravity in the WBV group they were required to produce more force, and thus received a greater training stimulus.

Ultimately it seems that intensity of effort affects performance outcome measures as is evidenced by the present study. Whilst the maximal isometric contraction in the ST group was sufficient to stimulate a chronic strength response, the addition of vibration appears not to have been sufficient to enhance strength beyond that of ST alone. With this in mind we should consider the nature of a maximal isometric contraction performed in both training groups. By its very definition a maximal contraction requires maximal intensity of effort and recruits as many muscle fibres as possible in order to produce as much force as possible. From this we might consider that, even with the application of direct and WBV, participants in both training groups were already maximally recruiting muscle fibres as a result of the maximal isometric deadlift training exercise. Therefore, the addition of vibration stimulated no further recruitment of muscle fibres and thus catalysed no greater changes in muscular strength. Future research might consider the implications of VT with regard to intensity of effort considering duration of maximal contraction as well as qualitative research considering the subjective feelings of effort.

## Conclusions

To date this appears to be the only study to have considered an isometric deadlift training protocol in addition to combined direct and whole-body vibration stimulus. The present study has reported favourable results for the use of isometric deadlift training in enhancing isometric strength. However, the addition of a vibratory stimulus to the isometric deadlift training regime appeared to induce no additional benefits. We suggest that for healthy, untrained individuals there are no benefits to the use of VT beyond that of traditional isometric ST. Whilst future research might consider greater frequencies and/or amplitudes we suggest that the frequencies and amplitudes used within the present study are typical of a commercial vibration platform and thus are likely to represent those encountered by lay persons entering a gym environment.

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# CHAPTER 6: One lumbar extension training session per week is sufficient for strength gains and reductions in pain in patients with chronic low back pain ergonomics

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# One lumbar extension training session per week is sufficient for strength gains and reductions in pain in patients with chronic low back pain ergonomics

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Chronic low back pain (CLBP) is the leading cause of absenteeism from the workplace and research into exercise interventions to address this problem is required. This study investigated training frequency for participants with CLBP. Participants either trained once a week (1 × week, $n = 31$), or twice a week (2 × week, $n = 20$) or did not (control group, $n = 21$). Participants were isometric strength tested in weeks 1 and 12 and trained dynamically either 1 × week (80% of maximum) or 2 × week (80% and 50%). The results (pre vs. post) showed significant increases in maximal strength, range of motion and reductions in pain for both training groups. Pain scores for the 1 × week and 2 × week both reached minimal clinical improvement change unlike the control group. Thus, one lumbar extension training session per week is sufficient for strength gains and reductions in pain in low back pain in CLBP patients.

**Practitioner Summary:** CLBP is the leading cause of absenteeism from the workplace. The present study using a modified randomised control trial design investigated exercise training frequency for participants with CLBP. One lumbar extension training session per week is sufficient for strength gains and reductions in low back pain in CLBP patients.

**Keywords:** occupational; exercise therapy; back pain



## Introduction

Low back pain is one of the leading causes of work absenteeism around the world (Hamberg-van Reenen *et al*. 2008, Higuchi *et al*. 2010) and is therefore considered a major international problem (Trevelyan and Legg 2010). Indeed, Maniadakis and Gray (2000) suggest 'Back pain is one of the most costly conditions for which an economic analysis has been carried out in the UK' (p. 95). Around the world musculoskeletal diseases are one of the most prevalent causes of disability, with back pain being the most common musculoskeletal disease (Brooks 2006). Dagenais *et al*. (2008) noted that research has shown the indirect costs incurred from low back pain resulting in lost work productivity, produced the largest cost (Australia, Belgium, Japan, Korea, the Netherlands, the UK and the USA). In the UK, up to 50 million working days are lost each year as a result of individuals suffering from lower back pain (Aylward and Sawney 2002), with 20% (one in five) of the UK reporting back pain to their general practitioner (National Institute for Health and Clinical Excellence 2009).

This financial loss to the economy brought the total cost of chronic lower back pain (CLBP) to over £10.6 billion in 1998 (Maniadakis and Gray 2000). This is also true of North America where the increase in CLBP is resulting in a mounting economic burden (May and Donelson 2008), with costs estimated anywhere between \$100 and \$ 200 billion per annum (£61–122 billion; Katz 2006), and Sweden where the costs were estimated at €1.8 billion (£1.6 billion) in 2001 (Ekman *et al*. 2001). Therefore, a greater understanding of how to implement interventions to reduce CLBP would be extremely valuable socially and financially.

One factor related to the development of CLBP is insufficient strength in the muscles that extend the lumbar spine (Graves *et al*. 1989, Pollock and Graves 1989, De Looze *et al*. 1998). In a similar vein but specifically in a work-related context, Hamberg-van Reenen *et al*. (2008) claimed that CLBP in the working population may be caused by the imbalance between exposure to work related factors and low physical capacity. Consequently, resistance training is often prescribed for prevention and treatment of CLBP (Nelson *et al*. 1995).

The lumbar extension machine (MedX, Ocala, FL) is a dynamometer that can be used to measure the isometric strength of the muscles that extend the lumbar spine and to provide dynamic, variable resistance exercise of those

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same muscles; it has proved to be a reliable and valid measuring and training tool (Graves *et al*. 1990a, Robinson *et al*. 1992). This machine isolates the lumbar muscles through stabilising the pelvis in order to minimise the contribution of the hip and leg muscles (Pollock and Graves 1989). It has been utilised successfully in numerous studies (see Smith *et al*. 2008 for a comprehensive review). The research on asymptomatic participants to date has found that one weekly set of approximately 8–12 repetitions of dynamic, variable resistance exercise to fatigue on the lumbar extension machine can produce significant increases in strength and decreases in low back pain (Tucci *et al*. 1992, Choi *et al*. 2005). A greater frequency or volume of heavy training does not produce greater improvements (Smith *et al*. 2008), and individuals who train more than once a week on the lumbar extension machine can experience orthopaedic discomfort (Graves *et al*. 1990b). However, to date there has been no research using this training on participants that are symptomatic and thus suffer from CLBP.

The manufacturer of the dynamometer, however, also recommends that in the early stages of such therapy a second session per week, involving performing lumbar extensions against very light resistance, is performed. This is hypothesised to improve range of motion (ROM) through maintaining joint mobility and aiding disc hydration (MedX Educational Program 2006). The use of a second dynamic training session, in addition to the one set of 8–12 repetitions, is commonly applied by clinicians, although as yet has still to be scientifically tested. The aim of this project, therefore, is to examine whether the second weekly session is actually beneficial in increasing isometric strength, ROM and decreasing perceived pain.



## Materials and methods

### *Participants*

Following approval by the relevant ethics committees, 75 non-specific CLBP patients were assessed for eligibility and of these 72 completed the intervention ($\bar{x} \pm$SD age $= 45.5 \pm 14.1$ years; males $n = 42$ and females $n = 30$). Non-completion of training intervention due to relocation from the area ($n = 3$). All participants were attending private physiotherapists in respect of low back pain and provided written informed consent to participate. They were randomly allocated to either training once a week ($1 \times$week; $n = 31$), twice a week ($2 \times$week; $n = 20$) or a control group ($n = 21$).

To be eligible, participants had to have suffered from low back pain for at least six months prior to the study but have no medical condition for which exercise is contraindicated. Potential participants completed a health screening form, and those reporting any of the following conditions, symptoms and/or history were excluded from participation: Malignancy or underlying disease, disc herniation, osteoporosis, neurologic or sciatic nerve root compression, previous vertebral fractures, major structural abnormality of the spine, tumour of the spine, problems passing fluid or solids, inflammatory arthritis and pregnancy. All participants were physically screened (by a Chartered physiotherapist with a musculoskeletal and spinal specialty) for significant disc pathology which would exclude their participation. Participants were excluded if the disc problem was significant and caused neural involvement.

A power analysis of previous research with CLBP participants (Holmes *et al*. 1996) was conducted to determine participant numbers ($n$) using a treatment effect size (ES), calculated using Cohen's $d$ (Cohen 1992), of 1.42 for the MedX lumbar extension. Participant numbers were calculated using equations from Whitley and Ball (2002) and showed that each group required eight to meet the required power of 0.8 at an alpha value of $p < 0.05$.

### *Study design*

A modified randomised control trial design, as defined by Dvir (2007), was adopted. All participants continued their normal course of low back pain treatment and or training, which involved mobilisations, McKenzie protocol, muscle imbalance protocol, home exercises and postural advice/ergonomics to avoid ethical implications of with-holding treatment. The control group continued their normal care but did not train on the lumbar extension machine. Participants within the control group were aware of the study objectives. Following completion of the study the control group were offered the chance to receive the lumbar extension training. Pre testing consisted of maximal lumbar isometric strength, ROM, modified-modified Schober's flexion test and completion of the Oswestry disability index (ODI) and the visual analogue scale (VAS). The intervention consisted of a 12 week training programme which was then followed by post testing (maximal lumbar isometric strength, ROM, modified-modified Schober's flexion test and completion of the ODI and the VAS). The study outcomes were changes in maximal strength, ROM (through measures from the machines goniometer and the modified-modified Schober's test) and reduction in pain (measured by the VAS and ODI).

***Strength tests***

All isometric strength tests and dynamic strength training sessions were conducted by members of the research team who were fully certified by the manufacturer to operate the lumbar extension machine (MedX, Ocala, FL). The machine incorporates a pelvic restraint mechanism and a counterweighting procedure to counterbalance the mass of the upper body and also the effects of gravity acting on the upper body. The validity and reliability of both the restraint and counterweighting procedures are well-established (Graves *et al.* 1990b, Inanami 1991) and the torque measurements show very high test–retest reliability at all angles ($r = 0.94$–$0.98$; Pollock *et al.* 1991).

Participants completed two isometric lumbar extension strength tests administered one week apart. As previous research (Graves *et al.* 1990b) has shown, it is important that participants are familiar with the testing procedure to produce reliable results, the initial testing session was designated as a familiarisation session. The second test was used to obtain pre-test measures of lumbar extension strength.

In accordance with standard procedure on this machine, isometric lumbar extension torque was measured at intervals of 12° from 0° to 72° of lumbar flexion with a 10 s rest between each joint angle. Prior to testing, the restraining and counterweighting procedures were carried out, and lumbar ROM in the machine was measured using the machine's goniometer.

Following these procedures, strength tests were conducted at each joint angle using the procedure described above, any tests in which the participant felt he or she did not give a maximal effort were repeated. Following completion of the training protocols described in the following section, the strength tests were repeated.

***Strength training***

Participants in the 1 × week group performed one lumbar extension training session per week for 12 weeks. This involved one set of approximately 8–12 repetitions at a weight equivalent to approximately 80% of the maximum TFT (tested functional torque, or maximal voluntary isometric torque) through the participant's full ROM on the lumbar extension machine to volitional fatigue within a time frame of 70–105 s. Participants in the 2 × week group performed two lumbar extension training sessions per week for 12 weeks. The first session was identical to that of the 1 × week group. The second weekly session (typically undertaken 3 days after the first session to allow for any delayed onset of muscle soreness to reside) was undertaken with a weight equivalent to approximately 50% of the maximum TFT that resulted in participants exercising for a period of time between 105 and 140s. Both intensities (50% and 80% of maximum TFT) were used as per the manufacturer's guidelines. Repetitions for both groups were performed slowly, with 2 s taken to lift the weight and 4 s taken to lower it. When participants could perform more than 12 repetitions (or for more than 140 s in the second weekly session in the 2 × week group), the weight was increased by approximately 5%. This training protocol is standard in studies using the machine, and has been found to produce optimal strength increases (Graves *et al.* 1990b).

***Range of motion tests***

ROM was measured by the goniometer within the MedX lumbar extension machine. Standing ROM was measured using the modified-modified Schober's test (Williams *et al.* 1993). The modified-modified Schober's test is a measure of the ROM of the lumbar spine and is widely used in health care settings (Tousignant *et al.* 2004). In order to undertake the modified-modified Schober's test pen marks were made at each of the posterior superior iliac spines (PSIS). Another mark was made at the midline of the lumbar spines horizontal to the PSIS and a final mark was then made 15 cm above this mark. Whilst holding a tape measure close to the participant's skin, he or she bent over as though to touch the toes whilst a reading was obtained to ascertain any change in the original 15 cm measure.

***Questionnaires***

The ODI was used in this study. It is a questionnaire that gives a subjective percentage score of level of disability in activities of daily living resulting from low back pain (Fairbank *et al.* 1980). It has a high degree of sensitivity as a measure of change following treatment (Fisher and Johnston 1997), high test–retest reliability (intraclass correlation of 0.94; Holm *et al.* 2003) and a high correlation with pain intensity (Gronblad *et al.* 1989). Participants were given explicit verbal instruction on how to complete the ODI and adequate time to ask questions prior to completing it.

The VAS used in this study consisted of a 10cm line anchored by two extremes of pain. Participants were given explicit verbal instruction on how to complete the VAS with appropriate and specific anchoring statements. The participants were given the instruction that the far left end of the line represented 'no pain at all'. They were then told that the far right end of the line represented 'the worst pain imaginable' and examples were given from the participants' own histories and they were asked to compare this to the worst pain they had ever felt. The participants were then asked to mark a straight line to dissect the VAS line at the point at which they felt their pain was at currently. All participants were asked to confirm they understood the instructions and were provided with opportunity for questions prior to completing the VAS. This method has been shown to be reliable, with no differences found when administered by different testers (Olagun *et al.* 2004) and possesses a high degree of predictive validity (Jensen *et al.* 1986). To investigate if the changes in VAS scores were meaningful, the minimal clinical important change (MCIC) was calculated from the mean differences between the post and the pre intervention VAS scores (Kovacs *et al.* 2008). A MCIC of between 15 and 35 is typically observed in patients with chronic low back pain (Kovacs *et al.* 2007, 2008).

### *Data analysis*

The TFT (maximal strength) was measured in foot pounds ($ft.lb^{-1}$) and converted to Newton meters (N.m) for analysis. Descriptive statistics were calculated for all dependent variables. A 3 × 2 (group × test) ANOVA was performed to examine the between (differences between the groups), within (differences between pre- and post-tests) and interaction effects (combination of both between and within effects) of the interventions on isometric torque, ODI, Schober's flexion and VAS scores, with Tukey LSD tests being completed when appropriate. On further analysis of the pre-test data for Schober's flexion and VAS, it was noted there were significant differences between the groups. To ensure the true effect of the intervention on these measures was determined, the delta values were analysed. The alpha level was set at $p < 0.05$. Paired samples *t*-tests with a Bonferroni adjustment were conducted on each group to determine the within groups effects. Taking into consideration the Bonferroni adjustment, the alpha level for each test was set at $p < 0.017$.

## Results

The performance characteristics of the participants are detailed in Tables 1 and 2.

Table 1. Mean (±SEM) torque (N.m) pre and post for 1 × week training ($n = 31$), 2 × week training ($n = 20$) and control group ($n = 21$).

| | 0°†* | 12°†* | 24°†* | 36°†* | 48°†* | 60°†* | 72°†* |
|---|---|---|---|---|---|---|---|
| 1 × week (Pre) | 121.0 (±13.2) | 179.5 (±19.6) | 202.5 (±19.6) | 223.3 (±22.6) | 243.4 (±24.5) | 276.7 (±25.8) | 283.3 (±30.2) |
| 1 × week (Post) | 215.6 (±15.3) | 260.4 (±19.8) | 288.1 (±22.1) | 295.1 (±24.0) | 311.7 (±26.8) | 337.9 (±29.5) | 332.3 (±29.9) |
| 2 × week (Pre) | 115.0 (±12.0) | 156.7 (±14.3) | 177.5 (±15.0) | 197.4 (±16.7) | 214.9 (±16.9) | 236.8 (±21.3) | 273.9 (±25.3) |
| 2 × week (Post) | 168.9 (±19.6) | 214.2 (±21.2) | 238.8 (±18.3) | 253.7 (±19.9) | 283.4 (±23.8) | 301.7 (±22.6) | 317.3 (±22.5) |
| Control (Pre) | 151.6 (±18.3) | 195.9 (±20.3) | 218.1 (±22.5) | 241.9 (±24.6) | 241.8 (±25.2) | 278.8 (±29.5) | 265.9 (±28.6) |
| Control (Post | 165.0 (±18.2) | 203.5 (±18.9) | 229.9 (±23.0) | 230.7 (±22.0) | 251.1 (±26.5) | 274.1 (±28.0) | 265.6 (±27.1) |

Note: † $p < 0.05$ between training group (1 × week/2 × week) and control; ‡ $p < 0.05$ between training conditions; * $p < 0.017$ between pre-test and post-test.

Table 2. $\bar{x}$ diff (±SD) and 95% CI for VAS scores, mean (±SEM) Schober's values, Oswestry disability index (ODI) and visual analogue (VAS) scores for 1 × week training ($n = 31$), 2 × week training ($n = 20$) and control group ($n = 21$).

| | VAS (mm) | | | | | |
|---|---|---|---|---|---|---|
| | $\bar{x}$ diff ± SD | 95% CI | | Schober's (cm) | ROM (°) | ODI (%) |
| 1 × week | −16.4 ± 14.6†* | −21.2 to −9.6 | 1 × week (pre) | 16.1(±0.6) | 65.5 (±1.6) | 31.4 (±2.6) |
| | | | 1 × week (post) | 16.7 (±0.6)†* | 67.8 (±1.3)* | 16.0 (±2.1)†* |
| 2 × week | −21.0 ± 16.4†* | −29.2 to −12.8 | 2 × week (pre) | 19.4 (±0.6) | 60.9 (±2.6) | 29.2 (±2.6) |
| | | | 2 × week (post) | 20.3 (±0.7)†* | 67.7 (±1.6)* | 17.1 (±2.4)†* |
| Control | −0.04 ± 4.5 | −2.5 to 1.7 | Control (pre) | 14.4 (±0.2) | 66.6 (±2.0) | 32.3 (±1.4) |
| | | | Control (post) | 14.0 (±0.5) | 66.6 (±2.0) | 30.4 (±2.0) |

Note: † $p < 0.05$ between training group (1 × week/2 × week) and control; ‡ $p < 0.05$ between 1 × week and 2 × week; * $p < 0.017$ between pre-test and post-test.

### *Maximal strength*

There was a significant within groups effect ($F_{(1, 69)} = 61.32$, $p < 0.001$, partial $\eta^2 = 0.47$) when comparing mean post-test scores with pre-test scores and a significant interaction effect ($F_{(1, 69)} = 15.63$, $p < 0.001$, partial $\eta^2 = 0.31$). Statistically significant pre-test differences were not apparent among any of the groups ($F_{(2, 69)} = 0.588$, $p = 0.588$, partial $\eta^2 = 0.017$). Three paired samples *t*-tests with a Bonferroni adjustment were conducted on each group. The findings indicated a significant increase in maximal strength scores when training 1 × week and 2 × week ($t_{(30)} = -6.42$, $p < 0.001$ and $t_{(19)} = -6.68$, $p < 0.001$), respectively (Table 1).

### *Range of movement (ROM)*

The 3 × 2 ANOVA produced a significant interaction ($F_{(2, 69)} = 8.86$, $p < 0.001$, partial $\eta^2 = 0.20$) and within groups effect ($F_{(1, 69)} = 23.23$, $p < 0.001$, partial $\eta^2 = 0.25$) but not between groups ($F_{(2, 69)} = 0.562$, $p = 0.573$, partial $\eta^2 = 0.016$). Paired samples *t*-tests with a Bonferroni adjustment were conducted on each condition. Significant increases in ROM were yielded by the 1 × week training ($t_{(30)} = -2.65$, $p = 0.01$) and the 2 × week training ($t_{(19)} = -3.85$, $p = 0.001$; Table 2).

### *Schober's flexion*

A significant interaction effect was also found for the Schober's test results ($F_{(2, 69)} = 4.47$, $p = 0.02$, partial $\eta^2 = 0.12$). The within groups effects were also significant ($F_{(1, 69)} = 4.90$, $p = 0.03$, partial $\eta^2 = 0.07$), as were the between groups effects ($F_{(2, 69)} = 19.91$, $p < .001$, partial $\eta^2 = 0.37$). However, further analysis of the difference in pre- and post-training values observed no significant differences between the 1 × week (0.6 ± 0.6) and 2 × week (0.8 ± 1.0) groups ($p = 0.89$). Further analysis using paired samples *t*-tests with a Bonferroni adjustment on each group showed an increase in Schober's flexion in participants in the 1 × week group ($t_{(30)} = -6.06$, $p = 0.001$) and 2 × week group ($t_{(19)} = -3.68$, $p = 0.002$) (Table 2).

### *Oswestry disability index (ODI)*

Significant within groups effects ($F_{(1, 63)} = 57.06$, $p < 0.001$, partial $\eta^2 = 0.48$), between groups effects ($F_{(2, 63)} = 3.95$, $p < 0.024$, partial $\eta^2 = 0.11$) and interaction effects ($F_{(2, 63)} = 15.13$, $p < 0.001$, partial $\eta^2 = 0.32$) were found for the ODI. Three paired samples *t*-tests with a Bonferroni adjustment were performed on the three groups. There were significant decreases in both the 1 × week (15.5 ± 12.7%) and 2 × week (13.0 ± 8.0%) training groups ODI scores, $t_{(28)} = 6.34$, $p < 0.001$ and $t_{(16)} = 6.56$, $p < 0.001$, respectively (Table 2).

### *Visual analogue scale (VAS) for pain*

Significant between group effects ($F_{(2, 62)} = 6.1$, $p = .004$, partial $\eta^2 = 0.16$) and within group effects ($F_{(1, 62)} = 56.11$, $p < 0.001$, partial $\eta^2 = 0.48$) were found for the VAS. There was also a significant interaction effect ($F_{(2, 62)} = 13.15$, $p < 0.001$, partial $\eta^2 = 0.30$). However, further analysis of the difference in pre- and post-training values observed no significant differences between the 1 × week (−15.4 ± 14.6 mm) and 2 × week (−21.0 ± 16.4 mm) groups ($p = 0.34$). To identify differences within the groups, three paired samples *t*-tests with a Bonferroni adjustment were conducted. Significant differences between pre- and post-test scores were found in both the 1 × week (16.4 ± 14.6 mm) and 2 × week (21.0 ± 16.4 mm) training groups ($t_{(26)} = 5.49$, $p < 0.001$; $t_{(17)} = 5.43$, $p < 0.001$), respectively. Table 2 shows the VAS $\bar{x}$ differences ± SD and 95% CI data between the VAS scores obtained before and after the intervention. The MCIC was obtained for both the 1 × week (−16.4 ± 14.6) and 2 × week groups (−21.0 ± 16.4) but not for the control group (−0.04 ± 4.5; Table 2).

## Discussion

Most previous lumbar extension research suggests that individuals do not gain greater isometric strength by performing such training more than once a week (Graves *et al.* 1990b, Carpenter *et al.* 1991, Boyce *et al.* 2008); these studies considered asymptomatic un-trained individuals, not those suffering from CLBP. The MedX Educational Program advocates two weekly workouts; the second of which is a 'light recovery session'. The present study was designed to identify whether this second weekly workout promotes improvements in isometric strength, flexibility (measured through the MedX goniometer and the Schober's test) and pain reduction (measured through the ODI and the VAS).

The pre- and post-isometric strength increases for both 1 × week and 2 × week groups in this study are consistent with previous findings (Graves *et al.* 1990b, Boyce *et al.* 2008). No significant differences between training groups were observed. However, it should be noted that not all literature supports the notion that increases in isometric strength would be of assistance in lessening low back pain or preventing this in the work place.

De Looze *et al.* (1998) reported that when nurses had the strength of their low back musculature tested and then compared this to the success of undertaking specific job demands, there was no evidence that strong low back musculature meant they could undertake their job more effectively. However, it is not clear as to how the researchers account for the effect of low back isolation during their isometric testing and in turn the contribution of other musculature during the job demands rendering the two modes (i.e. the low back isometric strength testing compared against the work place tasks) relatively incomparable. Interestingly, they conclude by suggesting strength-based exercises may still aid in reducing the frequency of low back pain prevalence in nurses.

Holmes *et al.* (1996) found that patients suffering from CLBP significantly ($p < 0.05$) increased ROM (from the MedX goniometer) from 59.2° to 68.2° which is consistent with the current study's findings. This is a 9° increase, equating to 15%, from an average of one workout every 4.85 days. Interestingly, Nelson *et al.* (1995) reported significant increases ($p < 0.001$) from 54° to 63° (also an increase of 9°), where participants performed an average of two workouts per week. The research from Nelson *et al.* (1995) appears to suggest that training twice weekly increases ROM although the present study showed it is still possible to significantly improve ROM training only once per week ($p = 0.01$). However, Nelson *et al.* (1995) incorporated aerobic exercise as well as training other muscle groups (abdominals, hamstrings and glutei) which in itself could have contributed to increased ROM, whilst Holmes *et al.* (1996) implemented a protocol where training time was greater than 2 min per workout, or 20 repetitions in comparison to the present study which involved workouts of 70–105 s and 105–140 s for 80% and 50% max TFT respectively. If we also consider the disparity between back pain ailments, that likely affect individual persons in different ways, it makes comparison of ROM between the studies highlighted highly unreliable, except to conclude simply that the evidence suggests training on the lumbar extension machine significantly increases ROM with no discernable difference between training 1 × week and 2 × week.

The Schober's flexion pre-test data from the present study supported an increased ROM and was similar ($\bar{x} \pm$ SD 6.1 $\pm$ 3.4 cm) to other data obtained for those with CLBP from research by Tousignant *et al.* (2004; $\bar{x} \pm$ SD 6.3 $\pm$ 1.4 cm). The results from the current study showed statistically significant increases in flexibility between pre- and post-tests for the 1 × week ($p = 0.001$) and 2 × week ($p = 0.002$) groups, of 0.6 cm (1 × week) and 0.9 cm (2 × week), with no improvement within the control group. Again these changes are consistent with other research using alternative methods of treatment such as acupuncture (Inoue *et al.* 2006: $\bar{x} \pm$ SD 1.0 $\pm$ 0.6). In the present study, with an absence of statistically significant differences between the 1 × week and 2 × week groups, we once again conclude that there is nothing to be gained by completing a second weekly workout.

In accordance with the strength and flexibility increases, the MedX training groups demonstrated significant reductions in self-rated disability (ODI) between pre- and post-tests, in contrast to the control group. The ODI showed decreases in subjective pain for both the 1 × week (48%), and 2 × week (41%) groups, respectively, but showed no statistically significant differences between these two groups. This is similar to other research undertaken on participants with CLBP by Brox *et al.* (2003). Their results also showed significant reductions in the ODI scores of 28% for those in the cognitive and exercise intervention group and 36% for those in the surgical lumbar fusion group.

The VAS showed a similar decrease in pain ($p < 0.017$) between pre- and post-test for both training groups, whilst no improvements were seen for the control group. Once again there was no difference in the improvements between the 1 × week and 2 × week groups showing reduction in pain was not further improved by a second weekly workout. Both the 1 × week and 2 × week group did show a reduction that meets the minimally clinical improvement change, which is consistent with other researchers (Kovacs *et al.* 2007, 2008). However, when compared to healthy asymptomatic participants (9 mm; Keyserling *et al.* 2005), who did not use the MedX lumbar extension machine, the change in VAS score in the current study was greater (16–21 mm). This may suggest a potential advantage of undertaking exercise on this machine for those with CLBP.

The data herein further support previous research that muscular pain is potentially a result of muscular weakness (Graves *et al.* 1989, Pollock *et al.* 1989) and that resistance training of the lumbar muscles improves isometric strength and both reduces lower back pain (Nelson *et al.* 1995) and increases flexibility. This is in addition to the findings of Warming *et al.* (2008) who noted that physical training (as the present study has done) in combination with correct lifting and manoeuvring techniques minimised the incidence of CLBP in nursing personnel. This all suggests important potential applications to the workplace through personnel training on the lumbar extension machine in order to help prevent and/or reduce CLBP.

Research by Mooney *et al*. (1995) has shown that using the MedX lumbar extension machine once a week can increase strength and also reduce the likelihood of injury in the workplace. This was evidenced through a reduction in back injuries from 2.94 per 200,000 employee hours to 0.52. Also, the average worker's compensation liability decreased from $14,430 per month to $ 380 per month. However, in terms of the aims of this study, our findings suggest that these benefits can be obtained from a single weekly workout to fatigue, and that a second weekly workout does not produce additional improvements in these variables. This has implications for workers as it requires less time (1 × week vs. 2 × week) completing the required exercise making this a very time efficient method to improve symptoms and address CLBP.

It should be noted that the present study considered the second weekly workout in the format of a 'light recovery session' (∼50% Max TFT) and whilst the consideration of a second or third weekly session to fatigue using a higher% Max TFT showed no benefits to untrained persons (Graves *et al*. 1990b), but it has not been considered with patients suffering from CLBP. This would therefore be an interesting avenue for future research. It has been suggested that regular movement of the lumbar spine may help to reduce the loss in hydration that occurs with aging of the intervertebral discs (Norris 2008) as discs with lower osmotic pressures and decreased annular stresses are more likely to enhance the opening of cracks in the annulus and lead to herniation (Wognum *et al*. 2006). Thus, further study using magnetic resonance imaging should be undertaken to confirm whether the second weekly workout allows for potential disc re-hydration.

In conclusion the present study suggests that in the rehabilitation of workers suffering from chronic lower back pain, resistance training of the lumbar muscles improves isometric strength and ROM, as well as decreasing pain. The data herein support previous literature that shows there is no greater strength benefit to be obtained by training more frequently than once per week which may suggest a more time effective mode of preventative and rehabilitative training. In addition, our findings show that training twice weekly will produce no greater improvements in flexibility (ROM), perceived pain or isometric strength compared to a single weekly workout to fatigue.



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# CHAPTER 7: The effects of pre-exhaustion, exercise order, and rest intervals on a full-body resistance training intervention

NRC Research Press

ARTICLE

# The effects of pre-exhaustion, exercise order, and rest intervals in a full-body resistance training intervention

James Peter Fisher, Luke Carlson, James Steele, and Dave Smith



**Abstract:** Pre-exhaustion (PreEx) training is advocated on the principle that immediately preceding a compound exercise with an isolation exercise can target stronger muscles to *pre-exhaust* them to obtain greater adaptations in strength and size. However, research considering PreEx training method is limited. The present study looked to examine the effects of a PreEx training programme. Thirty-nine trained participants (male = 9, female = 30) completed 12 weeks of resistance training in 1 of 3 groups: a group that performed PreEx training ($n$ = 14), a group that performed the same exercise order with a rest interval between exercises ($n$ = 17), and a control group ($n$ = 8) that performed the same exercises in a different order (compound exercises prior to isolation). No significant between-group effects were found for strength in chest press, leg press, or pull-down exercises, or for body composition changes. Magnitude of change was examined for outcomes also using effect size (ES). ESs for strength changes were considered large for each group for every exercise (ranging 1.15 to 1.62). In conclusion, PreEx training offers no greater benefit to performing the same exercises with rest between them compared with exercises performed in an order that prioritises compound movements.

*Key words:* strength, muscle, lean mass, body fat.

**Résumé :** Un entraînement physique qui fatigue le muscle au préalable (PreEx) est préconisé selon le principe qu'un exercice isolé précédant immédiatement une chaîne d'exercices permet de cibler des muscles plus forts et de les fatiguer au préalable pour susciter des adaptations supérieures sur le plan de la force et de la grosseur. Toutefois, il y a peu d'études traitant d'entraînement PreEx. Cette étude se propose d'examiner l'effet d'un programme d'entraînement PreEx; trente-neuf sujets dont 9 hommes participent à 12 semaines d'entraînement contre résistance dans l'un des trois groupes : un groupe d'entraînement PreEx ($n$ = 14), un groupe effectuant la série d'exercices selon la même séquence, mais avec un intervalle de repos entre les exercices ($n$ = 17) et un groupe de contrôle ($n$ = 8) effectuant les mêmes exercices, mais selon une séquence différente (la chaîne d'exercices précédant l'exercice isolé). On n'observe pas de différence significative entre les groupes sur le plan de la force au développé couché, au développé des jambes, à la traction vers le bas et de la modification de la masse corporelle. On analyse en outre l'importance du changement par la statistique de l'ampleur de l'effet (« ES »). Les ES de la modification de la force musculaire sont très marquées dans chaque groupe d'exercices (1,15 à 1,62). En conclusion, le programme PreEx ne procure pas plus d'avantages que les mêmes exercices présentés avec un intervalle ou effectués selon une séquence priorisant la chaîne d'exercices. [Traduit par la Redaction]

*Mots-clés :* force musculaire, muscle, masse maigre, gras corporel.

## Introduction

Pre-exhaustion (PreEx) training is an advanced resistance training (RT) method where 2 or more sequential exercises are performed in immediate succession. Whilst Jones (1970) is often credited for the hypothesis and application of PreEx RT, he suggests that the original concept existed prior to his description. The PreEx method is based upon the hypothesis that a point of momentary muscular failure (MMF) in a compound exercise occurs when the weakest muscles involved are no longer able to apply the required force to continue the exercise (Jones 1970). As such the "target" muscles can be "pre-exhausted" with an isolation exercise before moving immediately to a compound exercise. For example, the biceps might be the "weak-link" in a pulling exercise though the target might be to train the latissimus muscles. With this in mind, it is suggested to pre-exhaust the target muscles using an isolation exercise immediately prior to a compound exercise. It is hypothesised that this provides greater stimulation to the target muscles. Jones (1970) notes that "during the brief period while your weak-link muscles are actually stronger than your target muscles, you can take advantage of that momentary condition to use the strength of the weak-link muscles to train the target muscles much harder than would otherwise be possible."[1] Since evidence suggests training to MMF maximally recruits motor units and produces greatest gains in muscular strength (Fisher et al. 2011) and hypertrophy (Fisher et al. 2013*a*), the notion of attaining a greater fatigue to maximise adaptation appears logical.

However, PreEx research is limited to acute studies with methodological limitations. Augustsson et al. (2003) compared the acute effects of pre-exhausting the quadriceps with a knee extension exercise prior to completing a leg press exercise against completing the leg press exercise alone. They reported significantly fewer repetitions and lower rectus femoris and vastus lateralis muscle activation for the leg press following the PreEx. However, Carpinelli

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[1]This quotation has been amended from *arms* to *weak-link*, and *latissimus* to *target* to highlight application of the general principle.

(2010) has noted that whilst statistically significant, completing 7.9 ± 1.4 and 9.3 ± 2.3 repetitions for the PreEx and non-PreEx conditions, respectively, is unlikely to be *practically* significant. Additionally, that repetition duration was not controlled further invalidates these results.

Carpinelli (2010, 2013) also suggests Jones (1970) and Augustsson et al. (2003) were incorrect in the use of a knee extension exercise to pre-exhaust the quadriceps prior to performing the leg press. This is because the quadriceps may be the weak-link in a leg press exercise and instead the stronger hip extensors should be pre-exhausted. However, which muscles are indeed the weak-links in many compound exercises is largely speculative. Whilst Jones' (1970) original definition considered pre-exhausting the stronger muscles, we might consider PreEx as utilised upon specific target muscles. For example, many persons might be more interested in adaptations in their quadriceps over their hip extensors. As such, pre-exhausting the quadriceps by performing a knee extension exercise immediately prior to a compound exercise now seems appropriate. This might allow other muscles to assist the target quadriceps muscles to be trained "harder than would otherwise be possible", as per Jones' (1970) description. This amendment to our understanding of PreEx training now accommodates both Jones (1970) and Darden (1983) in their respective examples: barbell curls immediately followed by close grip pull-ups, and triceps extensions immediately followed by a dip exercise.

Gentil et al. (2007) and Brennecke et al. (2009) considered the acute effects of performing an isolation exercise for the pectorals prior to completion of a compound chest exercise. Both studies reported significantly greater number of repetitions for the compound exercise when not preceded by the isolation exercise. In addition, both studies also reported significantly higher activation of triceps muscles during the compound exercise when preceded by the isolation exercise. This suggests chest press performance required greater triceps contribution when the pectorals were pre-exhausted, but not that the pectorals themselves were any more activated. Gentil et al. (2007) also stated that the exercises were performed in sequence with an interval of less than 20 s, whilst Brennecke et al. (2009) state that the "mean time for exercise exchange" was 11.29 (±0.67) s. However, as clarified by Jones (1970) and Carpinelli (2010), the aim should be to move from the isolation exercise to the compound exercise as quickly as possible. Jones used the term "INSTANTLY" in uppercase to emphasise this point and noted separately times of 2–3 s between exercises. As such, the time between exercises was likely too large to truly test the PreEx method as originally proposed. It should be noted, however, that without the use of specialised equipment[2] designed for this purpose it is logistically difficult, if not impossible, to safely move from 1 exercise to another. As such the recommendation of ≤2–3 s seems impractical to recommend or test. Thus a further amendment to our understanding of PreEx might also be to accommodate as little rest as possible.

PreEx training is often recommended for advanced trainees to break plateaus (Darden 2004; Baechle and Earle 2008) and as such, since our literature search produced no chronic studies considering PreEx training, it is important that the efficacy of this method be examined. Thus the aim of the present study was to determine the effects of a 12-week PreEx training intervention upon muscular strength and body composition, comparing chronic adaptations between 3 groups: a PreEx group, a group performing the same exercises in the same order with moderate rest intervals between exercises, and a group performing the same exercises in a different order. This allows consideration of whether PreEx training enhances muscular performance beyond that of more conventional exercise routines.

## Materials and methods

### Study design

A randomised controlled trial design was adopted, with 3 experimental groups included. We examined the effects of 3 RT interventions in trained participants on strength and body composition. The study design was approved by the relevant ethics committee at the first author's institution.

### Participants

Participants were required to have had at least 6 months' RT experience and no medical condition for which RT is contraindicated to participate. Power analysis of research using low volume RT in trained participants (Fisher et al. 2013*b*) was conducted to determine participant numbers ($n$) using an effect size (ES), calculated using Cohen's $d$ (Cohen 1992) of 1.02 for improvements in strength. Participant numbers were calculated using equations from Whitley and Ball (2002), which revealed that each group required 15 participants to meet required power of 0.8 at an $\alpha$ value of $p \leq 0.05$. Written informed consent was obtained from all participants prior to any participation.

Seventy-one persons from the present membership pool in a fitness facility in the United States (Discover Strength, Plymouth, Minn., USA) attended an initial briefing and eligibility assessment regarding the research following advertisement. Forty-one asymptomatic participants (male = 11, female = 30) were recruited. Figure 1 shows a CONSORT diagram highlighting the participant numbers for enrolment, allocation, follow-up, and analysis stages for the study. Participants were randomised using a computer randomisation programme to 1 of 3 groups; PreEx without rest between isolated and compound exercises (PE; $n$ = 14), PreEx with rest between isolated and compound exercise (PER; $n$ = 17) and a control group who performed the same exercises in a different order (CON; $n$ = 8). Participants were asked to refrain from any exercise away from the supervised sessions.

### Equipment

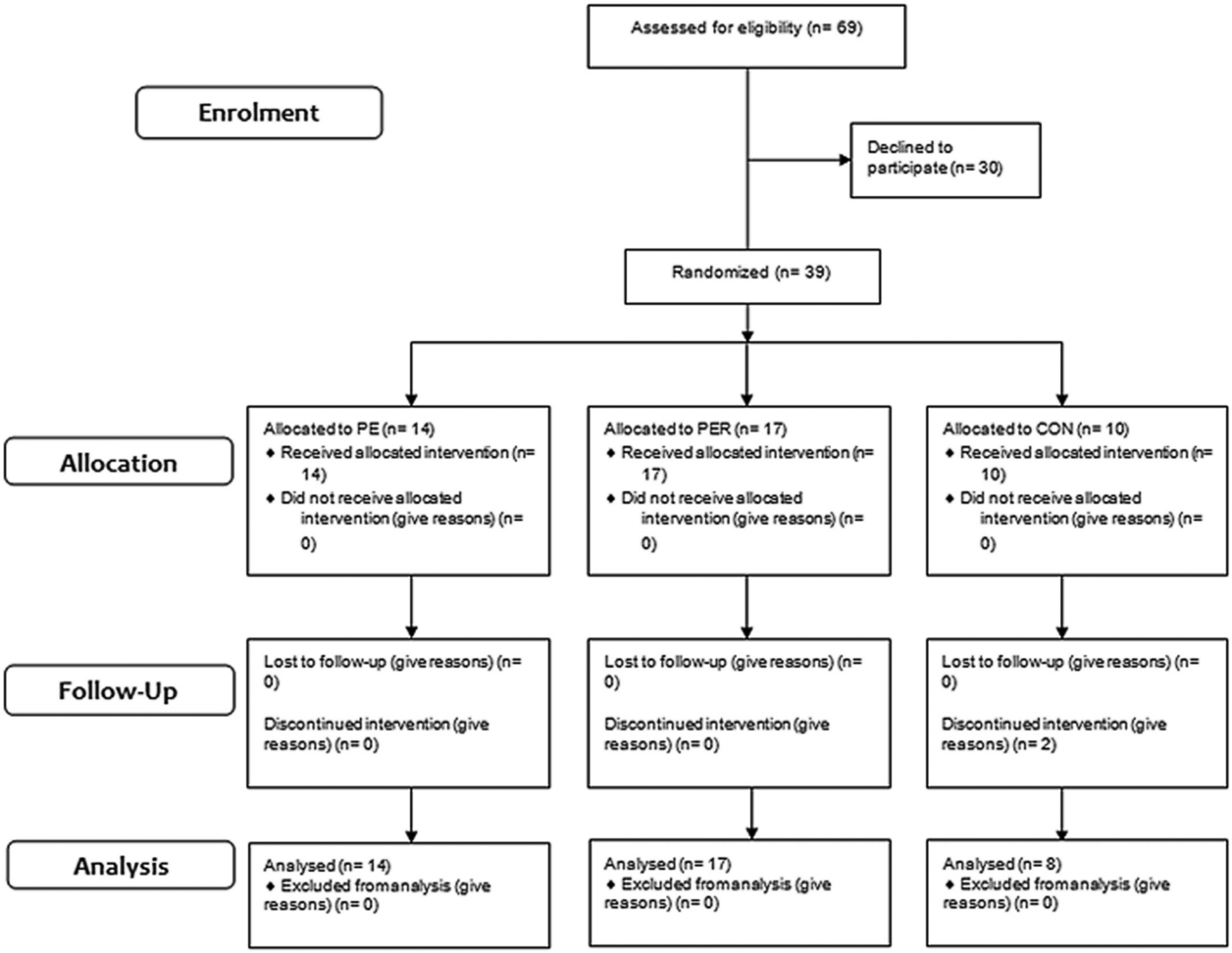
Strength was measured using chest press, leg press (MedX, Ocala, Fla., USA), and pull-down (Hammer Strength wide pull-down, Rosemont, Ill., USA) resistance machines. These were also used for the RT interventions in addition to pectoral fly (pec-fly) (Nautilus Nitro Plus, Vancouver, Wash., USA), leg extension (MedX, USA), pull-over (Nautilus 2ST, USA), abdominal flexion (MedX Core Ab Isolator, USA), and lumbar extension (MedX Core Lumbar Strength, USA) resistance machines. Procedures for strength testing are discussed below. Body composition was estimated using air displacement plethysmography (Bod Pod GS, Cosmed, USA).

### Testing procedures

Pre- and poststrength testing was performed in the following order with 120 s of rest between exercises: chest press, leg press, pull down. As participants were existing members of the facility where testing and training took place, all participants used their pre-existing training load for testing. It was estimated that this load would allow performance of 8 to 12 repetitions at the 2-s concentric, 4-s eccentric (2:4) repetition duration used for testing and training. Pre- and post-testing utilised the same absolute load allowing total volume (e.g., load × repetitions) to be calculated as has been completed in previous research (DeSouza et al. 2010). This method allows comparison of overall work output and is considered a representative method because of the direct relationship between muscular strength and the number of repeti-

[2]Nautilus (USA) previously manufactured *compound* and *double* machines to serve this exact purpose, accommodating both an isolation and compound exercise in a resistance machine. This might realistically be the only way to perform PreEx within the originally recommended time.

**Fig. 1.** CONSORT diagram. CON, control.




tions possible at a submaximal load (Carpinelli 2011). This also removes the need for potentially dangerous 1-repetition maximum testing, and provides greater ecological validity to realistic training conditions as most persons rarely test or use their maximal strength. The exercise was ceased when the participant failed during the concentric phase of a repetition or could not maintain the required repetition duration. Post-testing was performed at least 48 h following the final training session as per previous research (Fisher et al. 2014). The instructor performing the pre- and post-testing was blinded to group assignment. Details of the test procedures for estimation of body composition using air displacement plethysmography with the Bod Pod have been previously described in detail elsewhere (Dempster and Atkins 1995). Briefly, whilst wearing minimal clothing (swimsuit or tight fitting underwear) and a swim cap, participants were weighed using a calibrated digital scale. The participant was then seated in the Bod Pod for body volume measurement. From the body mass and body volume measurements, and predicted thoracic lung volumes, body density was estimated by the Bod Pod software and lean and fat mass estimations were calculated using the Siri equation.

**Training intervention (PE, PER, CON)**

Training was performed 2 times per week (with at least 48 h between sessions) for 12 weeks. Each exercise was performed for 1 set[3] per training session at a 2:4 repetition duration until MMF (i.e., when they reached a point of concentric failure during a repetition). Once participants were able to perform more than 12 repetitions before achieving MMF, load was increased by ~5%. This is in accordance with previous recommendations and research (e.g., Ratamess et al. 2009; and Fisher et al. 2013*b*, respectively). The PE group performed isolation exercises followed by compound exercises with as little rest as logistically possible (assessed prior to the study to be ≤5 s between exercises based upon their placement in the facility). In order, the exercises were pec-fly followed by chest press, leg extension followed by leg press, and pull-over followed by pull-down. These were followed by abdominal flexion and lumbar extension exercises. The PE group rested 120 s between finishing each compound exercise and beginning the next isolation exercise (i.e., between chest press and leg extension, and between leg press and pull-over). They then rested 60 s between pull-down, abdominal flexion, and lumbar extension ex-

[3]Whilst the authors accept that volume remains a contentious issue, previous research has reported considerable strength improvements in single-set RT with trained participants (e.g. Fisher et al. 2013*b*) and it unquestionably represents the most time-efficient approach.

ercises. The PER group performed the same exercises in the same order but rested 60 s between each exercise, removing the PreEx method whilst maintaining the same overall rest duration and exercise order. The CON group performed the same exercises in the following order, prioritising compound exercises: chest press, leg press, pull-down, pec-fly, leg extension, pull-over, abdominal flexion, and lumbar extension. They rested 60 s between each exercise. This approach retained parity between exercise completion and rest per workout. It also replicated the ideas of Jones (1970) and Darden (1983) with their brief (~23 min including rest intervals), high intensity of effort (performed to MMF), full-body workouts.

### Data analysis

Data were available from 39 participants (PE, $n = 14$; PER, $n = 17$; CON, $n = 8$). Data met assumptions of normality when examined using a Kolmogorov–Smirnov test. Baseline data were compared between groups using a one-way ANOVA to determine whether randomisation had succeeded. Between groups comparisons were performed using ANOVA, examining absolute changes in strength and body composition outcomes. Where baseline data differed significantly between groups, analysis of covariance (ANCOVA) was performed for that outcome with it input as a covariate. Significant between-group effects were examined further with post hoc Tukey testing to determine the location of significant differences. Statistical analysis was performed using IBM SPSS Statistics for Windows (version 20; IBM Corp., Armonk, N.Y., USA) and $p \leq 0.05$ set as the limit for statistical significance. Further, 95% confidence intervals (CIs) were calculated in addition to ES using Cohen's $d$ (Cohen 1992) for each outcome. This allowed comparison of the magnitude of effects between groups where an ES of 0.20–0.49 was considered as small, 0.50–0.79 as moderate, and ≥0.80 as large. Because of the considerable discrepancy in gender ratio between groups in this study, the above analyses were also conducted with the males excluded. It is noted in the Results section where these results differed from the combined sex findings. The researcher who performed the data analyses was blinded to group assignment.

## Results

### Participants

Participant baseline demographics are shown in Table 1. Demographic variables did not differ between groups at baseline.

### Strength

ANOVA did not reveal any significant between group effects for baseline strength data for any exercise. Figure 2 shows mean change in strength plus 95% CIs for each group and exercise. ANOVA did not reveal any significant between-group effects for change in strength for any of the tested exercises (all $p > 0.05$). Results for ANOVA did not differ when females were examined separately. ESs for strength changes were considered large and for the PE, PER, and CON groups, respectively, were 1.32, 1.67, and 1.25 for chest press; 1.15, 1.36, and 1.89 for leg press; and 1.82, 1.49, and 1.54 for pull-down.

### Body composition

Table 2 shows mean changes and ESs for body composition outcomes. ANOVA revealed a significant between group effect at baseline for body fat percentage ($F_{[2,36]} = 4.432$, $p = 0.019$). Multiple comparisons using post hoc Tukey revealed a significant difference between PE and CON groups ($p = 0.018$). No other outcomes differed at baseline. ANCOVA did not reveal any significant between-group effects for change in any body composition outcome examined. Examination of body fat change when body fat was used as a covariate also did not reveal any between group effects. Results for ANOVA did not differ when females were examined separately.

**Table 1.** Participant baseline demographics.

| | PE | PER | CON | $p$ |
|---|---|---|---|---|
| Age (y) | 49±6 | 47±12 | 47±13 | NS |
| Stature (cm) | 167.37±9.67 | 168.52±4.57 | 169.04±8.15 | NS |
| Body mass (kg) | 72.27±17.13 | 69.86±16.47 | 68.78±16.61 | NS |
| BMI | 25.7±5.3 | 24.4±4.8 | 23.9±3.9 | NS |
| Sex ratio (male:female) | 2:12 | 4:13 | 3:5 | NA |

**Note:** Results are means ± SD; BMI, body mass index; CON, control; NA, not applicable; NS, nonsignificant (analysed using ANOVA); PE, pre-exhaustion training; PER, rest interval between exercises.

## Discussion

This study examined the effects of PreEx training and also exercise order within 3 rest-equated RT programs in trained participants. Results indicated that neither PreEx or exercise order affected strength gains in a single-set, full-body RT intervention where exercises were performed to MMF. Neither pre-exhausting a target muscle through use of PreEx nor prioritisation of exercises used for testing offered any greater strength improvements in any of the exercises tested. Magnitude of strength gains for all groups and all exercises were considered large and significant from examination of ESs and 95% CIs.

Training to a point of MMF during an exercise has been argued to be the primary stimulus for strength gains irrespective of other variables such as set volume and load (Fisher et al. 2011). It is proposed that RT performed to a sufficiently high intensity of effort, such as MMF, maximally recruits available motor units facilitating adaptations (Carpinelli 2008; Fisher et al. 2011). However, is has previously been suggested that during compound exercises certain muscles may be considered to be weak-links, which reach MMF prior to other muscles. As such this might cause cessation of the exercise before maximal motor unit recruitment has been achieved for all involved muscles (Jones 1970). Thus, it has previously been hypothesised that use of PreEx, as described herein, might allow greater motor unit recruitment to facilitate adaptations.

Prior to the present study, no others had examined the use of PreEx as a training intervention and had only examined acute responses. However, acute electromyography (EMG) studies (Augustsson et al. 2003; Gentil et al. 2007; Brennecke et al. 2009) combined with our results suggest the above reasoning regarding application of PreEx may be faulty.

Gentil et al. (2007) and Brennecke et al. (2009) suggested that the proposed weak-link in the bench press, the triceps, was more active after pre-exhaustion of the pectorals using an isolation exercise (pec-deck/chest-fly). However, they reported no difference in pectoral activation over and above performing the bench press without the use of PreEx. Thus it seems this compound exercise already provided maximal pectoral recruitment and potentially greatest potential for adaptation similar to that of prioritising the bench press or performing it independently. In support, we reported no significant differences in strength gains for the chest press exercise between PreEx, PreEx with rest, and prioritisation conditions. This may be due to the fact that the muscles utilised within upper-body pressing movements, such as bench press and chest press, are already maximally active for that movement.

Muscular recruitment during compound exercises is likely a dynamic process and the proposal of weak-links in such exercises is premature in the absence of studies examining them. For example, during compound trunk extension the lumbar extensor musculature might be the weaker muscles compared with the larger hip extensors in terms of force production. However, there is evidence to suggest they do not in fact limit performance of such exercise and may de-recruit after a certain degree of fatigue is achieved (Steele et al. 2013). Whilst this might appear counterintuitive, it highlights the complex nature of attempting to determine weak-links for use of PreEx training. Normalised EMG data

**Fig. 2.** Mean strength changes and 95% confidence intervals for each group and exercise. CON, control; PE, pre-exhaustion training; PER, rest interval between exercises.

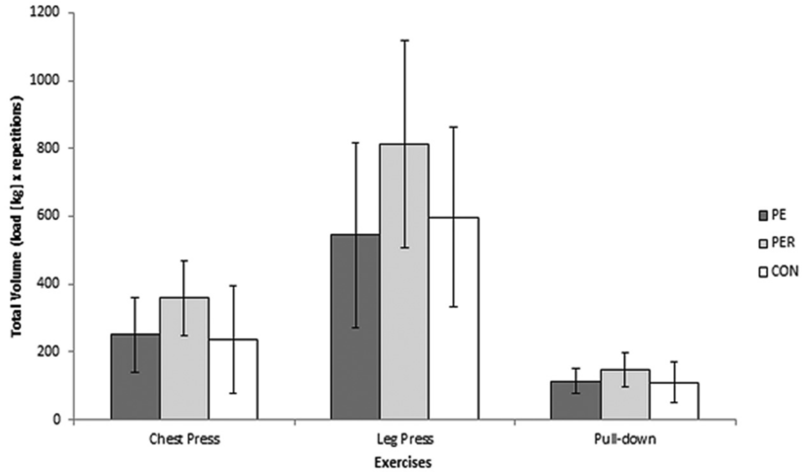



**Table 2.** Mean changes and effect sizes (ESs) for body composition outcomes.

| | PE | | | PER | | | CON | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Outcome | Change | 95% CI | ES | Change | 95% CI | ES | Change | 95% CI | ES | $p$ |
| Body mass (kg) | 0.09±0.90 | −0.43 to 0.62 | 0.10 | −0.36±1.16 | −0.96 to 0.23 | −0.31 | −0.60±1.74 | −2.06 to 0.85 | −0.35 | 0.388 |
| Body fat (%) | −0.2±1.45 | −1.04 to 0.64 | −0.14 | −0.78±1.65 | −1.63 to 0.07 | −0.47 | 0.01±2.30 | −1.91 to 1.93 | 0.01 | 0.487 |
| Lean mass (kg) | 0.41±1.08 | −0.21 to 1.03 | 0.38 | −0.34±3.37 | −2.08 to 1.39 | −0.10 | −0.40±0.60 | −0.91 to 0.10 | −0.67 | 0.620 |

**Note:** Results are means ± SD; ES was calculated using Cohen's *d*; Cohen 1992; *p* values for between group effects using ANCOVA. CI, confidence interval.

from Brennecke et al. (2009) in fact suggest that there is a similar degree of activation for pectorals, anterior deltoids, and triceps for compound upper-body pushing exercises, making determination of a weak-link difficult. Plus, assuming maximal motor unit activation is a primary driver of adaptations, the use of PreEx to target a specific muscle prior to such exercise would seem unnecessary. Indeed our results evidence this to be the case. In addition, Gentil et al. (2013) have demonstrated that gains in strength and hypertrophy for the elbow flexors and extensors are similar when performing compound upper-body exercises (bench press, pull-down) with or without single-joint exercises (elbow flexion, elbow extension). Thus it seems that for upper-body compound exercises, the majority of involved musculature may be maximally stimulated.

Whether the above reasoning is true of other compound exercises is difficult to say because of lack of evidence. The lumbar extensors appear an under-stimulated muscle group within trunk extension based exercise as evidence by their lack of adaptation from deadlift training (Fisher et al. 2013*b*). However, the inclusion of isolated lumbar extension exercise training does contribute to greater deadlift performance (Fisher et al. 2013*b*). For lower body compound pressing exercise, however, a similar situation appears to present with upper-body exercises. Using PreEx for the quadriceps through knee extension exercise prior to leg press produces similar activity in both the rectus femoris and vastus lateralis (though reported significantly different it was within EMG measurement error) and the gluteus maximus (Augustsson et al. 2003). In fact, gluteus maximus activity was similar to that of the rectus femoris, again highlighting difficulty in determining a weak-link and thus a suitable target muscle for use of PreEx. Again, we found no significant differences in strength gains for the leg-press exercise between PreEx, PreEx with rest, and prioritisation conditions.

Our results seem to suggest that for trained participants, performance of single set per exercise RT to MMF produces considerable strength gains independently of exercise order, rest intervals, or indeed application of PreEx. Previous publications have specifically suggested that exercise order is important in chronic adaptations. For example, Miranda et al. (2010) and Simão et al. (2012) reported a greater number of repetitions for exercises when performed at the beginning of a workout compared with at the end. From this they suggested that this greater volume with a given load might catalyse larger gains in strength. However, these were both acute studies, and whilst making recommendations towards chronic training intervention strategies they lack evidence to support these claims. In fact Carpinelli (2010, 2013) published extensive reviews of PreEx and exercise order, reporting that there is little evidence to support these recommendations.

The strength gains reported in this study were considered large and were similar to other studies of low-volume RT performed to MMF in trained participants (Fisher et al. 2013*b*). Body composition changes in this study, however, were minimal and likely within the measurement error (Fields et al. 2001; Collins et al. 2004). It may be that changes in body composition were not detected for this population of trained participants because of lack of control over dietary intake. However, though participants were not instructed to maintain or change their current diet we did not record this and so it is possible it may have changed spontaneously as a result of participation in the intervention. Indeed, it has been reported that active females participating in higher intensity of effort exercise may spontaneously increase energy intake (Pomerleau et al. 2004). We might also consider that as trained participants they are unlikely to have been performing an identical workout of 2 times per week for 12 weeks, without variation, prior to this programme. As such trained participants performing alternative exercises might have previously induced hypertrophic response in muscles, which did not receive sufficient stimulus from the present intervention. Marginal atrophy of these untrained muscles might equate to the degree of hypertrophy in the trained muscles thus presenting no change in body composition. This, in turn, might present evidence for regular modification of RT programmes.

The present study was conducted in trained participants and thus adds to the relatively sparse data existing on this population. However, whilst combined sex and female-only results did not differ, the small number of males in this study means it is imprudent to extrapolate these results to wider male populations.

## Conclusion

These results suggest that considerable improvements in strength are possible in trained participants when performing single set per exercise full-body RT to MMF. Further they also suggest that strength gains are not influenced by the use of PreEx, exercise order, or between-exercise rest intervals. We should acknowledge that the American College of Sports Medicine (Ratamess et al. 2009) has previously recommended larger volumes of exercise, heavier loads (and accordingly lower repetition ranges), and large inter-set/inter-exercise rest intervals for trained participants. However, the present data suggests that strength increases are possible in a far more time-efficient manner, and support alternative recommendations that have advocated a lower volume of exercise when training to MMF (Fisher et al. 2011). Studies on PreEx to date have been acute and utilised applications of this method differing from the original hypothesis. Whilst this study also differed in application from the original PreEx hypothesis, we utilised a more practical application of PreEx. In addition, this is the first chronic study to our knowledge that examined this method. However, based upon these results there appears no benefit to performing PreEx RT over and above simply performing individual exercises to MMF in a preferred order and with preferred rest between exercises.

### Conflict of interest statement

There are no conflicts of interest to declare.

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# CHAPTER 8: A comparison of volume equated knee extensions to failure, or not to failure, upon rating of perceived exertion and strength adaptations

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ARTICLE

# A comparison of volume-equated knee extensions to failure, or not to failure, upon rating of perceived exertion and strength adaptations

James Peter Fisher, Dominic Blossom, and James Steele



**Abstract:** The present study aimed to compare the effects of repetition duration-, volume-, and load-matched resistance training to muscular failure (MMF) or not to muscular failure (NMF) on maximal voluntary isometric knee extensor strength. This design also allowed testing of the efficacy of "5×5" training. Nine recreationally active males (age, 21.4 ± 1.2 years; height, 1.79 ± 0.07 m; weight, 78.4 ± 7.1 kg) performed unilateral resistance training at 80% of maximal torque at 2×/week for 6 weeks. Using their nondominant leg, participants performed 5 sets of 5 repetitions (NMF). Using their dominant leg, participants performed 25 repetitions in as few sets as possible (MMF). All repetitions were performed at a pace of 2 s concentric, 1 s isometric pause, and 2 s eccentric with a 2-min rest interval between sets. Analyses identified significant pre- to post-intervention strength increases for both MMF and NMF, with effect sizes (ESs) of 2.01 and 1.65, respectively, with no significant differences between conditions ($p > 0.05$). Peak and mean ratings of perceived exertion (RPEs) were significantly higher for MMF compared with NMF conditions ($p < 0.0001$), and a tendency for significantly higher RPE values reported for later sets for the NMF condition. Total training time per session was significantly longer for NMF compared with MMF ($p < 0.001$). The present study suggests that in untrained participants, resistance training NMF produces equivocally the same strength increases as training to MMF when volume-matched. However, resistance training to MMF appears to be a more time-efficient protocol and may produce greater strength gains as indicated by a larger ES.

*Key words:* resistance training, isometric strength, untrained males.

**Résumé :** La présente étude compare les effets d'un entraînement contre résistance basé sur la répétition de la durée ou du volume ou de la charge durant l'exercice jusqu'à une défaillance musculaire momentanée (« MMF ») ou pas (« NMF ») sur la force isométrique maximale volontaire des extenseurs du genou. Le devis expérimental permet aussi de tester l'efficacité de l'entraînement « 5×5 ». Neuf hommes physiquement actifs par loisir (âge, 21,4 ± 1,2 ans; hauteur, 1,79 ± 0,07 m; poids, 78,4 ± 7,1 kg) effectuent un entraînement unilatéral contre résistance sollicitant 80 % du moment de force maximal à raison de 2 séances par semaine durant 6 semaines. En utilisant leur jambe non dominante, les participants effectuent 5 séries de 5 répétitions (NMF). En utilisant leur jambe dominante, les participants effectuent le moins de séries possible pour totaliser 25 répétitions (MMF). Toutes les répétitions consistent en un exercice de 2 s en miométrie, 1 s en isométrie, 2 s en pliométrie avec un intervalle de repos de 2 min entre chaque série. Les analyses statistiques révèlent une augmentation significative de la force dans les deux conditions (MMF et NMF) du début à la fin de l'intervention; l'ampleur de l'effet (« ES ») est respectivement de 2,01 et 1,65, sans différence significative ($p > 0,05$) entre les conditions. Les perceptions de l'intensité de l'effort (« RPEs ») moyenne et de pointe sont significativement plus élevées dans la condition MMF comparativement à la condition NMF ($p < 0,0001$); la RPE présente une tendance significative vers de plus hautes valeurs lors des dernières séries dans la condition NMF. La durée totale de l'entraînement à chaque séance est significative plus longue dans la condition NMF comparativement à la condition MMF ($p < 0,001$). D'après les données de cette étude, l'entraînement contre résistance dans la condition NMF chez des sujets non entraînés procure de façon ambigüe les mêmes gains de force que dans la condition MMF quand le volume de l'entraînement est apparié. Toutefois, l'entraînement contre résistance dans la condition MMF s'avère un meilleur protocole pour des gains plus rapides et peut procurer une plus grande force comme le révèle ES. [Traduit par la Rédaction]

*Mots-clés :* entraînement contre résistance, force isométrique, hommes non entraînés.

## Introduction

Resistance training (RT) is evidenced to show considerable benefits for athletic participants (e.g., strengthening joints, muscles, tendons, and bones, and improving power, speed, and vertical jump; Stone 1990). In addition, the accompanying strength increases are evidenced to provide numerous health-related benefits (Westcott 2012) and even reduce risk of all-cause mortality in the lay population (Newman et al. 2006; Ruiz et al. 2008; Volaklis et al. 2015). With this in mind, a plethora of research has considered the variables associated with RT (e.g., volume, load, frequency, and repetition duration), and has been summarised in numerous review articles to attempt to most efficiently prescribe this exercise modality (Ratamess et al. 2009; Fisher et al. 2011).

An important variable within RT is that of intensity of effort (Steele 2014) and whether a person should exercise to momentary muscular failure (MMF). This has been defined as the "inability to perform any further concentric contractions without significant change to posture or repetition duration, against a given resistance" (Fisher et al. 2011). Previously it has been suggested that

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evidence supports training to MMF to enhance motor unit recruitment and growth-promoting hormones, but also advised that the method not be continued over long periods for risk of potential overtraining and overuse injuries (Willardson 2007).

Henneman's size principle states that as smaller, lower threshold motor units (MU) fatigue, larger, higher threshold MUs are recruited. MMF occurs when there is an inability to continue innervating MUs and/or a reduction in rate of discharge (rate coding; Enoka and Duchateau 2008). By this rationale, exercising to MMF seems a practical method of ensuring recruitment of all available muscle fibres. However, whilst some research has supported that training to MMF appears the most efficacious method of inducing strength adaptations (Rooney et al. 1994; Schott et al. 1995; Drinkwater et al. 2005; Giessing et al. 2014), other research has suggested equivalent gains when not training to failure (NMF; Izquierdo et al. 2006; Folland et al. 2002; Sampson and Groeller 2015). Additionally, that many of these studies have methodological discrepancies complicates understanding of this variable.

Willardson et al. (2010) previously suggested that research studies considering this area have significant limitations. For example, Izquierdo et al. (2006) instructed all repetitions for the measured exercises to be performed at "the highest possible speed", suggesting that irrespective of total volume or achieving MMF, the explosive nature of the repetitions might have been sufficient to maximally recruit available MUs.[1] Sampson and Groeller (2015), in attempting to assess and equate relative load between groups, required all participants to perform "a single set of elbow flexion to failure once each week" — a considerable limitation in a study professing to compare RT to MMF versus NMF. Indeed, a recent study has reported that adding a single set to MMF to a NMF RT program may induce significantly greater strength and hypertrophic adaptations, highlighting why this may be a limitation (Aguiar et al. 2015). Folland et al. (2002) required participants perform either 4 sets of 10 repetitions at 75% 1-repetition maximum (RM) with 30 s of rest between sets to a group performing 40 single repetitions with 30 s of rest between repetitions. However, whilst the use of inter-set rest periods is a common design for this research area, this protocol equates to 19 min and 30 s of *rest* between repetitions, which for only 1 exercise seems an impractical way to perform RT. Perhaps more importantly none of the studies comparing MMF to NMF reported any assessment of MU recruitment or intensity of effort level. This leaves us ignorant to what degree of effort was performed within these studies.

One recent study has attempted to compare training to MMF with training NMF when work was equated by attempting to control effort between groups through specific definitions of repetition cessation. Using trained participants, Giessing et al. (2014) required 1 group to perform repetitions to a self-determined RM (described as participants stopping when they felt their next attempted repetition would result in MMF; i.e., 1 perceived repetition short of MMF) and another group to actually train to MMF. They reported significant strength gains for the group training to MMF; however, the group training to self-determined RM did not significantly improve in strength. They speculated that this may be due to participants in the self-determined RM group being further from MMF than expected as other research has reported even experienced trainees under-predict the number of repetitions possible before achieving MMF (Hackett et al. 2012).

Though the present body of literature and our understanding of the size principle might appear to support training to MMF, it is still unknown the precise role, and to what degree, effort[2] specifically plays in determining strength adaptations. It has been reported (Giessing et al. 2014) that low-volume training (i.e., single-set RT) may be dependent upon sufficient intensity of effort through training to MMF, whereas RT involving higher volumes performed to NMF may result in a sufficient intensity of effort through cumulative fatigue across sets (Willardson, 2007). For example, a commercial method of training known as 5×5 (Starr 1978) involving the performance of 5 sets of 5 repetitions using ~80%1RM permits trainees to avoid training to MMF yet to accumulate a relatively high work volume. However, there appears to be no research examining this training method. Marshall et al. (2012) have acutely examined the effects of training involving 5 sets of 4 repetitions using 80%1RM using different rest periods with performing the same volume through consecutive sets to MMF. They reported greater electromyography amplitudes, and from this inferred higher MU activation, for the group training to MMF despite similar degrees of postexercise force reduction, suggesting that it may offer a more efficacious training method; however, RPE was not reported.

Previous research does not fully elucidate the role of intensity of effort and its relationship to volume in determining training adaptations because of noted methodological limitations. A further potential confounding factor is between participant variations in response. It is known that there is a large heterogeneity in response to RT (Hubal et al. 2005) and thus the use of within-subject designs could offer a more rigorous test of the role of intensity of effort and training to MMF. To date no previous studies appear to have compared load and volume equated unilateral training NMF with MMF. With this in mind, the present study aimed to compare the effects of 6 weeks load-, volume-, and repetition duration-equated, unilateral knee extension exercise with MMF or NMF using a 5×5 method, including the use of a exertion[3] scale to expand our understanding of this relationship.

## Materials and methods

### Study design

The present study aimed to compare the effects of a 6-week unilateral knee extensor RT programme using identical training loads, volumes, and repetition duration performed to MMF or NMF using a 5×5 method. To avoid bias as a result of individual responses to training, we used a within-subject research design, where participants trained 1 leg to MMF and the contralateral leg to NMF. This methodological approach is well represented in previous research (e.g., Alegre et al. 2014; Fisher and Langford 2014) and allowed for control of between participant confounding factors. Both legs were trained in the same session for the 6-week duration, alternating the leg that was exercised first (e.g., MMF or NMF) to nullify any effect of continued central fatigue.

### Participants

An a priori power analysis of effect sizes (ESs) for change in strength was conducted using ESs from recent meta-analysis of RT research (Fröhlich et al. 2010) to determine participant numbers (*n*) using ES calculated using Cohen's *d* (Cohen 1992) of ~1.1–1.3 for improvements in strength. Participant numbers were calculated

[1]The use of a protocol that requires maximal speed is effectively the same as training to MMF with regard to MU recruitment since intent and thus effort are likely maximal and in addition the muscular tension at peak velocity and peak force are likely similar (Behm and Sale 1993).

[2]Physiological effort is generally reported as a value from the rating of perceived exertion (RPE) scale. Previous application of this approach has been considered within the Discussion section.

[3]The terms effort and exertion have recently been discussed in detail (Abbis et al. 2015), identifying that they might differentiate in meaning; however, it is not within the scope of the present piece to consider similarities or differences and/or appropriation of terminology. The present piece uses the term effort other than in reference to a specific named scale (e.g. RPE).

**Table 1.** Participant characteristics.

| Characteristic | Mean ± SD |
|---|---|
| Age (y) | 21.4±1.2 |
| Height (cm) | 179.2±6.7 |
| Body mass (kg) | 78.4±7.1 |
| Body mass index (kg/m$^2$) | 24.4±1.8 |

using G*Power (Faul et al. 2007, 2009). These calculations showed that each group within the studies conducted required 6 to 7 participants to meet the required power of 0.8 at an $\alpha$ value of $p \leq 0.05$ for the statistical analyses proposed (see below). Thus 6 was taken as the minimum participant requirement for the studies primary outcomes of change in strength. Attempts were made to recruit a greater number of participants considering attrition rates of ~50%.

Following approval from the relevant ethics committee (Southampton Solent University, approval code: HESS#155), 9 recreationally active males were recruited from health and exercise science undergraduate degree courses (see Table 1 for participant characteristics). All participants had previous RT experience but had not been engaged in a structured programme (e.g., ≥2×/week) for the previous 6 months. All participants completed a physical activity readiness questionnaire (PARQ) and informed consent, and confirmed they were not using performance enhancing, or any other medication that might affect the study, and were free from injury.

### Testing procedures

All participants attended a familiarisation session where they performed a testing session in the exact format described below. This was to reduce any training effect of the tests pre- and post-intervention. Maximal voluntary isometric knee extension torque was measured unilaterally using a MedX knee extension/flexion dynamometer (MedX Corp., Ocala, Fla., USA) pre- and post-intervention. The final testing session was performed not less than 72 h following the final training session to allow adequate recovery. The methods used have been described previously (Starkey et al. 1996; Fisher and Langford 2014). Briefly, following a dynamic unilateral warm-up at 40 lbs/~18 kg using a 2-s concentric, 1-s isometric pause, and 2-s eccentric repetition duration, participants performed 3 practice unilateral isometric tests at an estimated 50% of maximal effort. Each participant then performed maximal unilateral isometric tests at 7 joint angles throughout the range of motion (102°, 96°, 78°, 60°, 42°, 24°, and 18° of knee flexion). For each maximal isometric contraction participants were requested to build up to maximal force over 2–3 s and were provided with ~10 s of rest between test angles. Following testing, participants were asked to identify their dominant and nondominant leg for assignment in to NMF and MMF training groups, respectively.

### Training intervention

Unilateral knee extension training was performed 2×/week for 6 weeks (with no less than 48 h between sessions) at 80% of maximal tested functional torque on the same MedX device used in testing. For the MMF protocol all participants performed 25 repetitions with their nondominant leg in the smallest number of sets possible, ensuring MMF was reached before cessation of each set (with the exception of the final set). Participants were required to attempt an additional repetition even when they felt it could not be completed, to ensure that MMF was reached. In a practical sense this meant that the MMF training always ended with an inability to complete a repetition. Repetition duration was controlled at 2-s concentric, 1-s isometric, 2-s eccentric as per the warm-up protocol. The MedX equipment was fitted with a sound to confirm completion of each repetition to ensure full range of motion. At the cessation of each set, participants were required to report perceived effort from the Borg 15-point RPE scale (Borg 1982). It was explained to participants that a rating of 20 on the RPE scale constituted maximal effort (i.e., MMF). Participants were provided 2 min of rest between exercise sets.

For the NMF protocol, participants performed 5 sets of 5 repetitions (Starr 1978) at the same repetition duration, and load as the MMF training protocol with their dominant leg. Upon completion of each set, each participant was again required to report effort from the Borg 15-point RPE scale, and then provided the same 2 min of rest between sets. Two minutes has been shown to allow sufficient ATP restoration to perform additional volume at the same loading (McMahon and Jenkins 2002; Baechle and Earle 2008). The loading remained constant throughout the intervention.

### Statistical analysis

Isometric force data was considered as a strength index (SI) provided by MedX clinical equipment. This has been reported previously (Fisher and Langford 2014; Fisher et al. 2013), where SI represents the area under a force curve created in each isometric test and accommodates potential increases or decreases throughout the entire strength curve for all 7 test positions. This negates biasing data by seeking average increases or decreases or only considering specific joint angles. The independent variable considered was the training condition (MMF or NMF) and the dependent variables included pre-strength, the absolute change in strength due to the intervention, average RPE across each set (averaged across the training intervention), peak RPE (averaged across the training intervention), and session duration for each protocol (averaged across the training intervention and including time to perform repetitions and rest time).

A Kolmogorov–Smirnov test was conducted to examine whether data met assumptions of normality of distribution. Where assumptions of normality were met, paired-samples *t* tests were used to compare within participants across the independent conditions (MMF vs. NMF). In addition, ANOVA with a Greenhouse–Geisser adjustment when assumptions of sphericity were violated was used to examine the effect of the factor "set" upon RPE in the NMF condition. Where a significant effect by set was found, post hoc pairwise comparisons with a Bonferonni procedure were conducted to examine differences between sets. All data were considered continuous and so met assumptions for parametric testing including RPE using the 15-point scale, which has been supported as producing interval data (Borg 1998).

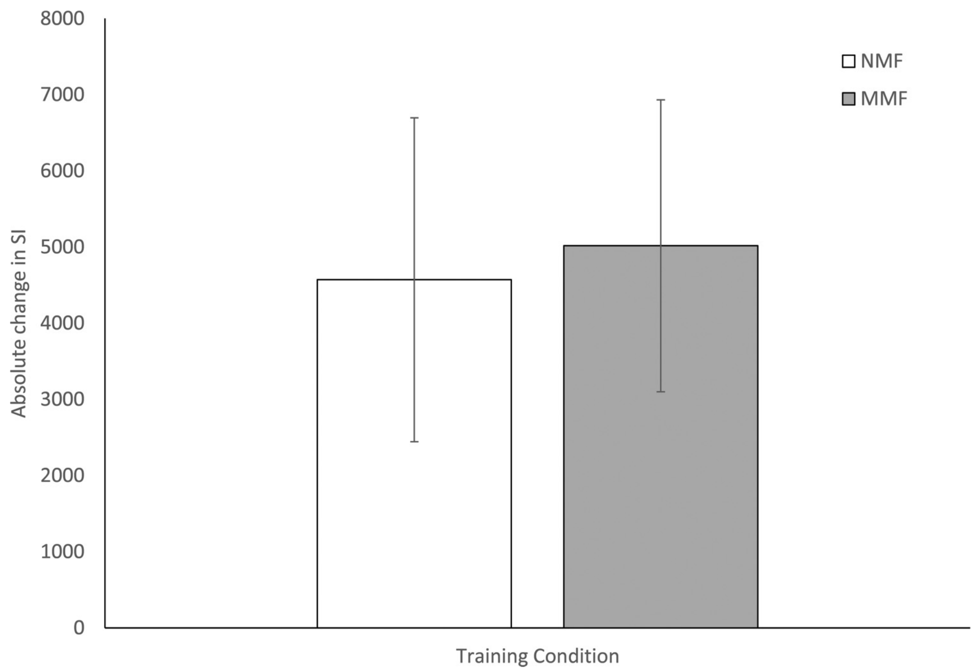
Statistical analysis was performed using IBM SPSS Statistics for Windows (version 20; IBM Corp., Portsmouth, Hampshire, UK) and $p \leq 0.05$ set as the limit for statistical significance. Further, 95% confidence intervals (CIs) were calculated to examine significance for within-condition changes in absolute strength (where a change was considered significant if the 95%CIs did not cross zero) in addition to ES using Cohen's *d* (Cohen 1992) for absolute change in strength for each condition, and differences between conditions for average RPE and peak RPE, to compare the magnitude of effects between conditions where an ES of 0.20–0.49 was considered as small, 0.50–0.79 as moderate, and ≥0.80 as large.

## Results

### Strength

Paired-samples *t* test revealed no significant difference between MMF and NMF for baseline strength ($t_{(8)} = 1.035$, $p = 0.331$; MMF = 10 948 ± 1910 vs. NMF = 11 348 ± 1697) and absolute change in strength ($t_{(8)} = -1.199$, $p = 0.265$). ESs for absolute changes in strength within conditions were considered large for both (MMF = 2.01 and NMF = 1.65) and 95%CIs suggested both conditions resulted in significant strength gains. Figure 1 shows absolute change in strength for both conditions with 95%CIs. The 95%CIs for change in absolute strength revealed that both conditions experienced a significant within-condition improvement.

**Fig. 1.** Mean absolute change in strength with 95%CIs for both momentary muscular failure (MMF) and not to muscular failure (NMF). SI, strength index.




**RPE**

Paired-samples $t$ test revealed a significant difference between MMF and NMF for both average RPE ($t_{(8)} = 16.835$, $p < 0.0001$; 95%CIs 4.21 to 5.55) and peak RPE ($t_{(8)} = 8.859$, $p < 0.0001$; 95%CIs 3.47 to 5.90). ESs for differences between conditions were considered large for both average RPE (5.61) and peak RPE (2.95). Table 2 shows average RPE and peak RPE for both conditions. Repeated-measures ANOVA found a significant effect by set for RPE for the NMF group ($F_{[1.142,28.508]} = 13.344$, $p = 0.004$). Pairwise comparisons revealed that set 1 differed significantly from set 5 ($p = 0.047$), set 2 differed significantly from set 5 ($p = 0.040$), set 3 differed significantly from sets 4 ($p = 0.044$) and 5 ($p = 0.013$), and set 4 differed significantly from set 5 ($p = 0.018$). Figure 2 shows RPE by set for NMF in addition to MMF for comparison.

**Table 2.** Average rating of perceived exertion (RPE) and peak RPE.

| | MMF | NMF |
|---|---|---|
| Average RPE* | 18.8±0.6 | 13.9±1.1 |
| Peak RPE* | 20.0±0.1 | 15.3±1.6 |

**Note:** Values are means ± SD.
*Significant difference between conditions ($p < 0.0001$).

**Session duration**

The MMF condition required 3.35 ± 0.70 sets to complete the 25 repetitions. Paired $t$ test revealed a significant difference between MMF and NMF for session duration ($t_{(8)} = -9.323$, $p < 0.001$). Average session duration for the MMF condition was 425.67 ± 97.93 s (~7 min and 6 s) compared with 720 s (12 min and 10 s) for NMF.

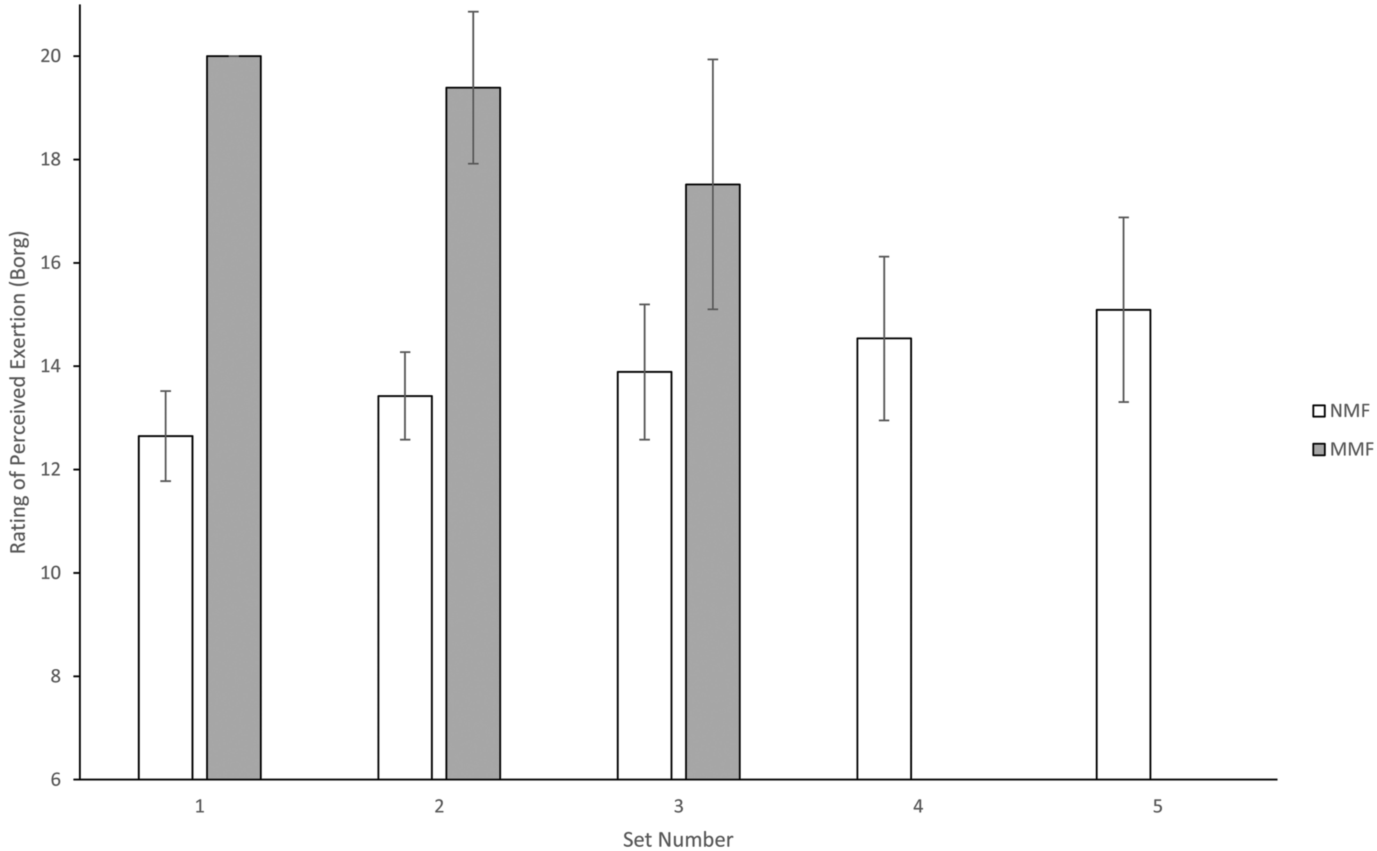
## Discussion

The aims of the present study were to compare training to MMF and NMF with load and volume equated, something that had previously not been presented in the literature. In doing so we also tested the efficacy of the commercialised 5×5 training programme originally proposed by the recently deceased Bill Starr (1978). Using a within-subject research design, recreationally active male participants performed a unilateral knee extension exercise to MMF and NMF using their nondominant and dominant legs, respectively.

Pre-intervention isometric testing revealed no statistically significant differences between dominant and nondominant leg. Following 2×/week unilateral knee extension training for 6 weeks, both interventions showed significant increases in maximal isometric force as indicated by 95% CIs (Fig. 1). Mean (±SD) values for SI increased for both groups; MMF: pre-intervention = 10 948 ± 1910, post-intervention = 15 964 ± 2528 (~46%); and NMF: pre-intervention = 11 348 ± 1697, post-intervention = 15 917 ± 2808 (~40%). Despite analyses revealing no significant differences in absolute change in strength between groups, it should be noted that ESs were greater in the MMF condition compared with the NMF condition (2.01 and 1.65 for MMF and NMF, respectively). Previous research has been equivocal in nature where some authors have reported more favourable adaptations following training to MMF (Rooney et al. 1994; Schott et al. 1995; Drinkwater et al. 2005; Giessing et al. 2014), whilst other authors have reported comparable results (Izquierdo et al. 2006; Folland et al. 2002; Sampson and Groeller 2015). However, multiple limitations of this existing body of research have restricted the extent to which these conclusions can be considered. For example; velocity of contraction (Izquierdo et al. 2006), performance of maximal exercise sets in both groups to determine training load (Sampson and Groeller 2015), and impractical training approaches (Folland et al. 2002) limit our confidence and application of this research area. The present study addresses many of these limitations and supports previous studies, suggesting there are likely no significant differences in strength adaptations between resistance training to MMF and NMF in untrained persons.

Research has previously suggested the use of RPE scales (see Morishita et al. (2013) for a review) to quantify intensity of effort. However, once again methodological issues limit the application of these resources. For example, Gearhardt et al. (2002) reported lower RPE values for participants performing 15 repetitions at 30% 1RM compared with those performing 5 repetitions at 90% 1RM. Initially it appears logical that a heavier load might equate to a higher degree of effort and indeed, recent research has shown

**Fig. 2.** Rating of perceived exertion across sets (mean + SD). MMF, momentary muscular failure; NMF, not to muscular failure.






that when work volume matched, heavier loads result in higher RPE values. However, when sets are performed to MMF, RPE is similar irrespective of other variables (Hiscock et al. 2015). Nevertheless, a lack of parity in volume complicates this issue. Previous research has suggested that 5 repetitions at 90% of 1RM is closer to MMF (and thus equates to a higher intensity of effort) than 15 repetitions at 30% of 1RM (Shimano et al. 2006; Hoeger et al. 1990). Thus, as discussed previously (Fisher et al. 2011), this represents the most common misconception; that load × repetitions = intensity of effort. Perhaps the most valuable of studies considering subjective rating of exertion is that of Shimano et al. (2006), who considered RPE values in trained and untrained males performing a single set to failure at 60%, 80%, and 90% 1RM for back squat, bench press, and arm curl. The authors reported no significant differences in RPE between load and exercise performed, with the exception of significantly higher exertion values for the back squat at 60% 1RM in trained persons (8.8 ± 0.7 vs. 6.9 ± 1.9). This suggests that the volume of repetitions preceding MMF may have incurred a greater degree of *discomfort*, resulting in a higher RPE value. We have quite specifically termed this *discomfort* rather than *exertion* for the following reason. The authors reported that participants exercised to muscular failure with verbal encouragement to ensure adequate motivation and effort, and RPE was measured using a Borg CR10 scale (Borg 1982), where a value of 10 indicates maximal effort. In this case, each trial, irrespective of exercise, load, or training status should have resulted in a maximal value for *effort* since participants were exercising to MMF. Since participants did not report maximal values we can only assume that the participants were unclear as to how to report their feelings of effort, and more likely expressed their feelings of *discomfort*.

Within the present research design participants reported RPE following each exercise set. As one might expect, analyses revealed significantly higher mean and peak RPE values for the MMF exercise sessions compared with NMF (see Table 2 for values). Since the MMF condition reported higher RPE values but failed to increase strength beyond that of the NMF condition, we might consider that for recreationally active (but nonresistance trained) persons there may be a threshold to adaptive responses to RT, but that beyond this threshold greater intensity of effort is unnecessary and results in diminishing magnitude of adaptations undetectable with the present sample size and analysis (e.g., $p > 0.05$). Henneman's size principle states that as smaller, lower threshold MUs fatigue so larger, higher threshold MUs are recruited. It seems likely that performance of multiple sets of an exercise with a minimal load and insufficient rest can incur a cumulative fatigue of muscle fibers and MUs incurring the recruitment of higher threshold MUs for adaptation. Previous research supporting similar adaptations between MMF and NMF have considered recreationally active participants and, whilst they failed to consider RPE, their respective protocols support this threshold hypothesis (Izquierdo et al. 2006; Folland et al. 2002; Sampson and Groeller 2015). It could, however, be suggested that, practically speaking and considering that prior research shows poor ability to estimate proximity to MMF even in trained adults (Hackett et al. 2012; Giessing et al. 2014), it may still be desirable to attempt to train to MMF with untrained recreationally active people. This might ensure that a threshold for optimising adaptations has been met.

In contrast with studies of untrained people, some of the previous research, which has suggested greater adaptations as a result of RT to MMF, have considered participants with previous RT experience (Drinkwater et al. 2005; Giessing et al. 2014), which might require greater stimulus or a higher threshold of effort to catalyse adaptation. Where protocols found favourable results for RT to MMF and considered participants without previous RT experience, it might be that subjects within MMF training groups simply made greater adaptations to the MMF RT protocol compared with those within NMF groups, potentially because of a larger rest period in the NMF groups preventing complete recruitment of the higher threshold MUs (Rooney et al. 1994; Schott et al. 1995).

Since the present study considered a unilateral training protocol it represents the first research study in this area that has adequately controlled for nutrition, sleep patterns, genetics, and hormonal responses to RT protocols. However, the use of a within-participants, unilateral RT protocol is not without limitations, which should be discussed. Whilst this methodological approach adequately controls the aforementioned variables, we should consider that there might be chronic neural adaptations resulting from cross-education, which could have impacted our results and limit the extent of our conclusions. Indeed meta-analysis of the cross-educational effect of unilateral training have suggested it contributes 7.8% absolute strength increase to the contralateral limb (Munn et al. 2004). However, this adaptation is hypothesised to result from neural mechanisms involving facilitation of an untrained contralateral motor cortex following excitation of a trained limb. As such, it could be argued that with our within-subjects design (where both limbs were trained) would have therefore controlled for this degree of improvement between limbs and any difference in strength gains or lack thereof would be due to the training conditions.

In addition, the cause of failure with different repetition ranges may differ. Behm et al. (2002) found that MMF occurred in low repetition (5) sets because of more centrally mediated fatigue whereas higher repetition sets (20) were more mainly owing to peripheral neuromuscular mediated fatigue. Thus depending on the number of sets performed to MMF there may be differential degrees of centrally stimulated adaptations and cross-educational effects. The MMF condition performed 12.31 ± 2.29 repetitions in the first set and so the effects of central fatigue may not have been so severe. However, despite these factors, it is currently unknown as to whether contralateral adaptations over a training intervention do indeed differ when the ipsilateral limb has been trained to MMF or NMF and as such this limitation should still be considered. Ultimately almost all RT research will be limited either by between-group differences, which are not controlled or said limitations of a within-group design. The present study appears the first to consider a within-participant design in the area of MMF versus NMF RT.

It is also feasible that training to MMF may impart greater adaptations in a contralateral limb because of potentially greater stimulus of centrally mediated neural factors through nonlocal muscular fatigue (NLMF; Halperin et al. 2015). Whilst it is not within the scope of this article to provide extensive discussion, in brief; NLMF indicates a deficit in acute muscular performance in unexercised muscles as a result of exercising other (including contralateral) muscle groups (see Halperin et al. 2015 for a comprehensive review). In context, NLMF might have resulted in the NMF limb equating to a higher degree of fatigue (potentially as a result of MU recruitment and muscle fibre activation) when performed subsequent to the MMF limb. Whilst we alternated priority of MMF and NMF training protocols, each session aiming to avoid systemic fatigue affecting results, we should consider that this is a complex area with equivocal results relating to intensity of effort and regarding contralateral force production and maximal force contraction time (Halperin et al. 2015). In review, Halperin et al. (2015) specifically noted that NLMF appears to be more prevalent in the knee extensors and may be impacted more by prolonged repetitive contractions (such as training to MMF) and as such, in the present study, each unilateral exercise session might have induced a degree of contralateral fatigue.

In context another potential limitation of the present study was the lack of randomization for dominance/nondominance of leg in to MMF and NMF groups. Considering the present sample size we felt that potentially dividing groups by another level (e.g., dominant and MMF, nondominant and MMF, dominant and NMF, nondominant and NMF) was unsuitable. In the context of our findings, however, this would seem to have been a minimally confounding factor. Training the dominant limb may have a greater impact on strength gains in the contralateral limb than the effect of training the nondominant limb (Farthing 2009). Thus our study design may in fact have favoured greater strength gains in the NMF condition. Our results, though nonsignificant, contrastingly revealed a greater ES within the MMF condition. Thus, despite meeting our sample size estimations for adequate power, it is possible that a type II error resulted. Future investigators should consider this factor in the design of studies.

Finally, we should consider the efficiency and practicality between training interventions. The MMF protocol required ~7 min and 6 s to complete, whereas the NMF 5×5 protocol required 12 min and 10 s to complete. This equates to ~40% greater time for the NMF group, which if extrapolated to consider multiple exercise protocols would require ~80 min and ~120 min for MMF and NMF, respectively, for 10 exercises using the same volume equated protocol. If statistically similar (or possibly greater based on ESs) strength gains are attainable in a shorter time then we might consider the MMF protocol to be far more time efficient and practically viable.

## Practical applications

The present research suggests that when training to NMF using a 5×5 approach, untrained people may attain similar strength increases when compared with training to MMF. This has application for people beginning or returning to a strength-training programme to provide a larger volume, which might allow individuals to practice the skill of technical movements and gain confidence in their exercise protocol. Additionally, the use of 5×5 training NMF might help adherence for those beginning exercise programmes or people with symptomatic conditions, which might prevent them from exercising at the high levels of discomfort associated with MMF. Future research should consider whether hypertrophic and health related adaptations are also similar between NMF using a 5×5 protocol and MMF training protocols. Coaches should consider using this research to support their exercise prescriptions in novice or untrained athletes wishing to develop strength, or in the periodization of trained athletes to prevent overtraining. In this sense NMF training might have application for the maintenance of strength in subsidiary musculature (e.g., to maintain upper body strength in endurance cyclists) without the physiological stresses associated with training to MMF. Conversely, programming some sessions to include training performed to MMF may offer slightly greater strength gains and it may positively affect fatigue resistance through improved mental toughness due to the high effort involved (Marcora et al. 2009). However, the present study supports that training to MMF appears a far more time-efficient RT protocol.

## Conflict of interest statement

The authors have no conflicts of interest to declare.

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# CHAPTER 9: General Results

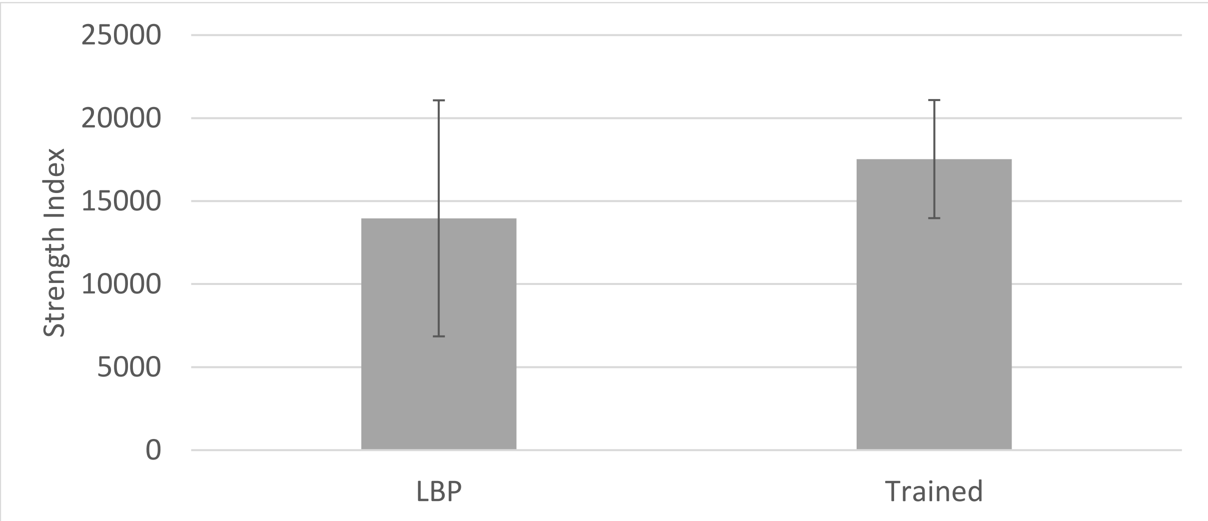
Whilst the studies presented within this thesis have independent and individual results sections within each respective publication, data has further been analysed and presented collectively or in comparison in an effort to provide a synthesis of the overall findings, as well as support practical application.

## 9.1 Trained males and Symptomatic low-back pain participants

Since two of the studies included in this thesis consider the use of the MedX isolated lumbar extension (ILEX) machine for testing and training, data was considered for comparison between these studies to identify any starting strength disparity between trained males (chapter 4) and low back pain symptomatic persons (chapter 6) for the lumbar extensors, as well as to consider the effect of the respective 10-week training interventions.

A Shapiro-Wilk test confirmed data to be normally distributed, permitting parametric analyses. An independent samples *t*-test for pre-intervention strength index comparing patients with CLBP (*n*=71) and males with previous resistance training experience (*n*=36) between the respective studies revealed a significant difference in starting strength; CLBP = 13962.7 ±7109.7; Trained males = 17530.4 ±3557.3; *t* (104) = 2.830, *p*= 0.006. See figure 9.1.1.

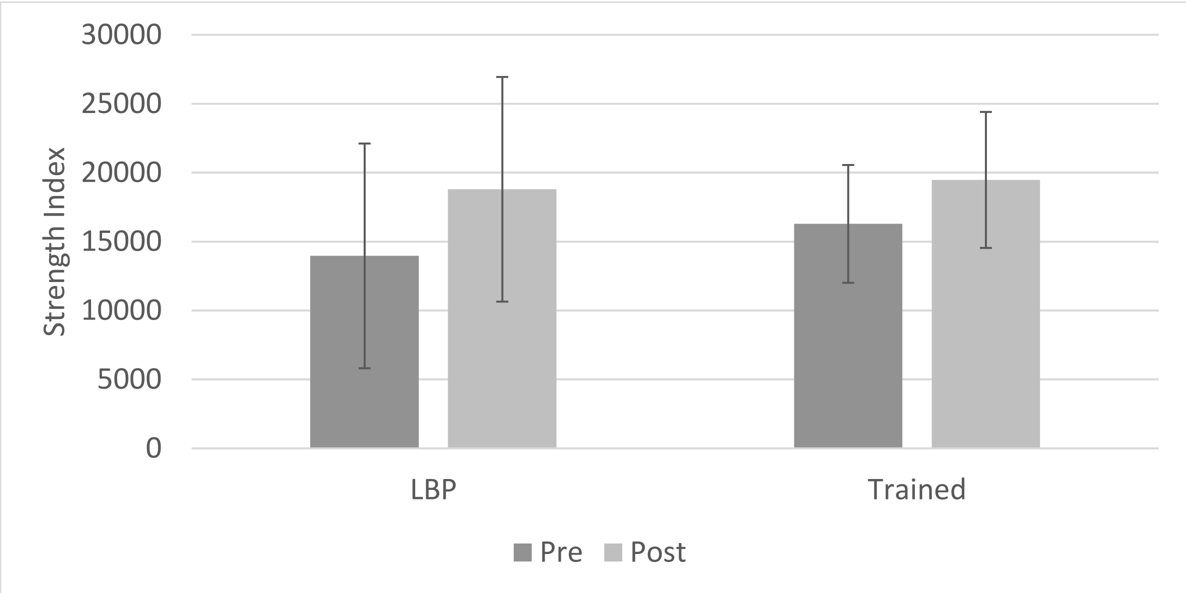
Figure 9.1.1 Starting strength between CLBP (n=71) and trained (n=36) participants




Error bars represent SD.

Data was also considered for participants who were tested and trained 1 x / week; e.g. the ILEX group from Chapter 4 (*n*=12) and the 1 x / week group from Chapter 6 (*n*=31). This allowed within and between groups comparison between persons asymptomatic of CLBP and males with previous resistance training experience. ANOVA with repeated measures revealed a significant effect for change in strength across time ($F_{(1, 41)}$ = 50.842, $p < 0.001$), with no significant between-group differences ($p = 0.152$). See figure 9.2. However, the group of participants with CLBP were initially weaker than the trained males, as expected (see independent samples *t*-test above), and this disparity in strength was reduced considerably following once weekly training. Table 9.1 shows absolute and relative increases in strength for both CLBP and trained participants.

Figure 9.1.2. Pre and Post SI for LBP (*n*=31) and trained (*n*=12) participants as a result of training $1 \cdot d \cdot wk^{-1}$




Error bars represent SD.

Table 9.1. Pre-, Post-, Absolute- and Relative- change in strength (strength index and %, respectively) for CLBP and trained participants following ILEX training $1 \cdot d \cdot wk^{-1}$ for 10 weeks (Mean ±SD)

| Group | Sample Size (*n*=) | Pre Strength (SI) | Post Strength (SI) | Absolute Change (SI) | Relative Change (%) |
|---|---|---|---|---|---|
| CLBP | 31 | 13961.3 ±8151.9 | 18791.9 ±8248.9 | 4830.5 | 34.6 |
| Trained | 12 | 16282.8 ±4273.0 | 19472.4 ±4932.3 | 3189.6 | 19.6 |

## 9.2. Advanced resistance training techniques and Predicted 1RM calculations from muscular performance

The introduction contains a discussion of repetitions to failure with an absolute load (absolute muscular endurance) as a measure of muscular performance (see section 1.4.2). However, in an attempt to support the practical application of the studies presented herein, any data presented as muscular performance from chapters 3 and 7 has been recalculated from load-volume (absolute muscular endurance) based on predictive equations of repetitions completed and load used, to calculate 1RM (Brzycki, 1993). Previous research has suggested this formula provides a very high correlation to actual 1RM (r = 0.99; do Nascimento et al., 2007). Table 9.2.1 ( data from chapter 3) and 9.2.2 (data from chapter 7) show the load used and pre- and post- intervention repetitions performed with that load, pre- and post-intervention predicted 1RM, the absolute change in 1RM and the relative change for the exercises tested (A: Chest press, B: Leg press and C: Pull-down) for all training groups.

Since both chapters 3 and 7 used the same tested exercises (chest Press, leg press and pull-down), Figure 9.2 A, B and C also present pre- and post-intervention predicted 1RM for all groups from both of these studies to show the comparative strength change between performing breakdown sets (BD) or heavy-load breakdown sets (HLBD; chapter 3) and pre-exhaustion (PE) or pre-exhaustion with rest (PER; chapter 7) as well as the respective control groups.

Table 9.2.1. Load, Pre- and Post-intervention repetitions, Pre- and Post-intervention predicted 1RM, absolute change 1RM and relative strength increase for breakdown resistance training (chapter 3; data presented as Mean ±SD).

A. Chest Press

| Group | Load (kg) | Pre-Repetitions | Pre 1RM (kg) | Post Repetitions | Post 1RM (kg) | Absolute Change 1RM (kg) | Relative Change (%) |
|---|---|---|---|---|---|---|---|
| BD | 73.06 (37.41) | 10.91 (2.81) | 101.61 (50.97) | 13.55 (2.66) | 113.07 (55.49) | 11.46 (9.91) | 11.3 |
| HLBD | 62.73 (18.14) | 10.64 (2.13) | 86.74 (28.54) | 15.86 (2.91) | 108.87 (36.91) | 22.13 (15.11) | 25.5 |
| CON | 88.18 (37.49) | 11.18 (2.56) | 123.91 (54.54) | 15.82 (3.16) | 155.98 (78.45) | 32.07 (34.18) | 25.8 |

B. Leg Press

| Group | Load (kg) | Pre-Repetitions | Pre 1RM (kg) | Post Repetitions | Post 1RM (kg) | Absolute Change 1RM (kg) | Relative Change (%) |
|---|---|---|---|---|---|---|---|
| BD | 113.64 (37.90) | 12.82 (6.06) | 184.01 (84.56) | 17.45 (7.55) | 261.48 (182.11) | 77.47 (116.74) | 42.1 |
| HLBD | 116.82 (24.77) | 9.93 (3.22) | 158.36 (44.68) | 15.43 (5.18) | 209.13 (88.66) | 50.77 (54.02) | 32.1 |
| CON | 142.40 (40.57) | 9.64 (4.11) | 196.09 (76.09) | 13.45 (5.52) | 239.53 (119.76) | 43.44 (55.83) | 22.2 |

C. Pull-Down

| Group | Load (kg) | Pre-Repetitions | Pre 1RM (kg) | Post Repetitions | Post 1RM (kg) | Absolute Change 1RM (kg) | Relative Change (%) |
|---|---|---|---|---|---|---|---|
| BD | 127.52 (44.96) | 11.0 (4.88) | 180.29 (63.98 | 15.64 (5.87) | 227.49 (82.16) | 47.20 (53.48) | 26.2 |
| HLBD | 116.69 (30.91) | 11.57 (2.10) | 165.38 (40.03) | 16.93 (3.25) | 211.35 (46.70) | 45.97 (26.61) | 27.8 |
| CON | 143.47 (44.65) | 10.55 (3.27) | 200.50 (70.42) | 14.27 (2.76) | 233.13 (82.74) | 32.64 (17.45) | 16.3 |

Table 9.2.2. Load, Pre- and Post-intervention repetitions, Pre- and Post-intervention predicted 1RM, absolute change 1RM and relative strength increase for pre-exhaustion resistance training (chapter 7; data presented as Mean ±SD).

A. Chest Press

| Group | Load (kg) | Pre-Repetitions | Pre 1RM (kg) | Post Repetitions | Post 1RM (kg) | Absolute Change 1RM (kg) | Relative Change (%) |
|---|---|---|---|---|---|---|---|
| PE | 73.06 (37.41) | 10.91 (2.81) | 88.97 (36.91) | 13.55 (2.66) | 110.21 (41.25) | 21.24 (19.71) | 23.88 |
| PER | 62.73 (18.14) | 10.64 (2.13) | 94.59 (37.57) | 15.86 (2.91) | 121.85 (49.02) | 27.26 (18.13) | 28.82 |
| CON | 88.18 (37.49) | 11.18 (2.56) | 96.01 (30.86) | 15.82 (3.16) | 112.34 (39.52) | 16.33 (12.68) | 17.00 |

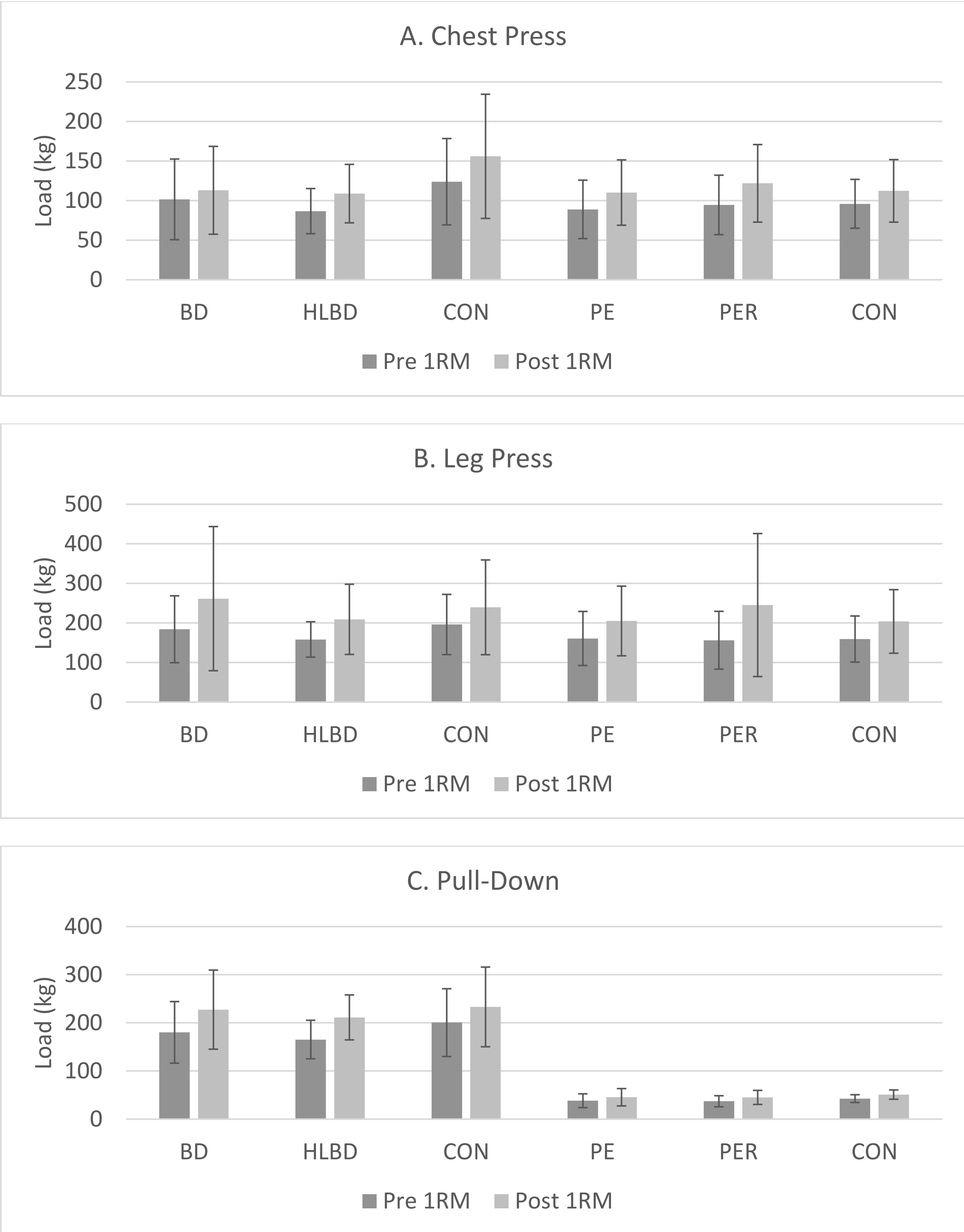
B. Leg press

| Group | Load (kg) | Pre-Repetitions | Pre 1RM (kg) | Post Repetitions | Post 1RM (kg) | Absolute Change 1RM (kg) | Relative Change (%) |
|---|---|---|---|---|---|---|---|
| PE | 114.48 (41.07) | 10.4 (4.4) | 160.78 (68.32) | 15.5 (6.0) | 205.03 (88.04) | 44.25 (41.48) | 27.52 |
| PER | 111.82 (38.17) | 9.6 (5.1) | 156.36 (73.04) | 17.2 (6.3) | 245.27 (180.74) | 88.91 (138.29) | 56.86 |
| CON | 110.80 (19.83) | 10.9 (3.6) | 159.34 (58.24) | 16.3 (3.7) | 203.85 (80.29) | 44.50 (28.48) | 27.93 |

C. Pull-Down

| Group | Load (kg) | Pre-Repetitions | Pre 1RM (kg) | Post Repetitions | Post 1RM (kg) | Absolute Change 1RM (kg) | Relative Change (%) |
|---|---|---|---|---|---|---|---|
| PE | 29.87 (10.10) | 8.3 (3.8) | 38.31 (14.30) | 12.4 (4.6) | 45.55 (18.00) | 7.24 (7.44) | 18.89 |
| PER | 30.21 (8.73 | 7.4 (2.5) | 37.17 (11.49) | 12.3 (4.0) | 45.19 (14.61) | 8.01 (5.73) | 21.55 |
| CON | 31.25 (10.45) | 11.1 (4.1) | 42.72 (8.08) | 14.9 (5.7) | 51.03 (9.64) | 8.31 (6.93) | 19.45 |

Figure 9.2. Pre- and Post-predicted 1RM for tested exercises from Chapters 3 and 7 (mean ±SD).




Notably the Pull-down resistance machine used was different between chapters 3 and 7 which accounts for the discrepancy between studies.

Analyses of data from within chapters 3 and 7, respectively, were then performed on the predicted 1RM values, as follows:

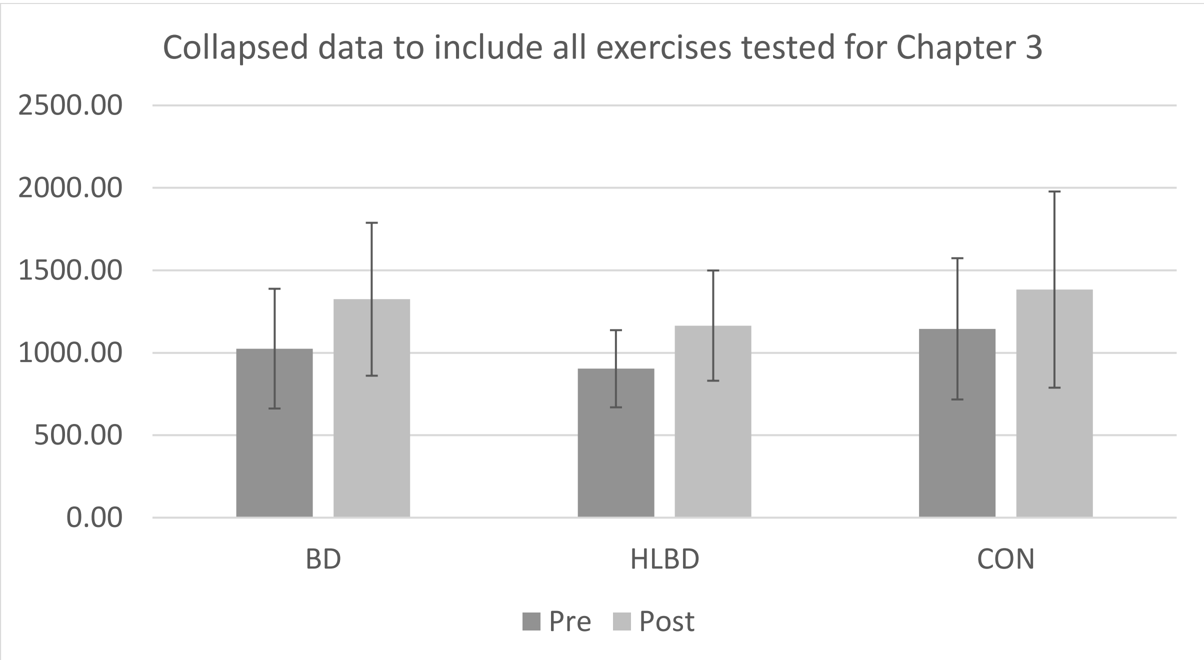
### 9.2.1 Analyses of predicted 1RM equations for Breakdown training (chapter 3)

ANOVA with repeated measures revealed a significant effect for time for predicted 1RM values for chest press ($F_{(1, 33)}$ = 35.935, $p < 0.001$), leg press ($F_{(1, 36)}$ = 18.698, $p < 0.01$) and pull-down ($F_{(1, 36)}$ = 50.500, $p < 0.001$) exercises, with no significant between-group differences (chest press, $p$ = .100; leg press, $p$ = .568; pull-down, $p$ = .556).

Furthermore, to assess the between group efficacy by including all resistance training exercises, data was collapsed to produce a single pre- and post-strength variable (the sum of predicted 1RM values for chest press, leg press and pull down exercises). Data was assessed using Shapiro-Wilk and determined not to be normally distributed.

A Wilcoxon signed-rank test revealed a significant increase for pre- to post-strength (Z = -5.232, $p < 0.001$). Median strength was; Pre = 398.39 Kg, Post = 505.39 Kg. However, Kruskal Wallis H-test revealed no significant differences between BD and HLBD; $X^2$ (1) = .363, $p$ =.547, BD and CON; $X^2$ (1) = .510, $p$ =.775, and HLBD and CON; $X^2$ (1) = .363, $p$ =.547. See figure 9.2.1.

Figure 9.2.1. Pre- and Post-predicted 1RM collapsed to incorporate all exercises from Chapter 3 (mean ±SD).




Error bars represent SD.

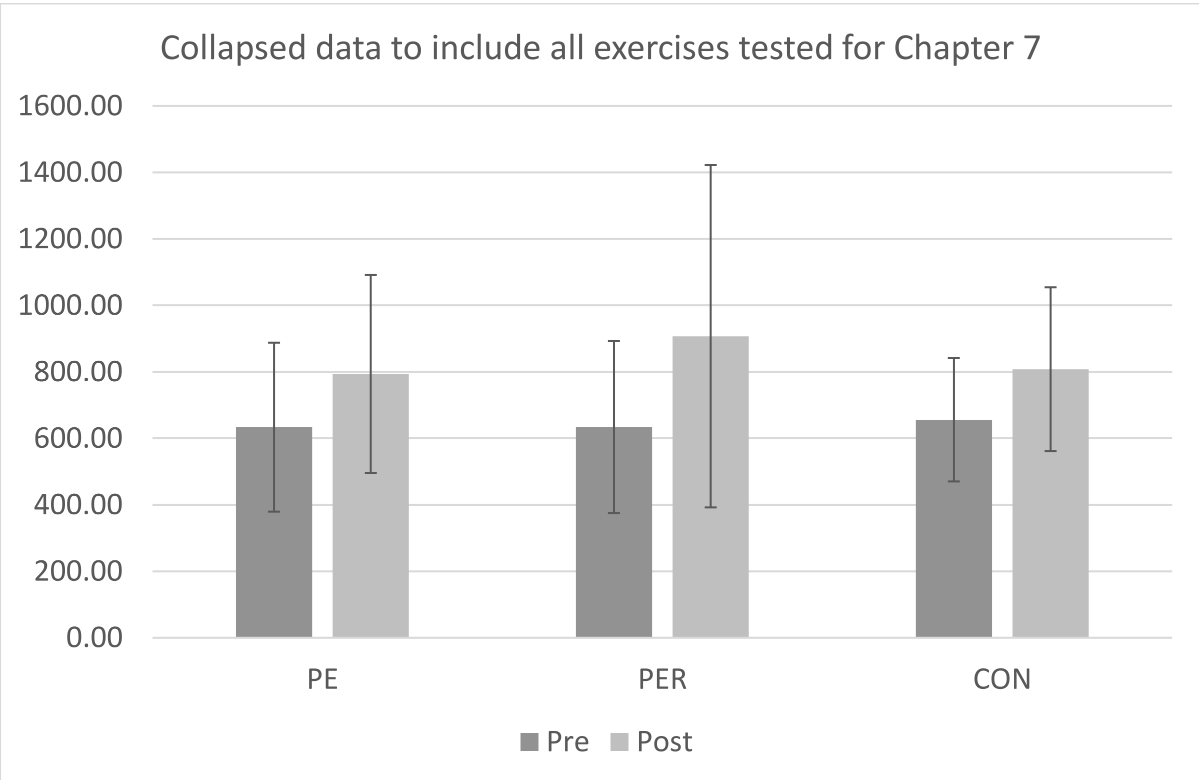
9.2.2 Analyses of predicted 1RM equations for Pre-Exhaustion training (chapter 7)

ANOVA with repeated measures revealed a significant effect for time for predicted 1RM values for chest press ($F_{(1, 36)} = 51.833$, $p < 0.001$), leg press ($F_{(1, 33)} = 13.326$, $p < 0.01$) and pull-down ($F_{(1, 33)} = 49.521$, $p < 0.001$) exercises, with no significant between-group differences (chest press, $p = .339$; leg press, $p = .368$; pull-down, $p = .921$).

Furthermore, to assess the between group efficacy by including all resistance training exercises, data was collapsed to produce a single pre- and post-strength variable (the sum of predicted 1RM values for chest press, leg press and pull down exercises). Data was assessed using Shapiro-Wilk and determined not to be normally distributed.

A Wilcoxon signed-rank test revealed a significant increase for pre- to post-strength ($Z = -5.429$, $p < 0.001$). Median strength was; Pre = 246.12, Post = 330.88. However, Kruskal Wallis H-test revealed no significant differences between PE and PER; $X^2$ (1) = .158, $p$ =.691, PER and CON; $X^2$ (1) = .085, $p$ =.771, and PE and CON; $X^2$ (1) = .243, $p$ =.885. See figure 9.2.2.

Figure 9.2.2. Pre- and Post-predicted 1RM collapsed to incorporate all exercises from Chapters 7 (mean ±SD).




Error bars represent SD.

# CHAPTER 10: General Discussion and Conclusions

The studies presented within this thesis show a coherent theme investigating optimal methods of increasing muscular strength by manipulating the variables load, type, frequency, rest interval, exercise order and intensity of effort. They follow from the published review of evidence-based resistance training recommendations (Fisher et al., 2011) which highlighted gaps within the literature and areas for future research where recommendations could not be made. Each article has been presented as published works and as such has respective discussion sections. However, the aim of this chapter is to provide a synthesis of the analyses performed in chapter 9 where data between studies has been compared, and provide an overall discussion of the findings of the studies presented in chapters' three to eight, concluding with coherent recommendations for resistance training prescription.

## 10.1. Isolated lumbar extension exercise

Within this thesis chapters 4 and 6 considered the use of an isolated lumbar extension (ILEX) machine for testing and training. The results sections from those chapters support that ILEX training produces greater isometric strength increases in the lumbar extensors compared to performing a Romanian deadlift exercise (chapter 4), and that using this exercise $1 \cdot d \cdot wk^{-1}$ is as efficacious as training $2 \cdot d \cdot wk^{-1}$ (chapter 6).

Further, comparative analyses between these studies revealed a significant difference in starting strength between previously trained males and persons symptomatic of chronic low back pain (CLBP; see section 9.1). This is fitting with previous research which suggests a relationship between low back pain and weak lumbar musculature (Luoto, Heliövaara, Hurri, & Alaranta, 1995; Risch et al., 1993) and further that deconditioning of these muscles contributes to recurrence of CLBP (Daneels et al., 2001). It is also worth noting that descriptively there was double the standard deviation in the CLBP symptomatic participants compared to trained males (7109.7 vs. 3557.3, respectively), suggesting that, in addition to weaker lumbar muscles there is also a greater heterogeneity; possibly resulting from differing degrees of back pain. Further analyses as a result of performing volume matched ILEX training $1 \cdot d \cdot wk^{-1}$ for 10-weeks revealed significant strength increases for both groups ($p<0.001$) with no between group differences ($p = 0.152$) suggesting that this low volume, low frequency training protocol was efficacious for both trained and CLBP symptomatic participants. However, the relative strength increases for the CLBP participants was greater than for trained males (34.6% vs. 19.6%, respectively; see table 9.1) suggesting that any deficit as a product of CLBP might be overcome to a degree as back pain is reduced. It should be acknowledged that this non-significant interaction is likely a result of the large standard deviations in both trained males and persons symptomatic of CLBP representing the large heterogeneity of both starting strength and strength changes across this population. Whilst there was no differences in chronic strength adaptation resulting from a change in frequency (e.g. $1 \cdot d \cdot wk^{-1}$ vs. $2 \cdot d \cdot wk^{-1}$; see section 10.3.3) in CLBP symptomatic participants, it might be that trained males, asymptomatic of CLBP adapt with greater increases in strength as a result of a higher training frequency.

## 10.2. Advanced resistance training techniques

One of the aims of this thesis was to consider the use of advanced resistance training techniques (breakdown sets; chapter 3, and pre-exhaustion; chapter 7) to increase the intensity of effort, to assess their efficacy of increasing muscular strength. The analyses performed within these published studies compared change (post-strength minus pre-strength) between groups. However, a more traditional examination is the use of analysis of variance (ANOVA) to compare within and between groups. In section 9.2.1 (breakdown sets) and 9.2.2 (pre-exhaustion) ANOVA revealed significant strength increases for all groups with no significant between group differences, supporting the previously published analyses.

Nevertheless, research has suggested a large heterogeneity of both starting strength and intervention based strength increases (Hubal et al., 2005). Furthermore, even though *a-priori* power analyses were performed, if we consider the possibility of a type II error (e.g. a sample size too small to detect a significant difference) there might have been small, but not statistically significant increases for any one group across all exercises. Since each group was tested across multiple exercises, further analyses were performed by collapsing the data for the different strength tested pieces to a single variable, and performing within- and between-group analyses for this pooled data. Ultimately this should reveal if any training method was more efficacious in producing chronic strength increases. Once again, this revealed significant increases in strength pre- to post-intervention, with no between-group differences (see figure 9.2.1 and 9.2.2).

Since these two studies considered a number of strength tested exercises which were identical the pre- and post-intervention predicted 1RM data has been presented in figure 9.2 to show the similarity across groups. It is noteworthy that the two interventions did consider different training protocols within each study (even between control groups; see table 2.1 for details of exercises performed) and in the case of the pull-down exercise used different pieces of equipment to measure muscular performance[9]. Furthermore, the accuracy of the predictive equation has been tested through a range of 7-10 repetitions (e.g. 7-10RM) and whilst the pre-intervention mean maximal repetitions was ~10, the post intervention mean maximal repetitions was ~15. The reliability of the predictive equation will likely deteriorate as a person performs more repetitions beyond those assessed.

## 10.3. General findings

### 10.3.1. Load

The American College of Sports Medicine (ACSM) and other authors have previously suggested that greater strength gains are attainable with the use of heavier compared to lighter training loads (Peterson et al., 2004; Ratamess et al., 2009). However, the present study *"The effects of breakdown set resistance training on muscular performance and body composition in young males and females"* (Chapter 3) considered the use of heavy and light load resistance training finding no significant strength differences between groups. This is concurrent with a previous review of the literature (Fisher et al., 2011) and our understanding of the size principle (Denny-Brown & Pennybacker, 1938; Carpinelli, 2008); that neither heavy- nor light-loads[10] produce greater adaptations with regard to strength gains when an

[9] Within Chapter 3; *"The effects of breakdown set resistance training on muscular performance and body composition in young males and females"* pull-down was measured using Hammer Strength, whilst within chapter 7; *"The effects of pre-exhaustion, exercise order, and rest intervals on a full-body resistance training intervention"* pull-down was measured using MedX. Chest press and leg press exercises were tested using MedX pieces in both studies.

[10] These have generally been described in the literature as heavy: $\geq$65% 1RM, and light: $\leq$60% 1RM (Schoenfeld, Wilson, et al., 2014)

exercise is continued to the point of MF. Indeed, a recent meta-analysis (Schoenfeld et al., 2016) comparing RT using heavy- and light-loads reported no significant differences between conditions.

However, empirical research which has since been published reported some contrasting results. Two studies by the same group of authors considered resistance training programmes which varied in loading strategies and reported significant increases in strength for heavier loads (3RM compared to 10RM; Schoenfeld, Ratamess, et al., 2014, and 70-80% 1RM compared to 30-50% 1RM; Schoenfeld, Peterson, Ogborn, Contreras, & Sonmez, 2015) for one of two exercises tested. Both of these studies considered maximal strength testing for the squat and bench press exercises. The first of these studies (Schoenfeld, Ratamess, et al., 2014) reported greater strength increases for the bench press for the heavier-load group where no between group differences were evident for the squat exercise. Whilst the second of these studies (Schoenfeld et al., 2015) reported greater strength improvements for the squat exercise, with no between group differences for the bench press. In light of these findings it is perhaps worth considering the underlying mechanisms by which muscular strength can be increased discussed in section 1.3.1.1.

Greater mechanical tension, as a result of heavier compared to lighter loads, has been proposed to produce favourable hypertrophic adaptations (Schoenfeld, 2010). Ultimately, this might result in a greater number of myofibres and thus a greater number of cross-bridges and binding sites per muscle, producing greater strength adaptation. Indeed, both studies (Schonenfeld, Ratamess, et al., 2014; Schoenfeld et al., 2015) reported significant increases in muscle thickness. However, there were no differences between the heavier or lighter load groups. This suggests that morphological, or at the least statistically significant muscle thickness adaptations, were not responsible for the strength change differences which occurred between heavy- and light-load groups. It is, therefore, perhaps more likely that any greater strength adaptations were a product of the skill specificity and synchronous motor unit recruitment as a result of practising resistance training with heavier loads. Motor control research suggests that a motor schema is highly specific to the task being practiced (Drowatzky & Zuccato, 1967; Mount, 1996) and indeed is load/force specific (Schmidt, 2003). With this in mind lifting a heavier load in a particular movement will serve to practise and refine that schema as a skill which might include the maximal synchronous recruitment of motor units and muscle fibres on demand. The tendency for greater strength gains in the heavier-load groups in the aforementioned studies (Schoenfeld, Ratamess, et al., 2014; Schoenfeld et al., 2015) may also be due to this specificity of motor schema refinement. Further, the 1RM tasks measured were multi-joint free weight movements (squat and bench press) which have been shown to require multiple (~3-5) familiarisation sessions even in moderately trained persons due to continued increases in 1RM (Soares-Caldeira et al., 2009) and improvements are likely attributable to neural and learning effects (Cronin & Henderson, 2007). Thus, in the studies mentioned the apparent superiority of heavier loads in enhancing strength may simply reflect better learning of the specific skills involved in the testing, rather than any greater strength improvement that can be transferred to other tasks.

In contrast, the published article presented herein (chapter 3) did not find significant differences with groups training using different loading schemes. Indeed, the testing method assessed muscular performance outcomes using repetitions to failure with an absolute load, and from this; predicted 1RM, rather than single maximal effort lifts (1RM) which can be influenced by practise. From the data presented it seems fitting to summarise that if a person wishes to improve maximal strength performing a specific movement then evidence suggests that person might do well to practice that exact movement with heavy loads to attain the potential neurological- (including motor specific) and morphological-adaptations. However, for more general increases there appear no specific loading strategies which catalyse superior strength adaptations.

### 10.3.2. Type

In the present thesis, the 'type' of resistance has been considered (and thus manipulated) within *"A Randomized trial to consider the Effect of Romanian deadlift exercise on the development of Lumbar Extension Strength"* (Chapter 4). This study compared the use of a free-weight Romanian deadlift exercise and ILEX resistance machine in relation to strength improvements of the lumbar extensors. Previous research has suggested that the deadlift is a practical exercise to strengthen the lumbar extensors (Mayer et al., 2008; Piper, 2001; Sheppard, 2003), and indeed, data considering sEMG amplitude of the lumbar extensors through variations of the deadlift exercise seem to support this premise (Chulvri-Medrano et al., 2010; Escamilla et al., 2002). However, the present research does not support this hypothesis. Analysis of data revealed that 10 weeks of Romanian deadlift resistance training significantly improved Romanian deadlift 1RM but did not improve isolated lumbar extension isometric torque. In contrast performing isolated lumbar extension exercise for 10 weeks significantly improved both isolated lumbar extension isometric torque and Romanian deadlift. These findings are supported by previous research which has suggested the need for pelvic stabilisation to optimally activate and strengthen the lumbar extensors (Graves et al., 1994; Mayer, Udermann, Graves, & Ploutz-Snyder, 2003; San Juan et al., 2005; Da Silva, Lariviere, Arsenault, Nadeau, & Plamondon, 2009). Previous authors have suggested that where there is no pelvic stabilization, and thus true isolation, it is the hamstrings and gluteal muscles that are primarily acting to de-rotate the pelvis, rather the lumbar muscles acting to provide lumbar extension (Graves et al., 1994). Whilst there is obvious disparity between a multi-joint, free-weight movement which has a large range of motion through the hip extensors (RDL) and a single-joint, machine based movement limited in range of motion through the lumbar extensors (ILEX), this represents an ecologically valid comparison of commonly used and accessible free-weight exercise compared to a proven testing and training device.

From the data, it seems apparent that whilst the RDL and other variations of the deadlift exercise provide stimulation of the lumbar extensors sufficient to produce sEMG amplitude (Chulvri-Medrano et al., 2010; Escamilla et al., 2002), RT using this exercise does not provide sufficient recruitment and/or muscular tension of these MUs and muscle fibres to produce chronic strength adaptation. This should be considered in context of the motor schema specificity mentioned in the previous section. A group practising on the ILEX produced greater strength increases when tested using ILEX. And the group practising the RDL produced greater strength increases when tested using the RDL. However, the group training on the ILEX also produced strength increases in the RDL 1RM; an exercise which they had not practised through the 10-week intervention. As such it seems unlikely that this strength increase was a product of improved motor schema and skill specificity but rather that ILEX training produces strength increases in the lumbar extensor musculature. We should also recognise that strengthening these muscles appears to have played a role in producing strength increases in the RDL 1RM, and as such whilst the RDL does seem efficacious in strengthening the lumbar muscles – these muscles seem to play a role in RDL strength.

### 10.3.3. Frequency

The frequency of resistance training has been considered in the presented article *"One lumbar extension training session per week is sufficient for strength gains and reductions in pain in patients with chronic low back pain ergonomics"* (Chapter 6). The ACSM (Ratamess et al., 2009) have previously recommended 2-3 $d \cdot wk^{-1}$ for novice, 3-4 $d \cdot wk^{-1}$ for intermediate and 4-5 $d \cdot wk^{-1}$ for advanced training persons. The sources cited by the ACSM to support these recommendations are, in fact, acute studies considering hormonal responses (Häkkinen, Pakarinen, Alén, Kauhanen, & Komi, 1988), or observations of Olympic weight-lifters or bodybuilders (Zatsiorsky & Kraemer, 2006). However, the ACSM (Ratamess et al., 2009) suggest that frequency of training should be dependent upon the manipulation of other variables such as volume, intensity of effort, level of conditioning, recovery ability, the number of muscle groups trained per workout and exercise selection. There is a surprising dearth of literature considering frequency of resistance training and as such the present study represents an important variable to consider. Whilst the presented article considers only one, single-joint exercise (lumbar extensions) the data supports that equivocally the same increases in strength are attainable when training 1 $d \cdot wk^{-1}$ or 2 $d \cdot wk^{-1}$. In addition the study suggests that an increased frequency made no greater impact on reduction in chronic low-back pain. On a practical level this was a single exercise performed for a single set to MF and might not be representative of other exercises and muscles/muscle groups. However, reviews of this area are supportive of these findings that low-frequency training can be as efficacious as higher frequencies for muscular strength adaptations (Carpinelli et al., 2004; Smith & Bruce-Low, 2004).

A more recent paper presented an ecologically valid approach to considering frequency by comparing the use of whole body (e.g. training most major muscle groups by using a variety of exercises in each workout) and split routine (e.g. training only a couple of body parts or muscle groups per workout) training protocols (Schoenfeld, Ratamess, Peterson, Contreras, & Tiryaki-Sonmez, 2015). These have previously been advocated by the ACSM (Ratamess et al., 2009) in their recommendations of higher frequency sessions (that when training >3 $d \cdot wk^{-1}$ body parts should be separated). The hypothesis underpinning the idea of using split routines is that this method allows total training volume per muscle group to be maintained with fewer sets performed per training session and greater recovery between for muscle groups (Kerksick et al., 2009). In the study by Schoenfeld, Ratamess, et al. (2015) participants were divided in to either a split routine protocol, where they performed 3 separate sessions consisting of chest and back, legs, or shoulders and arms, or a total body protocol where they trained all muscle groups in each workout. In this sense each muscle group was trained either 1 $d \cdot wk^{-1}$ (split routine) or 3 $d \cdot wk^{-1}$ (whole-body)[11]. The authors reported significant increases in strength, tested as 1RM bench press and squat exercises, for both groups with no significant between group differences. This provides further support that low frequency resistance training (1 $d \cdot wk^{-1}$) is as efficacious as higher frequencies.

### 10.3.4. Rest interval

Within the present thesis, as a product of testing the efficacy of an advanced technique, rest interval has also been considered in the study *"The effects of pre-exhaustion, exercise order, and rest intervals on a full-body resistance training intervention"* (Chapter 7). To date the studies considering between set/exercise rest intervals have produced equivocal results. Ahtainen et al. (2005) reported no difference in strength increases comparing 2- and 5-minute rest intervals, whilst Robinson et al. (1995) reported greater strength adaptations for longer (2-5 minutes) compared to shorter (30-40 seconds) rest intervals. In contrast, Bottaro, Russo, and Oliveira (2005) and Buresh, Berg, and French (2009) reported no differences between groups training with 30-, 60-, or 90 s rest intervals or 60s compared to 2m 30s rest intervals, testing isokinetic torque and 5RM squat and bench press, respectively. In the presented study the use of pre-exhaustion training, which requires moving from a single-joint to a multi-joint exercise for the same muscle group as quickly as possible ($\leq$5 s) was compared to a group performing the same exercises in the same order with a 60 s rest interval between exercises. Data from the study suggest that there were no chronic muscular performance differences between groups with minimal- compared to 60 s- rest intervals supporting previous research reporting similar findings (e.g. Bottaro et al., 2005; Buresh et al., 2009).

[11] It is noteworthy that whilst muscles were *targeted* only in the aforementioned frequency (e.g. 1 or 3 $d \cdot wk^{-1}$), there was likely a more frequent stimulus because of the synergist activation of certain muscles when performing multi-joint exercises (e.g. the triceps muscles would have been activated for multi-joint chest or shoulder exercises, and the biceps muscles for multi-joint back exercises).

However, a more recent study has since been published reporting contradictory results. Schoenfeld, Pope, et al. (2016) reported greater gains in 1RM squat and bench press for long- (3 mins) compared to short- (1 min) rest intervals following 8-weeks of resistance training. The authors also measured muscle thickness of the biceps, triceps and quadriceps muscle groups using ultrasound, reporting greater increases for quadriceps for long- compared to short-rest interval groups. Whilst this hypertrophy might have played a role in increased strength for the squat exercise, it does not explain the between group differences for bench press[12]. It might be worthwhile to consider that all participants were described as trained (>6 months experience) both in the presented study and that of Schoenfeld, Pope, et al. (2016). With this in mind the training protocols studied might or might not have represented significant variation from pre-existing routines which in itself might have helped catalyse adaptations. In consideration of the mechanisms, we might consider RI in context of load lifted and metabolic stress (see section 1.3.4.1). A longer RI permits a greater load and/or more repetitions to be performed in successive sets (Richmond & Goddard, 2004; Willardson & Burkett, 2005), and as such resistance training with a heavier load might permit greater practise of both synchronous MU recruitment as well development of the specific motor schema (Schmidt, 2003). Furthermore, metabolic stress might be favourably adapted both by a greater RI permitting a greater total volume of exercise, or by the use of a shorter RI and metabolite accumulation (Schott, McCully & Rutherford, 1995; Takada et al., 2012; MacDougall et al., 1999). This, in turn, might catalyse hypertrophic adaptations which, as previously mentioned, can result in strength increases.

The published study considering RI did not use maximal lifts which might have been enhanced through practice of lifting with a heavier load (e.g. 1RM) but rather assessed increases in muscular performance (repetitions at an absolute load) and from this predicted 1RM. Furthermore, neither metabolic stress, nor hypertrophy were measured within this study, and, as such, whilst the mechanisms are of interest; we cannot be certain by what mechanisms strength increases occurred – only that they did without difference resulting from RI. Finally, and perhaps of most significance; the current body of literature has

[12] The authors' statistical analyses for some variables was at best questionable; they state using a 2 x 2 ANOVA at an $\alpha$ of 0.05 but continue to run independent samples *t*-tests on change where *p* values were greater than 0.05. The authors also report a *trend* where $0.05 < p < 0.1$, something which cannot realistically be considered because a trend toward anything cannot be identified by a single data point.

considered inter-set rest intervals whereas because our participants only performed a single set per exercise, the research study presented within this thesis actually considers rest interval between exercises. A literature review reveals that this appears to be the first article to consider this variable. With this in mind the present discussion has highlighted the potential for inter-set rest intervals but ultimately the presented study supports that length of rest interval between exercises does not affect strength adaptations.

#### 10.3.5. Exercise order

Exercise order has previously been considered in context of prioritising exercises to the start of a workout to maximise acute performance (Miranda et al., 2010; Simão et al., 2012), and from this authors have suggested that to maximize performance of a specific exercise it should be placed at the beginning of a training session (Gentil et al., 2007). However, to date there appears no empirical research which has considered the chronic adaptations to prioritising exercises. Within the presented research study "The effects of pre-exhaustion, exercise order, and rest intervals on a full-body resistance training intervention" (Chapter 7), we have compared a group of participants performing the tested exercises at the start of the workout against groups of participant who performed a single joint exercise prior to the tested exercises. Results of analyses reveal no statistically significant differences between performing exercises at the start of the workout or having completed other exercises prior.

Once again, the mechanisms underpinning exercise order might best be thought of in relation to the load lifted. An exercise at the start of a workout will permit a greater load to be lifted than the same exercise placed at the end of a workout, as a result of both local and non-local muscular fatigue (Halperin, Chapman, & Behm, 2015). As such if a person practices the synchronous MU recruitment and motor schema of lifting heavier loads, it is possible that they might incur greater strength adaptations specific to that task. However, these potential adaptations were minimised by testing using repetitions to failure at an absolute load, and from this; predicted 1RM. As such similar strength adaptations, irrespective of exercise order, might be a product of complete MU recruitment by exercising to MF at each exercise throughout the workout. This is supported by our understanding of the size principle of motor unit recruitment; that when training to failure all motor units and muscle fibres are recruited sequentially from the smallest, least powerful to the larger, more powerful (Denny-Brown & Pennybacker, 1938; Carpinelli, 2008). In addition this relates to the body of literature discussed previously (see section 10.3.1) which suggests similar strength adaptations between heavy and light training loads. In this sense, the acute effects of training (or pre-exhausting) a muscle by performing a previous exercise might diminish the acute performance and necessitate the use of a lighter load. However, irrespective of load, when continuing the exercise to MF a person appears to still recruit all MUs and muscle fibres and optimise chronic strength adaptations.

### 10.3.6. Intensity of effort

There has previously been a relative dearth of research considering the use of advanced techniques such as breakdown- and pre-exhaustion- resistance training. These principles have been hypothesised to provide a higher intensity of effort by maximising recruitment of both type II and type I motor units through a combination of high muscular tension, metabolic stress and ischemia due to extended time under tension (Schoenfeld, 2011). Despite a lack of published research a large body of commercial (Jones, 1970; Westcott, 2003; Darden, 2004; Baechle & Earle, 2008; Philbin, 2004; Fleck & Kraemer, 2014) and peer reviewed (Darden, 1983; Baker & Newton, 2005; Schoenfeld, 2011) publications advocate these methods. The present research *"The effects of breakdown set resistance training on muscular performance and body composition in young males and females"* (Chapter 3) and *"The effects of pre-exhaustion, exercise order, and rest intervals on a full-body resistance training intervention"* (Chapter 7) specifically considered these advanced training principles aimed at increasing the intensity of effort and maximising recruitment to optimise adaptation.

In addition, the included article *"Combined isometric and vibration training does not enhance strength beyond that of isometric training alone"* (Chapter 5) also considered intensity of effort by comparing groups training with and without direct- and whole body-vibration. The addition of a vibratory stimulus is suggested to increase sensory in-flow of fast shortening and lengthening of muscle fibres, and as such the muscle elicits a reflec contraction and this deformation of tissues activates muscle spindles and leads to enhancement of the stretch-reflex loop. There is a resulting increase in MU recruitment by excitatory activation of the α-motor neuron (Cardinale & Bosco, 2003). Indeed, previous research also supports that there is an inability to voluntarily recruit all motor units, and that an additional 2-5% is possible following external stimulation (Gabriel et al., 2006). However, the present research failed to support any greater strength adaptations beyond isometric resistance training to MF without vibration. The present results are supported by previous research which has reported similar muscle activation and rating of perceived exertion (RPE) values for increasing loads and increasing intensity vibrations when comparing bodyweight isometric squats with vibration against isometric squats with an external load (Marín, Santos-Lozano, Santin-Medeiros, Delecluse, & Garatachea, 2011). Furthermore Delecluse et al., (2003) reported significant increases in knee extensors strength for VT and ST conditions with no significant differences between groups. The present study suggests that whilst the maximal isometric contractions in the ST group was sufficient to stimulate a chronic strength response, the addition of a direct- and whole body-vibratory stimulus appears not to have enhanced strength to any greater degree.

Finally, the study *"A comparison of volume equated knee extensions to failure, or not to failure, upon rating of perceived exertion and strength adaptations"* (Chapter 8) assessed intensity of effort through the methodological process of a within participants design performing volume- and load-controlled knee extension exercises to MMF or NMF. Following 2 $d \cdot wk^{-1}$ unilateral knee extension training for 6 weeks, both MMF and NMF groups showed significant increases in strength with no significant differences between groups. Previous research has reported equivocal results where some literature has reported greater strength increases for training to failure (Rooney, Herbert, & Balnave, 1994; Schott, McCully, & Rutherford, 1995; Drinkwater et al., 2005; Gießing et al., 2016) whilst other research has suggested equivalent gains when not training to failure (Izquierdo et al., 2006; Folland et al., 2002; Sampson & Groeller, 2016). However, a review published after the presented article considering resistance training to muscular failure or not to failure reports no meaningful difference upon muscular strength between these methods (Davies, Orr, Halaki, & Hackett, 2015).

The present thesis has considered the use of advanced training techniques such as breakdown training (chapter 4), and pre-exhaustion training (chapter 8) which have been advocated based, in part, on hypotheses that these methods maximally recruit all available

MUs and muscle fibres. Momentary failure occurs when there is an inability to continue innervating MUs and/or a reduction in rate of discharge (rate coding; Enoka & Duchateau, 2008). Based on our understanding of the size principle whilst some evidence suggests contrary, we might consider the nature of training to momentary failure and the accompanying fatigue/discomfort. With this in mind, the presented article also measured rating of perceived exertion (RPE) between MMF and NMF groups. In this sense the analysis might provide greater insight in to both training volume and training intensity of effort. Comparing RPE between groups revealed that, whilst the values for the MMF group were maximal from the outset due to the nature of the intensity of effort, the values for the NMF group increased with each consecutive set of exercise. Indeed analyses revealed a statistically significant difference for RPE between MMF and NMF with higher values for the MMF group. However, it might be that there is a minimum threshold necessary to maximally recruit MUs and muscle fibres and, in this case at least, cumulative fatigue resulting from performance of multiple sets of an exercise and insufficient rest ensured participants surpassed that minimal threshold for adaptation. Previous research supporting similar adaptations between MF and NMF have considered recreationally active participants and whilst they failed to consider RPE their respective protocols support this threshold hypothesis (Izquierdo et al., 2006; Folland et al., 2002; Sampson & Groeller, 2016). It could however be suggested that, practically speaking and considering prior research shows poor ability to estimate proximity to MF even in trained adults (Hackett, Johnson, Halaki, & Chow, 2012; Gießing et al., 2016), that it may still be desirable to attempt to train to MF with untrained recreationally active people. This might ensure that a threshold for optimising adaptations has been met.

These hypotheses were tested as a result of the absence of existing research (Fisher et al., 2011) and since they appeared to challenge our current understanding of the size principle (Denny-Brown & Pennybacker, 1938; Carpinelli, 2008). This existing body of research appeared to support that MUs are recruited from smallest to largest and as such training beyond MF (e.g. using advanced techniques such as breakdown sets and pre-exhaustion training) provides no additional stimulus which results in greater increases in muscular strength. Furthermore, that when performing a high volume approach (5 sets of an exercise) training NMF appears to produce equivocally the same adaptations in muscular strength as training to MF.

## 10.4. Limitations and directions for future research

All of the studies within this thesis have employed a standard statistical procedure based on hypothesis testing and a critical probability of 95% confidence of a difference, as is a prerequisite for publication within most exercise physiology journals (Drummond & Tom, 2011). However, we should consider that within the limitations of this approach in populations that yield highly variable adaptations (as is the case in human beings undertaking resistance training; Hubal et al., 2005); it might often be impractical to appropriately power studies to detect modest effects (Hopkins, Marshall, Batterham, & Hanin, 2009). For the studies presented herein an *a-priori* power analysis of effect sizes for previous research was conducted to determine participant numbers (n) based on a required power of 0.8 at an alpha value of $p \leq 0.05$. With this in mind, whilst large heterogeneity is evident, each of the studies met the required participant sample size for statistical power. However, other limitations should also be considered.

Within the presented article "The effects of breakdown set resistance training on muscular performance and body composition in young males and females" (Chapter 3) we should consider that there were a disparate number of males and females between groups. In consideration of this, statistical analyses were performed for independent genders however the female only comparisons might have resulted in reduced power and as such, reflect a type II error. Future research should consider gender counterbalanced groups. Furthermore, within the studies *"The effects of breakdown set resistance training on muscular performance and body composition in young males and females"* (Chapter 3) and *"The effects of pre-exhaustion, exercise order, and rest intervals on a full-body resistance training intervention"* (Chapter 7) strength was identified as change in muscular performance (repetitions) with an absolute load. Whilst evidence supports both the application and practicality of this method of testing, and predictive 1RM equations have been analysed and reported within this thesis, future research might consider the use of isometric or isokinetic testing to better identify maximal strength increases. Of course, these tests then become susceptible to the development of specific motor schema.

We might also consider additional types of resistance with a view to the strengthening of the lumbar muscles. The present study *"A Randomized trial to consider the Effect of*

*Romanian deadlift exercise on the development of Lumbar Extension Strength"* (Chapter 4) compared only deadlift training to specific isolated lumbar extension training. However, more recent research has suggested that Kettlebell swings can provide acute fatigue to the lumbar extensors, and as such a chronic intervention considering this modality might identify an alternative to the costly use of specific ILEX machine-based training (Edinborough, Fisher, & Steele, 2016). Indeed, other training modalities commonly found in strength training facilities might also be considered and to this extent the potential for research is somewhat unlimited. However, since a muscle does not identify what it contracts against, it simply either contracts or not, it is likely that where specific MUs are innervated and the resultant muscles are exercised to the same degree, similar adaptations are likely irrespective of modality. This is supported by our presented article *"Combined isometric and vibration training does not enhance strength beyond that of isometric training alone"* (Chapter 5) where the addition of a vibratory stimulus catalysed no greater strength adaptation beyond maximal isometric training alone.

It is also worthwhile to consider research design with the presented study *"A comparison of volume equated knee extensions to failure, or not to failure, upon rating of perceived exertion and strength adaptations"* (Chapter 8). The methodological approach of unilateral training/within participants design controls adequately for nutrition, sleep patterns, genetics and hormonal responses to resistance training protocols, where a between participants design might not. However, we should consider that there might be chronic neural adaptations resulting from cross-education which could have impacted the results and limit the extent of our conclusions. A previous meta-analysis of the cross-educational effect of unilateral training has suggested that it can contribute up to 7.8% absolute strength increase to the contralateral limb (Munn, Herbert, & Gandevia, 2004). However, this adaptation is hypothesised to result from neural mechanisms involving facilitation of an untrained contralateral motor cortex following excitation of a trained limb. With this in mind, where both limbs were trained (as in the present study) it could be argued that we controlled for this degree of improvement between limbs.

Since multiple studies herein addressed intensity of effort and training to MF (e.g. Chapter 8) or using advanced techniques or modalities to train to MF+ (e.g. Chapters 3, 5 and 7) it is worth considering the role of rating of perceived exertion (RPE) and muscular discomfort within these methods. The present study *"A comparison of volume equated knee extensions to failure, or not to failure, upon rating of perceived exertion and strength adaptations"* (Chapter 8) identified significantly different peak RPE values for training to MMF compared to NMF, and yet whilst reporting marginally different ESs reported no statistical differences for strength increase between these training groups. However, in chapters 3 and 7 techniques were used, and in chapter 5 an additional stimulus in the form of vibration was used, to attempt to train to a higher intensity of effort (e.g. MF+). A limitation and potential addition to future research considering these areas might be the inclusion of psychological exertion scales in attempt to gauge whether there is a higher degree of perceived intensity of effort or muscular discomfort, especially since acute studies have not shown higher sEMG amplitude as a result of these methods.

In this sense, future research should also attempt to identify the mechanisms by which strength has occurred based on the techniques considered within this thesis. The majority of studies present participants with previous resistance training experience (chapters 3, 4, 7 and 8) from which we might hypothesise that neurological adaptations might have been minimal and morphological adaptations more prominent. However, further studies should consider morphological mechanisms including, but not limited to; pennation angle (θp) of muscle fibres, change to anatomical- and physiological-cross sectional area, and motor unit recruitment and rate coding.

## 10.5. Practical applications

Whilst the research pieces presented herein have not considered the mechanistic processes (e.g. neurological or morphological) which underpin the strength adaptations, combined they represent significant forward progress in our understanding of how to prescribe resistance exercise for optimal strength improvements. Previous research has reported perceived difficulty as a barrier to exercise (Winett et al., 2009) however the present studies as a collective allow an overarching perspective towards resistance training, and in fact; demonstrate the relative simplicity that can be used to attain considerable strength improvements and as such the associated health benefits. Based on the evidence presented within this thesis future guidelines for resistance training might consider self-selected load (since there appears no difference between heavy- and light-load training), low frequency (e.g. 1.d·wk$^{-1}$) resistance training to a high degree of intensity of effort, with exercises performed in any order and with rest intervals between exercises to suit the participant's wishes. It might also be worth participants using both multi-joint and single joint exercises so as to properly stimulate specific muscles as necessary, and with regard to intensity of effort; it is worth considering the efficiency and practicality between training interventions. Within the presented thesis the MF protocol required ~7 minutes and 6 seconds to complete, whereas the NMF protocol required 12 minutes and 10 seconds to complete. This equates to ~40% greater time for the NMF protocol which if extrapolated to consider multiple exercise protocols would require ~80 minutes and ~120 minutes for MF, and NMF respectively for 10 exercises using the same volume equated protocol. If statistically similar (or possibly greater based on ESs) strength gains are attainable in a shorter time then persons might consider resistance training to MF protocol far more time efficient and practically viable.

# References

Please also see chapters 3 to 8; reference lists for these publications are provided within the specific chapters.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